University of Zabol

Agriculture, Environment & Society

Semiannual, Volume 2, Issue 1, 2022

Agriculture, Environment & Society (AES)
Volume 2, Issue 1, June 2022
Publisher: University of Zabol

Editor-in-Chief:
Mohammad Reza Asgharipour; *m_asgharipour@uoz.ac.ir*

Director-in-Charge:
(is changing)

Manager:
Esmaeel Seyedabadi; *e.seyedabadi@uoz.ac.ir*

Honorary Editor-in-Chief:
Daniel E. Campbell: Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, 2 East Alumni Avenue, Kingston, RI 02881 USA.

Editorial Board:


Abbasali Emamjomeh: Department of Biotechnology, Faculty of Agriculture, University of Zabol, Zabol, Iran.


Behnam Kamkar: Department of Agrotechnology, College of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran.


Benyamin Khoshnevisan: Chinese Academy of Agricultural Science, China Mainland.


Ehsan Rakhshani: Department of Plant Pathology, Faculty of Agriculture, University of Zabol, Zabol, Iran.


Farzad Bagherzadeh Kasmani: Department of Animal Science, Faculty of Agriculture, University of Zabol, Zabol, Iran.


Khosro Azizi: Department of Agronomy, College of Agriculture, Lorestan University, Khorramabad, Iran.


Maghsoud Farasatkhah: Department of Research, Institute for Research & Planning in Higher Education, Tehran, Iran.


Mahmood Solouki: Department of Biotechnology and Crop Breeding, Faculty of Agriculture, University of Zabol, Zabol, Iran.


Mehdi Khojastehpour: Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad (FUM), Mashhad, Iran.


Mohammad Armin: Department of Agronomy, Sabzevar Branch, Islamic Azad University, Sabzevar.


Mohammad Reza Asgharipour: Department of Agronomy, Faculty of Agriculture, University of Zabol, Zabol, Iran.


Mohammad Rokouei: Department of Animal Science & Bioinformatics, Faculty of Agricultural, University of Zabol, Zabol, Iran.


Reza Sadrabadi Haghighi: Islamic Azad University Mashhad Branch: Mashhad, Razavi Khorasan, Iran.


Hadi Veisi: Department of Agroecology, Environmental, Sciences Research Institute, Shahid Beheshti University, Evin, Tehran, Iran.

Editorial Office: ***Faculty of Agriculture, University of Zabol, Zabol, Iran, P.O. Box 538-98615***
Tel: +98-54-31232102
Website: http://www.aes.uoz.ac.ir
Email: aes@uoz.ac.ir, aes.uoz.journal@gmail.com

Editor Preface to the Second Issue

I am proud to present the second volume of the Agriculture, Environment & Society series (AES). This issue, prior issue, and additional resources can be found at http://www.aes.uoz.ac.ir. It is essential to emphasize that the Journal has maintained a high level of publication quality through peer review. I appreciate the time spent by the reviewers and editorial board to ensure that only high-quality articles pass the double-blind peer review process. The editors of AES are committed to collaborating with experts in both established and emerging fields to produce high-quality articles that advance knowledge in the field of sustainability and the interrelationship between agriculture, the environment, and society.

We will prioritize attracting the highest quality manuscripts from around the world. To achieve this objective, the editors are encouraging their research-active colleagues to submit manuscripts. Our second primary objective is to bolster the current team with more young, active, and mid-career scientists so that the journal can continue to be at the forefront of research dissemination within the Journal's aims and scopes. Thirdly, and perhaps most challenging, is identifying the most qualified peer reviewers to ensure that the article we publish have been adequately screened for novelty of research results and quality of research methodology.

The fourteen articles in this issue cover a vast array of topics, methodologies, and disciplines. As part of the mission of our journal to attract and cultivate international articles, the authors' and content's diversity demonstrates this objective. Topics range from use of plant compounds as an alternative to chemical control for one-day-old adult aphids; Examining the impact of ultrasonic and seed priming on certain cowpea quality traits; Using emergy analysis to evaluate the sustainability of three traditional, semi-mechanized, and mechanized sugar beet production systems; Effect of foliar application of two growth regulators, salicylic acid and potassium silicate, on onion thrips population density and onion cultivar characteristics; Study of the physical properties and mechanical behavior of the Sahand cultivar of green almonds; The influence of drought stress on the growth and mineral absorption of a peach and almond hybrid *in vitro*; Evaluation of mallow drying characteristics in a microwave dryer with varying levels of power; Determination of the critical period for weed control in rainfed lentils; Using the emergy analysis method to evaluate the sustainability of rainfed rapeseed production in Gorgan; Comparing the yield and characteristics of old and new bread wheat and durum wheat cultivars in tropical regions of the Kerman province; Determining the effect of human and natural factors to predict aquifer depletion in Qazvin using tree and clustering algorithms; Evaluation of population fluctuations of *Pulvinaria aurantii* and its predator in Tonekabon red orange orchards; and Determination of efficiency, effectiveness, and productivity of Kabodarahang potato production units utilizing various level-cut and fuzzy data envelopment analysis techniques.

Obviously, these accomplishments would not have been possible without the dedication and generosity of numerous individuals, to whom we extend our deepest gratitude and appreciation. First, we would like to thank those who submitted papers and congratulate those whose papers have been accepted for publication, especially for their patience and positive response to the review process, critical comments, and important suggestions from the faculty reviewers and editorial team. This issue would not have been completed without the invaluable editorial assistance of Drs. Daniel E. Campbell, Esmaeel Seyedabadi, and Mojtaba Keykhasaber. Dr. Peyman Afrasiab, the president of the university, and Dr. Majid Erfanian, the vice chancellor for research, deserve special recognition for their continued thoughtfulness and concern.

Finally, the AES Editorial Team wishes future editors and authors the best of luck. We believe that they will receive the same assistance, warmth, and generosity that we have received and appreciated from them over the past year. We have endured challenging, yet enriching, years of education that have greatly enriched our professional and life experiences. Thank you very much for this extraordinary opportunity and experience.

Mohammad Reza Asgharipour
Editor in Chief
Agriculture, Environment & Society (AES)
June 2022

Aims and Scopes

Agricultural, Environment and Society is an international journal that deals with interactions between agricultural systems and the life-supporting environment on which human wellbeing ultimately depends. The journal publishes original article, short communications and review article. The journal's focus should capture the current needs of the agricultural systems with the goal of advancing the well-being of the people. The papers in the journal should address the critical issues that will move agricultural systems forward and improve the living conditions of the people. In this regard, the three critical systems that we need to understand to accomplish this end are environment, agriculture and society. The role of Journal is to provide a forum to agricultural scientists to deliberate on important issues of agricultural research, education and extension and present views of the scientific community as policy inputs to planners, decision/opinion makers at various levels.

Agricultural, Environment and Society honors scientists at various levels, and encourages cutting edge research in a variety of agricultural disciplines. The journal's mission is to publish papers on new and emerging disciplines and concepts in order to provide future directions for agricultural research across the world. It is a unique journal that promotes inter-disciplinary research by encompassing all fields of crop sciences, animal sciences, fishery sciences, forestry sciences, agricultural machinery and natural resources management sciences, to stimulate interest in inter-disciplinary research.

The following should be included in all manuscripts submitted to *Agricultural, Environment and Society*:

- ***Generally should focus on the critical issues that will move agricultural systems forward and improve the living conditions of people.***
- ***Substantial natural science material (particularly farm- or landscape-level, sometimes coupled with social sciences), and***
- ***A thorough examination and discussion of the interconnections between agricultural system components and other systems.***

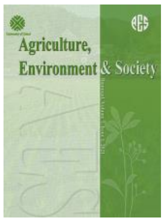
Agriculture, Environment & Society (AES)

Volume 2, Issue 1, June 2022

Contents

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir



Qualitative phytochemical screening and insecticidal effect of *Pimpinella stocksii* ethanolic extract on *Aphis gossypii*

Fatemeh Ordouni [a], Abbas Khani [*b], Najmeh Sahebzadeh [b], Ali Mirshekar [b]

[a] M.Sc. Graduate, Department of Plant Protection, Faculty of Agriculture, University of Zabol, Zabol, Iran
[b] Department of Plant Protection, Faculty of Agriculture, University of Zabol, Zabol, Iran

ARTICLE INFO

Article history:
Received: 31 January 2022
Accepted: 07 March 2022
Available online: 17 March 2022

Keywords:
Aphid
Bioassay
Contact toxicity
Phytochemical compounds
Pimpinella stocksii

ABSTRACT

In recent years, the use of herbal compounds to control pests has been proposed as one of the alternative sources to chemical control because of their selectivity, readily biodegradable, and low impacts on non-target organisms and the environment. In this research, qualitative photochemistry and the insecticidal effect of ethanol extract of aerial parts (without flowers) of *Pimpinella stocksii* Boiss. (Apiaceae) on one-day old adult aphids (*Aphis gossypii*) in a completely randomized design with four replications for each concentration, have been investigated under laboratory conditions (25 ± 1°C, 65 ± 5 % R. H, photoperiod 16:8 L: D). The results showed that the mortality of the tested insect increased significantly by increasing concentrations from 7 to 425 µg/cm^2. In the probit analysis, an ethanol extract of *Pimpinella stocksii* was found to be highly toxic to *Aphis gossypii* Glover, with a lethal concentration of 50 percent (LC_{50}), equal to 82.57 µg/cm^2. The mortality rate of one-day adult aphids treated with an ethanol extract of *P. stocksii* at concentrations ranging from 7 to 425 µg/cm^2 ranged from 25 to 80 percent. Preliminary phytochemical analysis showed the presence of various bioactive and insecticidal constituents in *P. stocksii*, like glycosides (anthraquinones), flavonoids, steroids, saponins, and triterpenoid compounds. The purpose of the study is to conduct preliminary and qualitative identification of the active components of the *Pimpinella stocksii* extract as well as to investigate its insecticidal activity.

Highlights

- Herbal compounds have recently been offered as an alternative to chemical pest control due to their selectivity, biodegradability, and little impact on non-target animals and the environment.
- An ethanol extract of *Pimpinella stocksii* was shown to be very poisonous to *Aphis gossypii* Glover, with an LC_{50} of 82.57 µg/cm^2.
- *P. stocksii* contains bioactive and insecticidal chemicals such as glycosides (anthraquinones), flavonoids, steroids, saponins, and triterpenoids.
- The study's goal is to identify the active components in *Pimpinella stocksii* extract and test its insecticidal activity.

1. Introduction

Aphids are among the economically important pests that are distributed worldwide and damage plants by feeding on plant sap. In addition to weakening and withering of the plant and resulting in young leaves being tangled, they cause the transmission of more than one hundred kinds of plant viruses. The cotton-melon aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae), is a polyphagous species with a worldwide distribution and a variety of biotypes (Luo et al., 2016). With the increase in the number of people living on Earth, the need for foodstuffs has increased, and almost a third of crops are destroyed by damage caused by pests, so pest control is essential. Therefore, in order to control aphids, modern and effective methods like the use of herbal pesticides are emphasized. Herbal Insecticides have fewer adverse effects on the environment compared to conventional pesticides and are less toxic to humans and mammals. In

* Corresponding author.
E-mail address: abbkhani@uoz.ac.ir or abbkhani@yahoo.com (A. Khani)
http://dx.doi.org/10.22034/aes.2022.327310.1016

addition, due to their low durability and ease of use in nature, they can be an alternative to chemical pesticides to control pests such as aphids. In recent years, there has been a tendency to increase the efficiency of agricultural products. In this regard, indiscriminate pesticide use has resulted in serious issues such as direct toxicity on parasitoids, predators, pollinators, fish and humans, the development of pesticide resistance, pesticide residues in food products and negative environmental effects (Damalas and Koutroubas, 2016).

Secondary compounds from some plants play an important role in natural defense and pest control. So the compounds derived from these plants can be a good alternative to synthetic insecticides in pest control programs. Moreover, these herbal compounds, compared to synthetic insecticides, have a lower degree of toxicity for mammals and non-target organisms, and they are also compatible with ecosystems and have less durability and stability in the environment (Geris et al., 2012; Lamarre et al., 2014).

All plants produce secondary metabolites, which are often specific to an individual genus or species and environmental conditions. A total of 74 plant species have been shown to hold secondary metabolites which have significant insecticidal properties and they are distributed in 33 families from which the major occurrence is found in the families Rutaceae (9.5%), Leguminosae (8.1%), Annonaceae (6.7%), Piperaceae (6.7%), Zingiberaceae (6.7%), Asteraceae (5.4%), and Verbenaceae (5.4%). The 51.5% remainder of the plant species are distributed into 26 families. The bioactive compounds reported here are diverse in structure and, according to their biosynthetic origins, are mainly distributed in terpenoids (30.2%), polyketides (including xanthones, quinones, and anthraquinones, 17.3%) and flavonoids (11.3%) classes (Geris et al., 2012).

The genus *Pimpinella* L., with about 170-180 species in the world, is one of the largest genera in the family Apiaceae (Umbelliferae). *Pimpinella stocksii* is a small, annual, herbaceous plant with white flowers and ovoid fruits that belongs to the Apiaceae family. Previous phytochemical studies of *Pimpinella* species have led to the isolation of various compounds like phenylpropanoids (Sajjadi et al., 2015; Reichling et al., 1991), sesquiterpenes, coumarins, and volatile oils (Sajjadi et al., 2015).

The main purpose of the study is to provide preliminary identification of the main active components of the *Pimpinella stocksii* extract that are responsible for its insecticidal activity against *Aphis gossypii* to support the usage of the plant as a safe insecticide. Based on our knowledge, no study has been reported previously relating to the activity of the tested plant extract against pest insects.

2. Materials and methods

2.1. Rearing insects in greenhouses

To create an initial population of A. gossypii Glover, leaves infected with aphids were collected from a greenhouse in the city of Hamoun, and they were transferred on the leaves of bush cucumbers, which were at five to six leaves stages; the pots containing cucumber plant were maintained in a greenhouse conditions (Temperature: 23-25 °C, Relative humidity: 70% and photoperiod 16:8 L: D). For conducting bioassay test, one-day old wingless adult aphids were applied (Tabacian et al., 2011).

2.2. Plant sample preparation and extraction

Pimpinella stocksii was collected in the city of Hamoun, Sistan and Baluchistan province (altitude 480 m, longitude 61° 14' East, latitude 30° 49' North) in October 2014. After recognition of the plant by the Research Center for Agriculture and Natural Resources of Sistan, it was transferred to the laboratory where aerial parts (without flowers) of the plant were held in a dark location at room temperature and dried under ventilation conditions, then held in paper bags in the refrigerator at 4 °C.

Extraction was conducted through a soaking plant on ethanol 96% (Noor Zakariayaye Razi Co., Iran) according to the method of Bahraminejad et al., 2008. The dried aerial parts of the plant were powdered by using electric mills. Then 50 grams of each powdered aerial part were mixed with 200 ml of ethanol solvent separately for 24 hours at room temperature on a shaker at 350 rpm. After each extraction, the considered extract was filtered using Whatman filter paper number one. Then the extract was stored in a dark glass jar in the refrigerator at 4 °C until the time of its usage.

In order to determine the concentration of the extract, the dry weight of the extract was measured in 1 mL of ethanol in three replicates. First the three empty watch glasses were weighed, then in each glass, 1 mL of extract was cast separately. The glasses were placed at 60 °C in the oven until their contents were completely dry. Watch glasses containing the dried extract were weighed and the difference between them and the empty watch glasses was determined, and then the amount of the dried extract in 1 mL of soluble was measured (Ghaemi et al., 2006). The yield of extraction was obtained at 4 mg/mL.

2.3. Bioassay test

This experiment was conducted in a completely randomized design with four replications for each concentration. Each tested unit consisted of a 6 cm petri dish (with an area of 28.26 cm^2). To study the effect of insecticide, different volumes of *P. stocksii* extract (0.05, 0.1, 0.3, 0.5, 1, 1.5, 2 and 3 ml) almost equal to the concentrations of 7.1, 14.2, 42.3, 70.8, 141.5, 212.3, 283.1 and 424.6 $\mu g/cm^2$ were gradually poured on the bottom of petri dishes by the sampler. In control, ethanol was poured by pipette on the bottom of the Petri Dish. The lid of the Petri Dish remained open for 30 minutes to evaporate the solvent, and then in each Petri Dish, 10 one-day old adults were placed, and the lid of the Petri Dish was closed (Rajashekar et al., 2010). The Petri dish was put in the incubator at 25±1°C with a relative humidity of 65 ± 5%, and a photoperiod of 16:8 L:D. Total mortality was determined based on the movement of the legs and antennae after 24 hours.

2.4. Qualitative phytochemical screening

We characterized the different chemical groups with reference to the technical descriptions by Hossain et al., 2013 and Krisgnaveni et al., 2014.

2.5. Test's for steroids (Salkowski test)

The dry ethanol extract (4 mg) was taken in a test tube and dissolved with chloroform (2 ml), then an equal volume of concentrated sulphuric acid was added to the test tube slowly. The formation of red color in the upper layer (chloroform phase) and yellow with green fluorescence in the sulphuric acid layer (lower layer) shows the presence of steroids (Hossain et al., 2013).

2.6. Test's for tri terpenoids

The dry crude plant extract (4 mg) was mixed with chloroform (2 ml) and then acetic anhydride (1 ml) was added to it. Concentrated sulphuric acid (1 ml) was carefully added to the solution. The formation of a reddish violet color indicated positive results for the presence of triterpenoids (Hossain et al., 2013).

2.7. Test's for soponins (Foam test)

The stock solution (1 mL) was taken in a test tube and diluted with 20 mL of distilled water. It was shaken by hand for 15 min. A foam layer was obtained on the top of the test tube, which indicated the presence of saponins (Hossain et al., 2013).

2.8. Test's for flavonoids (Ferric Chloride Test)

Alcoholic solution of leaf extract (1 ml) evaporated and the dry crude plant extract (4 mg) was dissolved in distilled water and reacted with a few drop of freshly prepared 1% ferric chloride ($Fecl_3$) solution. Formation of black fish green color indicates the presence of the flavonoids (phenolic hydroxyl group) (Krisgnaveni et al., 2014).

2.9. Test's for glycosides (Anthraquinone test)

The powdered leaves are extracted with either ammonia or caustic soda. If the aqueous layer shows pink, it indicates the presence of glycosides (Krisgnaveni et al., 2014).

2.10. Test's for tannins (Ferric chloride test)

Three drops of diluted solution of FeCl3 was added to the extract, production of a blue (hydrolysable tannins) or greenish-black (condensed tannins) color that changes to olive green as more ferric chloride is added indicates the presence of tannins (Krisgnaveni et al., 2014).

2.11. Statistical Analysis

SPSS software version 21 was used to perform statistical analysis on the data. Normalization of raw data was evaluated by using the non-parametric One-Sample Kolmogorov-Smirnov Test. For grouping the average of significant data, Tukey's test was used. The effective concentration of 50% lethality was determined by linear probit analysis using SPSS software version 21.

3. Results and Discussion

3.1. Lethal effect of plant extract

The results of the contact toxicity test of ethanol extract on *P. stocksii* on adult *Aphis gossypii* showed that with increasing concentrations, the mortality rate of tested insects increased significantly ($F_{7,\ 31}$= 4.46, P= 0.002; Figure 1). The mortality rate of one-day adult aphids treated with ethanol extract of *P. stocksii* at concentrations ranging from 7.08 to 426.63 µg/cm^2 ranged from 25% to 80%. The calculated LC_{50} value for *A. gossypii* treated with the ethanol extract of *P. stocksii* after 24 hours was 82.6 µg/cm^2 (Figure 2, Table 1).

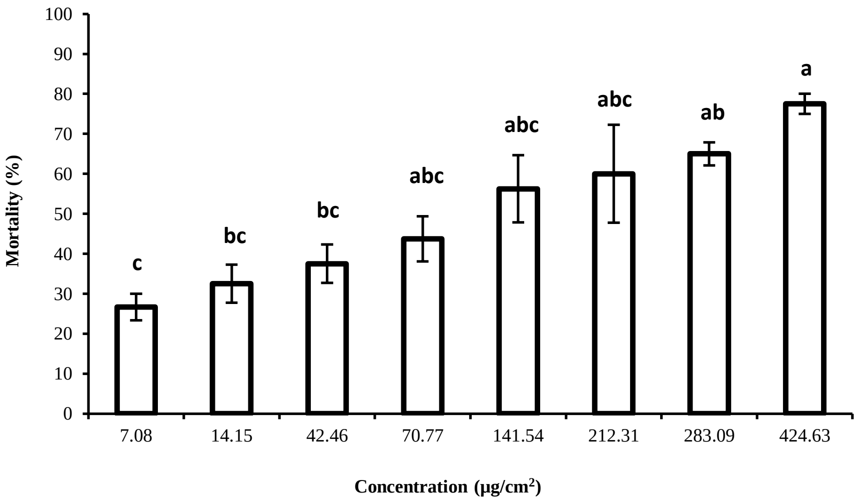


Figure 1. Mortality percentage of *Aphis gossypii* exposed to *Pimpinella stocksii* ethanol extract for 24 h. Means with the different letters are significantly different (p< 0.05) (Tukey post-hoc test after analysis of variance).

Table 1. The Contact toxicity of the *Pimpinella stocksii* ethanol extract on *Aphis gossypii* Glover after 24 hours

No of insects	95% CL	χ^2 (df)	Probability	LC_{50} (μg/cm^2)	Slope ± SE
390	(52.98-126.66)	2.73 (6)	0.84	82.57	0.72 ± 0.13

CL: Confidence limit, χ^2: Chi-square test, df: degrees of freedom and SE: standard error

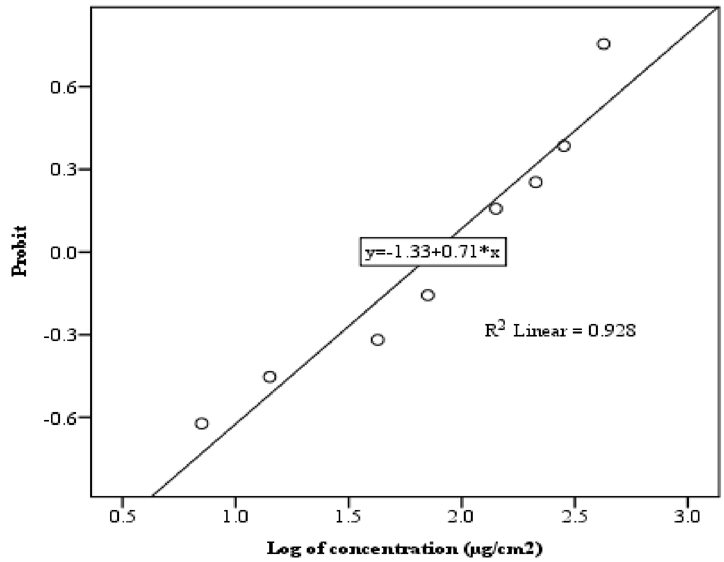


Figure 2. Mortality probit line and 95% confidence limits for *Pimpinella stocksii* on adult *Aphis gossypii*.

Studies indicated that no report suggesting the contact toxicity of ethanol extracts of *P. stocksii* on insects has been disclosed yet. However, the insecticidal activities of other *Pimpinella* species have been reported in several studies (Knio et al., 2007; Tunç and Şahinkaya, 1998). Tunç and Şahinkaya found that anise essential oils (*Pimpinella anisium* L.) were found to be effective fumigants against the cotton aphid (*Aphis gossypii* Glover) and *Tetranychus cinnabarinus* Boisd.

3.2. Qualitative phytochemical screening of plant extract

Preliminary phytochemical analysis showed the presence of various bioactive and insecticidal constituents in *P. stocksii*, like glycosides (anthraquinones), flavonoids, steroids, saponins, and triterpenoid compounds. But tannin (hydrolysable and condensed tannins) was not detected.

It has also been suggested that plant secondary metabolites may be involved in plant defense against insect pests. Similar to our results, phenylpropanoids (Reichling et al., 1991; Tabanca et al., 2005), flavonoids (Özbek et al., 2015), terpenes (Burkhardt et al., 1986), triterpene saponins and steroids (Özbek et al., 2015) were reported form other plants of genus *Pimpinella* in the previous phytochemical studies.

The insecticidal activities of some of these compounds were reported by Reichling *et al.*, 1991 and Tabanca *et al.*, 2005. Both the extracts and essential oils of *Pimpinella* are known to have a high content of pseudoisoeugenol type phenylpropanoids, which is unique to the genus (Sajjadi et al., 2015; Reichling et al., 1991; Knio et al., 2007; Tabanca et al., 2005). In fumigation tests, Anetol phenylpropanoid, the most important component of anise, was very efficient in controlling *Aedes aegypti* and *Culex pipiens* L. (Knio et al., 2007).

Flavonoids and other phenolic compounds have extensive distribution in plants, and various biological activities of these compounds, including insecticidal (Céspedes et al., 2014; Ghaly et al., 2014; Upasani et al., 2003), antioxidant, anti-microbial, and anti-inflammatory types (Jamshidi et al., 2010), have been reported in many surveys.

It has been proven that the flavonoids isolated from the methanolic extracts of the leaves of *Kalanchoe beharensis* and *K. longiflora* family Crassulaceae, has a high degree of inhibitory activity on pupal formation and adult emergence of cotton leaf worm, *Spodoptera littoralis* (Ghaly et al., 2014). The isolated flavonoids from aqueous leaf extract of *Ricinus communis* L. (Euphorbiaceae), showed potential insecticidal, ovicidal and oviposition deterrent activities against *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) (Upasani et al., 2003). Céspedes *et al.*, 2014, found that extracts from *Calceolaria* that contained secondary metabolites, including flavonoids, revealed insecticidal properties against *Spodoptera frugiperda* and *Drosophila melanogaster*. Flavonoids in particular have also been found to affect insect ecdysone-20 monoxygenase, which is responsible for the biosynthesis of 20- hydroxyecdysone (Mitchell et al., 1993).

Herbal essences may impact the inhibition of the acetylcholinesterase enzyme and inhibit the aforementioned enzyme (Savelev et al., 2003). Ethanolic extract from the fruits of *Pimpinella anisoides*, an aromatic plant, exhibited activity against acetylcholinesterase, with IC_{50} values of 227.5 μg/ml (Menichini et al., 2009).

4. Conclusion

Due to the toxicity of *Pimpinella stocksii* and its low risk to humans and other mammals, it seems that the extract from this plant could become a proper and viable alternative to conventional chemical control strategies. However, further studies need to be conducted in order to evaluate the safety of this plant before its practical use in insect pest control. Therefore, we can be hopeful that further studies will reveal, in the future by the extraction of active ingredients of *Pimpinella stocksii*, and the possibility of applying an insecticide in integrated pest management to reduce pesticide usage will be generated. These compounds can be applied along with pesticides in integrated pest management. It is also possible to open up a new horizon for producing effective and low-risk pesticides.

Acknowledgments

This study is a part of MSc program at the University of Zabol, Iran. The corresponding author gratefully acknowledges the financial support from the University of Zabol (Grant No 9618-63).

References

Bahraminejad, S., Asestorfer, R.E., Riley, I.T., Schalta, C.J., 2008. Analysis of the antimicrobial activity of flavonoids and saponins isolated from the schools of oats (*Avena sativa* L.). Journal of Phytopathology, 156, 1-7.

Burkhardt, G., Reichling, J., Martin, R., Becker, H., 1986. Terpene hydrocarbons in *Pimpinella anisum* L. Pharmaceutisch Weekblad, 8 (3), 190-193.

Céspedes, C.L., Salazar, J.R., Ariza-Castolo, A., Yamaguchi, L., Ávila, J.G., Aqueveque, P., Kubo, I., Alarcón, J., 2014. Biopesticides from plants: *Calceolaria integrifolia*. Environmental Research, 132, 391-406.

Damalas, C.A., Koutroubas, S.D., 2016. Farmers' exposure to pesticides: Toxicity types and ways of prevention. Toxics 4 (1), 1.

Geris, R., Ribeiro, P.R., Brandão, M.S., Silva, H.H.G., Silva, I.G., 2012. Bioactive natural products as potential candidates to control *Aedes aegypti*, the vector of dengue. In: Rahman A Ed. Studies in natural products chemistry, Vol. 37, Elsevier, Amsterdam, 277-376.

Ghaemi, A., Soleimani jahi, H., Farshbaf moghadam, M., Yazdani, N., Zaki dizaji, H., 2006. Assess the antiviral of the extract of milk thistle flower head growing body control virus Herpes simplex human type 1. Hakim Research Journal, (4), 59-64. (In Persian).

Ghaly, N.S., Mina, S.A., Abdel-Aziz, N.F., Sammour, E.A., 2014. Insecticidal activity of the main flavonoids from the leaves of *Kalanchoe beharensis* and *Kalanchoe longiflora*. Journal of Natural Products, 7, 196-202.

Hossain, M.A., AL-Raqmi, K.A., AL-Mijizy, Z.H., Weli, A.M., Al-Riyami, Q., 2013. Study of total phenol, flavonoids contents and phytochemical screening of various leaves crude extracts of locally grown *Thymus vulgaris*. Asian Pacific Journal of Tropical Biomedicine, 3(9), 705-10.

Jamshidi, M., Ahmadi, H.R., Rezazadeh, S.h., Fathi, F., Mazanderani, M., 2010. Study on phenolicd and anioxidant activity of some selected plant of Mazandaran province. Journal of Medicinal Plants, 9, 177-183. (In Persian).

Knio, K.M., Usta, J., Dagher, S., Zournajian, H., Kreydiyyeh, S., 2007. Larvicidal activity of essential oils extracted from commonly used herbs in Lebanon against the seaside mosquito, *Ochlerotatus caspius*. Bioresource Technology, 99 (4), 763-768.

Krisgnaveni, G., Sailaja, O., Mounika, K., 2014. Identification and estimation of phytochemicals from the plant *Pedicularis bicornuta* leaf extract by uv-spectrophotometry. Research Desk, 3(1), 410-418.

Lamarre, G.P.A., Mendoza, I., Fine, P.V.A., Baraloto, C., 2014. Leaf synchrony and insect herbivory among tropical tree habitat specialists. Plant Ecology, 215, 209–220.

Luo, J.Y., Zhang, S., Wang, L., Lv, L.M., Wang, C.Y., Li, C.H., Zhu, X.Z., Zhou, Z.G., Cui, J.J., 2016. The Distribution and host shifts of cotton-melon aphids in northern China. Plos One, 11(3), e0152103.

Menichini, F., Tundis, R., Loizzo, M.R., Bonesi, M., Marrelli, M., Statti, G.A., Menichini, F., Conforti, F., 2009. Acetylcholinesterase and butyrylcholinesterase inhibition of ethanolic extract and monoterpenes from *Pimpinella anisoides* V Brig. (Apiaceae). Fitoterapia, 80, 297-300.

Mitchell, J.M., Keogh, D.P., Crooks, J.R., Smith, S.L., 1993. Effects of plant flavonoids and other allelochemicals on insect cytochrome P-450 dependent steroid hydroxylase activity. Insect Biochemistry and Molecular Biology, 65, 65–71.

Özbek, H., Güvenalp, Z., Kuruüzüm-Uz, A., Kazaz, C., Demirezer, L.Ö., 2015. Trinorguaian and germacradiene type sesquiterpenes along with flavonoids from the herbs of *Pimpinella cappadocica* Boiss. & Bal. Phytochemistry Letters, 11, 74-79.

Özbek, H., Güvenalp, Z., Kuruüzüm-Uz, A., Kazaz, C., Demirezer, L.Ö., 2016. β-Hydroxydihydrochalcone and flavonoid glycosides along with triterpene saponin and sesquiterpene from the herbs of *Pimpinella rhodantha* Boiss. Natural Product Research, 30(7), 750-754.

Rajashekar, Y., Gunasekaran, N., Shivanandappa, T., 2010. Insecticidal activity of the root extract of *Decalepis hamiltonii* against stored-product insect pests and its application in grain protection. Journal of Food Science and Technology, 47(3), 310-314.

Reichling, J., Merkel, B., Hofmeister, P., 1991. Studies on the biological activities of rare phenylpropanoids of the genus *Pimpinella*. Journal of Natural Products, 54, 1416-1418.

Sajjadi, S.E., Ghanadian, M., Ahmadi, S.h., Shafiyan, S., 2015. Isolation and identification of a new phenylpropanoid derivative from the fruits of *Pimpinella Haussknechtii* and GC-MS analysis of the essential oil. Iranian Journal of Pharmaceutical Research, 14(4), 1233-1239.

Savelev, S., Okello, E., Perry, N.S.L., Wilkins, R.M., Perry, E.K., 2003. Synergistic and antagonistic interactions of anticholinesterase terpenoids in *Salvia lavandulaefolia* essential oil. Pharmacology Biochemistry and Behavior, 75, 661-668.

Tabacian, H., Ravan, S., Bandani, A., 2011. Susceptibilities of two populations of *Aphis gossypii* Glover to selected insecticides. African Journal of Biotechnology, 10(4), 670-674.

Tabanca, N., Bedir, E., Ferreira, D., Slade, D., Wedge, D.E., Jacob, M.R., Khan, I.S., Kırımer, N., Baser, K.H.C., Khan, I.A., 2005. Bioactive constituents from Turkish *Pimpinella* species. Chemistry and Biodiversity, 2(2), 221-232.

Tunç, I., Şahinkaya, Ş., 1998. Sensitivity of two greenhouse pests to vapours of essential oils. Entomologia Experimentalis et Applicata, 86(2), 183-187.

Upasani, S.M., Kotkar, H.M., Mendki, P.S., Maheshwari, V.L., 2003. Partial characterization and insecticidal properties of *Ricinus communis* L foliage flavonoids. Pest Management Science, 59(12), 1349-54.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 7-13

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Ultrasonic waves can have an effect on some of the physiological traits of cowpea when trifluralin is added to the soil

Abbas Nasiri Dehsorkhi [*a], Hassan Makarian [b], Mehrdad Mahlooji [c], Seyed Hassan Mirhashemi [d], Siavash Bardehji [e], Sima Sadat Seyedi [a], Navid Kargar Dehbidi [f]

[a] M.Sc. Graduate of Agroecology, Department of Agronomy and Plant Breeding, Faculty of Agriculture, Shahrood University of Technology, Shahrood, Iran
[b] Department of Agronomy and Plant Breeding, Faculty of Agriculture, Shahrood University of Technology, Shahrood, Iran
[c] Horticulture Crops Research Department, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran
[d] M.Sc. Graduate of Water Engineering, Faculty of agriculture, University of Zanjan, Zanjan, Iran
[e] Ph.D Graduate, Department of Agronomy and Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahan, Iran
[f] Ph.D Candidate of Natural Resources and Environmental Economics, Department of Agricultural Economics, School of Agriculture, Shiraz University, Iran

ARTICLE INFO

Article history:

Received: 21 February 2022

Accepted: 24 March 2022

Available online: 31 March 2022

Keywords:

Carotenoid

Herbicide

Hydro-priming

Leaf nitrogen

Treflan

ABSTRACT

An experiment was conducted at the Faculty of Agriculture, Shahrood University, as a randomized complete block design with four replications to investigate the effect of ultrasonic waves and seed priming on some quality traits of cowpea under soil application of trifluralin. Nine treatments were: T1: control, T2: ultrasonic waves, T3: ultrasonic waves + reduced herbicide dose (1 L ha^{-1}), T4: ultrasonic waves + recommended herbicide dose (2 L ha^{-1}), T5: hydro-priming, T6: hydro-priming + reduced herbicide dose, T7: hydro-priming + recommended herbicide dose, T8: reduced herbicide dose, T9: recommended herbicide dose. The results showed that the effect of treatments was significant on all traits except leaf phosphorus. The maximum chlorophyll a (1.30 mg g^{-1} FW), carotenoid (1.82 mg g^{-1} FW), leaf relative water content (79.9 %), and leaf nitrogen (3.97%) were obtained in ultrasonic treatment, which resulted in a significant increase of 28.7, 22.1, 7.9, and 18.5 percent, respectively, in comparison to the control. In comparison to the ultrasonic treatment, ultrasonic waves + recommended herbicide dose reduced chlorophyll b, RWC, and leaf nitrogen by 29.3, 21.1, and 35.3 percent, respectively. In comparison to herbicide application alone, the combination of ultrasonic waves and the recommended herbicide dose reduced chlorophyll a and total chlorophyll by 29.7 and 22.2 percent, respectively. Overall, the results of the present study showed that pretreating cowpea seeds with ultrasonic waves could increase photosynthesis pigments, relative water content, and leaf N (in the absence of herbicide use).

Highlights

- An experiment was conducted at the Faculty of Agriculture, Shahrood University, as a randomized complete block design with four replications to investigate the effect of ultrasonic waves and seed priming on some quality traits of cowpea under soil application of trifluralin.
- The results showed that the effect of treatments was significant on all traits except leaf P.
- The ultrasonic treatment increased chlorophyll a, carotenoid, RWC, and leaf N by 28.7, 22.1, 7.9, and 18.5 percent, respectively, compared to the control.
- Overall, the results of the present study showed that pretreating cowpea seeds with ultrasonic waves could increase photosynthesis pigments, relative water content, and leaf N (in the absence of herbicide use).

1. Introduction

Cowpea (*Vigna sinensis* L.) is mostly grown in India and West Africa, as well as in warmer South and North America and throughout the tropics and subtropics. The grain of cowpea is very rich and delicious and contains about 22% protein (up to 35%), 1.3 to 2% fat, and 60% to 67% carbohydrates. It has a significant energy value and 340 calories per 100 g of the food. The ratio of protein, carbohydrate, and B

* Corresponding author
E-mail address: abasnasiri110@yahoo.com (A. Nasiri Dehsorkhi)
http://dx.doi.org/10.22034/aes.2022.331872.1025

vitamin varies considerably depending on the variety and seed origin (Fallah, 2010).

One of the biophysical methods of seed priming is the pretreatment of seeds with ultrasonic waves. Continuous shocks of ultrasonic waves increase the permeability of the seed coat, accelerate water absorption, and increase tissue temperature. Increased inflammation rate and tissue temperature in ultrasonic waves-treated seed may be linked to accelerated changes in seed metabolism (Rasouli et al., 2020a). Under the influence of ultrasonic waves, due to heat production, many biochemical changes occur in tissues, including increasing the rate of chemical reactions, increasing the rate of diffusion of substances, and breaking down compounds such as enzymes and killing microorganisms, which results in an increase in rootlet length and weight (Ashnagar et al., 2019). By applying ultrasonic waves to the seeds, the mechanical resistance to the root outlet is removed. These seeds have more time to grow compared to control seeds, so the root length of treated seeds is longer than control seeds (Eisvand and Latifinia, 2020).

The researchers found that pretreatment with ultrasonic waves increased the activity of alpha-amylase, protease, alcohol dehydrogenase, glucose-6-phosphate dehydrogenase, total and soluble proteins, and total sugar concentrations in most treatments compared to the control. Increasing the activity of alpha-amylase, protease, alcohol dehydrogenase, arginase, and glucose-6-phosphate dehydrogenase enzymes increases germination percentage, germination rate, and dry weight of seedlings (Rasouli et al., 2020a). Improvement of seed germination characteristics due to the use of ultrasonic waves has been reported in several studies (Nazari et al., 2014; Ciu and Sung, 2014; Sharififar et al., 2015; Machikowa et al., 2013; Toth, 2012; Miyoshi and Mii, 1988; Wang et al., 2012; Aladjadjiyan, 2011). In another study, the results showed that irradiation of cowpea seeds with ultrasonic waves at two time periods of 4 and 8 minutes led to increased growth characteristics, yield, yield components, and quality characteristics of the plant (Jamshidi, 2016).

Trifluralin (treflan), which is used in soil and before planting, belongs to the family of dinitroanilines and acts by preventing the division and elongation of cells. It is used to control a wide range of broadleaf weeds and weeds of the Gramineae family (Esmaeilnejad Khiavi, 2019). However, this herbicide can have adverse effects on sensitive crops. For example, research has shown that the application of higher concentrations of the herbicide trifluralin reduces leaf chlorophyll content and nitrogen content in cowpea and soybean plants (Behran et al., 1979). The results of another study showed that the application of Treflan herbicide significantly reduces plant height, leaf number, shoot dry weight, and fresh weight of chickpea pods (Rasooli, 2012). In a study of soybean cultivars, the researchers said that with increasing trifluralin consumption, height, leaf area, shoot dry weight, root dry weight, and nodal dry weight decreased significantly, and that the lowest measured value of these traits was obtained with the use of the highest amount of herbicide (Roodi et al., 2009). In sunflower plants treated with trifluralin herbicide, root and stem length, fresh weight, and dry weight of shoots and roots were reduced, which was significant at high concentrations of herbicide (Moradbeigi and Khara, 2011). In another study, the results showed that with increasing the concentration of trifluralin, the content of photosynthetic pigments in plants inoculated with mycorrhizal fungi and not inoculated plants decreased (Esmaeilnejad Khiavi, 2019).

In the results of studies, it looks like priming and ultrasonic waves can be used to help plants grow better. This will help improve the plant's quality characteristics. On the other hand, it seems necessary to evaluate the effect of trifluralin herbicide in soil on primed seeds. Therefore, the aim of this study is to investigate the effects of ultrasonic waves and hydro-priming on photosynthetic pigments, relative leaf water content, nitrogen, and phosphorus of cowpea leaves.

2. Materials and methods

The experiment was performed as a randomized complete block design with four replications in greenhouse conditions in the Faculty of Agriculture, Shahrood University of Technology. Nine treatments were: T1: control, T2: ultrasonic waves, T3: ultrasonic waves + reduced herbicide dose (1 L. ha^{-1}), T4: ultrasonic waves + recommended herbicide dose (2 L. ha^{-1}), T5: hydro-priming, T6: hydro-priming + reduced herbicide dose, T7: hydro-priming + recommended herbicide dose, T8: reduced herbicide dose, T9: recommended herbicide dose.

Table 1. Soil physical and chemical characteristics

Soil texture	Clay	Sand	Silt	Total nitrogen	pH	EC	Potassium	Phosphorus
			%			dS/m	ppm	
Clay loam	30.7	20.1	49.2	0.105	7.79	1.34	181.4	14.4

Seven seeds were sown in pots with a diameter of 25 cm and a height of 30 cm. To create drainage, holes were made in the bottom of the pot, and then coarse-grained sand was poured into the bottom of the pot to a height of 2 cm, and the rest of the pot was filled with field soil. Seeds related to hydro-priming treatment were soaked in water for 7 hours before sowing and then planted in appropriate pots. The seeds were also soaked in water for 7 hours before using ultrasonic waves. To apply ultrasonic waves, an ultrasonic bath (Digital Ultrasonic Model 4820_CD) with a constant frequency of 24 kHz for 6 minutes at ambient temperature in distilled water was used.

The studied traits included chlorophyll a and b, total chlorophyll, carotenoids, relative water content, nitrogen, and phosphorus of the leaf. Finally, after collecting the data, they were analyzed using MSTATC software, and the means were compared using the LSD test at a probability level of 5%. Also, the correlation coefficients of the traits were estimated by SPSS software.

3. Results and discussion

The results of analysis of variance showed that the effect of experimental treatments on chlorophyll a, total chlorophyll, carotenoids, relative leaf water content, and leaf N was significant at one percent probability level and on chlorophyll b at five percent probability level. However, leaf phosphorus was not affected by the treatments (Table 2).

3.1. Chlorophyll a

The highest amount of chlorophyll a (1.3 mg g^{-1} FW) was related to ultrasonic waves treatment, which showed a significant difference with all treatments and compared to the control, it increased by 28.7% (Table 3). By applying ultrasonic waves to the seeds, the mechanical resistance to radicle emergence was removed. These seeds had a long time to grow compared to the control seeds, so the radicle length of the treated seeds was longer than the control seeds (Eisvand and Latifinia, 2020). It seems that using ultrasonic waves to stimulate and increase the germination rate and rapid establishment of the plant can increase the activity of the plant root in the absorption of water and nutrients, which will have a direct effect on chlorophyll content, photosynthesis, and finally plant yield. In this regard, increasing the germination rate due to the use of ultrasonic waves has been reported in several studies (Ciu and Sung, 2014; Goussous et al., 2010; Yaldagard et al., 2008).

Table 2. Analysis of variance for investigated traits of cowpea as affected by trial treatments

SOV	df	Mean Square						
		Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid	Relative water content	Leaf N	Leaf P
Block	3	0.110	0.012	0.066	0.190	49.028	0.519	0.145
Treatment	8	0.225 **	0.028 *	0.403 **	0.239 **	109.817 **	0.759 **	0.159 ns
Error	24	0.006	0.010	0.011	0.003	1.238	0.027	0.137
CV (%)	-	8.3	13.9	6.4	3.7	1.5	4.9	18.7

ns, * and ** are not significant, significant at the 5% and 1% probability levels, respectively.

The lowest amount of chlorophyll a was related to the ultrasonic waves + recommended herbicide dose and hydro-priming + recommended herbicide dose treatments, which were in a statistically significant group (Table 3). The results showed that the cultivation of primed seeds in soil containing a lower concentration of herbicide (reduced dose) produced a higher amount of chlorophyll a compared to the reduced herbicide dose treatment (in the absence of seed priming). However, the cultivation of primed seeds in soil containing a higher concentration of herbicide (recommended dose) resulted in lower chlorophyll production compared to the recommended herbicide dose treatment alone (Table 3). Using ultrasonic waves with the recommended herbicide and hydro-priming with the recommended herbicide significantly cut chlorophyll a by 29.7% and 19.8%. This is compared to the recommended herbicide dose application without pretreatment of seeds (Table 3).

Table 3. Mean comparison for investigated traits of cowpea as affected by trial treatments

Treatments	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid	RWC	Leaf N
	(mg g^{-1} FW)				(%)	
T1	1.01 c	0.71 abc	1.73 b	1.49 c	74.0 c	3.35 cd
T2	1.30 a	0.82 a	2.13 a	1.82 a	79.9 a	3.97 a
T3	1.07 bc	0.73 abc	1.80 b	1.66 b	73.2 cd	3.62 b
T4	0.57 e	0.58 c	1.16 d	1.09 f	63.1 g	2.57 g
T5	1.16 b	0.84 a	2.00 a	1.72 b	76.2 b	3.65 b
T6	1.05 bc	0.74 ab	1.79 b	1.65 b	72.2 d	3.55 bc
T7	0.65 e	0.64 bc	1.29 d	1.20 e	65.3 f	2.87 f
T8	0.89 d	0.65 bc	1.54 c	1.47 c	69.8 e	3.17 de
T9	0.81 d	0.67 bc	1.49 c	1.35 d	69.1 e	3.07 ef

Means within each column followed by the same letter are not at 5% level according to least significance difference (LSD) test.
T1: control, T2: ultrasonic waves, T3: ultrasonic waves + reduced herbicide dose (1 L ha^{-1}), T4: ultrasonic waves + recommended herbicide dose (2 L ha^{-1}), T5: hydro-priming, T6: hydro-priming + reduced herbicide dose, T7: hydro-priming + recommended herbicide dose, T8: reduced herbicide dose, T9: recommended herbicide dose

Under the influence of ultrasonic waves due to heat production, many biochemical changes occur in tissues, including increasing the rate of chemical reactions, increasing the rate of diffusion of materials, breaking down materials such as enzymes, and the destruction of microorganisms, which implies an increase in root length and weight (Ashnagar et al., 2019). It seems that the seeds treated with ultrasonic waves by increasing the root length use the resources in the soil more quickly, which ultimately improves the chlorophyll content of the leaves. There are also more conditions in place to make the herbicide work better on the plant, and this trait has been lessened in the herbicide treatments that have this trait. In this regard, the researchers stated that the main effect of trifluralin is to prevent root growth and the formation of lateral roots. Decreased root growth reduces the absorption of water and nutrients required by the plant and affects the growth of shoots (Roodi et al., 2009). Results showed that when the concentration of trifluralin was increased, the amount of photosynthetic pigments in plants that had been inoculated with mycorrhizal fungi and plants that had not been inoculated with mycorrhizal fungi both decreased (Esmaeilnejad Khiavi, 2019).

3.2. Chlorophyll b

The results showed that the highest amount of chlorophyll b was related to hydro-priming (0.84 mg g^{-1} FW) and ultrasonic waves (0.82 mg g^{-1} FW) (Table 3). In this regard, in a study conducted on cowpea, the results of the use of ultrasonic waves showed that the highest amount of chlorophyll b was obtained in 4 minutes of wave treatment (Jamshidi, 2016). In another study, the results showed that ultrasonic waves and magnetic fields had a statistically significant effect on the amount of chlorophyll in the leaves at a probability level of 1% (Marghaeizadeh et al., 2014).

The results of comparing the means of the treatments showed that the combined application of primed seeds (sonicated and primed with water) with herbicides (especially higher concentrations) significantly reduced chlorophyll b. The combined application of ultrasonic waves and recommended herbicide (2 L ha^{-1}) reduced chlorophyll b compared to ultrasonic waves treatment by 29.3%. Also, the use of hydro-priming with the recommended herbicide (2 L ha^{-1}) cut chlorophyll b by 23.9% when compared to the hydro-priming treatment (Table 3). Chlorophyll content may be down because trifluralin makes plants stop taking iron from their roots to their shoots, which stops chlorophyll synthesis and makes leaves look yellow. In plants that have been treated with trifluralin, a lack of chlorophyll can make them less able to use sunlight and thus less able to store carbon (Amiri et al., 2010). A decrease in wheat chlorophyll b content due to the use of herbicides has also been found (Hana et al., 2015).

3.3. Total chlorophyll

The results showed that the highest chlorophyll content of leaves was related to ultrasonic waves and hydro-priming treatments, which were in a statistically significant group and increased by 23.1% and 15.6%, respectively, compared to the control (no treatment) (Table 3). In this regard, the results showed that the highest amount of total chlorophyll in cowpea was related to hydro-priming and pretreatment of seeds with plasma radiation for 15 seconds, which were in a statistically significant group (Vaziri, 2018).

The lowest total chlorophyll content was related to the combined treatments of ultrasonic waves + recommended herbicide and hydro-priming + recommended herbicide, which were in a statistically significant group and had a significant difference with other treatments. Ultrasonic waves + recommended herbicide dose and hydro-priming + recommended herbicide dose reduced the total chlorophyll by 22.2% and 13.5% relative to only applying the recommended herbicide dose treatment. However, the combined application of these pretreatments with a reduced amount (1 L ha^{-1}) compared to the application of reduced herbicides alone showed a significant increase in total chlorophyll (Table 3). This result can be attributed to the greater effectiveness of the herbicide at higher concentrations in the pretreated seeds. It seems that the use of ultrasonic waves and hydro-priming accelerates the germination of seeds and that increasing the root length causes the plant to use more soil nutrients, thus increasing plant growth. On the other hand, elongation of root length exposes the plant to more herbicides, which reduces the absorption of water and nutrients and consequently reduces the chlorophyll content in herbicide treatments with treated seeds is not unexpected. In this regard, a decrease in chlorophyll content due to the application of higher concentrations of herbicide in sunflower (Sameni et al., 1976) and cowpea and soybeans (Behran et al., 1979) has also been reported.

3.4. Carotenoid

The highest content of carotenoid (1.82 mg g^{-1} FW) was obtained in ultrasonic waves treatment, which showed a significant difference with all treatments and increased by 22.1% compared to the control (no treatment). However, the lowest leaf carotenoid content (1.09 mg g^{-1} FW) was observed in the ultrasonic waves + recommended herbicide dose treatment, which had a significant difference with all treatments (Table 3). The results showed that the combined application of primed seeds (hydro-priming and ultrasonic waves) with a reduced dose of herbicide could significantly increase carotenoid compared to the control. Ultrasonic waves + reduced herbicide dose and hydro-priming + reduced herbicide dose treatments significantly increased carotenoid by 11.4% and 10.7%, respectively, compared to the control (Table 3). The treatment with a recommended dose of herbicide (2 L ha^{-1}) significantly reduced carotenoid by 8.2% compared to the treatment with a reduced dose of herbicide (1 L ha^{-1}). Also, the results showed that ultrasonic waves + recommended herbicide dose treatment significantly reduced carotenoid by 9.2% compared to hydro-priming + recommended herbicide dose treatment (Table 3).

In the present study, seeds were soaked in water for the same period in hydro-priming and ultrasonic waves treatments. Seeds that were exposed to ultrasonic waves in addition to soaking, due to their more permeable shells compared to hydro-primed seeds, were exposed to higher amounts of herbicides in a shorter time, and herbicide with faster penetration into these seeds caused adverse effects on the plant. In this regard, studies have shown that with increasing the concentration of trifluralin, the content of carotenoids in plants inoculated and not inoculated with mycorrhizal fungi decreased (Esmaeilnejad Khiavi, 2019). The use of higher doses of herbicide also reduced the total chlorophyll and carotenoid in chickpea (Khan et al., 2006).

3.5. Leaf relative water content (RWC)

The results showed that the highest RWC by 79.9% was related to ultrasonic waves treatment, which in comparison with hydro-priming and control treatments, had a significant increase of 4.8 and 7.9%, respectively (Table 3). In this regard, research has shown that the hydro-priming of cowpea seeds causes a significant increase in the RWC in the presence of weeds (Vaziri, 2018). Therefore, it can be concluded that primed seeds grow longer roots than untreated plants, which leads to better root efficiency, more water uptake, and more relative water content of the leaves.

The lowest RWC (63.1%) was observed in the ultrasonic waves + recommended herbicide dose treatment, which had a significant difference with all other treatments. The combined application of ultrasonic waves and recommended herbicide dose treatment (2 L ha^{-1}) reduced the relative water content compared to ultrasonic waves and control treatments by 21.1% and 14.8%, respectively. Also, the results showed that the ultrasonic waves + recommended herbicide dose treatment compared to the hydro-priming + recommended herbicide dose treatment caused a significant reduction in the RWC by 3.4% (Table 3). Based on the results, it is possible that the positive effects of hydro-priming and ultrasonic waves on seed germination and the increase in root length caused the seedlings to be exposed to more herbicide, and subsequently, in the later stages, the rootlet longitudinal growth and thus its access to soil moisture decreased. In this regard, research results have shown that with increasing trifluralin concentration, the relative water content in both inoculated and non-inoculated plants decreased, although mycorrhizal treatments had a higher relative water content than non-mycorrhizal plants (Esmaeilnejad Khiavi, 2019). The results of estimating the correlation coefficients of the traits showed a significant positive correlation between the RWC and chlorophyll a (0.92^{**}), chlorophyll b (0.40^{*}), total chlorophyll (0.87^{**}), and carotenoid (0.90^{**}) (Table 4). Considering the significant positive correlation between chlorophyll content and relative water content, it can be inferred that pretreatment of cowpea seeds will increase plant water uptake by improving root growth, which will ultimately improve growth and photosynthetic pigments. In this regard, a significant positive correlation has been reported between leaf chlorophyll and RWC in cantaloupe (Nasiri Dehsorkhi et al., 2020).

3.6. Leaf nitrogen

The results showed that the highest leaf N (3.97%) was related to ultrasonic waves treatment, which in comparison with hydro-priming and control treatments, had a significant increase of 8.7% and 18.5%, respectively. The lowest leaf N (2.57%) was observed in the ultrasonic waves + recommended herbicide dose treatment, which had a significant difference with all treatments (Table 3). Ultrasonic waves increase growth indices, especially root length in seedlings, which can play an important role in obtaining moisture and nutrients from the environment (Rasouli et al., 2020b). Jamshidi (2016) found that the best way to get the most protein from cowpea seeds was to not stress them out and use ultrasonic waves for 4 minutes.

The combined application of ultrasonic waves with the reduced dose of herbicide could significantly increase leaf N compared to the control treatment. However, the combination of primed seeds with the recommended dose of herbicide significantly reduced leaf N. The combined application of ultrasonic waves and recommended herbicide dose (2 L ha^{-1}) reduced leaf N compared to ultrasonic and control treatments by 35.3% and 23.3%, respectively. The ultrasonic waves and recommended herbicide dose treatment in comparison with hydro-priming and recommended herbicide dose treatment caused a significant reduction of leaf N by 10.5% (Table 3).

In this case, research results have shown that the application of higher concentrations of trifluralin herbicide reduced leaf chlorophyll content and nitrogen content in cowpea and soybean (Behran et al., 1979). The application of higher doses of herbicide reduced the nitrogen content of chickpea (Khan et al., 2006). With the application of Lentagran, Persoit, and Treflan herbicides, the nitrogen content of chickpea shoots decreased by 6%, 50%, and 78%, respectively (Rasooli, 2012). The results of trait correlation showed that leaf N had the highest significant positive correlation (0.85^{**}) with total leaf chlorophyll (Table 4). Due to the fact that nitrogen is involved in the structure of chlorophyll, the observed correlation is not far from what one would expect.

Table 4. Correlation coefficients for the investigated traits of cowpea

	1	2	3	4	5	6	7
1- Chlorophyll a	1						
2- Chlorophyll b	0.42^{**}	1					
3- Total chlorophyll	0.94^{**}	0.70^{**}	1				
4- Carotenoid	0.88^{**}	0.43^{**}	0.85^{**}	1			
5- RWC	0.92^{**}	0.40^{*}	0.87^{**}	0.90^{**}	1		
6- Leaf N	0.83^{**}	0.54^{**}	0.85^{**}	0.79^{**}	0.77^{**}	1	
7- Leaf P	0.31^{ns}	0.49^{**}	0.42^{**}	0.45^{**}	0.35^{*}	0.22^{ns}	1

ns, * and ** are not significant, significant at the 5% and 1% probability levels, respectively.

4. Conclusion

Overall, the results of the present study showed that the cultivation of cowpea seeds pretreated with ultrasonic waves and hydro-priming in soil treated with trifluralin herbicide reduced photosynthetic pigments, relative leaf water content, and leaf N content. Primed seeds appear to initiate enzymatic activities for germination. Therefore, after cultivation in the soil, they receive trifluralin more quickly and in a shorter time. The herbicide immediately affects the germination processes and stops or reduces germination. On the other hand, unprimed seeds have barriers, like shell and embryonic coatings, which stop or slow down the herbicide from getting into the seed and getting into the seedling.

References

Aladjadjiyan, A., 2011. Ultrasonic stimulation of the development of lentils and wheat seedlings. Romanian Journal of Biophysics, 21(3), 179-187.

Amiri, S., Kazemitabaar, S.K., Ranjbar, G., Azadbakht, M., 2010. The effect of trifluralin and colchicine treatments on morphological characteristics of jimsonweed (*Datura stramonium* L.). Trakia Journal of Sciences, 8(4), 47-61.

Ashnagar, N., Mir Mahmoodi, T., Jalilnejhad, N., 2019. Effects of electromagnetic field and ultrasonic waves on seed germination, seedling characteristics and essence percent of Thymes (*Thymus vulgaris* L.). Journal of Crop Ecophysiology, 13(1), 57-72. (In Persian).

Behran, Sh., Maftoun, M., Sheibany, B., Hojjati, S.M., 1979. Effect of fertilizer-N and herbicides on the growth and N content of soybeans and cowpeas. Agronomy Journal, 71, 533-538.

Ciu, K.Y., Sung, J.M., 2014. Use of ultrasonication to enhance pea seed germination and microbial quality of pea sprouts. International Journal of Food Science and Technology, 49, 1699-1706.

Eisvand, H.R., Latifinia, E., 2020. Effects of hydropriming and ultrasonic waves on seed leakage and germination of Artemisia (*Artemisia aucheri* L.). Iranian Journal of Seed Science and Research, 7(2), 179-190. (In Persian).

Esmaeilnejad Khiavi, N., 2019. Protective effects of mycorrhizal fungi, gamma amino butyric acid (GABA) and magnetic water on squash (*Cucurbita pepo*) morphological, physiological and biochemical charachterics under herbicide trifluralin induced to toxicity. PhD thesis in Plant Physiology, Department of Biology, Urmia University. (In Persian).

Fallah, S., 2010. Agronomy (General and Special). Shahrekord University Press. (Translated). (In Persian).

Goussous, S.J., Samarah, N.H., Alqudah, A.M., Othman, M.O., 2010. Enhancing seed germination of four crops species using an ultrasonic technique. Experimental Agriculture, 46, 231-242.

Hana, S., Leila, M.A., Nedjoud, G., Reda, D.M., 2015. Physiology and biochemistry effects of herbicides Sekator and Zoom on two varieties of wheat (Waha and HD) in semi-arid region. Annual Research & Review in Biology, 5(5), 449-459.

Jamshidi, M., 2016. Interaction of ultrasonic waves and salicylic acid on drought-stressed cowpea. MSc thesis, Faculty of Agriculture, Shahrood University of Technology. (In Persian).

Khan, M.S., Zaidi, A., Rizvi, P.Q., 2006. Biotoxic effects of herbicides on growth, nodulation, nitrogenase activity, and seed production in chickpeas. Communications in Soil Science and Plant Analysis, 37, 1783–1793.

Machikowa, T., Kulrattanarak, T., Wonprasaid, S., 2013. Effects of ultrasonic treatment on germination of synthetic sunflower seeds. International Journal of Biological, Biomolecular, Agricultural Food and Biotechnological Engineering, 7(1), 1-3.

Marghaeizadeh, Gh., Gharineh, M.H., Fathi, Gh., Abdali, A.R., Farbod, M., 2014. Effect of ultrasound waves and magnetic field on germination, growth and yield of *Carum copticum* (L.) C. B. Clarke) in lab and field conditions. Iranian Journal of Medicinal and Aromatic Plants, 30(4), 539-560. (In Persian).

Miyoshi, K., Mii, M., 1988. Ultrasonic treatment for enhancing seed germination of terrestrial orchid, Calanthediscolor, in a symbiotic culture. Scientia Horticulturae, 35, 127-130.

Moradbeigi, H., Khara, J., 2011. An evaluation of some physiological and biochemical parameters resulting from interaction of herbicide trifluralin and mychorrizal colonization by Glomus versiforme in sunflower plants (cv. Lakomka). Journal of Plant Biology, 3(10), 59-70. (In Persian).

Nasiri Dehsorkhi, A., Varnaseri Ghandali, V., Makarian, H., Ramezan, D., Estekhdami, P., 2020. The effect of poultry manure and zinc sulfate on growth and yield of cantaloupe (*Cucumis melo* L.) in competition with weeds. Horticultural Plants Nutrition, 2(2), 46-69. (In Persian).

Nazari, M., Sharififar, A., Asghari, H.R., 2014. *Medicago scutellata* seed dormancy breaking by ultrasonic waves. Plant Breeding and Seed Science, 69(1), 15-24.

Rasooli, R., 2012. The effect of Lentagran, Persoit and Treflan herbicides on growth, nodulation and nitrogen fixation of three varieties of chickpea (*Cicer aritinium* L.). MSc Thesis, Ferdowsi University of Mashhad. (In Persian).

Rasouli, F., Gholipour, M., Jahanbin, K., Asghari, H.R., 2020a. Effect of ultra-sonic waves on germination, some germination enzymes and biochemical parameters of *Echinacea purpurea* L. seed. Iranian Journal of Seed Science and Research, 7(1), 41-54. (In Persian).

Rasouli, F., Gholipour, M., Asghari, H.R., Hojjati, M., 2020b. The effect of imbibition time and ultrasound pretreatment on germination and biochemical feature of *Echinacea purpurea* L. Iranian Journal of Seed Science and Research, 7(2), 205-215. (In Persian).

Roodi, D., Ghadiri, H., Maftoon, M., 2009. Effect of trifluralin and iron on morphological characteristics and iron absorption of soybeans. Weed Research Journal, 1(1), 25-36. (In Persian).

Sameni, A.M., Maftoun, M., Hojjati, S.M., Sheibany, B., 1976. Effect of fertilizer-N and herbicides on the growth and N content of sunflower. Agronomy Journal, 68, 285-288.

Sharififar, A., Nazari, M., Asghari, H.R., 2015. Effect of ultrasonic waves on seed germination of *Atriplex* *lentiformis*, *Cuminum cyminum*, and *Zygophyllum eurypterum*. Journal of Applied Research on Medicinal and Aromatic Plants, 2(3), 102-104.

Toth I., 2012. The effects of ultrasound exposure on the germination capacity of birds foot trefoil (*Lotus corniculatus* L.) seeds. Romanian Journal of Biophysics, 22(1), 13-20.

Vaziri, R., 2018. Effect of seed pre-treatment with cold plasma on the growth and yield of cowpea (*Vigna sinensis* L.) in competition with weeds. MSc Thesis, Faculty of Agriculture, University of Shahrood. (In Persian).

Wang, Q., Chen, G., Yersaiyiti, H., Liu, Y., Cui, J., Wu, C, Zhang, Y., He, X., 2012. Modeling analysis on germination and seedling growth using ultrasound seed pretreatment in switchgrass. PLoS ONE, 7(10), e47204.

Yaldagard, M., Mortazavi, S.A., Tabatabaie, F., 2008. Application of ultrasonic waves as a priming technique for accelerating and enhancing the germination of barley seed: optimization of method by the Taguchi approach. Journal of Institute of Brewing, 114(1), 14-21.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 15-24

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Role of mechanization on the sustainability of sugar beet production using emergy approach

Samin Fallahinejad [a], Mohamad Armin [*a]

[a] Department of Agronomy and Plant Breeding, Sabzevar Branch, Islamic Azad University, Sabzevar, Iran

ARTICLE INFO

Article history:
Received: 2 February 2022
Accepted: 15 April 2022
Available online: 17 April 2022

Keywords:
Cropping systems
Emergy analysis
Sugar plant
Sustainability
Traditional production

ABSTRACT

Over 40% of agriculture on the planet is conducted on smallholder farms with low productivity but high production costs. As a result, governments have attempted to replace traditional farms with mechanized farms in recent years. The sustainability of three distinct production systems, namely traditional, semi-mechanized, and mechanized cultivation systems, were assessed using emergy approach in 2017-2018. These systems were practiced over areas of less than 2 ha, 2-10 ha, and more than 10 ha, respectively. The results indicated that the total emergy values for sugar beet production were 2.84E+16, 4.57E+16, and 6.21E+16 sej ha^{-1} yr^{-1}, respectively, for traditional, semi-mechanized, and mechanized systems. Historically, the proportion of renewable natural inputs, non-renewable natural inputs, and purchased inputs in total input emergy was 8.88E+14, 8.88E+15, and 1.86E+16 sej ha^{-1} yr^{-1}, respectively. However, the proportion of renewable natural inputs, non-renewable natural inputs, and purchased inputs was 9.06E+14, 2.56E+16, and 3.57E+16 sej ha^{-1} yr^{-1}, respectively, in mechanized farms. As the rate of mechanization increased, the unit emergy value, renewable emergy ratio, emergy exchange ratio, emergy yield ratio, emergy input ratio, and environmental loading ratio increased by 11.5, 77, 13.7, 11.9, and 1.32 percent, respectively; while the renewable emergy ratio and environmental sustainability index decreased by 20.1 and 28.9 percent, respectively. In general, the results indicated that mechanization protected the environment more than traditional cultivation.

Highlights

- Emergy approach was used to analyze the sustainability of three separate production systems: traditional, semi-mechanized, and mechanized.
- The overall emergy values for traditional, semi-mechanized, and mechanized sugar beet were 2.84E+16, 4.57E+16, and 6.21E+16 sej ha-1 yr-1, respectively.
- As the rate of mechanization increased, the UEV, R%, EER, EYR, EIR, and ELR increased; whereas the ESI index decreased.

1. Introduction

The agricultural sector serves as the largest trusted source of food production and security in society (Jelsøe. and Kjærgård, 2016). With the increasing population and rising demand for food urging farm labor recruitment from any other economic sector due to labour force migration from the agricultural sector, the use of machine labor has become commonplace for numerous of the most demanding agricultural activities. Agricultural mechanization is the use of machinery in the different stages of agricultural and livestock production in order to increase production speed, decline costs, reduce production time, facilitate operations, optimize agricultural inputs, and augment production in general (Kohansal and Mansoori, 2013). Mechanization is the basic condition representing the transition from traditional farming to modern farming. Catering to the needs of the current growing population and, in general, preventing the global food security crisis will not be possible by resorting to traditional methods. Over a 35% increase in crop production and a 50–60% decrease in production resulted from mechanization.

It is believed that the agricultural labor force will become scarce and costly, and production costs in this sector will increase in the future. Therefore, the research path in this field is tending towards alleviating labor

* Corresponding author
E-mail address: Armin@iaus.ac.ir (M. Armin)
http://dx.doi.org/10.22034/aes.2022.327793.1019

dependency and production costs and enhancing sustainable productivity (Schmitz and Moss, 2015). In this regard, agricultural mechanization is a critical factor for achieving highly efficient production and helping feed the growing population on earth. This technology has made the production of agricultural products more valuable through the more efficient use of labor, as well as timely operations and input management (Bagheri and Moazzen, 2009). According to the studies, agricultural mechanization increases crop yield, cultivated land area, labor productivity and use inside and outside agricultural lands (such as in machinery manufacturing industries), the profitability of crop production through timely and efficient production, and optimal uses of inputs and outputs (Moazzen, 2010). However, some researchers maintain that excessive applications of machinery and non-renewable resources like fossil fuels and fertilizers for producing more agricultural products endanger the sustainability of agricultural systems (Araujo et al., 2013).

Over the past decades, commercial farming has replaced traditional farming as the dominant mode of agricultural production in Iran (Tabar et al., 2010). Modern farming systems include ecosystems controlled by humans. These systems, on the one hand, are based on environmental inputs such as light, wind, water, and soil, and on the other hand, on such inputs as fertilizers, pesticides, fuel, electricity, equipment, and machinery that are purchased by farmers and included as economic inputs (Bazrgar et al., 2011). Demands for more food production have led to the use of chemical fertilizers, pesticides, agricultural machinery, and environmental resources like land and water resources extensively utilized in food production. Standard agricultural systems are highly dependent on intensive energy consumption, which is one of the main causes of such problems as global warming in most developed and developing countries (Notarnicola et al., 2017). Unfortunately, most of the time, farmers consume more energy to increase crop production, yet they do not know enough about how to enhance energy consumption efficiency (Ozkan et al., 2004). Increasing the use of environmental resources is incompatible with the sustainability of production systems. Any system using more environmental resources, especially non-renewable ones, would be less sustainable in any way (Hanif et al., 2019). Sustainability in agriculture is the ability to maintain and sustain long-term production and successful resource management to meet changing human needs, preserve environmental qualities, and protect natural resources (Jelsøe and Kjærgård, 2016).

Today, sustainability has become one of the most common terms in economic science, social science in general, and environmental science in particular (Moore et al., 2005). Accordingly, the ecosystem of agricultural systems must be carefully designed and managed so that optimal productivity and sustainability can be maintained by the improved systems. Production stability measurement is a quantitative approach to determining the desirable or undesirable effects of changes in a system. Among the different methods of measuring production sustainability, the use of emergy analysis technique as a suitable approach has been of interest to researchers. Emergy is a type of energy analysis that measures all the sources of the biosphere and human activities that are directly and indirectly utilized to obtain a particular product (Brown et al., 2016). Emergy analysis is an ecological estimation method that comprehensively estimates all the inputs, including energy, consumed natural resources, and financial and human costs, by using units of emergy usually measured in solar energy units (Odum et al., 2000). The impacts of mechanization on the stabilities of production systems using emergy analysis have not been investigated so far. Nonetheless, the emergy analyses of various production systems differing in the amounts of resources focused on many types of research. In their study, Ortega reported more sustainable soybean cultivation based on the biologic (ecological and organic) system than the industry (agrochemical and no-till using herbicide). Martin et al. (2006) compared three agricultural systems, including two conventional maize and blackberry cropping systems and one domestic system. They found that fertilization and irrigation of corn production (95% of purchased emergy input) were the most significant emergy inputs across the three systems. Sustainability indices for the corn, blackberry, and indigenous systems were determined to be 0.06, 0.65, and 115.98, respectively. Despite its high stability, the energy yields of the indigenous system were 14 and 53 times less than those of the blackberry and corn systems. In the two substantial and commercial rapeseed systems, it was reported that the ecological sustainability of a commercial rapeseed production system could be ameliorated by improving soil organic matter and preventing its degradation (Amiri et al., 2019). Evaluations of 12 different maize production systems under varied (low, high, and bio-tech) input intensities showed that the total amounts of emergy were enhanced by increasing the input levels. Accordingly, the total emergy in the low-input systems was 3.37E+15 sej ha-1 yr-1, whereas it was increased by 11.73 E+15 sej ha-1 yr-1 (248%) in the biotech production systems (Ortega et al., 2005). In the different bean production systems based on ecological, integrated, and low, medium, and high-input management practices, Asgharipour et al. (2019) reported that the ecological cropping systems had more sustainability and fewer more minor environmental impacts compared to high-yield cropping systems. Ecological production systems have provided more ecosystem services than other cropping systems. In a study on the emergy assessments of five different maize production systems (control, chemical fertilizer, poultry manure biochar, rice hull biochar, and sugarcane filter press), it was reported that the most emergy was consumed in the corn production with poultry manure biochar. Stability was higher for the systems with more renewable sources and fewer purchased inputs (Moonilall et al., 2020). Jiang et al. (2007) using emergy analysis, the sustainability and development of China's agricultural system were examined, and Chinese agriculture was reported to occur in a transitional stage from traditional to modern systems. Meanwhile, the pressure on natural resources was increased by consuming such resources as soils, fuels, and fertilizers. According to the results of this research, the total flow of emergy applied in Chinese agriculture based on the environment and economy had increased from 2000 to 2004.

Sugar beet (Beta vulgaris L.) is one of the strategic products, and together with sugar cane, serves as the primary source of sugar production. The sugar content of sugar beet is higher than that of sugar cane (about 25%). About a quarter of the sugar produced in the world comes from sugar beet. In addition to sugar production, this product has some by-products, such as pulp and molasses, which are used for animal feed and in the industry, respectively (Erdal et al., 2007). Khorasan Razavi (21%), Fars (13.8%), Kermanshah (6.5%), Hamadan (3.8%), and Lorestan (3.6%) Provinces have the first to fifth ranks of sugar beet production in Iran, respectively (Anonymous, 2021). These five provinces account for 83.3% of sugar beet production in Iran. Sugar beet is cultivated in Iran on very small farms (less than one hectare) and large farms (more than 50 hectares). Small farm cultivation is primarily dependent on family labor and the use of livestock manures and renewable environmental resources, whereas large farm cultivation is primarily dependent on machinery and the use of non-renewable environmental resources such as chemical fertilizers. Today, the tendency to use mechanization in agricultural lands is greatly expanding. The use of mechanization will be accompanied by a change in energy consumption per unit area. Therefore, this study was conducted to evaluate the sustainability of sugar beet production based on different production systems.

2. Materials and methods

2.1. Study area description

Jouvin County is located at 57◦ 34' East latitude and 36◦ 22' North longitude, with a height of 980 m above sea level. The average monthly temperature in the city varies from -3 ◦C in January to 40 ◦C in July, with an annual average temperature of 17.8 ◦C. Its average annual wind speed and average rainfall are 3.2 ms-1 and 250 mm, respectively.

Face-to-face questionnaires were used to collect data for this study from farmers in traditional and semi-mechanized farms, as well as experts from Barakat Agricultural Company in mechanized farms. Cochran's formula based on Eqs. 1 and 2 was applied to determine the number of samples (Cochran, 1997).

$$n = \frac{N(s \times t)^2}{(N-1)d2 + (s \times t)^2} \quad \text{Eq. 1}$$

$$n = \frac{t \times s}{\sqrt{n}} \quad \text{Eq. 2}$$

In these Eqs., t: 1.96 (95% confidence level), s: prediction of community standard deviation, d: optimal probability accuracy, n: community volume, and n: sample size.

In this research, 67, 20, and 5 farms were investigated for traditional, semi-mechanized, and mechanized systems (all fully mechanized farms), respectively. The definitions of traditional, semi-mechanized, and mechanized fields were determined based on Bazrgar's study (2011). A summary of field operations in the three planting systems is given in Table 1.

Table 1. Characteristics of sugar beet production systems

Operations	Subnational	Semi-mechanized	Mechanized
Average area	<2	2-15	>15
Planting date	5April- 5 May	20 March- 9 April	1 March-15 March
Machinery used	Moldboard plow, disc plow, leveler, Chisel, Seed drills	Subsoiler, moldboard plow, disc plow, leveler, Chisel, Sprayer, Seed drills and manual harvester	Subsoiler, moldboard plow, disc plow, leveler, Manure spreaders, Chisel, Sprayer, Seed drills and Sugar beet harvester
Harvesting period	December-July	December-May	November-May

2.2. Emergy analysis method

The first step in analysing emergy was to designate the spatial and temporal boundaries of the investigated systems and draw an emergy diagram to classify the inputs of the systems into renewable, non-renewable, local, and imported sources. Figure. 1 shows the cumulative emergy flow diagram for the production systems in this study. The driving inputs to the agricultural system come from two sources: environmental inputs and inputs from the human economy. In our model, the rectangular box displays the system's boundaries. On the left and right sides of the model, the natural inputs and valuable performance of the manufacturing systems are shown, respectively, while market inputs are listed at the top.

To analyze the production systems and calculate the indices, the inputs were divided into four types (Odum et al., 2000): free renewable environmental inputs (R), such as sun, rain, and wind; non-renewable environmental inputs (N), such as irrigation water, soil erosion, and soil organic matter losses; non-free renewable inputs (FR), such as seeds and manure purchased; and non-free inputs (FN), such as fertilizer, pesticide, machinery, fuel, and electricity.

To obtain the emergy value of each input, the raw information of each input was multiplied by their conversion coefficients in terms of joules, grams, or IR Rials. Total emergy was the sum of all energies from all the independent inputs. Finally, emergy indices were calculated and interpreted to evaluate the systems (Table 3).

After calculating all the input and output currents of emergy and materials for each production system, the obtained values were converted into units of emergy (sej) by multiplying their corresponding coefficients. These conversion coefficients were adapted for each item from the previous studies. Different conversion coefficients were calculated for each case based on the varied sources.

The coefficients were selected from the studies that were most similar to the conditions of this study (Agostinho et al., 2008; Amiri et al., 2019, 2020; Asgharipour et al., 2019; Moonilall et al., 2020; Odum et al., 2000).

Various emergy-based indices have been used to assess the environmental, ecological, and economic status of systems. The indices utilized in this research are presented in Table 2.

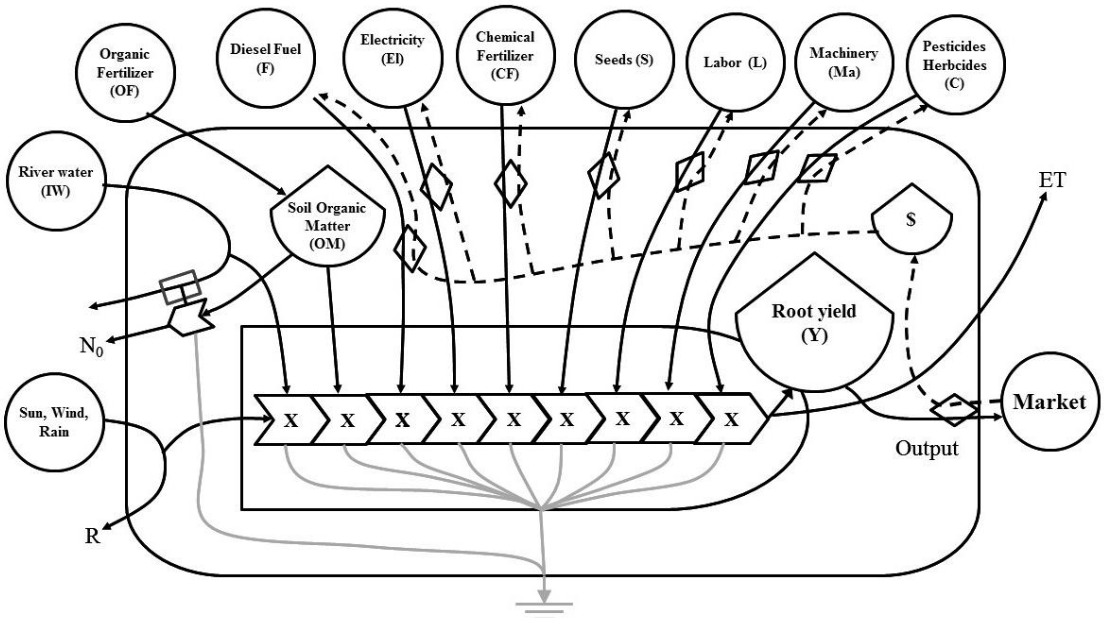


Figure 1. Emergy flow diagram of the sugar beet production systems in Jouvin, Iran.

Table 2. Indicators used to compare different sugar beet production systems

Indices	Formula	Specifications
Renewable environmental inputs	R	Local potentially renewable flows
Non-renewable environmental inputs	N	Local potentially renewable flows from free local resources that are being used in a non-renewable manner
Renewable purchased inputs	F_R	Renewable flows from purchased resources
Non-renewable purchased inputs	F_N	Non-renewable flows from purchased resources
Economic yield (J ha^{-1} or g ha-1)	E	Root yield of crops sold on the market
Market value of the economic yield (Rials g^{-1})	Y_M	Money received for the crops when sold.
Total emergy input	$U = R + N_0 + F_R + F_N$	Total emergy resources required to support the production system
Total emergy output	$Y = R + N_0 + F_R + F_N$	Total emergy of system products
Unit emergy value for economic yield	UEV =U / E (sej J^{-1})	Amount of emergy required to produce an economic output in joules, a measure of system efficiency.
Specific emergy	SE = U / W	Amount of emergy required to produce an output unit measured in grams. W is the accessible weight of the product.
Emergy renewability	$\%R = (R+F_R) / U$	Percentage of renewable emergy used by the system
Emergy exchange ratio	$EER_Y = Y_M / U$	Emergy exchange ratio based on crop yield per unit area
Emergy yield ratio	$EYR = U / F_R+F_N$	Ability of a process to use local renewable and non-renewable resources when economic resources from outside are invested in the system as a capital input.
Environmental loading ratio	$ELR = (N+F_N) / (R+F_R)$	The ratio of non-renewable emergy to renewable emergy used by the system. ELR* is an inverse measure of the sustainability of the system.
Emergy sustainability ratio	ESI = EYR / ELR	The ratio of system yield per unit of purchased input to the total loading on the local system. Systems with higher yields and lower loadings are more sustainable.
Emergy investment ratio	EIR = (FN + FR) / R	The ratio of purchased resources to renewable environmental resources, alone.

3. Results and discussion

3.1. Emergy flow structure in various production systems

3.1.1. Renewable environmental resources

Renewable sources in the three cropping systems studied are shown in Tables 3 and 4. As the intensity of mechanization increases, the percentage of use of renewable resources in the agricultural system declines. The highest share of the renewable environmental resources usage was observed in traditional cultivation, which was 51.20% and 114% more than semi-mechanized and mechanized cultivation, respectively (Figure. 2). The higher share of environmental renewables in the traditional cropping system can be attributed to the lower share of purchased resources compared to the other two cropping systems.

Table 3. Natural and economic flows of different production systems of sugar beet (units. ha^{-1}). The unit and the renewability factor (fraction renewable energy)

		Ren Factor	Traditional	Semi-mechanized	Mechanized
Renewable environmental inputs					
Solar energy	J	1	3.97E+13	4.05E+13	4.41E+13
Wind, kinetic energy	J	1	8.64E+10	9.25E+10	1.04E+11
Rain, chemical energy	J	1	2.89E+10	3.04E+10	2.94E+10
Evapotranspiration	J	1	2.95E+10	3.28E+10	2.99E+10
Non-renewable environmental inputs					
SOM reduction	J	0	6.96E+10	1.23E+11	1.23E+11
Soil erosion	g	0	6.00E+05	6.00E+05	6.00E+05
Irrigation	J	0	8.33E+09	6.91E+10	6.91E+10
Purchased inputs					
Human labour	J	0.1	1.89E+09	1.16E+09	9.43E+08
Machinery	g	0	1.34E+03	4.59E+03	1.54E+04
Fossil fuel and lubricants	J	0	5.98E+09	1.35E+10	1.65E+10
Nitrogen fertilizer	g	0	8.28E+04	1.38E+05	1.84E+05
Phosphorus fertilizer	g	0	8.14E+04	9.20E+04	8.05E+04
Potash fertilizer	g	0	7.15E+04	7.50E+04	7.50E+04
Boron fertilizer	g	0	0.00E+00	0.00E+00	2.00E+04
Micro fertilizer			4.00E+03	8.00E+03	8.00E+04
Organic fertilizer	g	0.8	2.00E+07	2.00E+07	6.00E+07
Pesticide	g	0	1.25E+03	3.50E+03	3.50E+03
Herbicide	g	0	2.00E+03	4.00E+03	7.00E+03
Electricity	J	0.01	7.20E+12	1.15E+13	1.22E+13
Installation of irrigation system	Rials	0.20	0.00E+00	3.00E+06	4.66E+06
Seed	Rials	0.43	4.80E+06	2.40E+06	2.40E+06
Output					
Root yield	g		5.60E+07	9.00E+07	1.10E+08
Root yield	J		9.13E+11	1.47E+12	1.79E+12

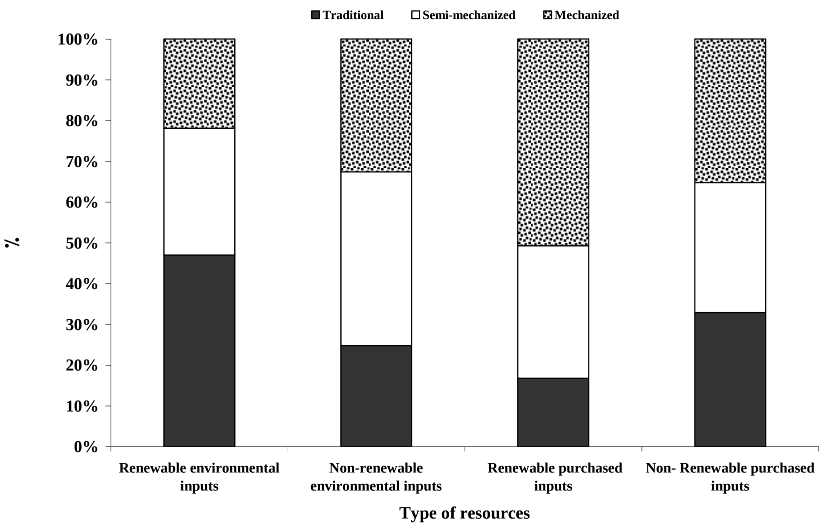


Figure 2. Structure of emergy inputs category for three sugar beet production systems.

In mechanized cultivation, due to the longer crop growth period due to the earlier cultivation date in this system, the solar energy (4.41E + 13 sej) was higher compared to the other two systems. In five corn production systems with different amendment applications, it was shown that the renewable environmental resources used in all cropping systems were almost similar. However, in corn production systems where biofuels were used, the share of environmental renewables was greater due to the use of more manpower and the renewables used in biofuel production (Moonilall et al., 2020). It has been reported that farming operations, such as planting at the right date or using longer-growing cultivars would make more use of environmental resources (Amiri et al., 2019; Amiri et al., 2020).

3.1.2. Non-renewable environmental resources

Semi-mechanized cultivation had the highest share of emergy (53.86%), and traditional cultivation had the lowest share of emergy (31.32%) from non-renewable environmental sources (Table 3, 4). In traditional cultivation, soil organic losses, and in semi-mechanized and mechanized cultivation, irrigation water had the highest share of non-renewable environmental resources. The share of organic losses in traditional cultivation was 22.98% of total emergy, and the share of irrigation water in semi-mechanized and mechanized cultivation was 27.93% and 21.35% of total emergy, respectively. In both semi-mechanized and mechanized planting systems, soil organic losses and erosion were almost equal. However, in mechanized cultivation, due to more water consumption during the growing period, the amount of irrigation water was higher than in semi-mechanized cultivation. Traditional cultivation had a lower organic loss rate than semi-mechanized and mechanized cultivation, which seems due to the reduced use of agricultural machinery and fewer variations in soil microbial flora that play a major role in soil organic matter degradation. Similar results have been reported by Amiri et al. (2019) who found that commercial canola cultivation had 86.36% more soil organic losses than traditional cultivation. The use of High-yield cultivars, single-crop cultivation, weed removal, herbicide application, and more intensive tillage operations were the main reasons for more soil losses in commercial cultivation.

Table 4. Emergy synthesis and input structure of Sugar beet in different production systems (sej ha^{-1}) except as noted

	Unit	Transformity	Refs. for transformity	Emergy (sej ha^{-1})					
				Traditional		Semi-mechanized		Mechanized	
				Quantity	%	Quantity	%	Quantity	%
Renewable environmental inputs									
Solar energy	J	1.00E+00	Definition	3.97E+13	0.14	4.05E+13	0.09	4.41E+13	0.07
Wind, kinetic energy	J	1.25E+03	Campbell, and Erban, 2017	1.08E+14	0.38	1.16E+14	0.24	1.30E+14	0.21
Rain, chemical energy	J	2.25E+04	Campbell (man.)	6.51E+14	2.30	6.85E+14	1.44	6.62E+14	1.06
Evapotranspiration	J	2.88E+04	Campbell (man.)	8.49E+14	2.99	9.44E+14	1.99	8.62E+14	1.39
				8.88E+14	**3.13**	**9.85E+14**	**2.07**	**9.06E+14**	**1.46**
Non-renewable environmental inputs									
SOM reduction	J	9.36E+04	Brandt-Williams, 2002	6.52E+15	22.98	1.16E+16	24.33	1.16E+16	18.59
Soil erosion	g	1.27E+09	Odum 1996	7.62E+14	2.69	7.62E+14	1.60	7.62E+14	1.23
Irrigation	J	1.92E+05	Campbell (man.)	1.60E+15	5.64	1.33E+16	27.93	1.33E+16	21.35
				8.88E+15	**31.31**	**2.56E+16**	**53.86**	**2.56E+16**	**41.16**
Purchased inputs									
Human labour	J	2.22E+06	Lu et al., 2009	4.19E+15	14.77	2.58E+15	5.44	2.09E+15	3.37
Machinery	g	1.01E+10	Campbell et al., 2005	1.35E+13	0.05	4.63E+13	0.10	1.55E+14	0.25
Fossil fuel and lubricants	J	8.60E+04	Bastianoni et al., 2009	5.14E+14	1.81	1.16E+15	2.45	1.42E+15	2.29
Nitrogen fertilizer	g	3.09E+10	Brandt-Williams, 2002	2.56E+15	9.02	4.267E+15	8.98	5.69E+15	9.15
Phosphorus fertilizer	g	2.82E+10	Brandt-Williams, 2002	2.30E+15	8.10	2.59E+15	5.46	2.27E+15	3.65
Potash fertilizer	g	2.23E+09	Odum, 1996	1.59E+14	0.56	1.67E+14	0.35	1.675E+14	0.27
Boron fertilizer	g	3.91E+09	Lan et al., 2002	-	-	-	-	4.10E+14	0.66
Micro fertilizer	g	2.96E+08	Odum, 1996	1.56E+13	0.06	3.13E+13	0.07	3.13E+14	0.5
Organic fertilizer	g	1.89E+10	Hu et al., 2010	5.92E+15	20.88	5.92E+15	12.47	1.78E+16	28.58
Pesticide	g	1.89E+10	Hu et al., 2010	2.38E+13	0.08	6.65E+13	0.14	6.65E+13	0.11
Herbicide	g	2.31E+05	This work	3.80E+13	0.13	7.60E+13	0.16	1.33E+14	0.21
Electricity	J			1.66E+15	5.87	2.66E+15	5.60	2.83E+15	4.55
Installation of irrigation system	Rials	2.50E+08	Amiri et al. (2019)	-	-	7.50E+14	1.58	1.75E+15	2.82
Seed	Rials	2.50E+08	Amiri et al. (2019)	1.20E+15	4.23	6.00E+14	1.26	6.00E+14	0.97
				1.86E+16	**65.56**	**2.09E+16**	**44.06**	**3.57E+16**	**57.38**
				2.84E+16		**4.57E+16**		**6.21E+16**	
Output									
Root yield	sej g^{-1}			5.06E+08		5.28E+08		6.65E+08	
Root yield	sej J^{-1}			3.11E+04		3.24E+04		3.47E+04	

3.1.3. Purchased renewable and non-renewable resources

Input and output data for different production systems are presented in Table 4. The shares of purchased resources from traditional, semi-mechanized, and mechanized cultivation of total input emergy were 65.56, 44.06 and 57.38%, respectively. In traditional cultivation, 39.88% of total emergy input belonged to purchased renewable resources (manpower, livestock manure and seed) and 25.68% of total emergy input was purchased non-renewable resources (fertilizers, pesticides, and establishment costs). The shares of purchased renewable and non-renewable resources in semi-mechanized cultivation were 19.17% and 24.89% of total emergy of purchased resources, respectively, and in mechanized cultivation, 29.98% and 27.48% of total emergy of purchased resources were purchased renewable and non-renewable resources (Figure. 3). An increase in the share of purchased resources in mechanized cultivation compared to semi-mechanized cultivation was due to the high consumption of animal manure in this planting system. Based on the results presented in Figure. 3 and Tables 2 and 3, the highest amounts of emergy form purchased non-renewable resources in traditional, semi-mechanized, and mechanized manure application were 5.92E+15, 5.92E+15, and 1.78E+15 sej (20.88%, 12.47%, and 28.58% of total input emergies, respectively). After livestock manure, in traditional cultivation, manpower (14.77%) and in semi-mechanized and mechanized nitrogen fertilizer the highest shares of purchased emergy resources were 8.98 and 9.15%, respectively. In traditional farming, the higher share of livestock manure is because most farmers in this type of farming system are also engaged in the cultivation of cattle and sheep and use the manure produced at their farms at the end of each year. In mechanized crops, because of their greater financial capacity, they buy and use these fertilizers in their planting systems. In sugar beet cultivation, the high nitrogen requirement and the farmers' tendency to use chemical fertilizers to increase economic yield (root yield) have increased the share of chemical fertilizers, and the use of manpower in controlling weeds and other operations, such as irrigation and harvesting, has increased the share of labor power.

3.2. Yield and emergy output

The economic yields of sugar beet in traditional, semi-mechanized, and mechanized cultivation were 56, 90, and 100 Mg ha^{-1}, respectively (Table4).Mechanized cultivation consumed 33.33% and 109% more total emergy than semi-mechanized and traditional farming, respectively. The main reason for the difference in the amount of output emergy in different planting systems is the amount and type of resources in each planting system. Greater use of inputs, especially purchased inputs in the mechanized planting system, results in a higher amount of emergy in this cultivation method. Asgharipour et al. (2019) reported the highest and lowest total emergy in the high input system and ecological cultivation of beans, compared to different planting systems. It is believed that the higher total emergy in a system, shows that the system is utilizing existing resources and has a high degree of industrialization (Lu et al., 2010). Asgharipour et al. (2019) believe that planting systems that have high amounts of environmental or purchased input also have higher total emergy.

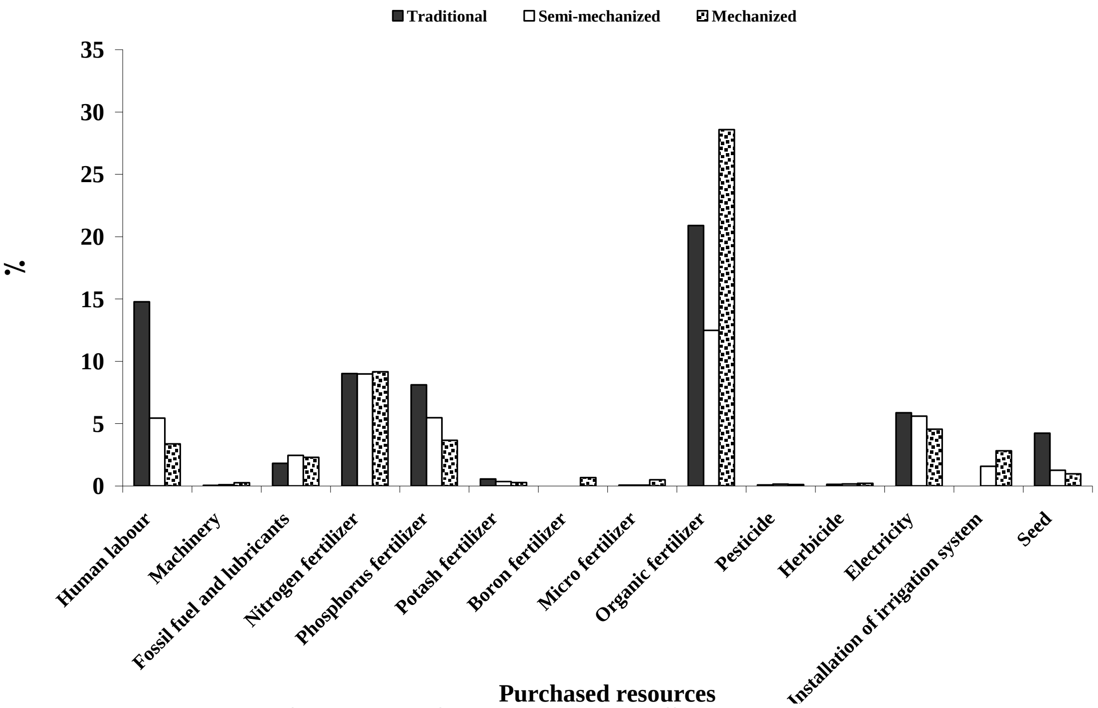


Figure 3. Structure of emergy inputs for purchased input at different sugar beet production systems

3.3. Emergy-based indices of production systems

3.3.1. Unit emergy value

The unit emergy value obtained by dividing the total input emergy by root yield (kgha^{-1}) for traditional, semi-mechanized, and mechanized cultivation was 3.11E+04, 3.24E+4 and 13.47E+04sejJ^{-1}, respectively (Table 5). The reason for the higher unit emergy value for mechanized cultivation, despite the higher yield, is the higher emergy consumption in this production system. Moonilall et al. (2020) reported that non-use of fertilizers significantly decreased yield but increased unit emergy value compared to fertilizer application. Consumption of Chemical fertilizer, Poultry manure biochar, Rice hull biochar and Sugarcane filter press compared to non-fertilizer treatment reduced yield by 779, 744, 715 and 658%, respectively, and reduced unit emergy value by 88.2%, 71.58%, 73.78% and 85.88%.

3.3.2. Renewable emergy ratio (R%)

Renewable emergy ratio (R%) representing the shares of renewable environmental resources and those purchased from all the production sources, was calculated by dividing the renewable emergy input resources by the total emergy, which was the highest and lowest for the traditional (43.01%) and semi-mechanized (21.24%) cultivations, respectively (Table 5). The higher R value indicates more reliance on a system on renewable resources and good sustainability, while its lower value represents its low renewability and poor sustainability. The higher R value in traditional cultivation was due to the lower system resources purchased. Its higher value in the mechanized compared to the semi-mechanized cropping system was because of its more frequent manure fertilizer application.

Table 5. Emergy indices for Sugar beet in different production systems

	Traditional	Semi-mechanized	Mechanized
UEV	3.11E+04	3.24E+04	3.47E+04
R (%)	43.01	21.24	34.38
EER	100	155	177
EYR	1.53	2.27	1.74
EIR	0.67	1.27	0.75
ELR	2.28	1.79	2.31
ESI	1.90	0.79	1.35

It should be noted that 24% of the total emergy in the mechanized cultivation was devoted to manure fertilizer, while only 11% of the total emergy in semi-the mechanized cultivation was made up of animal manure. It is believed that in crop systems with higher shares of renewable resources than total emergy, R value is also higher. In contrast, crop systems with purchased resources have a higher share of total emergy and a lower R value (Moonilall et al., 2020). It has been reported that proper management of field operations with the use of biological fertilizers can improve soil quality and reduce the amount of non-renewable emergy input to the production system. Under such conditions, the amount of soil erosion and decomposition, as well as the number of chemical fertilizers, decrease, and water storage capacity and carbon storage increase(Lal, 2018). These changes make the production system less dependent on purchased non-renewable resources and allow more use of renewable or purchased environmental resources (Moonilall et al., 2020).

3.3.3. Emergy exchange ratio(EER)

The emergy exchange ratio (EER), which is derived from economic yield into total emergy, reflects the amount of economic income per system in exchange for consumed emergy and, as a bridge, links economic analysis to emergy analysis.This indicator shows the relationship between the amount of purchased emergy received from the output of a product when sold in the market (Amiri et al., 2019). In our study, as the level of mechanization increased, EER was seen to be promoted from a traditional to a mechanized system. Therefore, the mechanized cultivation had 11.67% and 83.34% higher EER values than those of the semi-mechanized and traditional systems, respectively. The higher root yield in the mechanized cultivation was the main reason for the higher EER values despite the higher total emergy content in this system.EERs were 0.94 and 0.31 in the commercial canola and subsistence cultivation systems, respectively (Amiri et al., 2019).

3.3.4. Emergy Yield Ratio (EYR)

This ratio, which demonstrates the ability of a production system to use the purchased resources, was obtained by dividing the emergy of the yield into the total emergy of the purchased resources (Agostinho et al., 2008). Although both the mechanized and semi-mechanized systems had higher EYR values than the traditional system, this ratio decreased by 13.58% in the mechanized compared to the semi-mechanized system (Table 5).The lower EYR in the traditional system was due to the higher percentage of resources purchased in this system as compared to the semi-mechanized and mechanized systems.It is believed that a high EYR value cannot be a measure of the high sustainability of a system's production. Exploiting a system of available free resources may not necessarily reflect its efficiency.In fact, compared to industrial systems, traditional farming systems have a good ability to exploit free resources. however, their production efficiency is usually low, which reduces EYR.Contrary to the above results, it was observed that EYR in subsistence canola cultivation was higher than that of commercial cultivation (Agostinho et al., 2008).

3.3.5. Emergy Input Ratio (EIR)

The EIR index is the ratio of the sum of the emergy of non-free inputs to the sum of free inputs. In other words, this indicator indicates the degree of dependence of an agricultural system on the environment and the level of economic development. In this study, there was an inverse relationship between the mechanization level and the EIR.EIR values in the traditional, semi-mechanized, and mechanized systems were 0.67, 1.27, and 0.75, respectively (Table 5). Moonilall et al. (2020) also argued that a higher EIR index would be obtained by using more purchased resources in a production system, whereas the highest EIR value could be observed by the lower values of no-fertilizer planting systems as well as in planting systems that make use of chemicals or bio-fertilizers. These findings are consistent with the results of this research.

3.3.6. Environmental Loading Ratio (ELR)

This index is derived from the division of purchased and non-renewable environmental resources into renewable environmental resources and shows the amount of pressure and stress imposed on the environment by a cropping system. Higher values of this index reflect more enormous environmental pressure on local ecosystems due to the use of non-renewable resources (Odum et al., 2000). ELR values of <2, 2-10, and >10 correspond to low, moderate –to –high, and intense pressures on the environment imposed by a production system, respectively (Agostinho et al., 2008). In this study, the semi-mechanized systems had lower ELR values than 2, and the traditional (2.28) and mechanized (2.23) systems had higher ELR values than 2(Table 5). It has been reported that commercial cultivation has a higher ELR value than subsistence cultivation (Amiri et al., 2019). ELR values of less than 2 have been shown in different maize cultivation systems (Moonilall et al., 2020).

3.3.7. Environmental Sustainability Index (ESI)

The ESI is a composite index obtained by dividing the EYR index by ELR (Amiri et al., 2019). It measures the benefits of a system per unit area. In other words, this indicator measures a system's advantage over its costs. Therefore, ESI takes into account both the economy and the environment. Higher values of this index indicate greater stability of a system under study (Brown and Ulgiati, 2004).According to the research conducted by Brown and Ulgiati (2004) ESI values of >10,1-10, and <1 represent stable systems of low pressure, systems of good potential, and a high-power system with high environmental impacts that deplete system resources and require high emergy consumption to survive, respectively. The higher the share of renewables than non-renewables, the higher the index value and the more favorable the system will be. This indicator can help identify agronomic ecosystems that are less environmentally friendly and more dependent on local renewable resources for production.

In this research, semi-mechanized and traditional cultivation had the lowest (0.79) and highest (1.90) values of ESI, respectively. The values of this index in the two mechanized and traditional systems were slightly different. A production system with a high EYR and low ELR will always have higher ESI values, suggesting that it is more environmentally friendly, has fewer environmental impacts, and is thus more sustainable. Contrary to the above results, the highest ESI value was observed in maize without using fertilizer and chemical applications and the lowest ESI value was observed with biochar use (Moonilall et al., 2020). In the environmental assessments of different sugar beet cultivation systems, Bazrgar (2011) reported that the mechanized cultivation had fewer negative environmental impacts than semi-mechanized and traditional systems. The environmental superiority of the mechanized compared to the traditional systems was mainly due to their higher production, lower input consumption, and lower environmental emissions per tonne of sugar beet production. In terms of global warming potential, marsh potential, acidification potential, demand for non-renewable energy, ozone depletion potential, and land use, the mechanized fields revealed less-than-the-mean effects of environmental damage during the production process of one tonne of sugar beet. In their study, Ortega et al. (2005) reported that the biological (ecological and more biocompatible organic) approach provided more sustainability than the industrial (agrochemical and no-till using herbicide) approach in soybean cultivation.

3.4. Relationship between yield and sustainability

Among the studied systems, mechanized cultivation had the highest root yield and highest sustainability. Nonetheless, despite increased root yield, production sustainability decreased in semi-mechanized cultivation compared to traditional cultivation. It seemed that the main reasons for the higher production sustainability in the mechanized cultivation were the higher share of purchased inputs, increased efficiency of using inputs, and a higher share of purchased renewable resources, especially livestock manure. The results of this study are in line with the findings of Bazrgar (2011), who maintained that the mechanized cultivation of sugar beet had less environmental impact compared to traditional cultivation. Contrary to the above results, Moonilall et al. (2020) reported that the highest sustainability of maize production occurred in the non-chemical fertilizer treatment, while chemical or biochar applications increased the yield, but decreased sustainability. Ren et al. (2019) reported that by increasing farm size, significantly decreased fertilizers and pesticides could be consumed per hectare, which demonstrates the obvious benefits of protecting the environment.

5. Conclusion

Each of the three studied systems had different effects on the shares of the varied sources of total emergy. The traditional and mechanized cultivations required the least and the highest amounts of emergy for crop production, respectively. The mechanized cultivation had 119% and 36% more total emergy compared to the traditional and semi-mechanized cultivations, respectively. Except for the share of manpower in the traditional cultivation, which was higher than those of the semi-mechanized and mechanized cultivations, the other resources purchased in the traditional cultivation declined sharply as compared to the mechanized cultivation. The mechanized compared to the traditional crop production needed less manpower (50%) and 100% seed, but more machinery (1148%), fuel and oil (276%), nitrogen fertilizer (22%), phosphorus fertilizer (99%) ,potassium fertilizer (105%), manure (301%), insecticides (279%), herbicides (350%), and electricity (70%). The semi-mechanized cultivation was also more similar to the mechanized cultivation in most of the sources purchased compared to the traditional cultivation. The ELR index, as an indicator of production stability, was higher in traditional cultivation, but the mechanization of sugar beet cultivation did not significantly decrease this index. Since economic yield was higher in the mechanized cultivation, other emergy indices, except for renewable emergy ratio, were higher in the mechanized compared tothe traditional cultivation. Based on this result, it could be said that the mechanization of sugar beet cultivation in the study area had improved the yield while also maintaining the system stability.

References

Agostinho, F., Diniz, G., Siche, R., Ortega, E., 2008. The use of emergy assessment and the Geographical Information System in the diagnosis of small family farms in Brazil. Ecological Modelling, 210(1), 37-57.

Amiri, Z., Asgharipour, M.R., Campbell, D.E., Armin, M., 2019. A sustainability analysis of two rapeseed farming ecosystems in Khorramabad, Iran, based on emergy and economic analyses. Journal of Cleaner Production, 226, 1051-1066.

Amiri, Z., Asgharipour, M.R., Campbell, D.E., Armin, M., 2020. Extended exergy analysis (EAA) of two canola farming systems in Khorramabad, Iran. Agricultural Systems, 180, 102789.

Araujo, A.V.d., Brandão Junior, D.d.S., Colen, F., 2013. Energetic analysis of landrace varieties and hybrids of corn produced in different technological levels of management. Engenharia Agrícola, 33(4), 625-635.

Asgharipour, M.R., Shahgholi, H., Campbell, D.E., Khamari, I., Ghadiri, A., 2019. Comparison of the sustainability of bean production systems based on emergy and economic analyses. Environmental monitoring and assessment, 191(1), 1-21.

Bagheri, N., Moazzen, S., 2009. Optimum strategy for agricultural mechanization development in Iran. Journal of Agricultural Technology, 5(2), 225-237.

Bazrgar, A.B., 2011. Environmental Assessment of Khorasan Sugarbeet Production Systems Using LCA, Faculty of Plant Production. Gorgan University of Agricultural Sciences and Natural Resources, p. 205.

Bazrgar, A.B., Soltani, A., Koocheki, A., Zeinali, E., Ghaemi, A., 2011. Environmental emissions profile of different sugar beet cropping systems in East of Iran. African Journal of Agricultural Research, 6(29), 6246-6255.

Brown, M.T., Campbell, D.E., De Vilbiss, C., Ulgiati, S., 2016. The geobiosphere emergy baseline: a synthesis. Ecological Modelling, 339, 92-95.

Brown, M.T., Ulgiati, S., 2004. Energy quality, emergy, and transformity: HT Odum's contributions to quantifying and understanding systems. Ecological Modelling, 178(1-2), 201-213.

Erdal, G., Esengün, K., Erdal, H., Gündüz, O., 2007. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. Energy, 32(1), 35-41.

Hanif, I., Aziz, B., Chaudhry, I.S., 2019. Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia. Renewable Energy, 143, 586-595.

Jelsøe, E., Kjærgård, B., 2016. Sustainability in agriculture and food production, in: A new agenda for sustainability. Routledge, pp. 147-170.

Jiang, M., Chen, B., Zhou, J., Tao, F., Li, Z., Yang, Z., Chen, G., 2007. Emergy account for biomass resource exploitation by agriculture in China. Energy policy, 35(9), 4704-4719.

Kohansal, M., Mansoori, H., 2013. Socio-economic factors affecting agricultural machines ownership by farmers in Khorasan-Razavi province in Iran. Journal of Agricultural Mechanization, 1(1), 53-59.

Lal, R., 2018. Saving global land resources by enhancing eco-efficiency of agroecosystems. Journal of Soil and Water Conservation, 73(4), 100A-106A.

Lu, H., Bai, Y., Ren, H., Campbell, D.E., 2010. Integrated emergy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields: implications for agricultural policy in China. Journal of Environmental Management, 91(12), 2727-2735.

Martin, J.F., Diemont, S.A., Powell, E., Stanton, M., Levy-Tacher, S., 2006. Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management. Agriculture, ecosystems & environment, 115(1-4), 128-140.

Moazzen, S.A.A., 2010. Determination of the most important challenges for agricultural mechanization development in Iran. Agricultural Engineering International: CIGR Journal, 12(3-4), 87-91.

Moonilall, N.I., Homenauth, O., Lal, R., 2020. Emergy analysis for maize fields under different amendment applications in Guyana. Journal of Cleaner Production, 120761.

Moore, J., Pagani, F., Quayle, M., Robinson, J., Sawada, B., Spiegelman, G., Van Wynsberghe, R., 2005. Recreating the university from within: Collaborative reflections on the University of British Columbia's engagement with sustainability. International Journal of Sustainability in Higher Education, 6(1), 65-80.

Notarnicola, B., Sala, S., Anton, A., McLaren, S.J., Saouter, E., Sonesson, U., 2017. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. Journal of Cleaner Production, 140, 399-409.

Odum, H.T., Brown, M., Brandt-Williams, S., 2000. Handbook of emergy evaluation. Center for environmental policy.

Ortega, E., Cavalett, O., Bonifácio, R., Watanabe, M., 2005. Brazilian soybean production: emergy analysis with an expanded scope. Bulletin of Science, Technology & Society, 25(4), 323-334.

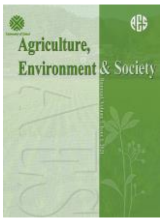
Ozkan, B., Akcaoz, H., Fert, C., 2004. Energy input–output analysis in Turkish agriculture. Renewable energy, 29(1), 39-51.

Ren, C., Liu, S., van Grinsven, H., Reis, S., Jin, S., Liu, H., Gu, B., 2019. The impact of farm size on agricultural sustainability. Journal of Cleaner Production, 220, 357-367.

Schmitz, A., Moss, C.B., 2015. Mechanized agriculture: machine adoption, farm size, and labor displacement. AgBioForum, 18(278-296).

Tabar, I.B., Keyhani, A., Rafiee, S., 2010. Energy balance in Iran's agronomy (1990–2006). Renewable and Sustainable Energy Reviews, 14(2), 849-855.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 25-30



Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Potassium silicate and salicylic acid effects on onion thrips population density and some growth indices of onion cultivars

Saleh Panahandeh [a], Maryam Pahlavan Yali [*a]

[a] Department of Plant Protection, Faculty of Agriculture, Shahid Bahonar University, Kerman, Iran

ARTICLE INFO

Article history:
Received: 23 March 2022
Accepted: 25 April 2022
Available online: 29 April 2022

Keywords:
Biofertilizer
Foliar application
Growth regulator
Induce resistance
Thrips

ABSTRACT

Thrips tabacci Lind. (Thysanoptera: Thripidae), the onion thrips, is one of the most damaging pests to onion fields. By using biotic or abiotic stimuli or growth regulators, it is possible to induce resistance, which activates the plant's natural defense. The effect of foliar application of two growth regulators, salicylic acid and potassium silicate, separately and in combination, on onion thrips population density, fresh weight, dry weight, chlorophyll concentration, and height of onion cultivars was investigated in the Jiroft region between 2016 and 2017. The experiment was conducted as a factorial design with 12 replications. Two onion cultivars (Gardesco and Milky Way F1), salicylic acid (0, 0.25, 0.5 mM), and potassium silicate (0, 1, 2 cc. lit^{-1}) were used in three different concentrations. The analysis of variance revealed that the effect of biological fertilizer on thrips population density, fresh and dry weight, chlorophyll concentration, and the effect of onion cultivar on plant height and thrips population density were all statistically significant ($P_{value \leq}0.01$). Additionally, the interaction between fertilizer and cultivar was significant only for the pest population density parameter at the 1% level. The treatment with potassium silicate (2 cc. lit^{-1}) resulted in the highest fresh and dry weight values, 363.29 and 120.25, respectively. Milky Way F1 plants were taller (41.16 cm) than Gardesco plants (37.10 cm). These findings indicate that salicylic acid and potassium silicate have the potential to significantly reduce the *T. tabaci* population and should be considered in integrated pest management programs for this pest.

Highlights

- Resistance in plants can be induced by using biotic or abiotic stimuli or growth regulators.
- The effect of foliar application of two growth regulators on onion thrips population density and plant characteristics was studied in Jiroft.
- An onion cultivar's effect on plant height and thrips population density was statistically significant.
- Salicylic acid and potassium silicate may be used in *T. tabaci* integrated pest management programs.

1. Introduction

The onion is a biennial plant, *Allium cepa* L. (Alliaceae). Onion thrips, *Thrips tabaci* Lind. (Thysanoptera: Thripidae), is one of the most important pests that damage onion fields (Rovenska and Zemek, 2006). Onion thrips indirectly reduce bulb yield by feeding on aerial parts of the plant (Trdan et al. 2005). Decreased bulb yield can be due to reduced leaf photosynthesis, degradation of transfer processes, and food consumption (Trdan et al. 2007). This pest is a vector of important viral diseases, such as tomato spot wilt disease and Iris yellow spot, and thus reduces the yield of onion fields by up to 50% (Trdan et al. 2007).

Considering the importance of the pest and its rapid resistance to various insecticides, it is necessary to develop a sustainable method for its integrated management. The use of resistance cultivars is also one of the environmentally friendly solutions and is one of the simplest and most important agronomic methods to manage onion thrips (Rovenska and Zemek, 2006). Insect-resistant cultivars can also increase the efficiency of natural enemies by reducing the ability of the pest to reproduce (Nouri-Ghanbalani, 1977). Many synthetic and hormonal compounds, including salicylic acid, have been used to control pests without considering their anti-vital effects (Vanpoecke and Dicke, 2004; Conrath, 2009). Induction resistance, which activates

[*] Corresponding author
E-mail address: pahlavanm@uk.ac.ir (M. Pahlavan Yali)
http://dx.doi.org/10.22034/aes.2022.336201.1030

the plant's natural defense mechanism, can be used as a safe alternative and thus contribute to the development of sustainable agriculture (Edreva, 2004). In general, inducing resistance in plants using biotic or abiotic stimuli is one of the solutions approved by researchers in pest management (Cao et al. 2014).

Compared to most modification methods, which are generally long-term and costly, increasing plant resistance in various ways, including the use of growth regulators, is possible. Bartels and Sunkar (2005). Salicylic acid belongs to a group of phenolic compounds that are widely present in plants and play a key role in the development of immune responses and systemic acquired resistance (SAR) (Carr et al. 2010). This is a growth regulator that participates in the regulation of several physiological processes in crop plants, such as stomata closure, ion uptake, inhibition of ethylene biosynthesis, and transpiration (Chrzanowski et al. 2004; El-Mergawi and Abdel-Wahed, 2004). In addition, salicylic acid plays a key role in the plant's response to abiotic environmental stresses such as ozone, heat stress, chilling stress, and drought stress (Khandaker et al. 2011; Hak et al. 2012; Pradhan et al. 2016). Various reports have also shown that low concentrations of salicylic acid in plants cause defensive reactions against insects by affecting some volatile plant compounds (Engelberth et al., 2011; Lotfi et al., 2014; Dinary et al. 2015; Nayebzadeh et al., 2016). This combination attracts more natural enemies of pests to the plant and thus reduces the population of pests (James and Price, 2004).

The effect of salicylic acid (600 and 800 μM) on wheat showed induced resistance in wheat against the Russian wheat aphid, *Diuraphis noxia* (kurdjumov) (Dinary et al. 2015). Salicylic acid treatment of the Okapi rapeseed cultivar made it resistant to cabbage aphid (Lotfi et al. 2014). Using changes in salicylic acid concentration, the researchers conducted studies on two winter wheat cultivars and concluded that increasing the concentration of this compound in resistant cultivars reduces the nutrition of the aphid, *Sitobion avenae* F. (Chrzanowski et al. 2004). It has been reported that β-aminobutyric acid (BABA) and salicylic acid (SA) can induce resistance against the peach green aphid, *Myzus persicae* (Sulzer) in broad beans (*Vicia faba*) (Nayebzadeh et al., 2016). Potassium silicate is the potassium salt of silicic acid that is easily absorbed by plants and plays an important role in enhancing growth as well as increasing the quality and quantity of agricultural crops (Reilly et al. 2007). Potassium silicate, when used as a spray, limits the population of mites, whiteflies, and other insects; the effect of this compound on crops, pome, and stone fruit trees has been proven (Reilly et al. 2007). In fact, the presence of a very thin film of silicon on the leaf surface, by creating a physical and biochemical barrier, protects the plant against the attack of sucking and chewing insects (Reilly et al. 2007). Silica consumption also reduces fungal infections such as *Pseudocercospora griseola* (Sacc.) Crous & U. Braun in bean, *Phakopsora pachyrhizi* Syd. P. Syd. in soybean and *Podosphaera xanthii* Haustorium in cucumber (Liang et al. 2005; Rodrigues et al. 2009; Rodrigues et al. 2010; Cruz et al. 2013). Due to the high level of onion cultivation in the southern regions of Iran and the importance of onion thrips as one of the important pests (Rovenska and Zemek, 2006), applied research in the field can solve many problems in the production, sale, and export of this crop. Since there is no comprehensive study on the use of biological fertilizers on pests in Iran, the purpose of this study was to investigate the effects of salicylic acid and potassium silicate separately and in combination on *T. tabaci's* population density and growth indices of onion cultivars to manage this pest in onion fields.

2. Materials and Methods

2.1. Experimental design and induction treatments

The field experiments were conducted during the growing seasons (2016 and 2017) in a field (lat. 28.38 N, long. 57.47 E) located in Jiroft city, Kerman, Iran. The experiment was performed as a factorial experiment with a completely randomized design with 12 replications. Seeds of two onion cultivars, Milky Way F1 and Gardesco, were used. Onion seedlings were grown in loamy-clay soil containing poultry manure and drip irrigation. About three months after planting, after the establishment and growth of onion seedlings at the beginning of bulb growth, foliar application of treatments was performed. Experimental treatments include control (distilled water), salicylic acid (0.25 mM), salicylic acid (0.5 mM), potassium silicate (1 $cc.lit^{-1}$), salicylic acid (0.5 mM) + potassium silicate (1 $cc.lit^{-1}$), Salicylic acid (0.5 mM) + potassium silicate (1 $cc.lit^{-1}$), potassium silicate (2 $cc.lit^{-1}$), salicylic acid (0.25 mM) + potassium silicate (2 $cc.lit^{-1}$), salicylic acid (0.5 mM) + Potassium silicate (2 $cc.lit^{-1}$). The field conditions are such that each treatment has two stacks. (each plot contains two stacks). The width of each stack was 50 cm and its length was 200 cm (the width and length of the empty space between treatments were 50 and 200 cm, respectively). In other words, the total width of the ridge for each treatment, taking into account the empty space between them, was one and a half meters. Twenty-five days after treatment spraying, for each treatment from each plot, four plants were randomly cut from the plant base and transferred to the laboratory in a plastic bag.

2.2. Determination of thrips population density and plant growth parameters

We measured the population density of *T. tabaci* per plant, wet weight, dry weight, chlorophyll concentration, and height of onion cultivars. The wet weight (g per plant) and dry weight (g after drying at 70 °C for 48 hours) of the whole plant were measured with a digital scale to the nearest thousandth of a gram. In order to calculate the height (cm), the length of each plant was measured from the beginning of stem growth, about five cm above the bulbs, to the sharp end of the largest leaf. Chlorophyll concentration (SPAD number) was measured using the SPAD-502 chlorophyll meter. The SPAD number does not indicate the amount of chlorophyll but is an estimate of the chlorophyll concentration that has a high correlation with the amount of leaf chlorophyll. A

Chlorophyll meter shows the relative concentration of leaf chlorophyll based on the amount of light passing through the leaf at two wavelengths at which chlorophyll absorption is different (Hasibi, 2007). Analysis of variance was performed after transforming the data by the equation log (x +2) using SAS software (SAS 9.4) and multiple comparisons were made using the Tukey test (SPSS 2015).

3. Results and Discussion

3.1. Determination of thrips population density and plant growth parameters

The results showed that different treatments significantly affected the dry weight, fresh weight, chlorophyll concentration, and population density of onion thrips, but did not have significant effects on plant height. The effect of onion cultivars on plant height ($P \leq 0.01$) and thrips population density ($P \leq 0.05$) was also significant (Table 1). The interaction effect of fertilizer and cultivar only on thrips population density showed a significant difference ($P \leq 0.01$; Table 1).

In this study, the analysis of chlorophyll data in potassium silicate treatment (2 cc.lit^{-1}) (58.58%) was significantly higher than in salicylic acid treatments (0.25 mM). The highest amount and the lowest amount of dry weight and wet weight were observed in the potassium silicate treatment (2 cc.lit^{-1}) (120.250 and 363.29 g, respectively) and in salicylic acid treatments (0.5 mM) (47.67 and 272.96 g) and control (55.11 and 271.92 g), respectively (Table 2). In addition, the comparison of the mean data showed that the plant height in the Milky Way F1 cultivar (41.16 cm) is higher than in Gardesco (37.10 cm) (Table 2).

Table 1. Analysis of variance effect of different treatments of salicylic acid and potassium silicate, on onion growth parameters and population density of onion thrips

		Mean Squares				
Sources of Change	**DF**	**Fresh weight (g/ plant)**	**Dry weight (g/ plant)**	**chlorophyll content index (SPAD number) (%)**	**Plant height (cm)**	**Density (insect / plant)**
Growth regulator	8	0.07^{**}	0.35^{**}	0.00^{*}	0.01^{ns}	0.35^{**}
Cultivar	1	0.01^{ns}	0.00^{ns}	0.00^{ns}	0.15^{**}	0.50^{*}
Growth regulator* Cultivar	8	0.03^{ns}	0.00^{ns}	0.00^{ns}	0.01^{ns}	0.30^{**}
Error	187	0.03	0.05	0.00	0.02	0.10
Coefficient of variation (%)	-	3.87	5.94	0.91	3.73	11.24

ns, * and ** non-significant and significant level on 5% and 1% respectively

Table 2. Population density (mean ± SE) of *Thrips tabaci* Lind. and agronomic traits of onion varieties by application of salicylic acid and potassium silicate

	Characters			
Treatments	**Plant height (cm)**	**chlorophyll content index (SPAD number) (%)**	**Dry weight (g / plant)**	**Fresh weight (g / plant)**
Growth regulators				
Control (distilled water)	40.71a	55.38 ab	55.11 bc	271.92 b
Salicylic acid 0.25 mM	40.13 a	54.65 b	75.93 bc	285.54 ab
Salicylic acid 0.5 mM	38.86 a	55.34 ab	47.65 c	272.96 b
Potassium silicate 1 cc.lit^{-1}	38.45 a	55.76 ab	73.07 bc	340.33 ab
Salicylic acid 0.25 mM* Potassium silicate 1cc.lit^{-1}	37.56 a	56.28 ab	87.92 ab	294.79 ab
Salicylic acid 0.5 mM* Potassium silicate 1cc.lit^{-1}	38.58 a	56.59 ab	71.23 bc	304.08 ab
Potassium silicate 2 cc.lit^{-1}	39.98 a	58.58 a	120.25 a	363.29 a
Salicylic acid 0.25 mM* Potassium silicate 2 cc.lit^{-1}	38.21 a	56.66 ab	84.22 abc	301.96 ab
Salicylic acid 0.5 mM* Potassium silicate 2 cc.lit^{-1}	39.70 a	57.73 ab	79.83 bc	336.17 ab
Cultivars				
Milky way F1	41.16 a	56.13 a	77.04 a	302.78 a
Gardesco	37.10 b	56.52 a	77.45 a	313.01 a

Means with the same letters in each column do not show significant differences according to Tukey's test at 5% level

In the present study, the significant effects of salicylic acid and potassium silicate were evident on plant growth parameters, and the combination of the two compounds significantly reduced thrips population density. According to the results of this study, increasing the concentration of potassium silicate enhances the growth parameters of onions and reduces the population density of onion thrips. Several studies have shown the positive effect of salicylic acid and potassium silicate on reducing the population density of some pests (Ma et al. 2001; Rogerio et al. 2005; Nayebzadeh et al. 2016). Also, increased plant resistance to disease, improved growth, and increased yield using silica have been reported in plants such as squash, rice, and faba beans (Ghasemi et al. 2013; Jayawardana et al. 2014). Ranganathan et al. (2006) reported that increasing the concentration of silica in plant tissues can enhance the protective properties of the plant against biotic and abiotic stresses.

Amin et al. (2007) reported that low concentrations of salicylic acid (50 and 100 mg/ml) caused a significant increase in the height, fresh weight, and dry weight of onion plants. Research on soybeans and various wheat and maize cultivars has shown that low concentrations of salicylic acid increase the growth parameters of these plants (Iqbal et al., 2006); while other studies on tomatoes, wheat, maize and onions proved the inhibitory effect of high concentrations of this compound on plant growth (Abdel-Wahed et al. 2006; Amin et al. 2007). Growth regulators such as salicylic acid also affect plant physiological processes such as ion uptake, cell elongation, cell division, enzymatic activity, protein synthesis, and photosynthetic activity (Abdel-Wahed et al. 2006).

Analysis of onion growth parameters treated with salicylic acid (250 mg/ml) at six different time points (30, 45, 60, 75, 90, and 105 days after transplanting) showed that the plant height and chlorophyll content (SPAD number) of the plant grow significantly over time (Pradhan et al. 2016). The positive effect of this compound might be due to its effect on plant properties such as stomata closure, ion uptake, and inhibition of ethylene biosynthesis and transpiration (Pradhan et al. 2016). Salicylic acid increases the photosynthetic activity of the plant and thus increases the number of leaves per plant, the chlorophyll content and plant height (Hattori et al. 2005). This compound also has a significant effect on the morphology and physiology of the plant (Gharib, 2006; Pradhan et al. 2016). Similar reports have been recorded on the beneficial effects of salicylic acid on plant growth in terms of plant height, leaf number, and leaf chlorophyll content in several crops such as pepper, eggplant, red Amaranthus, garlic, and green peas (El-Tayeb, 2005; Bideshki and Arvin, 2010; Gawade and Sirohi, 2011; Khandaker et al. 2011). The effect of three concentrations of 25, 50, and 75 mg/l potassium silicate on chlorophyll content index (SPAD number) and the number of Asian lilium florets showed that the highest chlorophyll content index at harvest was related to foliar application of potassium silicate at the rate of 25 mg per liter and the number of florets per plant at this time was 5.27% (Mir Abbasi Najafabadi et al. 2014). The Concentration of 25 mg/l potassium silicate spray increased the chlorophyll content by 11.63% compared to potassium silicate solution. Increasing the concentration of silica in plant tissues can enhance the protective properties of the plant against biotic and abiotic stresses (Ranganathan et al. 2006).

Since silica is absorbed as mono silicic acid and converted to polysilicic acid in leaf epidermal cells, it accumulates in the cell wall and increases the plant's protective properties against pathogen penetration, insect attack ,and resistance of different plants against drought stress and high temperatures (Ma et al. 2001; Baker and Pilbeam, 2007). Reinforced cell walls of plants during drought stress or heat stress help to withstand stress by preventing compression of the xylems and reducing transpiration by reducing the diameter of the stomata (Ma et al. 2001).

Additionally, it has been shown that the use of silicon-containing compounds by foliar and soil application can significantly kill *Bemisia tabaci* (Gennadius, 1889) in squash (Rogerio et al. 2005).

Foliar use of silica as potassium silicate on citrus reduces the oviposition and longevity of *Planococcus citri* (Risso). In the present study, the effect of cultivars on thrips population density and plant height was significant, which could be due to morphological and biochemical differences between the studied cultivars. In some studies, the amount of wax, leaf color, and distance between leaves have been reported as the most important factors affecting the population density of the pest (Vanpoecke and Dicke, 2004). Further, seed priming with salicylic acid caused a significant increase in plant height and fresh weight compared to the control (Sharifi et al. 2015). From the results of the present study and the research of other researchers, it can be inferred that the type of cultivar has a significant effect on the studied parameters, such as thrips population density. It should also be noted that the method of application, growth regulator concentration, plant species, and growth stage are among the factors affecting the effectiveness of fertilizer compounds such as salicylic acid and potassium silicate. For example, when maize seeds were treated with 0.5 mM salicylic acid, it enhanced drought resistance, while using the same concentration as foliar application reduced drought resistance (Nemeth et al. 2002).

4. Conclusion

Since the management of fertilizer compounds is an important factor in the success of crop cultivation, identifying their compatible types with nature and suitable for the plant can have favorable effects on plant yield and, of course, plant pests. In this study, salicylic acid and potassium silicate had a significant effect on plant growth indices such as fresh weight, dry weight, and chlorophyll concentration. In addition, the combined use of salicylic acid and potassium silicate in comparison with the separate use of these compounds caused a significant reduction in the onion thrips population. It is also suggested that the extent of changes in the biochemical composition of onion cultivars when using different growth regulators can identify the factors involved in reducing the population of thrips. Therefore, fertilization, with better relative control and prevention of thrips damage, indirectly increases plant growth indices.

Acknowledgment

We appreciate Shahid Bahonar University (Iran) for providing financial support for this study.

References

Abdel-Wahed, M.S.A., Amin, A.A., El-Rashad, S.M., 2006. Physiological effect of some bioregulators on vegetative growth, yield and chemical constituents of yellow maize plants. World Journal of Agricultural Science, 20, 149-153.

Amin, A.A., Rashad, EL-Sh, M., EL-Abagy, H.M.H., 2007. Physiological effect of indole-3-butyric acid and salicylic acid on growth, yield and chemical constituents of onion plants. Journal of Applied Science Research, 11(3), 11.1554-1563.

Baker, A.V. and Pilbeam, D.J. 2007. Handbook of plant nutrition USA, 613 pp.

Bartels D., Sunkar, R. 2005. Drought and salt tolerance in plants. Critical Review in Plant Science, 24, 23–58.

Bideshki, A., Arvin, M.J., 2010. Effect of salicylic acid (SA) and drought stress on growth bulb yield and allicin content of garlic in field. Plant Ecophysiology, 2, 73−79. (In Persian).

Cao, H.H., Zhang, M., Zhao, H., Zhang, Y., Wang, X.X., Guo, S.S., 2014. Deciphering the mechanism of β-aminobutyric acid-induced resistance in wheat to the grain aphid, *Sitobion avenae*. PloS One, 9(3), e91768.

Carr, J.P., Lewsey, M.G., Palukaitis, P., 2010. Signaling in induced resistance. Advances in Virus Research, 76, 57–121.

Chrzanowski, G., Ciepiela, A. P. Senpruch, C. Sprawka, I. Sytykiewicz, H., Czerniewicz, P., 2004. Accumulation of gallic and salicylic acids in winter triticale in response to aphid's attack. Plan Protection, 48, 257-260.

Conrath, U., 2009. Priming of induced plant defense responses. Advances in Botanical Research, 51, 361-395.

Cruz, M.F., Rodrigues, F.A., Diniz, A.P.C., Moreira, M.A., Barros, E.G., 2013. Potassium silicate and calcium silicate on the resistance of soybean to *Phakopsora pachyrhizi* infection. Bragantia Campinas, 72(4), 4373-377.

Dinary, A., Dolaty, L., Nematholahy, M., Forutan, S., 2015. Effects of different doses of SA, on wheat resistance induction against Russian aphid of wheat. The First Conference on New Finding in Environment and Agricultural Ecosystems, Tehran. Iran. (In Persian).

Edreva, A. 2004. A novel strategy for plant protection, Induced resistance, Journal of Cell and Molecular Biology, 3, 61-69.

El-Mergawi, R.A., Abdel-Wahed, M.S.A., 2004. Diversity in salicylic acid effect on growth criteria and different indole acetic acid forms among faba bean and maize. Egyptian Journal of Agronomy, 26, 49-61.

El-Tayeb, M.A., 2005. Response of barley grains to the interactive effect of salinity and salicylic acid. Plant Growth Regulator, 45, 215-224.

Engelberth, J., Viswanathan, S., Engelberth, M., 2011. Low concentrations of salicylic acid stimulate insect elicitor responses in *Zea mays* seedlings. Journal of Chemical Ecology, 37, 263-266.

Gawade, B., Sirohi, A., 2011. Induction of resistance in eggplant (*Solanum melongena*) by salicylic acid against root-knot nematode, *Meloidogyne incognita*. Indian Journal of Nematology, 41(2), 2.201-205.

Gharib, F.A., 2006. Effect of salicylic acid on the growth, metabolic activities and oil content of basil and marjoram. International Journal of Agricultural Biology, 4, 485−492.

Ghasemi, A., Ejraei, A., Rajaei, M., 2013. Effect of Silicon on vegetative and generative performance of broad bean (*Vicia faba* L.). Journal Novel Applied Science, 2, 881-884.

Hak, E.L., Gunes, A., Inal, A., Alpaslan, M., Eraslan, F., Guneri, B.E., Cicek, N., 2012. Salicylic acid induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in green pea *(Pisum sativum*) grown under salinity. Journal of Plant Physiology, 164, 728-736.

Hasibi, P. 2007. Physiological study of the effect of cold stress on seedling stage of different rice genotypes. Ph.D. Thesis, Shahid Chamran University of Ahvaz P 145.

Hattori, T., Inanaga, S., Araki, H., An, P., Morita, S., Luxova, M., Lux, A., 2005. Application of silicon enhanced drought tolerance in *Sorghum bicolor*. Physiologia Plantarum, 123, 459–-466.

Iqbal, M., Ashraf, M., Jamil, A., Shafiq, U.R.M., 2006. Does seed priming induce changes in the levels of some endogenous plant hormones in hexaploid wheat plant under salt stress? Journal of integrative plant Biology, 48(2), 2.181-189.

James, D., Price, T., 2004. Field-testing of methyl salicylate for recruitment and retention of beneficial insect in grapes and hops. Journal of Chemical Ecology, 30, 52-62.

Jayawardana, H.A.R.K., Weerahewa H.L.D., Saparamadu. M.D.J.S., 2014. Effect of root or foliar application of soluble silicon on plant growth, fruit quality and anthracnose development of capsicum. Tropical Agricultural Research, 26(1), 74-81.

Khandaker, L., Masum, A.S.M.G., Shinya, O.B.A., 2011. Foliar application of salicylic acid improved the growth, yield and leaf's bioactive compounds in red Amaranthus (*Amaranthus tricolor*). Vegetable Crop Research Bulletin, 74, 77-86

Liang, Y.C., Sun, W.C., Si, J., Romheld, V., 2005. Effects of foliar- and root-applied silicon on the enhancement of induced resistance to powdery mildew in *Cucumis sativus*. Plant Pathology, 54(5), 5.678-685.

Lotfi, R., Dolati, L., Shekari, F., 2014. Effect of SA on rapeseed (Brassica napus) resistance induction against cabbage aphid in greenhouse. The Second National Conference on Climate Change and Its Effect on Agriculture and Environment West Azarbaijan Iran (In Persian).

Ma, J.F., Miyake Y., Takahashi, E., 2001. Silicon as a beneficial element for crop plants. In: Datnoff, L.E., Snyder, G.H., Korndorfer, G.H. Silicon in agriculture. Amesterdam, Holand. Elsevier pp: 17-39.

Mirabbasi, N., Nikbakht, A., Etemadi, N., Sabzalian, M., 2013. Effect of different concentrations of potassium silicate, nano-silicon and calcium chloride on concentration of potassium, calcium and magnesium, chlorophyll content and number of florets of Asiatic lily cv. 'Brunello'. Journal of Soil and Plant Interactions, 14(4), 41-50 (In Persian).

Nayebzadeh, A. Shrifi-sirchi, G.R., Ahmadi, K., 2016. Resistance induction to green peach aphid (*Myzus persicae*) in broad been by salicylic acid and -aminobutyric acid. Plant Entomology and Phytopathology, 84(1), 1.1-7 (In Persian).

Nemeth, M., Janda, T., Horvath, E., Paldi, E., Szalai, G. 2002. Exogenous salicylic acid increases polyamine content but may decrease drought tolerance in maize. Plant Science, 162, 569-574.

Nouri-Ghanbalani, G. 1977. Host plant resistance to the pea leaf weevil, *Sitona lineatus* (L.), in pea (*Pisum* *sativum* L) and its inheritance, Ph.D. Thesis, University of Idaho Moscow Idaho USA .

Pradhan, M., Tripathy, P., Mandal, P., Sahoo, B.B., Pradhan, R., Mishra, S.P., Mishra, H.N., 2016. Effect of salicylic acid on growth and bulb yield of onion (*Allium Cepa* L.). International Journal of Bio-resource and Stress Management, 7(4), 960-963.

Ranganathan, S., Suvarchala, V., Rajesh Y.B. R.D., Srinivasa Prasad, M., Padmakumari, A.P., Voleti, S.R., 2006. Effects of silicon sources on its deposition, chlorophyll content, and disease and pest resistance in rice. Biological Plantarum, 50(4), 713-716.

Reilly, S.K., Hollis, L.A., Xue, M., Jones, R.S., Frazer, C.E. 2007. U.S. Environmental Protection Agency, Office of Pesticide Programs, Biopesticides and Pollution Prevention Division, Potassium Silicate. Biopesticides Registration Action Document (Potassium Silicate) 31pp.

Rodrigues, F.A., Duarte, H.S.S., Domiciano, G.P., Souza, C.A., Korndorfer, G.H., Zambolim, L., 2009. Foliar applications of potassium silicate reduce the intensity of soybean rust. Australasian Plant Pathology, 38(4), 366-372.

Rodrigues, F.A., Duarte, H.S.S., Rezende, D.C., Wordellfilho, J.A., Korndorfer, G.H., Zambolim, L., 2010. Foliar spray potassium silicate on the control of angular leaf spot on beans. Journal of Plant Nutrition, 33(14), 2082-2093.

Rogerio, S.B. Correa, J.C. Moraes, A.M. Auad, E.G., Carvalho, A., 2005. Silicon and acibenzolar-s-methyl as resistance inducers in cucumber, against the whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) Biotype B. Neotropical Entomology, 34(3), 429-433.

Rovenska, G.Z., Zemek, R., 2006. Host plant preference of aphids, thrips and spider mites on GNA-expressing and control potatoes. Phytoparasitica, 34, 139-148.

Sharifi, M., Arvin, M.J., Soleymani, M. 2015. The effect of Onion seed osmopriming on growth characteristics of two cultivars primavera and milk way at transplanting stage. First International Conference and Fourth National Conference on Medicinal Plants and sustainable agriculture 26th December-2015. Hamedan, Iran (In Persian).

Trdan, S., Mileoj, L., Zezlina, I., Raspudic, E.,jus, L., Vidrih, N., Bergant, K., Valic, N., Znidarcic, D., 2005. Feeding damage by onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), on early white cabbage grown under insecticide-free conditions. African Entomology, 13, 85-95.

Trdan, S., Valic, N., Znidarcic, D., 2007. Field efficacy of deltamethrin in reducing damage caused by *Thrips tabaci* lindeman (Thysanoptera: Thripidae) on early white cabbage. Journal of Pest Science, 80, 217-223.

Vanpoecke, R.M.P., Dicke, M., 2004. Indirect defense of plants against herbivores, using the *Arabidopsis thaliana* as a mod el plant, Plant Biology, 6, 387-401.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 31-39

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Evaluation of some engineering properties of green almond for mechanical harvesting

Hajarsadat Seyedalibeyk Lavasani [a], Jalal Baradaran Motie [*b]

[a] M.Sc student of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran
[b] Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ARTICLE INFO

Article history:
Received: 23 February 2022
Accepted: 27 April 2022
Available online: 15 May 2022

Keywords:
Almond
Compression test
Mass modelling
Mechanical properties
Physical properties

ABSTRACT

Green almonds are a seasonal treat, and mechanical harvesting of green almonds has the potential to increase their consumption while also introducing a new method of reducing almond processing costs and residue. The purpose of this study was to investigate the physical properties and mechanical behavior of green almonds of the Sahand variety. The physical properties measured were length, width, thickness, arithmetic and geometric mean diameters, which averaged 29.73, 20.23, 15.02, 21.66, and 20.81 mm, respectively. Additionally, the surface and projected areas, aspect ratio, sphericity, mass, volume, true density, and porosity were determined to be 1366.77 mm2, 473.59 mm2, 0.68, 0.70, 4.14 g, 3.78 cm3, 1.10 g/cm3, and 0.44. Almost all of the physical properties of green almonds studied were found to be correlated. Green almonds had a static friction coefficient of 0.519, 0.441, and 0.523 on MDF, galvanized iron, and rubber, respectively, and the static friction coefficients on MDF and rubber were not significantly different at the 1% confidence level. A uniaxial compression test was used to investigate the mechanical behavior of green almonds under compression. The tests were conducted in three directions (X, Y, and Z, which correspond to the length, width, and thickness of green almonds, respectively) and at three speeds (10, 15, and 20 mm/min). The results indicated that only direction had a significant effect on the mechanical test results and that green almonds can withstand greater deformation along their length before rapture.

Highlights

- This research looked into the physical and mechanical properties of Sahand green almonds.
- The average length, width, thickness, arithmetic and geometric mean diameters were 29.73, 20.23, 15.02, 21.66, and 20.81 mm.
- The surface and projected areas, aspect ratio, sphericity, mass, volume, true density, and porosity were determined to be 1366.77 mm2, 473.59 mm2, 0.68, 0.70, 4.14 g, 3.78 cm3, 1.10 g/cm3, and 0.44.
- Green almonds had static friction coefficients of 0.519, 0.441, and 0.523 on MDF, galvanized iron, and rubber, respectively.

1. Introduction

Over a period of ten years, almond production around the world has increased by one million tons and has almost reached 3.5 million tons in 2019 (FAOSTAT, 2021). The almond kernel consumed by humans only accounts for 15% of the mature almond fruit weight, while more than half of its total fresh weight is its hull (Prgomet et al., 2017). Therefore, managing and reducing almond residue, including its hull, is crucial. While almond by-products are used for energy production and as livestock feed, some novel applications have been discovered and utilized. For example, almond residue is a source of biomass (Akubude and Nwaigwe, 2016; Huang and Lapsley, 2019) and hydrothermal treatment of almond hulls can create biofuel (Remón et al., 2021). The green outer hull of almond is efficient for removing cobalt (Ahmadpour et al., 2009) and chromium(VI) (Nasseh et al., 2017) from contaminated water. It is also used as livestock feed (DePeters et al., 2020; Gupta et al.,

[*] Corresponding author
Email: j.baradaran@um.ac.ir (J. Baradaran)
http://dx.doi.org/10.22034/aes.2022.331121.1024

2020). Almond shell can be used in particleboard mixture (Pirayesh and Khazaeian, 2012; Ferrandez-Villena et al., 2019), polypropylene (Essabir et al., 2013; Appah et al., 2019), and polybutylene succinate (PBS) composite (Liminana et al., 2018). Deionization systems can use activated carbon made from an almond shell as an electrode material (Maniscalco et al., 2020).

Extensive research has been done on the importance and characteristics of almonds (Esfahlan et al., 2010; Özcan et al., 2011) and the physical properties and mechanical behavior of mature almond kernels and shells (Aydin, 2003; Ledbetter and Palmquist, 2006; Aktas et al., 2007; Rasouli et al., 2010; Demir et al., 2019; Sakar et al., 2019; Gradziel, 2020; Zahedi et al., 2020)(. It should be noted that the physical properties of fresh products can be used for classification purposes (Baradaran Motie et al., 2014). Moreover, new systems have been developed for estimating and predicting the physical properties of mature almonds based on variety (Eski et al., 2018) and shell features (Miraei Ashtiani et al., 2020). The Green almond is an unripe form of almond, which is harvested from almond trees before maturing (when it is harvested for its kernel) and is consumed whole in spring. Although green almonds are consumed in many countries around the world and are even sold online, no official statistics or data were found on green almond production. Green almonds are one of the most popular snacks in the middle east and some other parts of the world, which are consumed entirely with their hull and shell, so that by expanding their consumption. It can increase the profit of producers (due to higher selling prices) and also reduce the production of almond waste. However, data on green almonds is relatively scarce (Murathan et al., 2020). To our knowledge, no research has been done on the physical properties of green almonds.

This study aims to determine the physical properties of green almonds of the Sahand variety around 70 days after anthesis (Hawker and Buttrose, 1980; Martínez-Gómez et al., 2008; Serrano et al., 2011; Zhu et al., 2017; Guo et al., 2021) Because almond maturation is influenced by the environment (Sakar et al., 2019)(, climate (Oručević and Aliman, 2018; Parker and Abatzoglou, 2018; Díez-Palet et al., 2019), and irrigation strategies (Egea et al., 2009), green almond harvest varies from year to year and orchard to orchard. The aim of this study was to investigate the physical properties of green almonds for use in designing harvesting and sorting machines. Additionally, the mechanical behavior of green almonds under compression at three perpendicular directions and three different speeds was studied to evaluate their mechanical behavior under compression.

2. Materials and Methods

Green almonds of the Sahand variety (Figure 1) were obtained during spring (April) 2021 from a garden in Shiraz, Iran. Sahand almond is a hybrid late-blooming and hard-shelled variety that matures up to the end of summer (September) (Eskandari and Majidazar, 2009). Samples were stored $4\pm1^{\circ}C$ in a refrigerator for 24 hours and brought to room temperature (22˚C) before the experiments. In the laboratory, 50 samples were randomly selected, excluding samples with visible markings. The initial moisture content was obtained by oven drying the green almonds in a laboratory oven at $75\pm0.5^{\circ}C$ for 24 hours (Shirmohammadi et al., 2018). On three replicates, the moisture content was found to be 90% on a wet basis; the initial weight of each replicate before drying was about 40 g. All samples for measuring physical properties were randomly selected. During the experiment, the Laboratory temperature averaged 22 ˚C, with relative humidity ranging from 25 to 30 percent.

Figure 1. A green almond cut in half to view kernel appearance.

2.1. Physical Properties of green almonds

The physical properties of the green almonds were measured in random order. The properties of length (L), width (W), thickness (T), mass (M), and volume (V) were measured for each of the 50 samples. Dimensions were measured using a digital caliper with an accuracy of 0.01 mm (Mitutoyo, Japan), and weight was measured using a digital balance with an accuracy of 0.01 g (A &D FX-3000 GD, Japan). Arithmetic mean diameter (D_a) and geometric mean diameter (D_g) were calculated using Eq. 1 and Eq. 2 respectively (Mohsenin, 1986).

$$D_a = \frac{L + W + T}{3} \quad (1)$$

$$D_g = \sqrt[3]{LWT} \quad (2)$$

Eq. 3 and Eq. 4 were used to calculate the surface area (Sa) (Mohsenin, 1986) and projected area (Pa) (Khazaei et al., 2006) respectively.

$$S_a = \pi D_g^{\ 2} \quad (3)$$

$$P_a = \frac{\pi L W}{4} \quad (4)$$

Eq. (5) shows the ratio of width to length, which is called the aspect ratio (R_a). Sphericity () in Eq. (6) determines the closeness of the sample's shape to that of a sphere (Mohsenin, 1986). A sphere sample has a sphericity equal to one.

$$R_a = \frac{W}{L} \quad (5)$$

$$\Phi = \frac{\sqrt[3]{LWT}}{L} = \frac{D_g}{L} \quad (6)$$

The theoretical volume of the green almonds (Khazaei et al., 2006; Remón et al., 2021) was calculated using Eq. (7). The results can be compared with the actual volume of each sample as measured with Eq. (8) using the platform method (Mohsenin, 1986). Comparison of the theoretical and the actual volume has been done for other agricultural products as well (Seyedabadi et al., 2011). In this equation, W_T and ρ_T correspond with the weight and density of toluene (C_7H_8), respectively. Compared to water, toluene has a lower surface tension (McLinden and Splett, 2008) which makes it suitable for measuring the volume of textured samples like peach (Emadi et al., 2011). Toluene's density is also lower than water which ensures submergence of the sample (Yan et al., 2008). Therefore, green almond samples were submerged in toluene instead of water due to the texture of the green almonds.

$$V_t = \frac{\pi D_g^{\ 3}}{6} \quad (7)$$

$$V = \frac{W_T}{\rho_T} \quad (8)$$

Bulk density (ρ_b) is defined by the mass of green almonds divided by the volume of the container. In this study, green almonds were poured into a cylinder of known volume and the mass was measured by the digital balance. Bulk density (ρ_b) was used with true density (ρ_t) for calculating porosity (ε) with Eq. (9) (Mohsenin, 1986).

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \quad (9)$$

The static friction coefficient (μ) of samples was calculated with Eq. (10) (Mohsenin, 1986) on three surfaces of MDF (medium density fiberboard), galvanized iron, and rubber. These materials were chosen for this test because agricultural products come into contact with them during mechanical harvest and they have been used in previous studies (Askari Asli-Ardeh et al., 2017; Jahanbakhshi et al., 2019). Random samples were placed on the surface, and the slope of the surface was increased until the samples started to move down at constant speed. At this point, the angle of the surface with the horizon (α) was recorded, and the tangent of this angle is known as the static friction coefficient (Figure 2). This procedure was repeated ten times for each of the three surfaces.

$$\mu = \tan \alpha \quad (10)$$

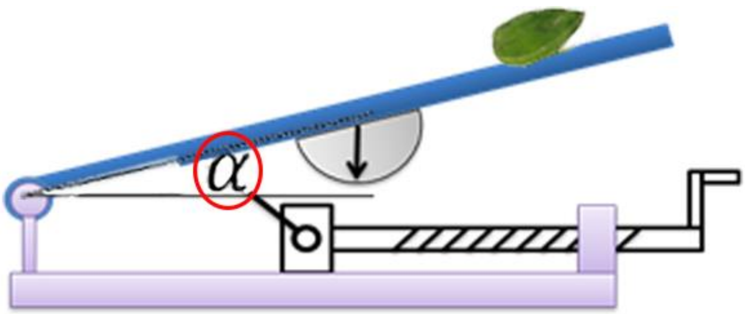


Figure 2. Schematic of slide angle coefficient of friction (COF) Tester.

2.2. Mechanical Behavior of green almonds

The behavior of green almonds under compression was studied using the uniaxial compression test (Tinus Olsen H5KS, England) with a completely randomized factorial experiment in triplicate. The tests (Figure 3) were conducted in three directions (X, Y, and Z), correlating with the sample's three dimensions (length, width, and thickness, respectively) and at three speeds (10, 15, and 20 mm/min) (Mirae et al. 2016). After each test, the rupture force, deformation, and absorbed energy until failure were recorded. A green almond under compression can be seen in Figure 4. Overall, the test was conducted on 27 green almonds.

Minitab (version 17.3.1) was used for statistical analysis of the results. The Pearson correlation method was used to find the correlation between green almond physical properties. General factorial regression was utilized for analyzing the results of compression tests. Means comparisons were made using the Fisher comparison method at specified confidence levels.

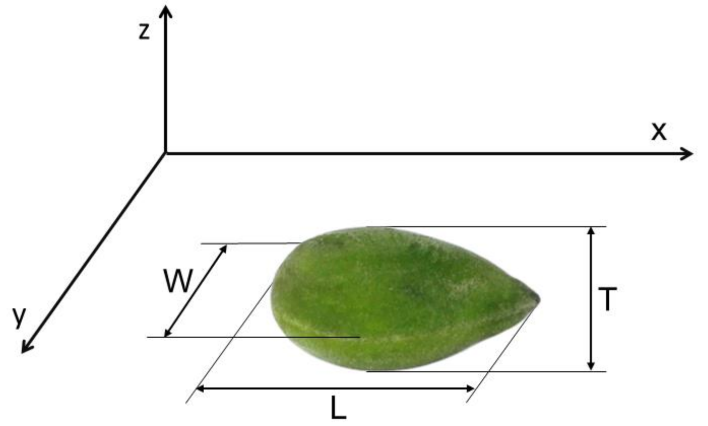


Figure 3. The coordinate system and the green almond's three dimensions.

Figure 4. A green almond under compression test along its length (X direction), SDL Atlas universal testing machine (Tinus Olsen LTD. UK).

3. Results and Discussion

3.1. Physical Properties

A summary of the physical properties of green almonds can be seen in Table 1. The average values for length, width, and thickness of green almonds were 29.73, 20.23, and 15.02 mm, respectively. The arithmetic and geometric mean diameters were 21.66 and 20.81 mm, respectively. The surface area was 1366.77 mm^2, and the projected area was found to be 473.59 mm^2. Additionally, aspect ratio and sphericity were 0.68 and 0.70, respectively. On average, a green almond weighed 4.14 g with a volume of 3.78 cm^3. Finally, the average true density of green almond was 1.10 g/cm^3 and, with a bulk density of 0.62 g/cm^3, green almond porosity was 0.44.

Table 1. Physical properties of green almond

Parameter	Abbreviation	Mean	Min	Max	SD	CV%
Length (mm)	L	29.73	26.72	33.89	1.60	5.37
Width (mm)	W	20.23	16.40	24.44	1.73	8.54
Thickness (mm)	T	15.02	12.36	18.51	1.44	9.57
Arithmetic Mean Diameter (mm)	D_a	21.66	18.96	24.65	1.40	6.46
Geometric Mean Diameter (mm)	D_g	20.81	17.86	24.11	1.46	7.02
Surface Area (mm^2)	S_a	1366.77	1002.46	1826.96	192.56	14.09
Projected Area (mm^2)	P_a	473.59	362.20	600.47	59.88	12.64
Aspect Ratio	R_a	0.68	0.58	0.79	0.05	6.74
Sphericity	Φ	0.70	0.63	0.78	0.03	4.60
Mass (g)	M	4.14	2.84	6.25	0.85	20.57
Theoretical Volume (cm^3)	V_t	4.79	2.99	7.34	1.02	21.23
Volume (cm^3)	V	3.78	2.41	6.17	0.87	22.96
True Density (g/cm^3)	ρ_t	1.10	0.87	1.33	0.07	6.31
Porosity	ε	0.44	0.29	0.53	0.04	8.42

The length and width of green almonds were about 83% of that of mature almonds, and the green almonds' thickness was 90% of that of mature almonds of the same variety without the green hull (Rasouli et al., 2010). The sphericity and mass of mature almonds of Sahand variety were found to be

0.67 and 4.18 g, respectively (Rasouli et al., 2010), which are very close to that of the green almonds in this study. Another study (Murathan et al., 2020) has also measured the weight of green almonds. However, due to the differences between varieties, the samples' weights are more than twice the average weight measured in this study.

A correlation between most of the physical parameters using the Pearson method can be seen in Table 2. All of the parameters shown in this table are highly correlated except for green almonds' true density, which is only correlated to volume. Length and sphericity are also not correlated.

Table 2. Pearson correlation coefficients for physical properties of green almond

	L	W	T	D_a	D_g	S_a	Φ	M	P_a	V
W	0.615**									
T	0.548**	0.831**								
D_a	0.821**	0.930**	0.892**							
D_g	0.753**	0.941**	0.934**	0.993**						
S_a	0.755**	0.939**	0.933**	0.993**	0.999**					
Φ	-0.014	0.720**	0.781**	0.558**	0.647**	0.641**				
M	0.743**	0.904**	0.857**	0.948**	0.947**	0.947**	0.577**			
P_a	0.847**	0.939**	0.797**	0.981**	0.960**	0.961**	0.478**	0.930**		
V	0.720**	0.863**	0.830**	0.913**	0.912**	0.913**	0.552**	0.959**	0.893**	
ρ_t	-0.162	-0.192	-0.222	-0.217	-0.221	-0.219	-0.153	-0.202	-0.201	-0.464**

**Significant at 0.01 probability level

Theoretical volume is significantly (1% confidence level) larger than the actual volume of the green almonds, and therefore, Eq. (7) does not accurately represent the volume of green almonds.

Based on the Pearson correlation coefficients in Table 2, the volume of green almond is correlated with its three dimensions and mass. A model for volume based on the three dimensions is shown in Eq. (11). Additionally, using Eq. (12), volume can be modelled using mass with an R^2 greater than 90%. Linear model of volume based on mass is shown in Figure 5.

$$V = -8.023 + 0.1549L + 0.2071W + 0.2006T,\ R^2 = 83.58\% \quad (11)$$

$$V = -0.2650 + 0.9768M,\ R^2 = 91.9\% \quad (12)$$

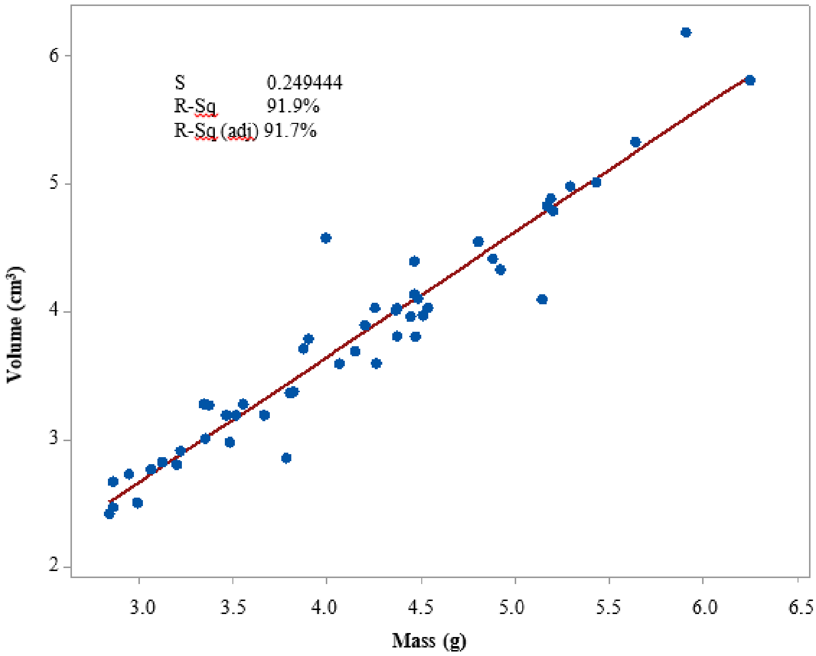


Figure 5. Linear model for green almond's volume based on mass

Green almond mass can be modelled based on its dimensions. Using only one dimension, width can give the most accurate model with an R^2 of 81.72%, as shown in Eq. (13) and Figure 6. The linear model for mass based on the green almond's dimensions in Eq. (14) has an R^2 of around 90%.

$$M = -4.883 + 0.4462W,\ R^2 = 81.72\% \quad (13)$$

$$M = -7.818 + 0.1507L + 0.2336W + 0.1835T,\ R^2 = 90.28\% \quad (14)$$

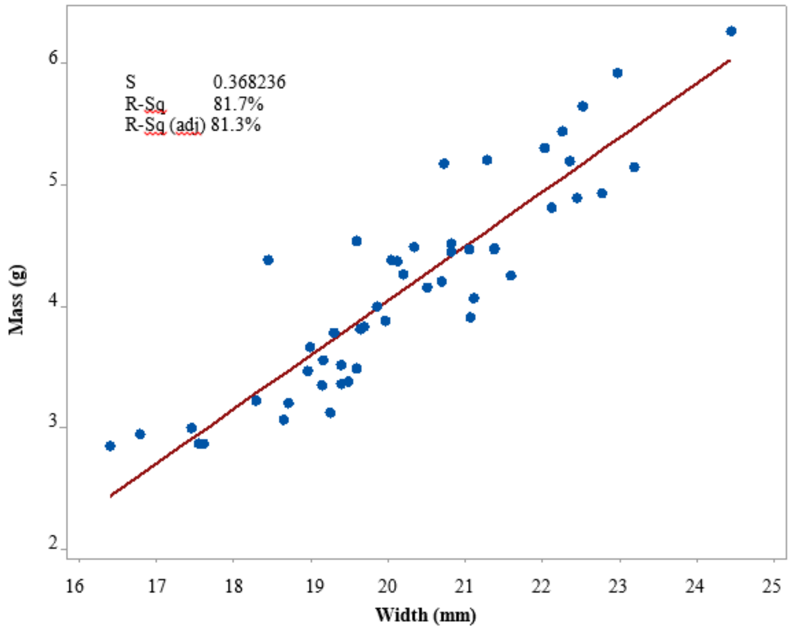


Figure 6. Linear model for green almond's mass based on width

The static friction coefficient of green almonds on three surfaces is presented in Table 3. Different letters within a column represent statistically significant differences by Fisher's test at 1% confidence level. The static friction coefficient of green almonds on MDF and rubber is not significantly different at 0.519 and 0.523, respectively. The static friction coefficient of green almonds on galvanized iron is significantly lower than that of MDF and rubber. This coefficient is essential for the design of harvest, transport, and storage equipment.

Table 3. Static friction coefficient of green almond

Surface Type	Mean	Min	Max	SD	CV%
MDF	0.519[a]	0.488	0.554	0.025	4.88
Galvanized Iron	0.441[b]	0.424	0.466	0.017	3.96
Rubber	0.523[a]	0.488	0.577	0.034	6.51

Table 4. Analysis of variance for the mechanical properties of green almond in compression test.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	8	61.246	61.20%	61.246	7.6557	3.55	0.012**
Linear	4	52.403	52.36%	52.403	13.1008	6.07	0.003**
Direction	2	51.164	51.12%	51.164	25.5818	11.86	0.001**
Speed	2	1.240	1.24%	1.240	0.6198	0.29	0.754ns
2-Way Interactions	4	8.843	8.84%	8.843	2.2107	1.02	0.421ns
Direction*Speed	4	8.843	8.84%	8.843	2.2107	1.02	0.421ns
Error	18	38.830	38.80%	38.830	2.1572		
Total	26	100.076	100.00%				

3.2. Mechanical Behavior

As explained in the materials and methods section, the mechanical behavior of green almonds was studied using two factors: compression direction and compression speed. While the direction of compression significantly affected the results (confidence level of 1%), for the speed range investigated in this experiment (10 to 20 mm/min), speed had no significant effect on the results (confidence level of 1%) (Table 4). A study conducted on the mechanical behavior of mature almonds under compression found that both compression direction and speed significantly affect the rupture force of almonds with a confidence level of 1% (Altuntas et al., 2010). Therefore, the mechanical properties of green almonds are only grouped according to compression direction in Table 5. This table shows that the greatest rapture force was observed in the Z direction, while the most energy was absorbed in the X direction. Using the Fisher comparison method, the mean of deformation in the X direction is significantly higher than the means in the other two directions at a 5% confidence level. Figure 7 presents a slight but insignificant (1% and 5% confidence levels) increase in deformation before rupture with increased compression speed from 10 to 15 mm/min, which then drops to around 5 mm at 20 mm/min. Furthermore, deformation decreases significantly from 7.317 mm in the X direction to 5.390 and 3.957 mm in the Y and Z directions. The combined effect of speed and direction on deformation can be seen in Figure 7.

Table 5. Mechanical properties of green almond.

Parameter	Direction	Mean	Min	Max	SD
Rupture Force (N)	X	70.96	45.50	104.00	18.91
	Y	67.18	43.50	120.10	23.50
	Z	86.63	44.85	146.90	34.31
Deformation (mm)	X	7.317	4.913	9.730	1.344
	Y	5.390	3.825	9.070	1.603
	Z	3.957	2.560	6.920	1.318
Absorbed Energy (J)	X	0.3366	0.1755	0.9810	0.2600
	Y	0.1691	0.0578	0.4360	0.1115
	Z	0.1289	0.0482	0.2786	0.0779

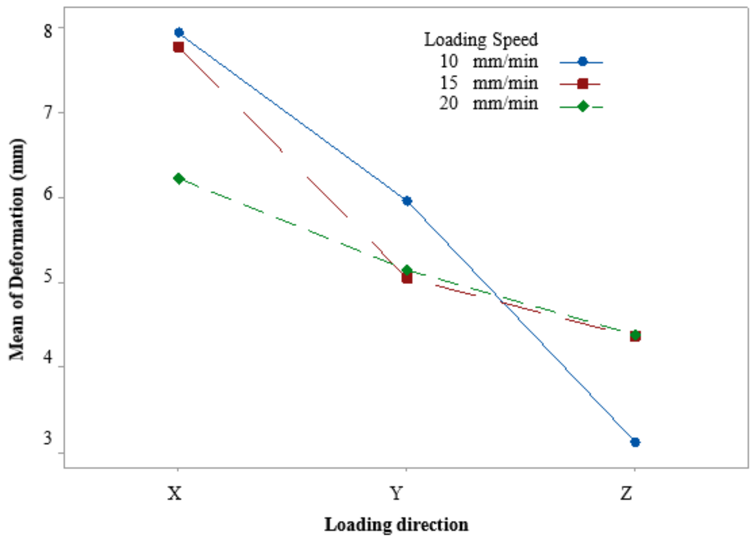


Figure 7. Interaction plot showing the effect of direction and speed on green almond deformation.

4. Conclusion

This study evaluated the physical properties of the Sahand variety of green almond and its behavior under compression at different directions and speeds. It was found that, because of its shape, the theoretical equation for volume could not accurately represent green almond volume, and a new model for calculating the volume was proposed. The static friction coefficient of green almonds on MDF and rubber is greater than that on galvanized iron. The results of the uniaxial compression test suggest that compression speed does not significantly affect the mechanical behavior of green almonds and that they can endure the most deformation along the X direction (length). These findings may be used to facilitate studies and further developments in mechanical harvesting and post-harvesting of green almonds.

Declarations

Funding and competing interests

The authors have no relevant financial or non-financial interests to disclose.

CRediT authorship contribution statement

Jalal Baradaran Motie: Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Reviewing and Editing, Supervision. **Hajarsadat S Lavasani:** Conceptualization, Formal analysis, Investigation, Resources, Writing - Original Draft, Visualization.

Acknowledgements

The authors would like to thank the almond producer for providing the green almonds.

References

Ahmadpour, A., Tahmasbi, M., Bastami, T.R., Besharati, J.A., 2009. Rapid removal of cobalt ion from aqueous solutions by almond green hull. Journal of Hazardous Materials 166, 925-930.

Aktas, T., Polat, R., Atay, U., 2007. Comparison of mechanical properties of some selected almond cultivars with hard and soft shell under compression loading. Journal of Food Process Engineering 30, 773-789.

Akubude, V.C., Nwaigwe, K.N., 2016. Economic importance of edible and non-edible almond fruit as bioenergy material: a review. American Journal of Energy Science 3, 31-39.

Altuntas, E., Gercekcioglu, R., Kaya, C., 2010. Selected mechanical and geometric properties of different almond cultivars. International Journal of Food Properties 13, 282-293.

Appah, S., Wang, P., Ou, M., Gong, C., Jia, W., 2019. Review of electrostatic system parameters, charged droplets characteristics and substrate impact behavior from pesticides spraying. International Journal of Agricultural and Biological Engineering 12, 1-9.

Askari Asli-Ardeh, E.A., Mohammad Zadeh, H., Abbaspour-Gilandeh, Y., 2017. Determination of dynamic friction coefficient in common wheat varieties on different contact surfaces. Agricultural Engineering International: CIGR Journal 19, 136-141.

Aydin, C., 2003. Physical properties of almond nut and kernel. Journal of food engineering 60, 315-320.

Baradaran Motie, J., Miraei Ashtiani, S.H., Abbaspour-Fard, M.H., Emadi, B., 2014. Modeling physical properties of lemon fruits for separation and classification. International Food Research Journal 21, 1901-1909.

Demir, B., Sayinci, B., Çetin, N., Yaman, M., Çömlek, R., 2019. Shape discrimination of almond cultivars by Elliptic Fourier Descriptors. Erwerbs-Obstbau 61, 245-256.

DePeters, E., Swanson, K., Bill, H., Asmus, J., Heguy, J., 2020. Nutritional composition of almond hulls. Applied Animal Science 36, 761-770.

Díez-Palet, I., Funes, I., Savé, R., Biel, C., de Herralde, F., Miarnau, X., Vargas, F., Àvila, G., Carbó, J., Aranda, X., 2019. Blooming under Mediterranean climate: Estimating cultivar-specific chill and heat requirements of almond and apple trees using a statistical approach. Agronomy 9, 760.

Egea, G., González-Real, M.M., Baille, A., Nortes, P.A., Sánchez-Bel, P., Domingo, R., 2009. The effects of contrasted deficit irrigation strategies on the fruit growth and kernel quality of mature almond trees. Agricultural water management 96, 1605-1614.

Emadi, B., Abolghasemi, R., Aghkhani, M.H., Beyraghi Toosi, S., 2011. Physical and mechanical properties of peach. World Applied Sciences Journal 12, 119-122.

Esfahlan, A.J., Jamei, R., Esfahlan, R.J., 2010. The importance of almond (*Prunus amygdalus* L.) and its by-products. Food chemistry 120, 349-360.

Eskandari, S., Majidazar, M., 2009. Introduction of new hybrid varieties of almond (*Prunus amygdalus* Batsch) for almond producing regions of Iran. World Applied Sciences Journal 6, 323-330.

Eski, İ., Demir, B., Gürbüz, F., Kuş, Z.A., Yilmaz, K.U., Uzun, M., Ercişli, S., 2018. Design of neural network predictor for the physical properties of almond nuts. Erwerbs-Obstbau 60, 153-160.

Essabir, H., Nekhlaoui, S., Malha, M., Bensalah, M., Arrakhiz, F., Qaiss, A., Bouhfid, R., 2013. Bio-composites based on polypropylene reinforced with Almond Shells particles: Mechanical and thermal properties. Materials & Design 51, 225-230.

FAOSTAT, 2021. FAO Global Statistical Yearbook. FAO, Rome.

Ferrandez-Villena, M., Ferrandez-Garcia, C.E., Garcia Ortuño, T., Ferrandez-Garcia, A., Ferrandez-Garcia, M.T., 2019. Study of the utilisation of almond residues for low-cost panels. Agronomy 9, 811-820.

Gradziel, T.M., 2020. Redomesticating almond to meet emerging food safety needs. Frontiers in Plant Science 11, 778.

Guo, C., Wei, Y., Yang, B., Ayup, M., Li, N., Liu, J., Liao, K., Wang, H., 2021. Developmental transcriptome profiling uncovered carbon signaling genes associated with almond fruit drop. Scientific reports 11, 3401.

Gupta, A., Sharma, R., Sharma, S., 2020. Almond. In: Nayik, G.A., Gull, A. (Eds.), Antioxidants in Vegetables and Nuts-Properties and Health Benefits. Springer, Singapore, pp. 423-452.

Hawker, J., Buttrose, M., 1980. Development of the almond nut (*Prunus dulcis* (Mill.) DA Webb). Anatomy and chemical composition of fruit parts from anthesis to maturity. Annals of Botany 46, 313-321.

Huang, G., Lapsley, K., 2019. Almonds. In: Pan, Z., Zhang, R., Zicari, S. (Eds.), Integrated Processing Technologies for Food and Agricultural By-Products. Academic Press, pp. 373-390.

Jahanbakhshi, A., Rasooli Sharabiani, V., Heidarbeigi, K., Kaveh, M., Taghinezhad, E., 2019. Evaluation of engineering properties for waste control of tomato during harvesting and postharvesting. Food science & nutrition 7, 1473-1481.

Khazaei, J., Sarmadi, M., Behzad, J., 2006. Physical properties of sunflower seeds and kernels related to harvesting and dehulling. Lucrari Stiintifice 49, 262-271.

Ledbetter, C.A., Palmquist, D.E., 2006. Comparing physical measures and mechanical cracking products of 'Nonpareil'almond (*Prunus dulcis* [Mill.] DA Webb.) with two advanced breeding selections. Journal of food engineering 76, 232-237.

Liminana, P., Garcia-Sanoguera, D., Quiles-Carrillo, L., Balart, R., Montanes, N., 2018. Development and characterization of environmentally friendly composites from poly (butylene succinate)(PBS) and almond shell flour with different compatibilizers. Composites Part B: Engineering 144, 153-162.

Maniscalco, M., Corrado, C., Volpe, R., Messineo, A., 2020. Evaluation of the optimal activation parameters for almond shell bio-char production for capacitive deionization. Bioresource Technology Reports 11, 100435.

Martínez-Gómez, P., Sánchez-Pérez, R., Dicenta, F., 2008. Fruit development in almond for fresh consumption. Journal-American Pomological Society 62, 82-86.

McLinden, M.O., Splett, J.D., 2008. A liquid density standard over wide ranges of temperature and pressure based on toluene. Journal of Research of the National Institute of Standards and Technology 113.

Miraei Ashtiani, S.H., Rohani, A., Aghkhani, M.H., 2020. Soft computing-based method for estimation of almond kernel mass from its shell features. Scientia Horticulturae 262, 109071.

Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York.

Murathan, Z.T., Kaya, A., Erbil, N., Arslan, M., Dıraz, E., Karaman, Ş., 2020. Comparison of bioactive components, antimicrobial and antimutagenic features of organically and conventionally grown almond hulls. Erwerbs-Obstbau 62, 463-472.

Nasseh, N., Taghavi, L., Barikbin, B., Khodadadi, M., 2017. Advantage of almond green hull over its resultant ash for chromium (VI) removal from aqueous solutions. International Journal of Environmental Science and Technology 14, 251-262.

Oručević, A., Aliman, J., 2018. The phenology of flowering and ripening of almond cultivars Nonpareil, Texas, Ferraduel and Genco in Herzegovina. International Journal of Plant & Soil Science 21, 1-9.

Özcan, M.M., Ünver, A., Erkan, E., Arslan, D., 2011. Characteristics of some almond kernel and oils. Scientia Horticulturae 127, 330-333.

Parker, L.E., Abatzoglou, J.T., 2018. Shifts in the thermal niche of almond under climate change. Climatic change 147, 211-224.

Pirayesh, H., Khazaeian, A., 2012. Using almond (*Prunus amygdalus* L.) shell as a bio-waste resource in wood based composite. Composites Part B: Engineering 43, 1475-1479.

Prgomet, I., Gonçalves, B., Domínguez-Perles, R., Pascual-Seva, N., Barros, A.I., 2017. Valorization challenges to almond residues: Phytochemical composition and functional application. Molecules 22, 1774.

Rasouli, M., Mollazade, K., Fatahi, R., Zamani, Z., Imani, A., Martínez-Gómez, P., 2010. Evaluation of Engineering Properties in Almond Nuts. International Journal of Natural & Engineering Sciences 4, 17-26.

Remón, J., Latorre-Viu, J., Matharu, A.S., Pinilla, J.L., Suelves, I., 2021. Analysis and optimisation of a novel 'almond-refinery'concept: Simultaneous production of biofuels and value-added chemicals by hydrothermal treatment of almond hulls. Science of The Total Environment 765, 142671.

Sakar, E.H., El Yamani, M., Rharrabti, Y., 2019. Geometrical Traits in Almond Fruit as Affected by Genotypic and Environmental Variations in Northern Morocco. Erwerbs-Obstbau 61, 103-112.

Serrano, N., Lovera, M., Salguero, A., Arquero, O., Casado, B., Fernández, J., 2011. Flowering and maturation dates of the main late-blooming almond varieties of the Mediterranean basin. Acta horticulturae, 99-102.

Seyedabadi, E., Khojastehpour, M., Sadrnia, H., Saiedirad, M.-H., 2011. Mass modeling of cantaloupe based on geometric attributes: A case study for Tile Magasi and Tile Shahri. Scientia Horticulturae 130, 54-59.

Shirmohammadi, M., Charrault, E., Blencowe, A., 2018. Micromechanical properties of almond kernels with various moisture content levels. International Journal of Food Properties 21, 1820-1832.

Yan, Z., Sousa-Gallagher, M.J., Oliveira, F.A.R., 2008. Shrinkage and porosity of banana, pineapple and mango slices during air-drying. Journal of Food Engineering 84, 430-440.

Zahedi, S.M., Abdelrahman, M., Hosseini, M.S., Yousefi, R., Tran, L.-S.P., 2020. Physical and biochemical properties of 10 wild almond (Amygdalus scoparia) accessions naturally grown in Iran. Food Bioscience 37, 100721.

Zhu, Y., Wilkinson, K.L., Wirthensohn, M., 2017. Changes in fatty acid and tocopherol content during almond (*Prunus dulcis*, cv. Nonpareil) kernel development. Scientia Horticulturae 225, 150-155.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 41-46

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Influence of drought stress on growth and mineral uptake of GF677 (peach and almond hybrid) rootstock under *in vitro* conditions

Mehri Mashayekhi [a], Mohammad Esmaeil Amiri [b], Fariborz Habibi [*b]

[a] M.Sc student, Department of Horticultural Science, Faculty of Agriculture, University of Zanjan, Zanjan, Iran
[b] Department of Horticultural Science, Faculty of Agriculture, University of Zanjan, Zanjan, Iran

ARTICLE INFO

Article history:
Received: 31 March 2022
Accepted: 30 April 2022
Available online: 5 May 2022

Keywords:
Culture medium
Nitrogen
Polyethylene glycol
Proliferation rate

ABSTRACT

The effect of drought stress induced by polyethylene glycol (PEG-6000) on the growth and mineral uptake of GF677 (peach and almond hybrid) rootstock was investigated *in vitro* using solid and liquid mediums. Plantlets of the GF677 rootstock were subcultured into the Murashige and Skoog (MS) proliferation medium containing 1 mg/l BA (6-Benzyladenine) and 0.1 mg/l NAA (naphthaline acetic acid) under four different drought stress conditions: 0 (control), 1, 2, and 3 percent polyethylene glycol. After six weeks, results indicated that the highest drought level reduced fresh weight, dry weight, shoot length, and proliferation rate, with the reduction being greater in the solid medium than in the liquid medium. Leaf abscission was greater in the solid medium than in the liquid medium. In the liquid medium, the GF677 rootstock absorbed more nitrogen (N) than in the solid medium. Drought stress had no effect on phosphorus (P) uptake. Potassium (K) uptake increased when drought levels were evaluated in both mediums, but was greater in the liquid medium than in the solid medium. Calcium (Ca), magnesium (Mg), and iron (Fe) uptake decreased in both mediums as drought levels increased. The GF677 rootstock was capable of uptake of N and K at a high concentration. Mineral uptake was greater in a liquid medium than in a solid medium. In conclusion, the GF677 rootstock exhibited a high capacity for N and K uptake under drought stress.

Highlights

- *In vitro* drought stress induced by PEG on peach and almond hybrid rootstock growth and mineral uptake was studied using solid and liquid media.
- In the Murashige and Skoog proliferation medium with 1 mg BA and 0.1 mg NAA, rootstock plantlets were subcultured under four different drought stress conditions: 0, 1, 2, and 3 percent PEG.
- The results showed that the highest level of drought reduced fresh weight, dry weight, shoot length, and proliferation rate.
- Potassium uptake increased with drought levels in both liquid and solid media, but more so in the liquid.
- Finally, the GF677 rootstock had high N and K uptake capacity under drought stress.

1. Introduction

Drought stress is one of the most important problems in fruit tree production in arid and semi-arid areas, which reduces the growth and yield of fruit trees. Therefore, evaluation of rootstocks of fruit trees to stresses and their ability to grow in these conditions is very important to identify resistant and tolerant rootstocks (Kozlowski, 2002; Yadav et al., 2021).

GF677 is a hybrid of peach (*Prunus persica* L.) and almond (*Prunus amygdalus* Batsch), which is widely used in the world. One of the advantages of this drought - resistance rootstock is calcareous soils, high soil moisture, and iron deficiency (Antonopoulou et al., 2005).

More than 80% of plant tissue is water, and its deficiency quickly reveals severe side effects in plants. This is the most important factor limiting the growth and development of plants and reduces plant height due to drought stress (Zhang et al., 2006). Under drought stress conditions, the water potential of the plant is more negative than in normal conditions, and water uptake by the plant is difficult (Anjum et al., 2011). Plants in

* Corresponding author
Email: fariborz_h659@yahoo.com (F. Habibi)
http://dx.doi.org/10.22034/aes.2022.335677.1027

response to drought stress show responses that vary depending on the intensity of stress, duration of stress, genotype, age, and developmental stage of the plant at the time of stress (Chartzoulakis et al., 2002). Therefore, different plant species show a wide range of drought resistance mechanisms that lead to morphological, physiological, and biochemical adaptations (Anjum et al., 2011).

Polyethylene glycol (PEG) is a flexible, non-toxic polymer that can cause negative osmotic pressure. It also has no tendency to react with chemicals and biology, and this property has made polyethylene glycol one of the most useful molecules for generating negative osmotic pressure in scientific experiments (Sivritepe et al., 2008). This substance is not absorbed by the plant, and its concentration remains constant throughout the stress period. Therefore, it is known as the best treatment for osmotic stresses compared to other osmolytes, such as mannitol, salt, etc. (Georgieva et al., 2004). The difference between liquid and solid mediums is that in the solid medium, a jelly-like substance such as agar is used, but in the liquid medium it lacks it. Agar as a gel-producing agent in culture mediums is one of the factors reducing the water potential of the culture medium and inducing drought stress (Al-Khayri and Al-Bahrany, 2004).

The use of *in vitro* culture techniques to select plant species that tolerate salinity and drought is very common because it is possible to have more control compared to field conditions (Habibi and Amiri, 2013). Under field conditions, plants are exposed to variable climatic conditions that can affect research results. Plant tissue culture techniques can overcome these limitations and allow the plant to grow under controlled nutritional and climatic conditions, and it is possible to perform experiments under the same conditions throughout the year (Habibi and Amiri, 2013). Also, evaluating the salinity tolerance of plants in field and greenhouse conditions is expensive and requires a lot of time. For example, in a study, increasing drought stress levels induced by PEG-8000 reduced fresh callus weight, relative growth rate, and water content in two date palm genotypes (Al-Khayri and Al-Bahrany, 2004). The enzymatic and antioxidant responses of two banana genotypes were investigated under drought stress induced by PEG-6000. With the increasing drought, the activities of catalase, glutamine, ascorbate peroxidase, and superoxidase superoxide increased, as well as lipid peroxidation (Chai et al., 2005). In a study, the *in vitro* response of Gisela5 sweet cherry rootstock to different concentrations of PEG-8000 showed that shoot dry weight, shoot length, water content, and leaf chlorophyll content of explants decreased with increasing drought levels. Malondialdehyde (MDA) and antioxidant enzymes such as superoxide dismutase, ascorbate peroxidase, peroxidase, and catalase increased significantly with increasing drought stress. In addition, the concentrations of potassium (K), calcium (Ca), iron (Fe) and manganese (Mn) in the explant tissue also decreased (Sivritepe et al., 2008).

The GF677 rootstock is widely used around the world as a drought-resistant rootstock for stone fruits. However, no definite report has been found about the mineral uptake potential of this rootstock under drought stress conditions. Therefore, the purpose of this study was to investigate the growth responses of the GF677 rootstock and to evaluate the potential of mineral uptake under drought stress *in vitro* and compare it in solid and liquid mediums.

2. Materials and methods

One-year-old buds were used as plant material in this experiment to prepare explants. After disinfection, plant samples were transferred to Moraschig and Skock (MS) medium with 0.5 mg/l BAP. After budding, they were transplanted to MS basal medium. Baseline compounds included macro elements, microelements, vitamins, and iron, 30 g/l sucrose, 1 mg/l benzyl adenine (BA), and 0.1 mg/l naphthalene acetic acid (NAA).

Drought stress was performed in solid and liquid mediums. To prepare the drought treatment mediums, after calculating the required amount of PEG-6000 (0, 1, 2, and 3%) for each treatment level, add it to the prepared MS medium and mix well, and then label the containers. The pH was measured. The pH of the culture medium was adjusted from 5.7 to 5.8. Then 7 g/l of agar was added to the culture medium and completely dissolved by stirring and continuous heating on the heater. The medium was then distributed in culture dishes and autoclaved for 15 minutes at 121 ° C and 15 pounds per square inch. To apply drought stress in liquid conditions, the steps for preparing the liquid culture medium were the same as for preparing the solid culture medium; the difference is that agar was not added after adjusting the pH. Also, a cellulose filter (sorbol) was used to establish and prevent the explants from drowning in the liquid medium, and the explants were placed in the middle of the filter. Three uniform explants (approximately 1.5 cm) were planted in each culture dish. The storage conditions of all cultures (establishment stage, filling stage, and salinity treatment) in the growth chamber were at 25±2 °C with 16 hours of light and a light intensity of 30002500 lux.

This study was conducted in a completely randomized design (CRD) in the tissue culture laboratory of the Department of Horticultural Sciences, Zanjan University. Six weeks after drought stress, growth parameters (fresh weight, dry weight, shoot height, proliferation rate, number of new leaves, leaf abscission) and mineral concentrations in GF677 explants were measured. At the end of the stress period (sixth week), the shoot length of explants was measured by a ruler (with an accuracy of 0.1) in centimeters. To measure fresh weight, explants were removed from the culture dishes and washed with distilled water (to remove MS medium from the bottom of the explants). Then, the fresh weight of explants was measured with a digital balance with an accuracy of 0.0001. After measuring the fresh weight, the explants were placed in a paper bag and placed in an oven at 65 ° C for 48 hours, after which time they were taken out of the oven and their dry weight was measured with a digital balance with an accuracy of 0.0001. The proliferation rate was obtained by counting shoots produced in the sixth week. Each replication was counted to determine the number of new leaves produced in each treatment (Ghaleb et al., 2010).

Dried explants were used in the oven to measure mineral concentration. First, all dried explants of each treatment were completely pulverized with the help of a laboratory mill and passed through a 0.5 mm sieve, and then 0.3 g of the powdered sample was extracted by the wet ashing method with sulfuric-salicylic acid and oxygenated water. After extraction, total nitrogen (N) by the Kjeldahl method, phosphorus (P) by a calorimetric method by a spectrophotometer (Cecil.Series 2, England), potassium (K) by flowmeter (Jenway PFP7, England), calcium (Ca), magnesium (Mg), and iron (Fe) were measured by atomic absorption spectrometry (Varian-Specter AA 20, Australia) (Emami, 1996).

The obtained data were analyzed using MSTAT-C statistical software, and the means were compared at a 5% probability level using the Duncan multiple range test.

3. Results and discussion

Increasing the drought level of solid and liquid mediums caused more weight loss in GF677 explants. According to Table 1, the highest fresh weight loss was achieved at the 3% dry level with 450 mg. The highest fresh weight, with 1013 mg, was observed in the control treatment. In the liquid medium, the highest fresh weight loss was achieved at the dry level of 3% with 600 mg. The highest fresh weight, at 1147 mg, was observed in the control treatment. In the liquid medium, no significant difference was observed between levels of 2 and 3% PEG-6000 (Table 2). In the solid medium, fresh weight at different levels of drought than liquid medium was more affected by different levels of PEG-6000.

Table 1. Influence of drought levels on growth parameters of GF677 rootstock after six weeks on solid MS basal medium

Drought levels (%)	Fresh weight (mg)	Dry weight (mg)	Shoot length (cm)	Proliferation rate (shoot/month)	Leaf number (leaf/explant)	Leaf abscission (Number)
0	1013 a	91.67 a	5 a	5 a	14 a	0.7 c
1	830 b	82.67 b	4.16 b	3.33 ab	13 ab	3.04 b
2	627.7 c	65 c	3.5 c	2 bc	11 b	5.04 a
3	450 d	45.33 d	3.16 c	1 c	8 c	5.7 a

Means in each column with similar letters are not significantly different.

Table 2. Influence of drought levels on growth parameters of GF677 plantlets after six weeks on liquid MS basal medium

Drought levels (%)	Fresh weight (mg)	Dry weight (mg)	Shoot length (cm)	Proliferation rate (shoot/month)	Leaf number (leaf/explant)	Leaf abscission (Number)
0	1147 a	98.33 a	5.33 a	4.66 a	13.67 a	0.7 c
1	983.3 a	88.33 a	5.16 a	4 a	12 ab	1.37 b
2	763.3 b	68.33 b	4.16 b	2.33 b	11 bc	1.7 b
3	600 b	56.67 b	3.5 c	1.66 b	10 c	2.7 a

Means in each column with similar letters are not significantly different.

The dry weight of GF677 explants decreased with increasing drought levels in both mediums. In the solid medium, the highest dry weight loss was achieved at 3% dry surface with 45.33 mg. The highest dry weight, at 91.67 mg, was observed in the control treatment (Table 1). In the liquid medium, the highest dry weight loss was achieved at 3% dry surface, with 56.67 mg. The highest dry weight, with 98.33 mg, was observed in the control treatment (Table 2). Dry weight at different levels of drought in the solid medium was more reduced than in the liquid medium.

According to Table 1, in the solid medium, the highest shoot height was obtained in the control treatment at 5 cm. The lowest shoot height of 3.16 cm was observed in the 3% PEG-6000 treatment. There was no significant difference in shoot levels of 2 and 3% in terms of shoot height. In the liquid medium, the highest shoot height was obtained in the control treatment at 5.33 cm (Table 2). The lowest shoot height of 3.5 cm was observed in the 3% PEG-6000 treatment. There was no significant difference between shoot control and the 1% level in terms of shoot height (Table 2).

Table 2 shows that in the solid medium, the lowest proliferation rate with one shoot per month was obtained in the 3% PEG-6000 treatment. The highest proliferation rate, with 5 shoots per month, was observed in the control treatment. In liquid medium, the lowest proliferation rate of 1.66 shoots per month was obtained in the 3% PEG-6000 treatment (Table 2). The highest proliferation rate, with 4.66 shoots per month, was observed in the control treatment.

In solid mediums, the highest and lowest number of new leaves, with 14 and 8 leaves, were observed in the control treatment and 3% PEG-6000 treatment, respectively. There was no significant difference between the control treatment and 1% treatment and also between 1% and 2% treatments (Table 1). According to Table 2, in the liquid medium, the highest and lowest number of new leaves, with 13.67 and 10 leaves, were observed in the control treatment and 3% PEG-6000 treatment, respectively.

Leaf abscission increased with increasing drought levels in the solid medium. Table 1 shows that the lowest leaf abscission was in the control treatment. The highest leaf abscission was observed at drought levels of 2 and 3%, which did not differ significantly. In the liquid medium, the lowest leaf abscission was obtained in the control treatment. The highest leaf abscission was observed with a 2.7 number of leaves on the dry surface of 3% (Table 2). In the solid medium, leaf abscission was more affected by different levels of PEG-6000 than in the liquid medium.

GF677 rootstock growth parameters in the solid medium were more affected by different drought levels than in the solid medium (Tables 3 and 4). This is because increasing PEG levels reduces the water availability to the plant by creating a negative osmotic pressure (especially osmotic stress) (Al-Khayri and Al-Bahrany, 2004). Under these conditions, the water potential of the plant's environment is more negative than under normal conditions, and water uptake by the plant is difficult. These results are also obtained under drought stress in date palm (Al-Khayri and Al-Bahrany, 2004), raspberries (Georgieva et al., 2004), banana genotypes (Chai et al., 2005) and Gisela5 cherry rootstock (Sivritepe et al., 2008). Therefore, growth reduction indicates the effect of osmotic stress induced by polyethylene glycol on GF677 growth parameters (Macar et al., 2009). The effect of osmotic stress, which occurs immediately after increasing the PEG concentration in the explant culture medium, significantly reduces growth (Shibli and Al-Juboory, 2002). Fresh weight and dry weight loss in plants under drought stress seem to be due to inhibition of cell development and growth due to the reduction of turgor pressure (Al-Khayri and Al-Bahrany, 2004). The researchers reported that under drought stress conditions, plant dry matter production also decreased due to reduced water availability.

Also, the growth response of the branches to water shortages is highly dependent on the plant genotype (Munns, 2002). Growth inhibition may play a role in adapting to drought stress. Also, when plants do not have enough access to water, the amount of growth inhibitors, including abscisic acid, in the plant increases. On the other hand, some researchers have reported a decrease in the amount of growth-promoting hormones, such as auxins, gibberellins, and cytokinins, in the plant due to a lack of water (Macar et al., 2009). On the other hand, a decrease in growth hormones and an increase in growth inhibitors could be the reasons for this decrease in growth (Xu et al., 2001). Drought stress in solid and liquid conditions reduced the vegetative growth of GF677 rootstock, but this rootstock was able to continue its growth and did not dry out, which indicates the resistance of this plant to drought stress and the appropriate internal mechanism of this plant to cope with drought stress (Figure 1 and Figure 2).

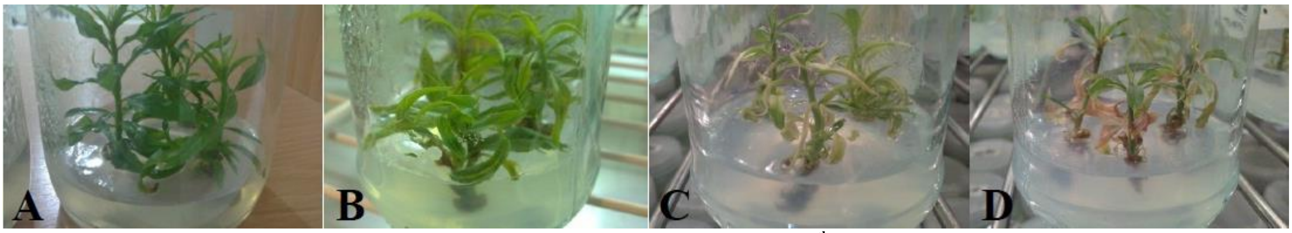


Figure 1. Influence of different PEG-6000 concentrations on GF677 plantlets at 6th week culture in solid medium A) Control, B) 1%, C) 2%, D) 3%.

Figure 2. Influence of different PEG-6000 concentrations on GF677 plantlets at 6th week culture in liquid medium A) Control, B) 1%, C) 2%, D) 3%.

As can be seen in Table 3, in the solid medium, the highest N concentration was obtained in the control treatment with 4.73%. The lowest tissue N concentration, with 4.5%, is observed on the dry surface of 3%. There was no significant difference between control and 1% treatments, and also between 1% and 2% treatments. In the liquid medium, the highest N concentration was obtained in the control treatment, at 5.33%. The lowest tissue N concentration is observed at 1.5% on the dry surface of 3%. There was no significant difference between control and 1% treatments and between 2% and 3% treatments (Table 4). GF677 rootstock in liquid medium uptakes more N at different levels of drought than in solid medium.

According to Tables 3 and 4, it can be seen that drought stress had a small effect on P uptake, so that with increasing drought levels, P uptake decreased in both mediums, which was not significant.

In the solid medium, with increasing drought, tissue K concentration in GF677 rootstock increased as the highest concentration of K was observed in the treatment of 3% with 0.8%. There was no significant difference in K concentration between the control treatment and levels of 1 and 2% (Table 3). According to Table 4, with increasing drought, tissue K concentration in the GF677 rootstock increased as the highest concentration of K was observed in the treatment of 3% with 1.11%. There is no significant difference in K concentration between 1 and 2% levels. In general, the GF677 rootstock was more capable of adsorbing K in the liquid medium than in the solid medium.

According to Table 3, the concentration of Ca in the GF677 rootstock tissue decreased with increasing dry levels in the solid medium. The lowest concentration of calcium on the dry surface was 3% with 0.47%. The highest tissue Ca concentration was in the control treatment, at 1.22%. In the liquid medium, the lowest concentration of Ca on the dry surface was 3% with a tolerance of 0.56%. The highest tissue Ca concentration was in the control treatment with a 1.48%.

At GF677 rootstock, the lowest Mg concentration in tissue was at a 3% dry level, at 641.2 ppm. The highest concentration of Mg was in the control treatment with 679.5 ppm. There was no significant difference in Mg uptake between levels 2 and 3% of PEG-6000 (Table 3). GF677 had the lowest Mg concentration in the tissue at a dry surface of 3% at 624 ppm. The highest concentration of Mg was in the control treatment, with 955 ppm.

According to Table 3, the highest concentration of Fe in the solid medium was obtained in the control treatment with 283.7 ppm, and the lowest concentration of Fe, with 280.9 ppm, was obtained at the dry level of 3%. In the liquid medium, the highest concentration of Fe was in the control treatment, with 300.7 ppm, and the lowest concentration of Fe, with 296.3 ppm, was obtained at the dry level of 3%. There was no significant difference in Fe concentration between 1 and 2% levels (Table 4). Fe uptake at different dry levels of PEG-6000 in the solid medium was more reduced than in the liquid medium.

Table 3. Influence of different PEG-6000 concentrations on mineral uptake of GF677 plantlets after six weeks in solid MS basal culture medium

Drought levels (%)	Nitrogen (N) (%)	Phosphorous (P) (%)	Potassium (K) (%)	Calcium (Ca) (%)	Magnesium (Mg) (ppm)	Iron (Fe) (ppm)
0	4.73 a	0.67 a	0.72 b	1.22 a	679.5 a	283.7 a
1	4.68 ab	0.66 a	0.75 ab	1.03 b	652.3 b	282.5 ab
2	4.6 b	0.64 a	0.78 ab	0.7 c	645 c	281.6 bc
3	4.5 c	0.63 a	0.8 a	0.47 d	641.2 c	280.9 c

Means in each column with similar letters are not significantly different.

Table 4. Influence of different PEG-6000 concentrations on mineral uptake of GF677 plantlets after six weeks in liquid MS basal culture medium

Drought levels (%)	Nitrogen (N) (%)	Phosphorous (P) (%)	Potassium (K) (%)	Calcium (Ca) (%)	Magnesium (Mg) (ppm)	Iron (Fe) (ppm)
0	5.33 a[†]	0.68 a	0.81 c	1.48 a	955 a	300.7 a
1	5.25 a	0.58 a	0.88 bc	1.2 b	665 b	298.7 ab
2	5.16 b	0.69 a	0.96 b	0.83 c	655.7 c	298 b
3	5.1 b	0.69 a	1.11 a	0.56 d	642.7 d	296.3 b

Means in each column with similar letters are not significantly different.

Drought stress, in addition to the negative effects on growth, causes a lack of nutrients in the plant, and one of the most harmful effects of drought stress is a disorder in the process of nutrient uptake, which reduces growth and yield (Hu and Schmidhalter, 2005). Because water is the most important molecule in the plant growth medium, any factor that reduces water uptake reduces the uptake and availability of elements by the plant, and the uptake of elements in these conditions mainly depends on water availability (Amiri and Arzani, 2006). In this experiment, drought stress induced by PEG also affected the uptake of high-consumption and low-consumption basic elements. Nitrogen, Ca, Mg, and Fe uptake decreased significantly with increasing dry levels. While K consumption has increased. The potential of elements' uptake in a liquid medium was higher than in a solid medium. No change in phosphorus uptake was observed in solid or liquid mediums (Tables 3 and 4).

Reduction of mineral uptake has also been reported in an olive (Brito et al., 2003), an apple (Molassiotis et al., 2006), and a Gisela5 cherry rootstock (Sivritepe et al., 2008) under in vitro drought stress. The mechanisms of mineral uptake and transport in plants are more or less a function of the amount of water availability in the medium, and in the case of a lack of moisture, the intensity and amount of mineral uptake are affected (Sivritepe et al., 2008). The availability of an element for the plant is also affected by other available elements, as well as available water (Molassiotis et al., 2006). The K uptake increased in both mediums with increasing dry levels. Reports from various researchers also confirm that the uptake of K increases during drought stress, and its reason is the mechanism of uptake of this ion (Hu and Schmidhalter, 2005). During drought stress, in order to increase drought resistance, it increases K uptake by consuming energy. Increasing K uptake has a positive effect on ATP and NADP production, more protein synthesis, and the most important issue during drought stress is increasing plant water uptake (Cakmak, 2005). If drought stress is associated with K deficiency, these damages will be more severe because K induces dehydration tolerance in plants, and this element is mainly considered as an important osmotic regulator in plants (Hu and Schmidhalter, 2005). Under drought stress, the transfer of K ions ultimately prevents damage to plant cells. If the drought stress is severe, then complete plasmolysis is performed and the contents of the cells leak out, resulting in the death of the cells (Hu and Schmidhalter, 2005). There are some reports that the plant needs K ion. The K accumulation in plant leaves during long periods of drought indicates the role of this ion in regulating stomatal function and increasing the activity of antioxidant enzymes in leaves (Cakm 2005).

In this experiment, GF677 was the capable rootstock for K uptake under drought stress conditions, and the results of other studies have shown that increasing the K concentration under drought stress conditions reduces the drought effects (Hu and Schmidhalter, 2005)

4. Conclusion

Vegetative growth of GF677 rootstock was reduced in both culture mediums under drought stress, but this rootstock was able to continue the growth, which indicates the appropriate internal mechanism of this plant to cope with drought stress. GF677 was a capable rootstock for N and K uptake and was able to uptake high concentrations of these elements. Also, by comparing drought stress in solid and liquid mediums, it can be concluded that the exerting of drought stress by polyethylene glycol in liquid medium is more accurate than in solid medium because the liquid culture system provides a more uniform medium for growth and mineral uptake. In the solid medium, agar induces more drought stress in the culture medium because it reduces the water potential, which affects plant growth. Therefore, it is recommended to use a liquid medium with drought stress to study the drought tolerance of plants.

References

Al-Khayri, J.M., Al-Bahrany, A.M., 2004. Growth, water content, and proline accumulation in drought-stressed callus of date palm. Biologia Plantarum, 48, 105-108.

Amiri, M.E., Arzani, K., 2006. Mineral availability and growth of banana (*Musa acuminate* var. Dwarf Cavendish) explant under various relative matric potential *in vitro*. Journal of Food Agriculture and Environment, 4, 105-109.

Anjum, S.A., Xie, X.Y., Wang, L.C., Saleem, M.F., Man, C., Lei, W., 2011. Morphological, physiological and biochamical of plants to drought stress. African Journal of Agricultural Research, 6, 2026-2032.

Antonopoulou, C., Dimassi, K, Therios I., Chatzissavvidis C., Tsirakoglou V., 2005. Inhibitory effects of riboflavin on *in vitro* rooting and nutrient concentration of explants of peach rootstock GF677. Scientia Horticulturae, 106, 268-272.

Brito G., Costa, A., Fonseca, H.M.A.C., Santos, C.V., 2003. Response of *Olea europaea* ssp. maderensis *in vitro* shoots exposed to osmotic stress. Scientia Horticulturae, 97, 411-417.

Cakmak, I., 2005. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. Journal of Plant Nutrition and Soil Science, 168, 521-530.

Chai, T.T., Fadzillah, N.M., Kusnan, M., Mahmood, M., 2005. Water stress-induced oxidative damage and antioxidant responses in micropropagated banana plantlets. Biologia Plantarum, 49, 153-156.

Chartzoulakis, K., Patakas, A., Kofidis, G., Bosabalidis, A., Nastou, A., 2002. Water stress affects leaf anatomy, gas exchange, water relation and growth of two avocado cultivars. Scientia Horticulturae, 95, 39-50.

Emami, A. 1996. Methods of plant analysis. Agriculture research and promotion organization. Agriculture Ministry, 128 pp. (in Persian)

Georgieva, M.D., Djilianov, D., Konstantinova, T., Parvanova, D., 2004. Screening of Bulgarian raspberry cultivars and elites for osmotic tolerance *in vitro*. Biotechnological Equipment, 18, 95-98.

Ghaleb, W.Sh., Sawwan, J.S., Akash, M.W., Al-Abdallat, A.M., 2010. *In Vitro* response of two citrus rootstocks to salt stress. International Journal of Fruit Science, 10, 40-53.

Habibi, F., Amiri, M.E., 2013. Investigation of physiological responses of two citrus rootstocks to *in vitro* salt stress. Journal of Horticulture Science, 27, 350-357. (in Persian)

Hu Y., Schmidhalter, U., 2005. Drought and salinity: a comparison of their effects on mineral nutrition of plants. Journal of Plant Nutrition and Soil Science, 168, 541-549.

Kozlowski, T.T., 2002. Acclimation and adaptive responses of woody plants to environmental stresses. Botanical Review, 68, 270-334.

Macar, T.K., Ozlem, T., Ekmekci, Y., 2009. Effect of deficit induced by PEG and NaCl on chickpea (*Cicer arientinum* L.) cultivars and lines at early seedling stages. Gazi University Journal of Science, 22, 5-14.

Molassiotis, A.N., Sotiropoulos, T., Tanou, G., Kofidis, G., Diamantidis, C., Therios, I., 2006. Antioxidant and anatomical responses in shoot culture of the apple rootstock MM106 treated with NaCl, KCI, manitol or sorbitol. Biologia Plantarum, 50, 331-338.

Munns, R., 2002. Comparative physiology of salt and water stress. Plant Cell and Environment, 25, 239-250.

Murashige, T., Skoog, F. 1962. A revised medium for rapid growth and bioassay with tobacco tissue culture. Physiologia Plantarum, 15, 473-497.

Shibli, R.A., Al-Juboory, K., 2002. Comparative responses of Nabali olive Microsshoot, Callus, and suspension cell cultures to salinity and water deficit. Journal of Plant Nutrition, 25, 61-74.

Sivritepe, N., Erturk, U., Yerlikaya, C., Turkan, I., Bor, M., Ozdemir, F., 2008. Response of the cherry rootstock to water stress induced *in vitro*. Biologia Plantarum, 52, 573-576.

Xu, Y.C., Li, S.H., Cai, C.L., Liu, G.J., Chen, S.W., 2001. Carbohydrate metabolism in source leaves of Jonagold apple tree under water stress and after water stress relief. International Journal of Fruit Science, 18, 1-6.

Yadav, B., Jogawat, A., Rahman, M. S., Narayan, O. P., 2021. Secondary metabolites in the drought stress tolerance of crop plants: A review. Gene Reports, 23, 101040.

Zhang, J., Jia, W., Yang, J., Ismail, A.M., 2006. Role of ABA in integrating plant responses to drought and salt stresses. Field Crops Research, 97, 111-119.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 47-52

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

The critical period of weed control in rain-red lentil (*Lens culinaris* Medik.) in Lorestan Province

Abdolreza Ahmadi [*a]

[a] Department of Plant Protection, Faculty of Agriculture, Lorestan University, Khorramabad, Iran

ARTICLE INFO

Article history:
Received: 1 February 2022
Accepted: 25 April 2022
Available online: 5 May 2022

Keywords:
Competition
Gamprtz
Interference
logistic
Yield loss

ABSTRACT

The critical period of weeds refers to the stage of the plant's growth cycle during which weeds must be controlled to avoid crop damage. Understanding the critical period of weed control is beneficial for both biological and economic reasons when making weed control decisions and scheduling. Field experiments were conducted in 2018 in Khorramabad, Iran to determine the critical period of weed control (CPWC) in rain-fed lentil. The treatments were divided into two series: weed interference with the crop from emergence to 10, 20, 30, 40, 50, or 70 days after emergence with a control treatment (weed infested), and weed-free treatments up to the aforementioned stages. The logistic and Gamprtz nonlinear models were used to determine the start and end of the critical period of weed control, respectively. *Galium tricornutum*, *Turgenia latifolia*, *Cerastium dichotomum*, and *Lathyrus aphaca* were the most significant weed species in the experiment due to their greater biomass and size. The results indicated that weed control and interference treatments significantly increased lentil yield. Grain yields were 471 and 187 kg ha^{-1} for weed-free and interference-control treatments, respectively. Thus, when compared to weed-free control, weed interference reduced grain yield by 60%. The critical period of weed control began and ended 43 and 26 days after emergence, respectively, based on acceptable yield reductions of 5% and 10%.

Highlights

- Knowing the critical period of weed control is beneficial for both biological and economic reasons.
- In 2018, field trials in Khorramabad, Iran, determined the weed control critical period in rain-fed lentil.
- *Galium tricornutum, Turgenia latifolia, Cerastium dichotomum, and Lathyrus aphaca* had the highest biomass and size in the experiment.
- Weed control was critical 43 and 26 days after emergence, based on acceptable yield reductions of 5% and 10%.

1. Introduction

Lentil (*Lens culinaris* Medik.) is one of the world's oldest domesticated plants (Sarker and Erskine, 2006). Lentil is an important cool-season grain legume crop, mainly grown in South and West Asia. This plant has 23% of the cultivated area among legumes in Iran. Due to its ability to fix nitrogen, this plant causes soil fertility and, in rotation with some crops, especially cereals such as wheat and barley, will improve and maintain yield (Hoseyni et al., 2011). Over the past 30 years, many agronomic improvements to lentil have been made, such as improved disease resistance, height, lodging tolerance, and yield potential (Elkoca et al., 2005; Sarker and Erskine, 2006). However, weed control is a major concern and one of the greatest limiting factors in lentil production (Erman et al., 2004). Weeds compete with the crop for nutrients, soil moisture, light and space and may also harbour insects, pests and pathogens that can affect the lentil crop (Brand et al., 2007). Weed competition has resulted in lentil yield losses of 14–100% (Elkoca et al., 2004), and can also cause problems for mechanical harvest (Brand et al., 2007). Additionally, several important weeds in lentil, such as *Lathyrus aphaca* L., *Vicia sativa* L., and *Vicia hirsuta* L. Gray, produce seeds similar in shape and size to that of lentil, and separation from the crop is difficult, resulting in lower quality and value of the harvested crop (Brand et al., 2007). Lentil is a poor competitor with weeds due to its short stature, slow canopy closure, and slow rate of development, especially early in the growing season (Blackshaw et al., 2002;

[*] Corresponding author
Email: Ahmadi.a@lu.ac.ir (A. Ahmadi)
http://dx.doi.org/10.22034/aes.2022.327667.1018

Elkoca et al., 2004). As a result, lentils are ranked as the least competitive crop grown in western Iran.

The critical period of weed control (CPWC) defines the period in a crop life cycle in which weeds must be controlled to prevent yield losses and is a useful tool to determine the optimal timing of weed control (Knezevic et al., 2002). The CPWC has been determined in many crops and has helped producers identify the optimal weed control timing and method. Comprehension of the CPWC will increase the understanding of lentil-weed competition and will enable lentil producers to optimize weed control timing to maximize yield. The CPWC was first documented by Nieto et al. (1968). Since its inception, the CPWC has been determined for many crops, including maize (*Zea mays* L.) (Nieto et al., 1968; Dong and Albay, 2004; Williams, 2006), soybean (Knezevic et al., 2003), canola (Martin et al., 2001), chickpea (*Cicer arietinum* L.) (Mohammadi et al., 2005), lentil (*Lens culinaris* Medik.) (Mohamed et al., 1997; Taherabadi et al., 2016), dry bean (*Phaseolus vulgaris* L.) (Ahmadi et al., 2004), and potato (*Solanum tuberosum* L.) (Ahmandvand et al., 2009). The goal of this study was to determine the critical period for lentil weed control as well as to investigate the response of this crop to weed competition in the Lorestan province climatic conditions. CPWC comprehension provides insights into the required weed control timing and guidance on how long weed control remains to prevent weed diminished yields.

2. Materials and Methods

2.1 Materials

Field experiment was conducted during the 2018 growing season at the Agricultural Research Station of Lorestan University, Iran (46.21°E, 32.3°N, altitude), 1100 m above sea level with a yearly average precipitation and temperature of 461 mm and 18.2 °C respectively. The experiment was carried out on a soil characterized as clay loam. The physicochemical properties of soil are presented in Table 1.

Table 1. Physicochemical properties of the soil at surface and surface depth

Parameters	Values	
	0-15 cm	15-30 cm
Clay (%)	35	35
Silt (%)	40	40
Sand (%)	25	25
texture	Clay loam	Clay loam
Organic C (%)	0.7	0.65
pH	7.8	7.8
EC (ds/m)	2.03	2.03
Available N (%)	0.09	0.07
Available P_2O_5 (ppm)	6.8	6.0
Available K (ppm)	278	278

2.2. Experimental layout

The experimental design was a randomized complete block with four replications and 10 treatments. The treatments included two series: weed interference with the crop from emergence to 10, 20, 30, 40, 50, or ~70 days after emergence with control treatment (weed infested), and the second series included weed-free treatments up to the above stages. Planting operations, including plowing with reversible plowing, disc cutting to crumble, and leveling the land with a trowel, were carried out in early October. Each block consisted of 10 plots. Each plot consisted of ten planting rows, each five meters long. Seeds were planted in rows by hand. Lentil (Gachsaran variety) was sown at a density of 80 seeds per m^2 by hand on February 20, 2018.The distance between planting rows was 20 cm, and the distance between plants on each planting row was 2-cm. Cultivation was carried out in early January. In order to measure the number and dry weight of weeds for interference treatments. Weed sampling was performed in the first series of treatments at the end of the growth period and in the second series at the end of the interference period using a frame (11 m^2) with two replications in each plot. The weeds were dried at 70 °C in an oven and then weighed. Harvesting was done on June 10, 2018 by removing marginal effects. In order to estimate the yield by removing the marginal effects, an area of 6 square meters was harvested from each plot, and its grain yield was calculated based on 14% seed moisture.

2.3. Statistical analysis

ANOVA was used to analyze the data, and the treatment means were separated using the least significant difference test at P<0.05. Non-linear regression analysis was done to estimate the CPWC. To determine the beginning of CPWC, the logistic equation was fitted to relative yield (% of season-long weed-free period) with the increasing duration of weed interference, whereas to determine the end of CPWC, the modified Gompertz equation was fitted to relative yield with an increasing length of weed-free period (Knezevic et al., 2002).

Gamprtz equation the general form (A):

$$y = A.\exp^{(\beta \exp(-kt))} \quad (1)$$

Where y = relative yield, A = Asymptotic percent yield, b and k are Constant coefficient equation, and t is days after crop emergence in weed- free treatments.

Logistic equation the general form (B):

$$Y = \left[\left(\frac{1}{D\exp^{k(t-x)} + F} \right) + {(F-1)}\Big/{F} \right] \times 100 \qquad (2)$$

In this equation, Y= Yield (% of control without competition), K, D, and F are Constant coefficient equations, t is days after emergence, and x is the per day milestone curve. (Knezevic et al., 2003).

Finally, using these two curves for two cases of allowable yield reduction of 5 and 10%, the critical period of weed control was estimated. For statistical analysis of data, MSTAT-C software for drawing graphs in Excel and Sigmaplot software were used.

3. Results and Discussion

3.1. Mean weed species density

A comparison of the mean densities of 42 common weed species at the lentil field level is shown in Table 2. The average weed density of *galium tricornutum* in lentil field was 16.6 plants m^{-2}, and it was clearly different from other weeds. The mean densities of *Turgenia latifolia*, *Cerastium dichotomum*, and *Lathyrus aphaca* were 5.4, 4, and 3.76 plants m^{-2}, respectively.

Table 2. Mean density of common weed species in lentil field

Row	Weed species	Average density (m^2)	Row	Weed species	Average density (m^2)
1	*Galium tricornutum*	16.6	22	*Cardaria draba*	0.4
2	*Vicia villosa*	2.8	23	*Goldbachia laevigata*	0.87
3	*Vaccaria grandiflora*	1.9	24	*Fumaria* sp.	0.13
4	*Lathyrus aphaca*	4.7	25	*Cichorium intibus*	0.20
5	*Centaurea depressa*	1.4	26	*Lactuca serriolla*	0.92
6	*Papaver dubium*	3.7	27	*Malabaila* sp.	0.18
7	*Cerastium dichotomum*	4.0	28	*Cirsium arvense*	0.11
8	*Anthemis cotula*	2.4	29	*Achillea millefolium*	0.21
9	*Neslia apiculata*	1.0	30	*Tragopogon graminifolius*	0.45
10	*Scandix pecten-veneris*	2.4	31	*Garhadiolus angulosus*	0.07
11	*Turgenia latifolia*	5.4	32	*Taeniatherum crinitum*	0.53
12	*Conringia orientalis*	0.7	33	*Aegilops cylindrica*	0.15
13	*Carthamus oxyacantha*	0.9	34	*Salvia* spp.	0.18
14	*Avena ludoviciana*	1.0	35	*Alyssum* sp.	0.04
15	*Euphorbia helioscopia*	0.8	36	*Hordeum murinun*	0.04
16	*Sinapis arvensis*	1.4	37	*Sonchus asper*	0.04
17	*Hordeum spontaneume*	0.6	38	*Anagalis arvensis*	0.04
18	*Silene conoidea*	1.0	39	*Aristolochia maurorum*	0.04
19	*Bromus* sp.	2.2	40	*Cephalaria syriaca*	0.04
20	*Convolvulus arvensis*	0.4	41	*Senecio vulgaris*	0.15
21	*Pimpinella* sp.	0.5	42	*Linaria* sp.	0.17

3.2. Critical period of weed control for lentil

The critical period of weed control (CPWC) was realized for lentil by combining the yield responses to the duration of weed interference and the duration of the weed-free period. Also, CPWC was determined based on 5% and 10% acceptable yield loss. The CPWC based on 5% acceptable yield loss began at 11 days after emergence and continued until 54 days after emergence, and the CPWC for 10% acceptable yield loss began 16 days after germination and continued until the 43 DAE (Figure 1). The critical period of weed control in lentils covered a large part of the plant's growing season. The length of the critical period can indicate the weak strength of the lentils in competition with weeds. It was observed that the end of the CPWC often coincided with lentil canopy closure. Therefore, the CPWC for lentil generally begins at 14 days after emergence and ends 56 days after emergence. The defined CPWC encompasses all sites, and weed growth outside of this period should not affect yield. Relatively low, weeds should be removed with herbicide application or hand weeding at least 14 days after the emergence of the crop. The end of the CPWC was observed to often coincide with lentil canopy closure, which likely shaded the soil and restricted subsequent weed cohorts (Norworthy and Oliveira, 2004). In this experiment, CPWC was shown using Gamprtz and logistic curves by drawing a mathematical coordinate system, and there is overlap between the two curves, the critical period of weed control in the levels of 5% and 10% yield reduction, respectively, 2-8 and 2-6 weeks after emergence (Tables 3 and 4).

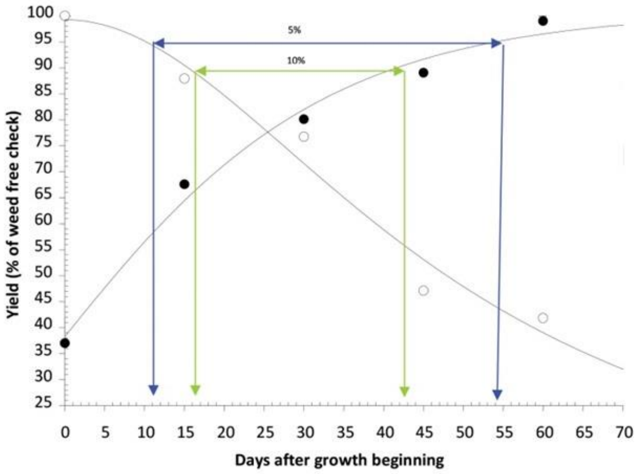
Table 3. Estimated coefficients for the percentage of the control function based Gamprtz days after emergence. Refer to text (Equation A) for model description.

Coefficient	A	B	K	R	R^2
Estimated value	100	5.2076	0.0415	0.9383	0.8804

Table 4. Estimated coefficients of the logistic function for the yield reduction compared to control on days after emergence. Refer to text (Equation B) for model description.

Coefficient	F	K	D	R	R^2	X
Estimated value	0.0307	0.0977	1.9262	0.9810	0.9625	26.86

The duration of the weed-free period had a significant effect on lentil yield (Table 5). Lentil yield increased with an extended weed-free period (Figure 1). The yield of weedy and weed -free treatments ranged from 187 to 471 kgha^{-1} at Khorramabad in 2017. The Gompertz equation (Table 1) adequately described the relationship between lentil yield and increasing weed-free periods.



Increasing duration of weed interference (○) and fitted curves as calculated by the logistic equation; increasing weed-free period (●) and fitted curves as calculated by the Gompertz equation. Horizontal lines indicate the 5% and 10% acceptable yield loss levels used to determine the CPWC, whereas vertical lines indicate the beginning and end of CPWC. Parameters for fitted curves given in Table 1and 2.

Figure 1. Effect of weed interference on total yield of lentil.

Table 5. Number of weeds (plant m^{-2}) in Lentil's farm divided by species during weed Interference

Interference Period	*Galium tricornutum*	*Turgenia latifolia*	*Cerastium dichotomum*	*Lathyrus aphaca*
10 DAE	13d	1.1d	1.1d	0d
20 DAE	31.1c	2.2c	2.2d	4.4b
30 DAE	48.9b	5.5b	5.6bc	5.6bc
40 DAE	50b	6.7ab	15.6b	17.1b
50 DAE	80a	7.8ab	24.5a	22.2b
Whole season weed- interference	87.8a	12.2a	30a	34.5a

Means with the same letter are not significantly different based on LSD test (p≤0.05).

3.4. Duration of weed interference:

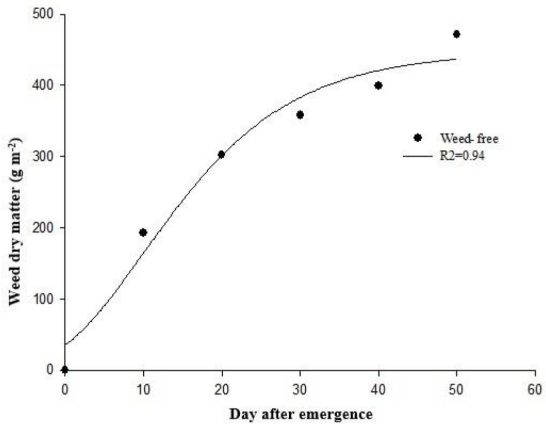
3.4.1. Weed dry matter

There was a significant weed dry matter response to increasing durations of weed interference. Weed dry matter measured at the time of weed control increased as the duration of weed interference increased (Figure 2). There was little weed dry matter when weed removal took place at 10, 20, and 30 days after the growth of lentils. Weed dry matter began to increase when weed control was delayed until 50 or 60 days after the growth of lentils. Presumably, weed growth and dry matter accumulation plateaued after the WI_4 stage since both the crop and weeds were nearing the reproductive stages where vegetative growth would have slowed. Therefore, the effect of weed control timing on weed dry matter accumulation is constant along with the relative rate of dry matter accumulation. Mohammadi et al. (2005) also stated that reducing the length of the weed control period in chickpeas led to an increase in weed dry weight.

3.5. Duration of the weed-free period

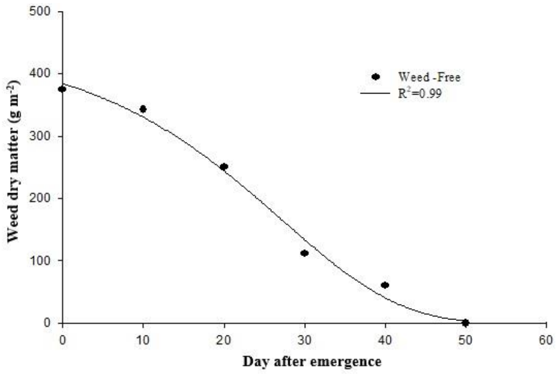
3.5.1. Weed dry matter

Weed dry matter decreased significantly as the duration of the weed-free period increased (Figure 3). Overall, weed dry matter at harvest was greatest when weeds emerged early in lentil development. For example, weeds emerging at the one node stage (10 DAE) produced biomass comparable to that of weeds that emerged at the same time as the crop (i.e., zero node). There was a near linear decrease in weed dry matter beginning at the two -node stage (15 DAE) and continuing until 50 or 60 days after emergenc. The Gompertz regression described the effect of the duration of the weed-free period on weed dry matter, and a common value for the rate of weed dry matter accumulation (*K*) was significant (Table1). There was a drastic decrease in weed biomass when the weed-free period lasted until 50 days after emergenc (Figure 3). The decrease in weed dry matter was nearly linear after the one node stage until 50 or 60 days after emergence for lentil cultivars for Gachsaran in Khorramabad in 2017 and 2018 as well as in western Canada (Fedoruk et al., 2011).



Points represent observed mean values whereas the lines represent the fitted curves of the three-parameter logistic equation.

Figure 2. Weed dry matter response to increasing duration of weed interference.



The points represent the observed values whereas the lines represent the fitted curves for the modified tree parameter Gompertz equation.

Figure 3. Weed dry matter response to the duration of the weed-free period.

3.6. Lentil yield

Lentil is a vulnerable crop to weed competition because of its short stature, slow establishment, and limited vegetative growth (Mousavi and Ahmadi, 2008). Lentil yield responses to increasing durations of weed interference were significant. Based on the results of this study, it can be concluded that lentil variety Gachsaran is able to function without any reduction one week after planting with a mixture of annual weed competition. With a delay in weed removal, lentil yield decreased (Table 5). According to this table, long-term interaction of weeds with lentils significantly reduced grain yield, so that in the treatment of complete weed interference, plant grain yield was reduced by 60. 29% compared to the complete control treatment. The findings of this study were consistent with the results of the experiment of Taherabadi et al. (2016). There were no weed-related performance losses in WI_1, WI_2 or WI_3; all three weed removal times were comparable to weed-free treatment. Delayed weed removal past the WI_3 stage (i.e., 30 days of weed infestation) generally results in a reduced lentil yield in comparison to the weed-free treatment. When weed removal was delayed until the WI_4 stage, there was a linear decrease in yield until the WI_T stage, when the yield reached a minimum and was comparable to season -long weed growth (i.e., until Physiological maturity). Lentil yield response to the duration of weed interference was adequately described by the four -parameter logistic equation (Equation B; Table 6).

Table 6. Mean yield of lentil at different treatments of weed interference and weeding

Treatments	Yield (kg ha^{-1})	Treatments	Yield (kg ha^{-1})
WF_1 (10DAE)	193e	WI_1 (10DAE)	423b
WF_2 (20DAE)	302d	WI_2 (20DAE)	393bc
WF_3 (30DAE)	358c	WI_3 (30DAE)	343c
WF_4 (40DAE)	399bc	WI_4 (40DAE)	211e
WFT (weed free total)	471a	WIT (weed interference total)	187e

4. Conclusion

Following the emergence of lentil under Khorramabad climatic conditions, the results showed that the critical periods for weed control in lentil were 43 and 26 days after emergence, respectively, based on a 5 percent and 10 percent acceptable yield reduction. Increased weed interference duration resulted in a decrease in lentil (*Lens culinaris* Medik.) yield and biomass, whereas increasing the control period resulted in an increase in both yield and biomass of lentil. In order to avoid lentil yield losses of more than 5 and 10 percent during the critical period, weed control must be implemented during this time period.

References

Ahmadi, A., Rashed Mohassel, M.H., Baghestani Meibodi, M.A., Rostami, M., 2004. The effect of critical period of weed competition on yield, yield components, and morphological characteristics of dry bean (*Phaseolus vulgaris* L.) cultivar. Derakhshan. Pest and Plant Diseases, 72(1), 31-49.

Ahmandvand, G., Mondani, F., Golzardi, F., 2009. Effect of crop plant density on critical period of weed competition in potato. Scientia Horticulturae, 121(3), 249-254.

Blackshaw, R.E., O'Donovan, J.T., Harker, K.N., Li, X., 2002. Beyond herbicides: new approaches to managing weeds. In Proceedings of the International Conference on Environmentally Sustainable Agriculture for Dry Areas, PP: 305-312.

Brand, J., Yaduraju, N.T., Shivakumar, B.G., McMurray, L., 2007. Weed management. In: Yadav, S.S., McNeil, D.L., Stevenson, P.C. (eds) Lentil: an Ancient Crop for Modern Times. pringer, Dordrecht, The Netherlands, PP: 159–172.

Dong, M.N., Unay, A., Albay, F., 2004. Determination of optimum weed control timing in maize (Zea mays L.). Turkish Journal of Agriculture and Forestry, 28(5), 349-354.

Elkoca, E., Kantar, F., Zengin, H., 2004. Effects of chemical and agronomical weed control treatments on weed density, yield and yield parameters of lentil (*Lens culinaris* L. Cv. Erzurum-89). Asian Journal of Plant Sciences, 3, 187-192.

Elkoca, E., Kantar, F., Zengin, H., 2005. Weed control in lentil (*Lens culinaris* Medik.) in eastern Turkey. N. Z. New Zealand journal of crop and horticultural science, 33, 223–231.

Erman, M., Tepe, I., Yazlik, A., Levent, R., Ipek, K. 2004. Effect of weed control treatments on weeds, seed yield, yield components and nodulation in winter lentil. Weed Research, 44(4), 305-312.

Fedoruk, L.K., Johnson, E.N., Shirtliffe, S.J., 2011. The Critical Period of Weed Control for Lentil in Western Canada. Weed Science, 59(4), 517 – 526.

Hosseini, F.S., Nezami, A., Parsa, M., Hajmohammadnia Ghalibaf, K., 2011. Effects of supplementary irrigation on yield and yield components of Lentil (*Lens culinaris* Medik.) cultivars in Mashhad climate. Journal of Water and Soil, 25(3), 625-633.

Johnson, D.E., Wopereis, M.C.S., Mbodj, D., Diallo, S., Haefele, S.M., 2004. Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. Field Crop Research, 85, 31-42.

Kasasian, L. Seeyave, J., 1969. Critical periods for weed competition. PANS Pest Articles & News Summaries, 15(2), 208-212.

Knezevic, S.Z., Evans, S.P., Mainz, M., 2003. Row spacing influences the critical timing of weed removal in soybean (*Glycine max* L.). Weed technology, 17(4), 666-673.

Knezevic, S.Z., Evans, S.P., Blankenship, E.E., Van Acker, R.C., Lindquist, J.L., 2002. Critical period for weed control: the concept and data analysis. Weed Science, 50(6), 773-786.

Martin, S.G., Van Acker, R.C., Friesen, L.F., 2001. Critical period of weed control in spring canola. Weed Science, 49, 326-333.

Mohamed E.S., Nourai, A.H., Mohamed, G.E., Mohamed, M.I., Saxena, M.C., 1997. Weeds and weed management in irrigated lentil in Northern Sudan. Weed Research, 37, 211-218.

Mohammadi, G., Javanshir, A., Khooei, F.R. 2005. Period of weed interference in chickpea. Weed Research 45, 57-63.

Mousavi, S.K., Ahmadi, A. 2009. Weed population and interference response to sowing date and lentil (*Lens culinaris* Medik.) cultivar in dryland condition of Khorramabad Electronic. Journal of Crop Production, 2(2), 111-128.

Nieto, J., Brondo, M.A. Gonzalez, J.T., 1968. Critical periods of the crop growth cycle for competition from weeds. PANS, 14,159-166.

Norworthy, J.K., Oliveira, M.J., 2004. Comparison of the critical period of weed control in wide- and narrow-row corn. Weed Science, 52, 802-807.

Sarker, A., Erskine, W., 2006. Recent progress in ancient lentil. The Journal of Agricultural Science, 144(1), 19-29.

Taherabadi, Sh., Ghobadi, M. Allahmoradi, P., 2016. The Critical period of weed competition in Lentil (*Lens culina*ris Medik.) under Kermanshah condition. Iranian Journal of Pulses Research, 7(2), 10-26.

Williams, M.M., 2006. Planting date influences critical period of weed control in sweet corn. Weed Science, 54(5), 928-933.

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Microwave drying of mallow leaves, drying kinetics and energy analyses

Esmaeel Seyedabadi [*a], Mehdi Aran [b], Abdolrahman Rahimian Boogar [b]

[a] Department of Agronomy, Faculty of Agriculture, University of Zabol, Zabol, Iran
[b] Department of Horticultural Science, Faculty of Agriculture, University of Zabol, Zabol, Iran

ARTICLE INFO

Article history:
Received: 24 March 2022
Accepted: 16 May 2022
Available online: 19 May 2022

Keywords:
Consumption energy
Effective diffusivity
Malva sylvestris
Microwave drying
Moisture ratio
Regression

ABSTRACT

The drying characteristics of mallow (*Malva sylvestris* L.) in a microwave dryer were examined at different microwave power levels. To dry 30 g of mallow leaves, microwave power levels of 360, 450, 540, 720, and 900 W were used. The initial moisture content of samples was 6.31±0.01 g water/ g dry base. To determine the kinetic parameters, which were calculated by comparing the ratio of the difference between the initial and final moisture contents to the equilibrium moisture content, experimental data were fitted to seven distinct models. At various microwave power levels, the moisture diffusivity and energy consumption were measured. Based on the results, increasing microwave power from 360 to 900 W resulted in a drying time reduction between 14 and 5 minutes. A comparison of the proposed models demonstrated that the logarithmic model (MR= a.exp(-k.t)+b) provided the best fit because it had the highest coefficient of determination (R^2), the lowest sum of squared errors (SSE), and the lowest root mean square error (RMSE). This model can therefore be used to estimate the moisture content of mallow leaves during microwave drying. Also, the maximum and minimum energy consumptions for drying with 360 W and 720 W microwaves were 84.0 and 67.5 W.h, respectively. Moreover, the effective diffusivity of mallow leaves varied from 1.098×10^{-10} to 3.532×10^{-10} m^2/s for different microwave powers.

Highlights

- The drying characteristics of mallow in a microwave dryer were investigated.
- The kinetic parameters were calculated by comparing the difference between the initial and final moisture contents to the equilibrium moisture content.
- Increasing microwave power from 360 to 900 W reduced drying time by 14 to 5 minutes.
- The logarithmic model had the best fit, with the highest R^2, lowest SSE, and lowest RMSE.

1. Introduction

Mallow (*Malva sylvestris* L.) is commonly used as a vegetable and medicinal plant in Iran**,** where it is called Panirak. This plant is usually found near marshes, ditches, oceans, riverbanks, and meadows as well as other moist locations (Razavi et al., 2011). It is used extensively to add a distinctive aroma and flavor to food, such as salads and soups. (Samavati and Manoochehrizade, 2013). This medicinal plant is traditionally used for treating many different infections and diseases, including colds, burns, coughs, tonsillitis, bronchitis, digestive problems, eczema, and cut wounds under different weather conditions. (Pirbalouti et al., 2010).

This plant, like most fruits and vegetables, loses its freshness over time after harvest because of its high moisture content and availability of nutrients to microbes. The use of drying is one of the methods commonly used to restrain microbial growth, inactivate enzymes, and preserve seasonal plants over the course of the year (Lijuan et al., 2005). Furthermore, drying may be used to minimize packaging requirements and to reduce shipping weight (Maroulis and Saravacos, 2003).

Traditional methods for drying agricultural products, such as hot air drying and sun drying, have many disadvantages, including the inability to handle large quantities of agricultural products**,** inconsistent quality standards, contamination problems, and long drying times (Soysal, 2004). In hot air drying, for instance, the heat transfer to the inner sections of foods is very slow because the thermal conductivity of food materials is low during the falling rate period of the drying process. (Maskan, 2000). Over the past few years, microwaves have become popular as an alternative method of rapidly transferring

[*] Corresponding author
Email: E.seyedabadi@uoz.ac.ir
http://dx.doi.org/10.22034/aes.2022.339398.1034

electromagnetic energy (Chen et al., 2001). The drying process can be drastically shortened by replacing hot air with microwave energy (Sharma and Prasad, 2004), and the finished product will be of higher quality, at least in some stages (Yongsawatdigul and Gunasekaran, 1996).

Microwaves are electromagnetic waves with a wavelength of one millimeter to one meter in the frequency range of 300 MHz to 300 GHz. Microwaves are unique in that as they travel through a soft medium, a temperature increase can be observed across the medium (Sadeghi et al., 2019b). Consequently, it has many applications in the food, agricultural, and daily life industries. A typical example is the widespread use of microwaves in the home as food drying devices. Microwave drying reduces the drying time and prevents enzymatic decomposition of the food (Zhang et al., 2006). Additionally, this method of drying is more uniform and energy-efficient than conventional hot air drying (Decareau, 1985).

In a study by Doymaz et al. (2006), they examined microwave drying of dill leaves and presented a mathematical model for it. Alibas (2007) utilized microwaves and other dryers to dry nettle leaves and conducted an analysis of the energy consumption of the leaves under different drying conditions. The mathematical modeling was done for the drying of peppermint leaves by Torki-Harchegani et al. (2016). Zhang et al. (2014) investigated the effects of microwave power on the drying characteristics of *Anoectochilus roxburghii* during drying. Also, several researchers have investigated the spinach drying kinetics (Ozkan et al., 2007; Karaaslan and Tuncer, 2008). The effect of different microwave power levels on chrysanthemum drying was investigated by Wang et al. (2018). Many other studies have been done on the drying kinetic modeling of foods and vegetables such as parsley (Soysal, 2006), apple (Wang et al., 2007), carrot (Stanislawski, 2005), chard leaves (Alibas, 2006), wild cabbage (Yanyang et al., 2004), coriander leaves (Sarimeseli, 2011), basil (Ghasemi Pirbalouti et al., 2013), banana (Pereira et al., 2007), garlic (Figiel, 2009; Sharma and Prasad, 2004) and black tea (Panchariya et al., 2002). However, the literature reviews show there have been no reports regarding the drying kinetics of mallow leaves in microwave ovens. As a result, the main objectives of this study were to investigate the drying behavior of mallow leaves; to investigate the effect of microwave output power levels on drying kinetics and energy consumption; and to compare the experimental data obtained during the drying process with the predicted values obtained using a few thin-layer drying models.

2. Materials and methods

2.1. Materials

The fresh mallow samples were purchased from a local supplier in Zabol (Iran). After washing, they were kept in a refrigerator for 24 hours at 4°C in order to equilibrate their moisture content (Taghinezhad et al., 2021a). Leaf samples were separated from stems and divided into portions of 30 grams each before drying experiments. In order to determine the initial moisture content, four portions were dried in an oven at 105°C for 48 hours. Using the following equation (Mohsenin, 1970), it was determined that mallow leaves had an initial moisture content of 6.31 g water per g dry basis:

$$M_0(d.b) = \frac{W_o - W_d}{W_d} \quad (1)$$

Where W_0 and W_d are the initial mass and the mass of the product after drying, respectively.

2.2. Drying equipment and drying procedure

For drying treatments, a digital microwave oven (GMO 330, GOSONIC, China) with a maximum (100%) output power of 900 W and frequency of 2450 MHz was used. By employing a digital control system, it was possible to select the power level and emittance time of microwaves. The microwave oven contained a rotating glass disk that was powered by an electrical motor. This disc was vital to ensuring homogeneous drying and reducing microwave reflections onto the magnetrons (Sadeghi et al., 2019a). The microwave oven was operated at five different power settings, i.e., 360, 450, 540, 720, and 900 W.

During drying, the mallow leaves were weighed on a digital weight balance (GF-2000 AND, Japan) with a precision of 0.01 g in order to observe and record the moisture loss. Three replications were done for each experiment.

2.3. Mathematical modeling

For the development of thin layer drying models, the changes in moisture content of agricultural products were usually measured and correlated to drying parameters (Midilli et al., 2002). The moisture ratio of mallow leaves was calculated using the following equation (Seyedabadi et al., 2019):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

Where MR is the moisture ratio, M_t is the moisture content at a specific time (g water/g dry base), M_0 is the initial moisture content (g water/g dry base), and M_e is the equilibrium moisture content (g water/g dry base) (Soysal 2004). For microwave drying, the equilibrium moisture content was regarded as zero according to (Maskan, 2000; Alibas, 2006).

The energy consumption of microwave drying was derived from Eq. (3) (Torki-Harchegani, 2016):

$$E_t = P.t \quad (3)$$

Where E_t is the total amount of energy consumed per drying period (W.h), P is the microwave output power (W) and “t” is the drying time in hours (Hebbar et al., 2004).

There have been several models proposed to predict the moisture loss over time for different food products. In the present study, seven different thin-layer drying models were selected because they are among the most widely employed. In these models, regression analysis was performed by relating the dimensionless moisture ratio (MR) to the drying time for microwave powers of 360, 450, 540, 720, and 900 W. They are described in Table 1 with their names, equations, and references.

Table 1. The mathematical thin-layer models applied to the drying curves of mallow leaves

Model	Equation	Reference
Page's	$MR = \exp(-k \cdot t^{n})$	Mundada et al. (2010)
Regression	$MR=\exp(-(bt+at^2))$	Shi et al. (2008)
Logarithmic	$MR = a \cdot \exp(-k \cdot t) + b$	Ertekin and Yaldiz (2004)
Henderson and Pabis	$MR = a \cdot \exp(-k \cdot t)$	Togrul and Pehlivan (2004)
Lewis	$MR=\exp(-kt)$	Roberts et al. (2008)
Wang and Singh	$MR = 1 + a \cdot t + b \cdot t^2$	Ozdemir and Devres (1999)
Midilli	$MR = a \cdot \exp(-k \cdot t^n)+b.t$	Akar et al. (2019)

For fitting the above models to experimental data, Matlab 2019a (Mathworks Inc., Natick, MA) was used. The coefficient of determination (R^2), root mean square error (RMSE), and sum of squared errors (SSE) were used to compare models, and their mathematical equations are given in Eqs. (4) to (6).The model predicted drying behavior better when SSE and RMSE were close to zero and R^2 was high (Aral and Bese, 2016).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i}-MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{pre,i}-MR_{exp,i})^2} \quad (4)$$

$$SSE = \sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2 \quad (5)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{pred,i} - MR_{exp,i})^2\right)^{\frac{1}{2}} \quad (6)$$

Where $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental and predicted moisture ratios at time i, respectively.

2.4. Determination of the effective moisture diffusivity

Fick's diffusion equation can be used to describe the drying characteristics of agricultural products in the falling rate period. Assuming a uniform initial moisture distribution, Eq. (7) can be used for samples with slab geometry (Taghinezhad et al., 2021b).

$$MR = \frac{8}{\pi^2}\exp\left[-\pi^2 \frac{D_{eff}}{4L^2} \times t\right] \quad (7)$$

In this formula, t, D_{eff}, and L are the drying time (s), the effective diffusivity (m^2/s), and the half thickness of the slab (m), respectively. A digital caliper was used to measure the mean thickness of mallow leaves and resulted in a value of 0.00028 m

For the purpose of obtaining effective diffusivity, Eq. (7) can be written in the straight-line form as follows (Al-Harahsheh et al., 2009; Dadali et al., 2007; Wang et al., 2007);

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\pi^2 \frac{D_{eff}}{4L^2}\right) \times t \quad (8)$$

By plotting experimental drying data in terms of Ln (MR) versus time and then calculating the slope of linear fits, the effective moisture diffusivity was determined (Seyedabadi et al., 2017).

3. Results and discussions

It is possible to investigate the effect of microwave power on drying processes by using the variation of moisture ratio over time. A total of five microwave powers were used in this study: 360, 450, 540, 720, and 900 W. The mass of the samples was 30 g. Figure 1 shows the variation of the moisture ratio (dry basis) over time. As moisture content decreases with time in the drying process, the process is characterized by a progressive reduction in moisture content. At the beginning of the drying process, products have a high moisture content and are losing moisture rapidly. When the moisture content of the product is reduced during the drying process, the natural rate of drying is decreased because the microwave power is absorbed by the product depending on its moisture content. The finding is similar to that of several other studies (Wang et al., 2007; Panchariya et al., 2002; Soysal, 2004).

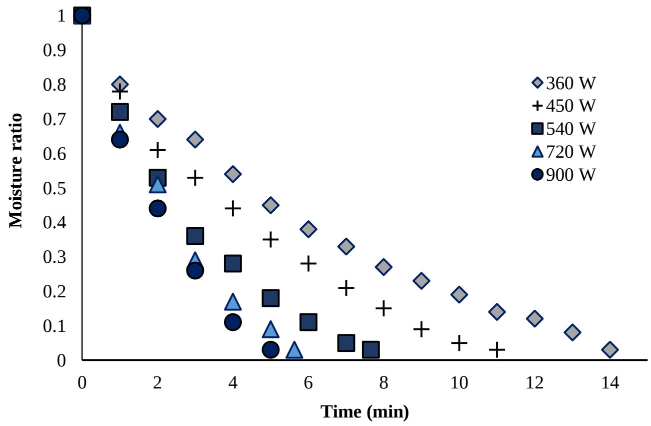


Figure 1. Variation of moisture ratio vs. time during drying of mallow leaves in different microwave powers

Under microwave power levels of 360, 450, 540, 720, and 900 W, the mallow leaves required 35, 19, 14, and 8 minutes to reach the final moisture content, respectively. With the microwave power of 360 W, moisture content decreases gradually, while it decreases dramatically with the microwave power of 900 W. In fact, the microwave power increases the thermal gradient within the sample, thereby increasing the moisture evaporation rate. Thus, the drying time is decreased. There are several authors who have reported similar findings for various foods (Dadali et al., 2007; Al-Harahsheh et al., 2009; Wang et al., 2007).

In addition, it was found that by using 900 W instead of 360 W microwave power, the drying time could be decreased by as much as 64%.

Figure 2 shows the drying energy consumption in Watt-hours (W.h) for different microwave power levels for 30 g mallow leaves.

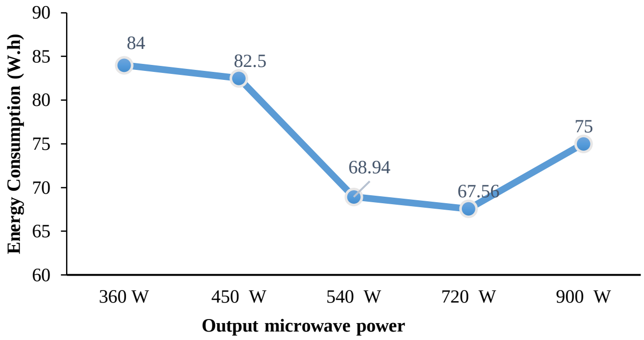


Figure 2. The drying energy consumption (W.h) of mallow leaves in different microwave powers

Table 2. The statistical analysis of fitted models for drying of mallow leaves with various microwave powers.

Power	Model	R^2	RMSE	SSE
360 W	Regression	0.9403	0.0706	0.0649
	Page's	0.9903	0.0284	0.0105
	Henderson and Pabis	0.9896	0.0295	0.0113
	Lewis	0.9803	0.0285	0.0114
	Midilli	0.9976	0.0142	0.0022
	Logarithmic	0.9956	0.0191	0.0044
	Wang and Singh	0.9864	0.0337	0.0148
450 W	Regression	0.9360	0.0775	0.0601
	Page's	0.9889	0.0323	0.0104
	Henderson and Pabis	0.9877	0.0340	0.0115
	Lewis	0.9888	0.0324	0.0115
	Midilli	0.9981	0.0133	0.0014
	Logarithmic	0.9951	0.0214	0.0041
	Wang and Singh	0.9860	0.0363	0.0132
540 W	Regression	0.9366	0.0832	0.0485
	Page's	0.9961	0.0207	0.0030
	Henderson and Pabis	0.9835	0.0297	0.0150
	Lewis	0.9840	0.0256	0.0053
	Midilli	0.9989	0.0110	0.0006
	Logarithmic	0.9987	0.0119	0.0008
	Wang and Singh	0.9923	0.0289	0.0059
720 W	Regression	0.9448	0.0823	0.0339
	Page's	0.9888	0.0370	0.0069
	Henderson and Pabis	0.9817	0.0474	0.0112
	Lewis	0.9843	0.0439	0.0116
	Midilli	0.9854	0.0424	0.0054
	Logarithmic	0.9937	0.0277	0.0031
	Wang and Singh	0.9926	0.0302	0.0046
900 W	Regression	0.9408	0.0883	0.0312
	Page's	0.9908	0.0348	0.0049
	Henderson and Pabis	0.9835	0.0466	0.0087
	Lewis	0.9863	0.0424	0.0090
	Midilli	0.9974	0.0185	0.0007
	Logarithmic	0.9971	0.0194	0.0011
	Wang and Singh	0.9950	0.0256	0.0026

The energy has a minimum value for drying at 720 W. Other microwave powers led to an increase in consumed energy. Based on the assumption that the quality of dried mallow may be negligible, it is recommended that the drying should be done at 720 W of microwave power in order to reduce drying energy consumption.

As shown in Table 2, the parameters R^2, RMSE and SSE are calculated for models fitted to the experimental data of drying mallow leaves with different microwave powers. According to the comparison of these parameters, it was found that, except for the Regression model, all other models were good approximates to predict experiment results, but the logarithmic models were found to have the best fits due to higher R^2 values and lower values of RMSE and SSE.

According to Taheri-Garavand et al. (2011), the Midilli model was capable of illustrating the drying curve of basil leaves under different convective drying conditions. Additionally, another researcher has reported the validity of this microwave-drying model in coriander leaves (Sarimeseli, 2011).

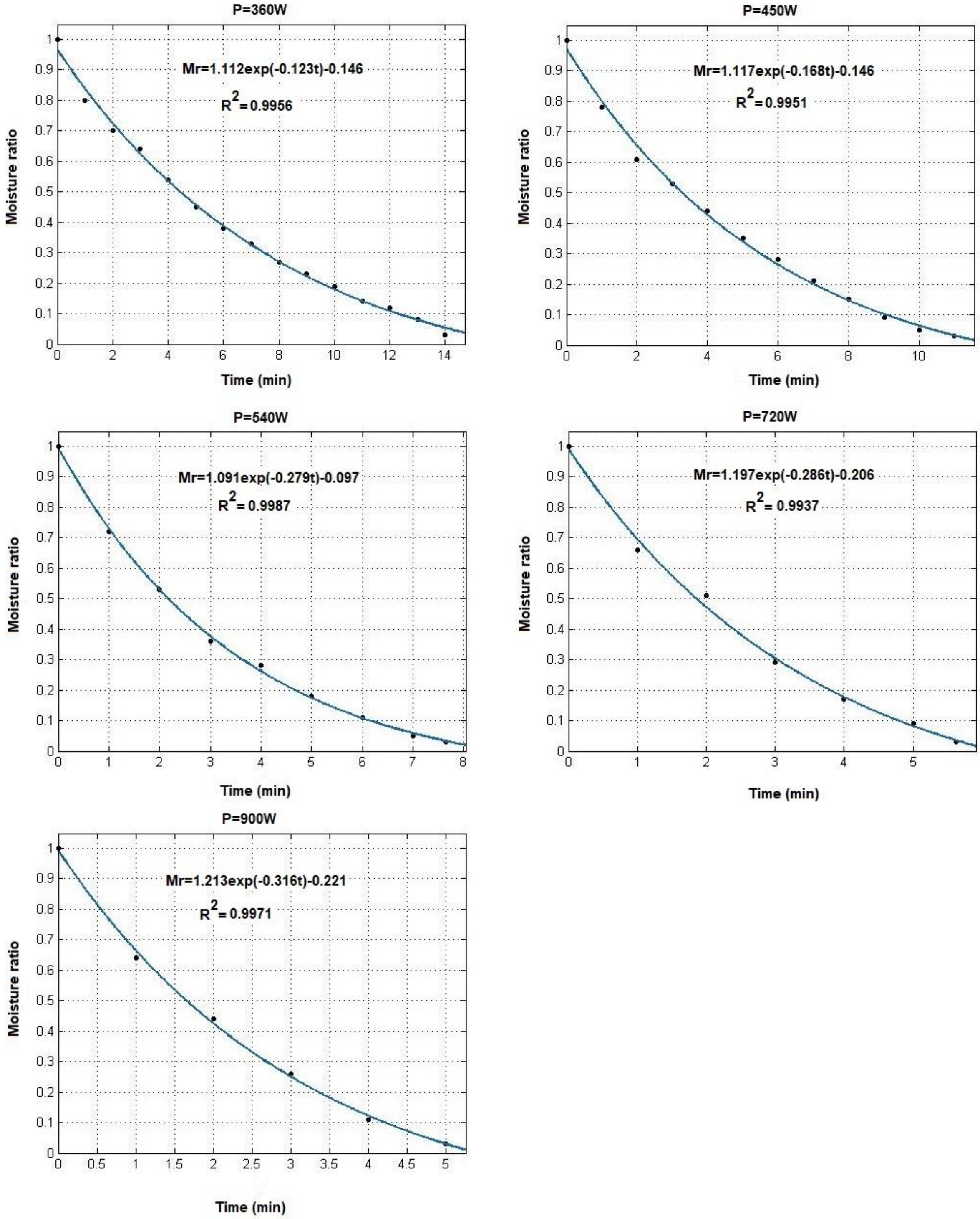


Figure 3. The fitted logarithmic models for drying of mallow leaves in different microwave powers.

Figure 3 shows the logarithmic models that were fitted to the experimental data for different microwave powers. The horizontal axis in the figures has been scaled to facilitate reading. The logarithmic model showed higher coefficient of determination values, which indicate that it is more accurate at predicting drying. Consequently, these models can be used in industrial settings.

Table 3 shows the effective moisture diffusivity values of mallow leaves under 360–900 W microwave powers. These values are found to be within the general range of 10^{-12} to 10^{-6} m^2/s for food materials and agricultural crops (Erbay and Icier, 2010). The minimum and maximum values of the effective moisture diffusivity were 1.098×10^{-10} and 3.532×10^{-10} m^2/s for 360 and 900 W, respectively. This reveals that the moisture diffusivity increases as microwave intensity increases. These findings are in agreement with those of other researchers (Ozbek and Dadali, 2007; Demirhan and Ozbek, 2011).

Table 3. The estimated effective moisture diffusivities for drying of mallow leaves under different microwave powers.

	Microwave power levels				
	360 W	450 W	540 W	720 W	900 W
D_{eff} ($\times10^{-10}$ m^2/s)	1.098	1.582	2.325	3.033	3.532

According to Saramezeli (2011), the effective moisture diffusivity of coriander leaves for microwave powers of 180-360 W ranged from 6.3×10^{-11}-2.19×10^{-10} m^2/s. There have been previously reported results indicating the effective moisture diffusivities of coriander leaves (Sarimesli, 2001) and mint leaves (Ozbek and Dadali, 2007) for microwave drying at 180-900W ranged from 6.3×10^{-11} to 2.19×10^{-10} and 3.982×10^{-11} to 2.073×10^{-10} m^2/s, respectively. Their results are comparable with what we observed in the drying of mallow leaves. Furthermore, microwave drying of foods yielded higher effective diffusivities than convective drying (Erbay and Icer, 2010; Al-Harahsheh et al., 2009).

4. Conclusion

This study investigated a range of microwave power settings for drying mallow leaves. It has been found that the times required to reduce the moisture content of mallow leaves from 6.31 to 0.03 (g water /g dry base) are 14, 11, 7.66, 5.63, and 5 min depending on microwave powers applied of 360, 450, 540, 720, and 900 W. For all microwave powers, the logarithmic model provided the most accurate predictions. Using microwave powers of 720 and 360W, the minimum and maximum values of drying energy were 67.5 and 84.0 watt-hours, respectively. The effective moisture diffusivity was in the range of 1.098×10^{-10} to 3.532×10^{-10} m^2/s for microwave powers of 360 - 900 W.

Acknowledgements

The authors are grateful for financial support to Department of Agronomy of University of Zabol under grant number GR-6280.

References

Akar, G., Barutçu Mazı, I., 2019. Color change, ascorbic acid degradation kinetics, and rehydration behavior of kiwifruit as affected by different drying methods. Journal of Food Process Engineering, 42(3), e13011.

Al-Harahsheh, M., Ala'a, H., Magee, T.R.A., 2009. Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Engineering and Processing: Process Intensification, 48(1), 524-531.

Alibas, I., 2007. Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. Biosystems Engineering, 96(4), 495-502.

Alibas, I., 2006. Characteristics of chard leaves during microwave, convective, and combined microwave-convective drying. Drying Technology, 24(11), 1425-1435.

Aral, S., and Beşe, A.V., 2016. Convective drying of hawthorn fruit (Crataegus spp.): Effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. Food Chemistry, 210, 577-584.

Chen, G., Wang, W., Mujumdar, A.S., 2001. Theoretical study of microwave heating patterns on batch fluidized bed drying of porous material. Chemical Engineering Science, 56(24), 6823-6835.

Dadali, G., Kilic Apar, D., Ozbek, B., 2007. Microwave drying kinetics of okra. Drying Technology, 25(2): 917-924.

Decareau, R.V., 1985. Microwave in the food processing industry. New York: Academic Press.

Demirhan, E., Ozbek, B., 2011. Thin-layer drying characteristics and modeling of celery leaves undergoing microwave treatment. Chemical Engineering Communications, 198(7), 957–975.

Doymaz, I., Tugrul, N., Pala, M., 2006. Drying characteristics of dill and parsley leaves. Journal of Food Engineering. 77(3), 559-565.

Erbay, Z., Icier, F., 2010. A review of thin layer drying of foods: theory, modeling, and experimental results. Critical Reviews in Food Science and Nutrition, 50(5), 441-464.

Ertekin, C., Yaldiz, O.S.M.A.N., 2004. Drying of eggplant and selection of a suitable thin layer drying model. Journal of Food Engineering, 63(3), 349-359.

Figiel, A., 2009. Drying kinetics and quality of vacuum-microwave dehydrated garlic cloves and slices. Journal of Food Engineering, 94(1), 98-104.

Hebbar, H.U., Vishwanathan, K., Ramesh, M., 2004. Development of combined infrared and hot air dryer for vegetables. Journal of Food Engineering, 65(4), 557-563.

Karaaslan, S., Tuncer, I., 2008. Development of a drying model for combined microwave–fan-assisted convection drying of spinach. Biosystems Engineering, 100(1), 44-52.

Lijuan, Z., Jianguo, L., Yongkang, P., Guohua, C., Mujumdar, A.S., 2005. Thermal dehydration methods for fruits and vegetables. Drying Technology, 23(9-11), 2249-2260.

Maroulis, Z.B., Saravacos, G.D., 2003. Food process design. Vol. 126: CRC Press.
Maskan, M., 2000. Microwave/air and microwave finish drying of banana. Journal of Food Engineering, 44(2), 71-78.
Midilli, A., Kucuk, H., Yapar, Z., 2002. A new model for single-layer drying. Drying Technology, 20(7), 1503-1513.
Mohsenin, N.N. 1970. Physical properties of plant and animal materials. Vol. 1. Structure, physical characteristics and mechanical properties.
Mundada, M., Hathan, B.S., Maske, S., 2010. Convective dehydration kinetics of osmotically pretreated pomegranate arils. Biosystems Engineering, 107(4), 307-316.
Ozbek, B., Dadali, G., 2007. Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. Journal of Food Engineering, 83(4), 541-549.
Ozdemir, M., Devres, Y.O., 1999. The thin layer drying characteristics of hazelnuts during roasting. Journal of Food Engineering, 42(4), 225-233.
Ozkan, I.A., Akbudak, B., Akbudak, N., 2007. Microwave drying characteristics of spinach. Journal of Food Engineering, 78(2), 577-583.
Panchariya, P., Popovic, D., Sharma, A., 2002. Thin-layer modelling of black tea drying process. Journal of Food Engineering, 52(4), 349-357.
Pereira, N.R., Marsaioli, A., Ahrne, L.M., 2007. Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated bananas. Journal of Food Engineering, 81(1), 79-87.
Pirbalouti, A. G., Azizi, S., Koohpayeh, A., Hamedi, B., 2010. Wound healing activity of *Malva sylvestris* and *Punica granatum* in alloxan-induced diabetic rats. Acta Pol Pharm, 67(5), 511-516.
Pirbalouti, A. G., Mahdad, E., Craker, L., 2013. Effects of drying methods on qualitative and quantitative properties of essential oil of two basil landraces. Food Chemistry, 141(3), 2440-2449
Razavi, S.M., Zarrini, G., Molavi, G., Ghasemi, G., 2011. Bioactivity of *Malva sylvestris* L., a medicinal plant from Iran. Iranian journal of basic medical sciences, 14(6), 574.
Roberts, J.S., Kidd, D.R., Padilla-Zakour, O., 2008. Drying kinetics of grape seeds. Journal of Food Engineering, 89(4), 460-465.
Sadeghi, R., Seyedabadi, E., and Mirabi Moghaddam, R., 2019a. Evaluation of microwave and ozone disinfections on the color characteristics of Iranian export raisins through an image processing technique. Journal of Food Protection, 82(12), 2080-2087.
Sadeghi, R., Seyedabadi, E., and Mirabi Moghaddam, R., 2019b. Microwave application for controlling *Oryzaephilus surinamensis* insects infesting dried figs and evaluation of product color changes using an image processing technique. Journal of Food Protection, 82(2), 184-188.
Samavati, V., and Manoochehrizade, A., 2013. Polysaccharide extraction from *Malva sylvestris* and its anti-oxidant activity. International Journal of Biological Macromolecules, 60, 427-436.
Sarimeseli, A., 2011. Microwave drying characteristics of coriander (*Coriandrum sativum L.*) leaves. Energy Conversion and Management, 52(2), 1449-1453.
Seyedabadi, E., Khojastehpour, M., and Abbaspour-Fard, M.H., 2017. Convective drying simulation of banana slabs considering non-isotropic shrinkage using FEM with the Arbitrary Lagrangian–Eulerian method. International Journal of Food Properties, 20(sup1), S36-S49.
Seyedabadi, E., Khojastehpour, M., and Abbaspour-Fard, M.H., 2019. Online measuring of quality changes of banana slabs during convective drying. Engineering in Agriculture, Environment and Food, 12(1), 111-117.
Sharma, G.P and Prasad, S., 2004. Effective moisture diffusivity of garlic cloves undergoing microwave-convective drying. Journal of Food Engineering, 65(4), 609–617.
Shi, J., Pan, Z., McHugh, T.H., Wood, D., Hirschberg, E., Olson, D., 2008. Drying and quality characteristics of fresh and sugar-infused blueberries dried with infrared radiation heating. LWT-Food Science and Technology, 41(10), 1962-1972.
Soysal, Y., 2004. Microwave drying characteristics of parsley. Biosystems Engineering, 89(2), 167-173.
Soysal, Y., Oztekin, S., Eren, O., 2006. Microwave drying of parsley: modelling, kinetics and energy aspects. Biosystems Engineering, 93(4), 403-413.
Taghinezhad, E., Kaveh, M., and Szumny, A., 2021a. Optimization and prediction of the drying and quality of turnip slices by convective-infrared dryer under various pretreatments by RSM and ANFIS methods. Foods, 10(2), 284.
Taghinezhad, E., Kaveh, M., and Szumny, A., 2021b. Thermodynamic and quality performance studies for drying kiwi in hybrid hot air-infrared drying with ultrasound pretreatment. Applied Sciences, 11(3), 1297.
Taheri-Garavand, A., Rafiee, S., Keyhani, A., 2011. Effect of temperature, relative humidity and air velocity on drying kinetics and drying rate of basil leaves. Electronic Journal of Environmental, Agricultural and Food Chemistry, 10(4), 2075-2080.
Togrul, I.T., Pehlivan, D., 2004. Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. Journal of Food Engineering, 65(3), 413-425.
Torki-Harchegani, M., Ghanbarian, D., Pirbalouti, A. G., Sadeghi, M., 2016. Dehydration behaviour, mathematical modelling, energy efficiency and essential oil yield of peppermint leaves undergoing microwave and hot air treatments. Renewable and Sustainable Energy Reviews, 58, 407-418.
Wang, Y., Li, X., Chen, X., Li, B.O., Mao, X., Miao, J., Gao, W., 2018. Effects of hot air and microwave-assisted drying on drying kinetics, physicochemical properties, and energy consumption of chrysanthemum. Chemical Engineering and Processing-Process Intensification, 129, 84-94.

Wang, Z., Sun, J., Chen, F., Liao, X., Hu, X., 2007. Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air pre-drying. Journal of Food Engineering, 80(2), 536-544.

Yanyang, X., Min, Z., Mujumdar, A.S., Le-qun, Z., Jin-cai, S., 2004. Studies on hot air and microwave vacuum drying of wild cabbage. Drying Technology, 22(9), 2201-2209.

Yongsawatdigul, J., Gunasekaran, S., 1996. Microwave-vacuum drying of cranberries: Part II, Quality evaluation. Journal of Food Processing and Preservation, 20(2), 145–156.

Zhang, M., Tang, J., Mujumdar, A., Wang, S., 2006. Trends in microwave-related drying of fruits and vegetables. Trends in Food Science and Technology, 17(10), 524-534.

Zhang, Y., Zeng, H., Huang, Z., Wang, Y., and Zheng, B., 2014. Drying Characteristics and Kinetics of *Anoectochilus roxburghii* by Microwave Vacuum Drying. Journal of Food Processing and Preservation, 38(6), 2223-2231.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 61-70

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Evaluation of sustainability of rainfed rapeseed production in Gorgan county using Emergy analysis

Hamid Reza Shahhoseini *[a], Hossein Kazemi [b]

[a] M.Sc. Graduated of Agronomy, Faculty of Agriculture, Shahrood University of Technology, Shahrood, Iran
[b] Department of Agronomy, Faculty of Plant Production, Gorgan University of Agricultural Sciences and Natural Resources (GUASNR), Gorgan, Iran

ARTICLE INFO

Article history:
Received: 11 April 2022
Accepted: 08 May 2022
Available online: 10 May 2022

Keywords:
Emergy indices
Environmental pressure
Fossil fuels
Renewability
Soil erosion

ABSTRACT

Excessive use of environmental resources and excessive consumption of chemicals have exacerbated environmental problems and harmed agroecosystem sustainability. As a result, it is beneficial to study energy consumption patterns and efficient energy use in agriculture, which is one of the fundamental principles of sustainable agriculture. The aim of this study was to assess the sustainability of rapeseed production (*Brassica napus* L.) in Gorgan county during the 2017-2018 crop year using emergy essessment. Sixty questionnaires were considered for this purpose. After establishing spatial and temporal boundaries and classifying resources into four categories: renewable environment, non-renewable environment, purchased renewable, and purchased non-renewable, and some emergy indices were calculated in rapeseed agroecosystems. The results indicated that the total emergy input for the rapeseed agroecosystems consumed a total of 6.39E+15 sej ha^{-1} yr^{-1}. In rapeseed agroecosystems, dependence on market and non-renewable inputs was much higher than environmental and renewable inputs. With 59.94 percent of total emergy input in rapeseed agroecosystems, fossil fuels were the primary source of emergy. The transformity of rapeseed agroecosystems was 1.09E+05 sej J^{-1}, the specific emergy was 3.09E+09 sej gr^{-1}, the renewability was 12.46 percent, the emergy yield ratio was 1.22, the standard emergy investment ratio was 4.56, the modified emergy investment ratio was 9.23, the standard environmental loading ratio was 10.25, the modified environmental loading ratio was 7.02, the standard emergy sustainability index was 0.12, and the modified emergy sustainability index was 0.17. Based on the evaluation of emergy indices, the rapeseed agroecosystem has an acceptable crop production efficiency and resource consumption efficiency, and a significant potential for economic productivity increase. By implementing conservation tillage and modernizing machinery, will reduce our reliance on non-renewable and economic inputs, alleviate environmental pressure, and increase the agroecosystem's sustainability.

Highlights

- The purpose of this study was to assess the sustainability of rapeseed production in Gorgan county in 2017-2018.
- Agroecosystem emergy indices were calculated in rapeseed agroecosystems.
- The rapeseed agroecosystems consumed 6.39E+15 sej ha^{-1} yr^{-1}.
- Rapeseed agroecosystems had Tr of 1.09E+05 sej J^{-1}, SpE of 3.09E+09 sej gr^{-1}, EYR of 1.22, EIR of 4.56, ELR of 10.25, and ESI of 0.12.
- With acceptable crop production and resource consumption efficiency, the rapeseed agroecosystem has a significant potential for economic productivity growth.

1. Introduction

Agricultural systems, as consumers of natural and economic resources, have negative effects by over-consuming natural resources and adding polluting compounds to the environment (Quintero-Angel and Gonzales-Acevedo, 2018). Food security depends on the agricultural productivity, resource efficiency, and long-term sustainability of agricultural systems. Sustainability in agriculture is balancing act between food security and maintaining the quality of the environment. Agricultural operations are sustainable when they maintain the quality of the environment and have social acceptance and economic benefits (Kumaraswamy, 2012). Achieving this

* Corresponding author
Email: hamidshahoseini@yahoo.com (H.R Shahhoseini)
http://dx.doi.org/10.22034/aes.2022.337172.1031

requires assessment methods that provide useful information about the state of the ecosystem and its intensity and direction of change. These methods should include environmental, social, and economic aspects (Quintero-Angel and Gonzales-Acevedo, 2018). Environmental assessment methods are used to assess resource utilization, pollution, and sustainability in a system and include environmental input-output assessment, ecological footprint determination, such as carbon footprint, ecological assessment, life cycle assessment, energy analysis, and emergy analysis (Patterson et al., 2017).

Emergy analysis is a type of energy analysis in which the contribution of the environment and natural resources, which are largely ignored in intensive agriculture, is quantified and evaluated on a unit-by-unit basis (Brown and Ulgiati, 2004). The advantage of the emergy evaluation method over other methods is that it reflects the various flows of energy and matter uniformly in the system under study, which indicates both its quantity and quality (Brown et al., 2016). Emergy analysis thoroughly examines the sustainability of an ecosystem by converting all currents, natural resources, and economic resources into solar emergy units (Odum, 1996). Emergy assessment enhances our understanding of these systems and how they interact with each other by determining the degree of sustainability of continuous ecological and economic systems. Emergy indices are a good tool for integrating ecological and economic systems and make it possible to measure and compare different aspects of these ecosystems (Patterson et al., 2017). These indices are able to determine the efficiency, renewability, environmental pressure, and environmental and economic sustainability of a system (Odum, 2000; Brown and Ulgiati, 2004). Emergy is called embodied energy or energy memory, expressed as the solar emjoule (sej) (Odum, 1996).

Emergy assessment is used to assess the sustainability of production systems at different scales (Xi and Qin, 2009; Zhai et al., 2017). For example, evaluations of three agricultural systems in the United States, including corn production, blackberry production, and the traditional multiple cultivation system, showed that the traditional system had the lowest environmental load and maximum sustainability and that the corn production system had the highest environmental load and the least sustainability (Martin et al., 2006). Evaluation of the sustainability of two subsistence production and commercial rapeseed production systems in Khorramabad based on emergy and economic analysis showed that the subsistence system is more sustainable than the commercial rapeseed production system in this county (Amiri et al., 2019). Also, the evaluation of the sustainability of garlic, onion, and wheat production systems in the Sistan region with emergy analysis showed that wheat production was a superior system for achieving sustainability compared to garlic and onion production (Yasini et al., 2020). A comparison of traditional and mechanized production systems of rapeseed using emergy based production functions in Lorestan province showed that the sustainability of the mechanized production system is less than the traditional production system in this province (Amiri et al., 2020). However, very little research has been done on crop emergy assessment on a case-by-case basis in Iran and worldwide. The purpose of this study was to evaluate the emergy of the rapeseed ecosystem (*Brassica napus* L.) in order to determine its sustainability and to provide suggestions for optimal and sustainable management of the production system of this important crop in the study area, which is one of the rapeseed production hubs in Iran.

2. Materials and methods

2.1. Details of the study area and data collection

This research was conducted in the crop year of 2017-2018 in Gorgan county, in Golestan province. Data was collected through questionnaires and face-to-face interviews with rapeseed growers. Cochran's relation (Equation (1)) was used to determine the number of questionnaires (Cochran, 2003).

$$n = \frac{\frac{z^2pq}{d^2}}{1+\frac{1}{N}\left(\frac{z^2pq}{d^2}-1\right)} \quad (1)$$

where n is the sample size, N is the statistical population size (106), z is the standard error of acceptable reliability coefficient (1.96), p is the proportion of the population with a specific attribute (0.5), q is the proportion of the population without a specific attribute (0.5), and d is the desired level of precision (0.07). The number of questionnaires for rapeseed farmers was 60. Farmers were selected by a random sampling method.

2.2. Emergy analysis

The first step in emergy analysis is to determine the spatial and temporal boundaries, the most important inputs into the system, and the material, energy, and economic flows (Figure 1) (Odum, 1996; Odum, 2000). This action divides system inputs into environmental or non-environmental, purchased or free, and renewable or non-renewable (Odum, 2000).

Emergy analysis is based on dividing all inputs into four groups: 1) renewable environmental inputs (R) such as sunlight, rain, and wind; 2) environmental inputs that are potentially renewable but are considered non-renewable environmental inputs due to their long recovery time (N0), such as soil organic matter erosion; 3) renewable purchased Inputs (FR); and 4) purchased non-renewable inputs (FN) (Campbell and Laherrere, 1998; Asgharipour et al., 2019). All selected farms, from land preparation to harvest, are monitored. Information including agricultural farm history, time and type of land preparation operations, planting method, fertilizer spraying, spraying and harvesting, type and amount of inputs such as chemical fertilizers and chemical pesticides, type of machinery and frequency of their use, type and fuel consumption in each field operation, type, number, and duration of labor, and grain yield were recorded. Data related to erosion, soil organic matter, and climatic data were collected from the General Department of Natural Resources and Watershed Management and the General

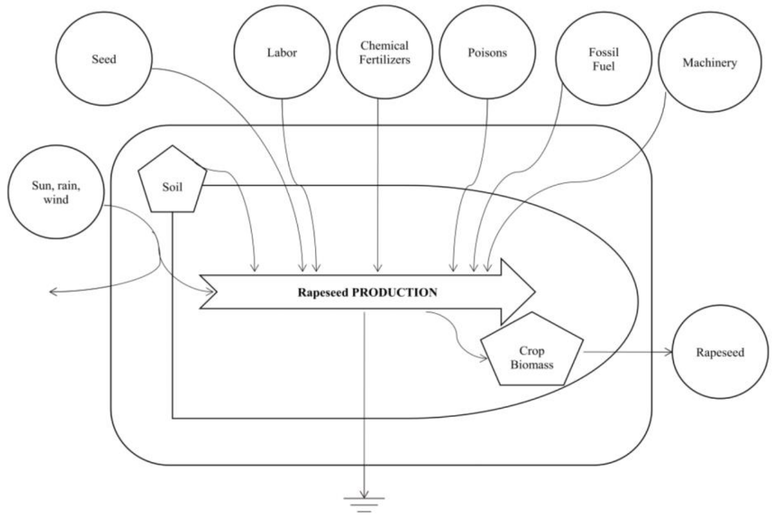


Figure 1. Emergy flow diagram of rapeseed farming ecosystem in Gorgan county

Table 1. Average climatic and edaphic variables in Gorgan county

Variable	Unit	Annual average
Solar radiation	j/m^2	1.74×10^7
Rainfall	mm	500
Wind speed	m/s	6.24
Soil erosion	kg/ha	16000
Soil organic matter	%	1.7

Meteorological Department of Golestan Province, respectively (Table 1).

The emergy flow of renewable resources was considered the same for all farms in this study. The effective composition of fertilizers and chemical toxins was determined (Jafari et al., 2018). To calculate the machine input, the total weight of the machines used was divided by their annual application area and then by their useful life. The annual application area and useful life of machines in Iran are 1000 hectares and 10 years, respectively (Houshyar et al., 2018). The coefficient of renewability was also determined for all inputs. The coefficients for labor and rapeseed are 0.10 (Ulgiati and Brown, 2002) and 0.43 (Amiri et al., 2019), respectively. All calculations related to emergy analysis were performed by EXCEL 2019 software. To calculate the solar emergy of inputs and outputs in the rapeseed ecosystem, most important inputs and outputs (grains) in each of the 60 farms were first determined in terms of mass (g), energy unit (joules), or currency (rials) per hectare per year. The conversion factor for calculating the amount of fossil fuel energy was 56.31 (Houshyar et al., 2018), the labor force was 1.96 (Rajabi Hamedani et al., 2011), and rapeseed was 28.3 (Kazemi et al., 2016). Equations 2-5 were used to calculate the environmental inputs of sunlight, wind, rain, and soil erosion in joules, respectively.

Solar energy= (10000 m^2/ha)×(radiation)×(1-albedo) (2)

In which the amount of albedo for rapeseed was 0.23 (Amiri et al., 2019).

Wind energy= (10000 m^2/ha)×(density of wind)×(drag coefficient)×(wind speed)^3×(time) (3)

In which wind density was 1.3 kg/m^3, drag constant was 0.001 and time was 2.33E+07 s (Ghaley et al., 2018).

Rain energy= (10000 m^2/ha)×(rainfall)×(density)×(gibbs free energy) (4)

Where rain density was 1000 kg/m^3 and Gibbs free energy was 4940 j/kg (Houshyar et al., 2018).

Energy of soil erosion= (soil loss)×(organic matter %)×(organic matter energy)×(conversion) (5)

Where the energy of organic matter was 5400 kcal/kg and the conversion factor was 4186 j/kcal (Houshyar et al., 2018).

After determining the most appropriate solar emergy conversion factor for each input, the solar emergy value was calculated by multiplying the numerical value of that input by its corresponding unit emergy value (UEV) (Odum, 2000). Emergy assessment in this study was based on the planet's coefficient of 12.00E+24 sej yr^{-1}, and UEVs were determined accordingly (Brown et al., 2016). Total emergy input to each farm was calculated by summing the emergy values of all inputs to that farm. Then, emergy input and emergy output for the rapeseed agroecosystem were calculated by averaging across all 60 farms studied. Finally, transformity (Tr), specific emergy (SpE), emergy yield ratio (EYR), standard emergy investment ratio (EIR), and modified emergy investment ratio (EIR^*) were calculated to evaluate efficiency and standard environmental loading ratio (ELR), modified environmental loading ratio (ELR^*), standard emergy sustainability index (ESI) and modified emergy sustainability index (ESI^*) were calculated to assess the sustainability of the rapeseed agroecosystems (Table 2).

Table 2. Specifications and formula of emergy-based indices for evaluation of rapeseed agroecosystems

Index	Formula	Specifications	Reference
Renewable environmental inputs	R	Renewable flows from free local resources	Asgharipour et al., 2019
Non-renewable environmental inputs	N0	Local potentially renewable flows from free local resources that is being used in a non-renewable	Campbell and laherrere, 1998
Renewable purchased inputs	F_R	Renewable flows from purchased resources	Asgharipour et al., 2019
Non-renewable purchased inputs	F_N	Non-renewable flows from purchased resources	Asgharipour et al., 2019
Total emergy input	$U=R+N0+F_R+F_N$	Total emergy resources required to support the production system	Asgharipour et al., 2019
Total emergy output	$Y= R+N0+F_R+F_N$	Total emergy of system products	Asgharipour et al., 2019
Transformity	$Tr = \frac{U}{AE}$	Amount of emergy required to produce an output unit in joules. AE is the accessible energy of the product	Brown and Ulgiati, 2004
Specific emergy	$SpE = \frac{U}{W}$	Amount of emergy required to produce an output unit in grams. W is the mass of the product	Brown and Ulgiati, 2004
Emergy renewability	$R\% = \frac{R + FR}{U} \times 100$	Percentage of the renewable energy used by the system	Odum, 2000
Emergy yield ratio	$EYR = \frac{Y}{FR + FN}$	Ability of a process to use renewable and non-renewable environmental resources with economic resources as a capital	Odum, 2000
Standard emergy investment ratio	$EIR = \frac{FR + FN}{R + N0}$	Indicates the intensity of economic investment and its matching to the free renewable and non-renewable resources of the environment	Asgharipour et al., 2019
Modified emergy investment ratio	$EIR^* = \frac{FR + FN}{R}$	The ratio of purchased resources to renewable environmental resources	Amiri et al., 2021
Standard environmental loading ratio	$ELR = \frac{N0 + FR + FN}{R}$	Environmental pressure produced by a process	Lu et al., 2014
Modified environmental loading ratio	$ELR^* = \frac{N0 + FN}{R + FR}$	Environmental pressure produced by a process	Lu et al., 2014
Standard emergy sustainability index	$ESI = \frac{EYR}{ELR}$	Measure of the sustainability of the system	Lu et al., 2014
Modified emergy sustainability index	$ESI^* = \frac{EYR}{ELR^*}$	Measure of the sustainability of the system	Lu et al., 2014

3. Results and discussion

3.1. Input emergy structure

The emergy values of the most important environmental resource flows, inputs purchased, and the share of each of them in the total emergy input to the rapeseed farming ecosystem are shown in Table 3.

Solar emergy for each input in this table is obtained by multiplying the value of that input by its corresponding solar conversion factor. Total emergy input was calculated as total emergy supporting a rapeseed farming ecosystem equal to 6.39E+15 sej ha^{-1} yr^{-1} (Table 3). Previously, this amount for the subsistence and commercial production systems of rapeseed in Khorramabad county was 2.47E+16 and 4.13E+16 sej ha^{-1} yr^{-1}, respectively (Amiri et al., 2019).

3.2. Renewable environmental inputs (R)

These inputs include sunlight, rain, and wind. The share of these inputs from total emergy input in the rapeseed ecosystem was low (8.89%), which indicates the

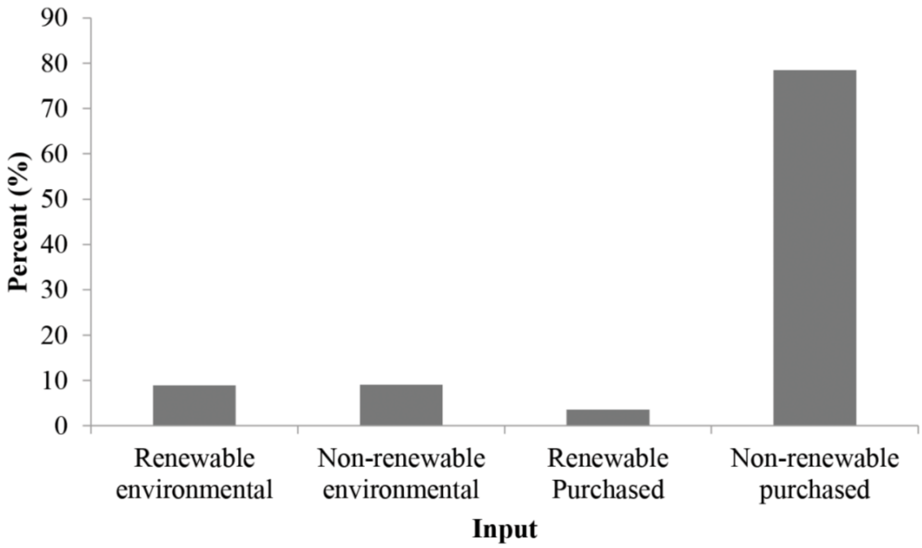


Figure 2. Share of environmental and purchased renewable and non-renewable inputs in rapeseed agroecosystems

low consumption of renewable environmental resources for rapeseed production in Gorgan (Figure 2).

Rain had the highest amount of emergy among the environmentally renewable resources in the rapeseed system (Table 3).

Renewable environmental inputs branch directly from sunlight. Therefore, in order to avoid double counting, the sum of renewable environmental inputs with the highest amount of emergy and emergy of sunlight input is considered as the total renewable environmental emergy (Amiri et al., 2021), which in this study was rain. More rain emergy than other renewable environmental inputs is due to favorable rainfall and high cloudy days as well as low wind speeds in this county. In the study of the evaluation of the sustainability of autumn and spring potato ecosystems in Gorgan county, it was found that the highest amount of emergy among renewable environmental inputs belonged to rain (Shahhoseini et al., 2020).

Table 3. Natural and economic flow, renewability, transformity, and solar emergy for rapeseed

Variable	Unit	Raw annual flow	Renewability factor	Solar transformity (sej unit^{-1})	Solar emergy (sej ha^{-1} yr^{-1})	Solar emergy (%)	References for transformity
Renewable environmental inputs							
Sunshine	J	1.34E+11	1	1	1.34E+11	0.00	Odum, 1996
Rainfall	J	2.47E+10	1	2.30E+04	5.68E+14	8.89	Odum, 1996
Wind	J	7.36E+10	1	1.86E+03	1.37E+14	2.14	Odum, 1996
Subtotal					5.68E+14	8.89	
Non-renewable environmental inputs							
Soil erosion	J	6.15E+09	0	9.42E+04	5.79E+14	9.06	Ghaley et al., 2018
Subtotal					5.79E+14	9.06	
Purchased inputs							
Nitrogen fertilizer	g	9.59E+04	0	4.84E+09	4.64E+14	7.26	Ghisellini et al., 2014
Phosphorus fertilizer	g	5.28E+04	0	4.97E+09	2.62E+14	4.10	Ghisellini et al., 2014
Potash fertilizer	g	2.04E+04	0	1.40E+09	2.86E+13	0.44	Ghisellini et al, 2014
Sulphur fertilizer	g	2.13E+04	0	6.94E+07	1.48E+12	0.02	Martin et al, 2006
Herbicide	g	1.35E+03	0	1.13E+10	1.53E+13	0.24	Bastianoni et al., 2001
Insecticide	g	1.25E+03	0	1.13E+10	1.41E+13	0.22	Bastianoni et al., 2001
Fungicide	g	1.30E+03	0	1.13E+10	1.47E+13	0.23	Bastianoni et al., 2001
Machinery	g	2.92E+03	0	1.01E+10	2.95E+13	0.46	Campbell et al., 2005
Seed	Rials	2.06E+06	0.43	2.50E+08	5.15E+14	8.06	Amiri et al., 2019
Fossil fuel and lubricant	J	4.52E+10	0	8.48E+04	3.83E+15	59.94	Brandt-Wiliams, 2002
Human labor	J	3.11E+07	0.10	2.22E+06	6.90E+13	1.08	Lu et al., 2009
Subtotal					5.24E+15	82.05	
Total					6.39E+15	100.00	
Grain yield	J	5.86E+10		1.09E+05	6.39E+15		Calculated

3.3. Non-renewable environmental inputs (N0)

Non-renewable environmental inputs for this study included soil erosion, and its share of total emergy input was significant (9.06%) (Table 3). The main reasons for this are the relatively high annual rainfall in this county (500 mm), improper tillage operations, and heavy use of machinery in rapeseed fields in Gorgan county. It seems that the implementation of conservation tillage methods and the use of multi-purpose machinery, with the aim of reducing the number of times they enter the field, is effective in preventing increased soil erosion and thus reducing the entry of emergy into the fields. The share of soil erosion from total emergy input in a study with similar conditions to this one study for common forage maize cultivation in Denmark was 3.3% (Ghaley et al., 2018).

3.4. Renewable and non-renewable purchased inputs (FR & FN)

Renewable market inputs had the lowest share among environmental and purchased renewable and non-renewable inputs (3.57%). While the share of non-renewable market inputs was much higher (78.48%) (Figure 2), which shows the high dependence of purchased inputs on non-renewable sources and consequently high pressure on the environment for rapeseed production in Gorgan county. Also, the large share of purchased inputs, which are often foreign, in the rapeseed production system indicates that this cropping system is an open system and is strongly influenced by the inputs purchased from the market. Therefore, optimal management and consumption of market practices, especially non-renewable inputs, is necessary to control and reduce the share of non-renewable resources in product production. In a study, the amount of emergy input purchased for the potato ecosystem in Florida was calculated to be 1.03E+16 sej ha^{-1} (Brandt-Wiliams, 2002).

In this study, fossil fuels had the largest share among all inputs to the rapeseed ecosystem (59.94%) (Table 3). According to the field study, irrigation pumps in most fields were diesel and worn out. Also, frequent tillage operations and the use of worn-out machinery, especially tractors, on most farms increased fuel consumption and as a result, the large share of this input in rapeseed production in the county. Also, the emergy rate of labor input was 6.90E+13 sej ha^{-1} yr^{-1}. The very small share of this input in crop production (1.08%) shows that the rapeseed production system in Gorgan is, to a large extent, commercial. Labor emergy for wheat, onion, and garlic production systems in the Sistan region was calculated to be 5.22E+14, 2.82E+15, and 5.04E+15 sej ha^{-1}, respectively (Yasini et al., 2020).

In this study, the emergy rate for seed input was 5.15E+14 sej ha^{-1} yr^{-1} (Table 3), which is higher than the reported amounts for subsistence production (4.40E+14 sej ha^{-1} yr^{-1}) and commercial production (3.30E+14 sej ha^{-1} yr^{-1}) of rapeseed in Khorramabad (Amiri et al., 2019). According to the information from the questionnaires, the consumption of seeds for sowing in Gorgan county, in both hand-spraying and machine conditions, was more than the recommended amount. Therefore, educating farmers on how to cultivate properly and set up planting machines can be effective in reducing the consumption of this input, which would thus reduce emergy input and increase efficiency in the rapeseed production system. The share of pesticide input in the rapeseed system in Gorgan county was low (0.69%), which indicates the relative health of this product in terms of the use of chemical pesticides on the farms in this county. Manual weed control and the absence of pests and diseases in most fields were effective in significantly reducing the share of this input in rapeseed production. Nitrogen fertilizer also had the largest share of total emergy input among chemical fertilizers (7.26%) (Table 3). Consumption of organic fertilizers can be as effective as possible in reducing the share of this chemical input and thus increasing crop health.

3.5. Evaluation of emergy indices

Emergy indices are used to determine the efficiency, renewability, environmental pressure, and sustainability of production systems (Odum, 2000; Brown and Ulgiati, 2004). Assessing these indices in ecosystems helps to identify and quantify their environmental, economic, and sustainability effects, and their results are effective at the local level for farmers and policymakers to make the best decisions to achieve sustainable agriculture (Jafari et al., 2018).

3.5.1. Transformity (Tr) and specific emergy (SpE)

The average grain yield in the studied farming ecosystem was 2070.6 kg ha^{-1}, which shows the efficiency of the system in converting inputs to economic output. Also, emergy dedicated to grain yield in the rapeseed production system in Gorgan county was estimated at 6.39E+15 sej ha^{-1} yr^{-1}. Transformity and specific emergy, as unit emergy values, indicate the efficiency of a production system. Lower values of these indices indicate greater performance and efficiency of the production process in environmental and economic competition. This means that less emergy input is allocated per unit of output (Odum, 2000). The transformity and specific emergy of the rapeseed cultivation system were 1.09E+05 sej J^{-1} and 3.09E+09 sej gr^{-1}, respectively (Table 4), which shows the rapeseed ecosystem in Gorgan county with high production efficiency. Transformity in this study was less than 8.02E+05 and 2.06E+05 sej J^{-1} for subsistence and commercial systems of rapeseed production in Khorramabad, respectively. Also, the specific emergy in this study was less than 2.25E+10 and more than 7.24E+09 sej gr^{-1} for subsistence and commercial production of rapeseed in Khorramabad, respectively (Amiri et al., 2019).

Table 4. The values of emergy indices in the rapeseed production system

Index	Unit	Rapeseed ecosystem
Transformity	sej j^{-1}	1.09E+05
Specific emergy	sej g^{-1}	3.09E+09
Renewability	%	12.46
Emergy yield ratio	-	1.22
Standard emergy investment ratio	-	4.56
Modified emergy investment ratio	-	9.23
Standard environmental loading ratio	-	10.25
Modified environmental loading ratio	-	7.02
Standard emergy sustainability index	-	0.12
Modified emergy sustainability index	-	0.17

3.5.2. Emergy renewability (%R)

This index indicates the share of renewable resources in supporting a production system (Odum, 2000). The emergy renewability ratio in this study for rapeseed systems was 12.46% (Table 4). In other words, 87.54% of the total input of emery in this production system is dependent on non-renewable resources, the major part of which is related to fossil fuels and soil erosion. By reducing the share of these resources in the rapeseed system as much as possible, it is possible to increase the renewability and, consequently, the sustainability of the farming ecosystem. Increasing the share of renewable resources and reducing the consumption of non-renewable resources in a production system lead to the success of that system in economic competition and thus increase sustainability (Asgharipour et al., 2019) because non-renewable resources become scarcer over time (Brown and Ulgiati, 2004). The amount of renewability in this study was more than 5.30 for the commercial system and less than 19.90% for the subsistence of rapeseed production in Khorramabad (Amiri et al., 2019). This index for the ecosystem of conventional forage maize production in Denmark is reported to be 16% (Ghaley et al., 2018).

3.5.3. Emergy Yield Ratio (EYR)

This index indicates the efficiency of resource consumption and the ability of a system to consume environmental resources by investing in purchased resources, and higher values indicate more absorption of environmental emergy in the system (Brown and Ulgiati, 2004). The EYR value in this study was 1.22 (Table 4), which shows that the rapeseed farming ecosystem in Gorgan county has an acceptable resource consumption efficiency. The minimum value for EYR is 1, in which the share of environmental resources in a production system is the lowest and the dependence on economic resources is at the highest level. Therefore, higher values of this index are more desirable (Asgharipour et al., 2019). Implement strategies to reduce the consumption of economic resources. For example, modernization of irrigation machinery and pumps to increase efficiency and thus reduce fuel consumption, as well as the use of seeds with higher germination percentage to reduce seed consumption (as an economic input) will increase this index and, as a result, will increase consumption efficiency. This index is the result of dividing the total emergy output (environmental and purchased) by the purchased emergy input. Therefore, reducing the consumption of economic resources and increasing the consumption of environmental inputs is effective in increasing this index and improving efficiency (Odum, 2000). EYR values in this study are less than 1.53 and 2.31 values for subsistence and commercial rapeseed production systems in Khorramabad (Amiri et al., 2019) and more than 1.20, 1.15, 1.05, and 1.07, respectively, for corn production systems (Zhang et al., 2012), and rice, vegetables, and rice and vegetable rotation in China (Lu et al., 2010.

3.5.4. Standard emergy investment ratio (EIR) and modified emergy investment ratio (EIR*)

The EIR shows the amount of investment a production system makes in economic resources and the degree of its dependence on the environment (Odum, 2000). The EIR value in this study was 4.56 (Table 4), which indicates the low economic efficiency of the rapeseed system. Lower values for this index in a system indicate lower economic costs and greater dependence on the environment and are therefore more desirable (Odum, 2000). Therefore, some effective factors in reducing this index and increasing economic efficiency and sustainability are increasing the share of environmental resources in the production system, reducing the consumption of economic inputs, and replacing these inputs with environmental resources, such as using environmental energy sources in the fuel supply or biological pest control. The EIR values in this study are higher than the values of 0.76 and 1.86 for the commercial and subsistence systems of rapeseed production in Khorramabad (Amiri et al., 2019), 2.74 and 2.29 for wheat and corn production in Jahrom, respectively (Houshyar et al., 2018), and 2.94 and 1.30 for wheat and oat production in China, respectively (Zhai et al., 2017).

EIR* is introduced as a more direct measure of the compliance of market inputs with renewable environmental resources (Amiri et al., 2019). Therefore, this index was used to test the better adaptation of foreign investment in the rapeseed crop system to free renewable environmental resources, and its value in this cropping system in Gorgan was 9.23. The amount of EIR* obtained for the rapeseed production in this study is higher than the calculated values of 9.00 for commercial production and 8.94 for subsistence production of rapeseed in Khorramabad (Amiri et al., 2019), which indicates more emergy investment in rapeseed production in Gorgan compared to Khorramabad.

3.5.5. Standard environmental loading ratio (ELR) and modified environmental loading ratio (ELR*)

ELR indicates the pressure of a production system on the environment (Asgharipour et al., 2019). This index was 10.25 for rapeseed agroecosystems (Table 4), which indicates the high pressure of this production system on the environment and low environmental sustainability. The main reasons for this are the large amount of soil erosion (as a non-renewable environmental input) in the rapeseed farming ecosystem and the unreasonable use of some economic inputs, especially fossil fuels, in this system, which concentrates a large flow of non-renewable resources into a small environment. This index indicates the pressure caused by the consumption of non-renewable environmental and economic inputs, and its lower values are more desirable (Lu et al., 2014).

ELR is calculated by dividing the non-renewable and market emergy input by the renewable emergy input from the environment (Asgharipour et al., 2019). Therefore, some effective factors in reducing environmental pressure are changing the quantity and quality of consumption of these inputs in order to reduce their share of total emergy input. Increasing the cultivation area with the aim of reducing the concentration intensity of non-renewable inflows and implementing conservation tillage methods to reduce soil erosion (as a non-renewable environmental input) along with the use of renewable resources to provide economic inputs, such as the use of organic fertilizers instead of chemical fertilizers, is effective in reducing environmental pressure and thus increasing the sustainability of the rapeseed production system. Evaluation of the sustainability of bean production systems in Khorramdasht showed that the application of conservation tillage methods and the replacement of chemical fertilizers with organic fertilizers is effective in increasing the environmental sustainability of the production system (Asgharipour et al., 2019). Justifying farmers about the importance of reducing environmental pressure in achieving long-term sustainability and financially supporting them to modernize equipment to consume fewer non-renewable resources is effective in achieving this goal. The ELR value in this study for the rapeseed cultivation system is less than 31 values for potato production in China (Zhai et al., 2017) and 12.68 and 19.75 for subsistence and commercial production of rapeseed in Khorramabad (Amiri et al. al., 2019) and more than 0.47 for corn production in China (Wang et al., 2014), respectively.

ELR* represents the relationship between the total renewable emergy and the total non-renewable emergy and is the inverse scale of sustainability. Therefore, lower values of this index are more desirable (Asgharipour et al., 2019). The ELR* value for the rapeseed ecosystem was 7.02 (Table 4), which indicates the average environmental pressure in this production system. In both the ELR and ELR* indices, values of < 2, 2-10, and >10 indicate low, medium, and high environmental pressure, respectively (Brown and Ulgiati, 2004). The difference between ELR and ELR* is the displacement of the purchased renewable input from the fraction in the ELR to the denominator of the fraction in the ELR*.

Due to the very small share of renewable economic resources from total emergy input in the rapeseed production system, the values of the two indices, ELR and

ELR* in this production system were slightly different. Therefore, the recommended solutions to reduce the amount of ELR, especially reducing the consumption of non-renewable economic inputs, are also effective in reducing the amount of ELR*. This index emphasizes the inconsistency between renewable and non-renewable sources and is a complement to the transformity (Martin et al., 2006). Increasing the share of renewable resources in both environmental and purchased inputs will reduce environmental pressure and increase environmental sustainability in the system. Expanding the facilities and equipment needed to supply renewable environmental energy such as sunlight and wind in supplying electricity required by irrigation pumps reduces the share of non-renewable inputs and thus increases the environmental sustainability of the rapeseed farming ecosystem. Because ELR* is the ratio of non-renewable inputs to renewable inputs, reducing the share of non-renewable resources reduces this index and makes the ecosystem more sustainable in the long run as non-renewable resources become rarer over time. ELR* value in this study is less than 17.85 for the commercial rapeseed production system in Khorramabad (Amiri et al., 2019), and more than 4.00, 4.18, 4.35, 4.46, and 4.62 for the subsistence rapeseed production in Khorramabad (Amiri et al., 2019) and greenhouse production of cucumber, tomato, bell pepper, and eggplant in Jiroft (Asgharipour et al., 2020), respectively.

3.5.6. Standard Emergy Sustainability Index (ESI) and Modified Emergy Sustainability Index (ESI*)

ESI is a composite index that determines the amount of profit earned per unit area relative to its costs in a system. Therefore, it focuses more on the economic aspect of sustainability (Asgharipour et al., 2019). The value of this index for the rapeseed production system was 0.12 (Table 4), which shows the low economic sustainability of this farming ecosystem in Gorgan. The lowest and highest values for this index are zero and infinite, respectively. Systems in which the value of this index is less than one have very high energy consumption, intensify environmental effects, and require a lot of energy to survive (Ulgiati and Brown, 1998).

Despite the importance of efficient energy consumption in sustainable agriculture, according to the questionnaire, the most important reasons for the low ESI in the rapeseed system are the high share of market inputs, especially fossil fuels, seeds, and nitrogen fertilizers, and high soil erosion in this system of production (as a non-renewable environmental input), which reduced sustainability. Therefore, some effective factors in reducing the consumption of non-renewable environmental and economic inputs are Informing, encouraging, and educating farmers about the benefits of implementing conservation tillage methods, modernizing machinery, using quality seeds, using livestock fertilizers instead of chemical ones (as much as possible), and using renewable environmental energy. As a result, these items reduce the pressure on the environment and increase the economic sustainability of the rapeseed production system. In production systems, increasing performance and decreasing environmental pressure increase ESI and thus economic sustainability (Jafari et al., 2018). The ESI value in this study is higher than 0.03 for the potato growing system in China (Zhai et al., 2017), 0.117 for the commercial rapeseed production system in Khorramabad (Amiri et al., 2019), and 0.08, 0.09, and 0.05 for wheat, onion, and garlic production systems in the Sistan region (Yasini et al., 2020), respectively.

ESI*, the inverse measure of stability, is related to the performance ratio of a system and expresses the benefits of the system in relation to its relative sustainability. The minimum and maximum values for this index are zero and infinity, respectively (Lu et al., 2014). The value of this index for the rapeseed production system was 0.17 (Table 4), which shows the high environmental pressure during crop production and the low environmental sustainability of this system in Gorgan. Both the ESI and ESI* indices examine the ecology of a production system from different perspectives, and the higher values of both indices indicate the greater ecological sustainability of the system. In both the ESI and ESI* indices, values of >10, 1--10, and <1 indicate a sustainable system with very low pressure, living and good systems, and resource depleting systems (Asgharipour et al., 2019). Considering the importance of environmental sustainability to maintain the economic advantage of a production system, the most desirable policy for rapeseed production in Gorgan is to maintain a balance between economic advantage and environmental sustainability.

ESI* indicates the environmental sustainability of the system, and its higher values are more desirable (Amiri et al., 2019). The effective factor in reducing pressure and increasing environmental sustainability and thus increasing ESI* in the rapeseed crop system is increasing the share of renewable resources, including the use of renewable resources instead of non-renewable resources in the supply of economic inputs. The value of ESI* in this study is greater than 0.13 for the commercial rapeseed production system in Khorramabad (Amiri et al., 2019), and the values of 0.04, 0.06, and 0.11 for the system with high, medium, and low input for bean production in Khorramdasht (Asgharipour et al., 2019), respectively, and less than 0.38 for subsistence rapeseed production in Khorramabad (Amiri et al., 2019), 0.45 for corn production in China (Zhang et al., 2012), and 1.48 for the ecological system of bean production in Khorramdasht (Asgharipour et al., 2019).

4. Conclusion

The highest share of total emergy inputs in the rapeseed ecosystem was related to non-renewable purchased inputs, and the lowest share was related to renewable purchased inputs. Fossil fuels accounted for the largest share of total emergy inputs of all inputs. Evaluation of transformity and specific emergy indices showed that the rapeseed ecosystem has high production efficiency in Gorgan. Indeed, the evaluation of the emergy renewability index showed that renewability in this production system was low due to its high dependence on non-renewable resources.

Based on the emergy yield ratio, resource efficiency was also acceptable in this cropping system. The analysis of emergy investment ratios showed that the economic costs in this system are high and the economic efficiency is low. Based on the analysis of environmental loading ratios, this system puts a lot of pressure on the environment, and its environmental sustainability is low. This was due to the unreasonable use of some purchased non-renewable inputs such as fossil fuel and nitrogen fertilizers, and high soil erosion as a non-renewable environmental input. Implementation of conservation tillage methods and use of renewable environmental energies, such as solar energy, in supplying electricity required for irrigation pumps, reduces the consumption of non-renewable resources, thus reducing environmental pressure and increasing environmental sustainability in this system.

Evaluation of emergy sustainability indices showed that economic sustainability in this farming ecosystem was low due to high dependence on some economic inputs and high environmental pressure in this system. Reducing the consumption of purchased non-renewable resources along with maintaining or improving performance in this farming ecosystem will improve this index and increase economic sustainability. Reducing the consumption of fossil fuels by modernizing irrigation machinery and pumps and using organic fertilizers instead of chemical ones is as effective as possible. As a final result, production efficiency, resource consumption efficiency, and economic efficiency in the rapeseed farming ecosystem were acceptable. Despite the low dependence on environmental inputs in this system, the high share of soil erosion as a non-renewable environmental input resulted in low renewability, high environmental pressure, and low environmental and economic sustainability in this system. Implementation of recommended strategies to reduce the consumption of non-renewable resources and increase the use of renewable resources in the supply of purchased inputs, along with awareness, education, and encouragement of farmers in this field, is effective in increasing the environmental and economic sustainability of rapeseed agroecosystems.

Acknowledgments

We would like to thank the rapeseed farmers and the General Directorate of Agricultural Jihad in Golestan Province for their assistance and cooperation in this research.

References

Amiri, Z., Asgharipour, M.R., Campbell, D.E., Aghapoor Sabaghi, M. 2020. Comparison of the sustainability of mechanized and traditional rapeseed production systems using an emergy-based production function: A case study in Lorestan Province, Iran. Journal of Cleaner Production 258, 120891.

Amiri, Z., Asgharipour, M.R., Campbell, D.E., Armin, M. 2019. A sustainability analysis of two rapeseed farming ecosystems in Khorramabad, Iran, based on emergy and economic analyses. Journal of Cleaner Production 226, 1051-1066.

Amiri, Z., Asgharipour, M.R., Campbell, D.E., Azizi, K., Kakolvand, E., Hassani Moghadam, E. 2021. Conservation agriculture, a selective model based on emergy analysis for sustainable production of shallot as a medicinal-industrial plant. Journal of Cleaner Production 292, 126000.

Asgharipour, M.R., Amiri, Z., Campbell, D.E. 2020. Evaluation of the sustainability of four greenhouse vegetable production ecosystems based on an analysis of emergy and social characteristics. Ecological Modelling 424, 109021.

Asgharipour, M.R., Shahgholi, H., Campbell, D.E., Khamari, I., Ghadiri, A. 2019. Comparison of the sustainability of bean production systems based on emergy and economic analyses. Environmental Monitoring and Assessment 191(2), 1-21.

Bastianoni, S., Marchettini, N., Panzieri, M., Tiezzi, E. 2001. Sustainability assessment of a farm in the Chianti area (Italy). Journal of Cleaner Production 9, 365-373.

Brandt-Williams, S.L. 2002. Handbook of Emergy Evaluation: Folio #4 Emergy of Florida Agriculture. Center for Environmental Policy, Univercity of Florida, Gainesville, FL, USA.

Brown, M.T., Campbell, D.E., De Vilbiss, C., Ulgiati, S. 2016. The geobiosphere emergy baseline: A synthesis. Ecological Modelling 339, 92-95.

Brown, M.T., Ulgiati, S. 2004. Energy quality, emergy, and transformity: H.T. Odum,s contributions to quantifying and understanding systems. Ecological Modelling 178, 201-213.

Campbell, D.E., Brandt-Williams, S.L., Meisch, M.E.A. 2005. Environmental accounting using Emergy: Evaluation of the state of West Virginia. EPA/600/R-02/011. USEPA, Office of research and Development, Washigton, DC, P. 116.

Campbell, D.E., Laherrere, J. 1998. The end of cheap oil. American Journal of Science 278(3), 78-83.

Cochran, J. 2003. Patterns of sustainable agriculture adoption/non-adoption in Panama a thesis submitted to McGill University. McGill University, Montreal, Canad, 1-114.

Ghaley, B.B., Kehli, N., Mentler, A. 2018. Emergy synthesis of conventional fodder maize (*Zea mays* L.) production in Denmark. Ecological Indicators 87, 144-151.

Ghisellini, P., Zucaro, A., Viglia, S., Ulgiati, S. 2014. Monitoring and evaluating the sustainability of Italian agricultural system. An emergy decomposition analysis. Ecological Modelling 271, 132-148.

Houshyar, E., Wu, X.F., Chen, G.Q. 2018. Sustainability of wheat and maize production in the warm climate of southwestern Iran: An emergy analysis. Journal of Cleaner Production 172, 2246-2255.

Jafari, M., Asgharipour, M.R., Ramroudi, M., Galavi, M., Hadarbadi, G. 2018. Sustainability assessment of date and pistachio agricultural systems using energy, emergy and economic approaches. Journal of Cleaner Production 193, 642-651.

Kazemi, H., Hassanpour Bourkheili, S., Kamkar, B., Soltani, A., Gharanjic, K., Nazari, N.M. 2016. Estimation of greenhouse gas (GHG) emission and energy use efficiency (EUE) analysis in rainfed rapeseed production (case study: Golestan province, Iran). Energy 116, 694-700.

Kumaraswamy, S. 2012. Sustainability issues in agro-ecology: Socio-ecological perspective. Agricultural Sciences 3(2), 153-169.

Lu, H., Bai, Y., Ren, H., Campbell, D.E. 2010. Integrated emergy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields: Implications for agricultural policy in China. Journal of Environmental Management 91, 2727-2735.

Lu, H.F., Kang, W.L., Campbell, D.E., Ren, H., Tand, Y.W., Fengd, R.X., Luo, J.T., Chen, F.P. 2009. Emergy and economic evaluations of four fruit production systems on reclaimed wetlands surrounding the Pearl River Estuary, China. Ecological Engineering 35, 1743-1757.

Lu, H., Yuan, Y., Campbell, D.E., Qin, P., Cui, L. 2014. Integrated water quality, emergy and economic evaluation of three bioremediation treatment systems for eutrophic water. Ecological Engineering 69, 244-254.

Martin, J.F., Diemont, S.A.W., Powell, E., Stanton, M., Levy-Tacher, S. 2006. Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management. Agriculture, Ecosystems and Environment 115, 128-140.

Odum, H.T. 1996. Environmental accounting: Emergy and Environmental Decision Making. John Wiley & Sons, New York. USA.

Odum, H.T. 2000. Handbook of Emergy Evaluation. A Compendium of Data for Emergy Computation Folio #2 Emergy global processes. Center of Environmental Policy, University of Florida, Gainesville.

Patterson, M., McDonald, G., Hardy, D. 2017. Is there more in common than we think? Convergence of ecological footprinting, emergy analysis, life cycle assessment and other methods of environmental accounting. Ecological Modelling 362, 19-36.

Quintero-Angel, M., Gonzalez-Acevedo, A. 2018. Tendencies and challenges for the assessment of agricultural sustainability. Agriculture, Ecosystems and Environment 254, 273-281.

Rajabi Hamedani, S., Shahabi, Z., Rafiee, Sh. 2011. Energy inputs and crop yield relationship in potato production in Hamadan province of Iran. Energy 36, 2367-2371.

Shahhoseini, H.R., Ramroudi, M., Kazemi, H. 2020. Evaluating the resources use efficiency and sustainability indices for two potato production systems using emergy analysis (Case Study: Gorgan county). Journal of Agroecology 12(1), 127-142. (In Persian with English Summary).

Ulgiati, S., Brown, M.T. 1998. Monitoring patterns of sustainability in natural and man-made ecosystems. Ecological Modelling 108, 23-36.

Ulgiati, S., Brown, M.T. 2002. Quantifying the environmental support for dilution and abatement of process emissions. The case of electricity production. Journal of Cleaner Production 10, 335-348.

Wang, X., Dadouma, A., Chen, Y., Sui, P., Gao, W., Qin, F., Zhang, J., Xia, W. 2014. Emergy analysis of grain production systems on large-scale farms in the North China Plain based on LCA. Agricultural Systems 128, 66–78.

Xi, Y.G., Qin, P. 2009. Emergy evaluation of organic rice-duck mutualism system. Ecological Engineering 35, 1677-1683.

Yasini, H., Ghanbari, S.A., Asgharipour, M.R., Seyedabadi, E. 2020. Evaluation of Sustainability in Wheat, Onion and Garlic Cropping Systems by Joint Use of Emergy and Economic Accounting. Journal of Agricultural Science and Sustainable Production 30(2), 269-288. (In Persian with English Summary).

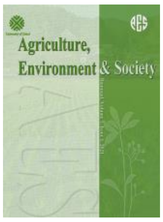
Zhai, X., Huang, D., Tang, S., Li, S., Guo, J., Yang, Y., Liu, H., Li, J., Wang, K. 2017. The emergy of metabolism in different ecosystems under the same environmental conditions in the agro-pastoral ecotone of northern China. Ecological Indicators 74, 198-204.

Zhang, L.X., Song, B., Chen, B. 2012. Emergy-based analysis of four farming systems: insight into agricultural diversification in rural China. Journal of Cleaner Production 28, 33–44.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 71-76

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir



Evaluation of several novel bread wheat cultivars in Kerman province's warm regions

Mohammad Ali Javaheri *[a]

[a] Assistant Professor of Seed and Plant Improvement Research Department, Kerman Agricultural and Natural Resources Research and Education Center, Agricultural Research Education and Extension Organization (AREEO), Kerman, Iran.

ARTICLE INFO

Article history:
Received: 12 April 2022
Accepted: 7 May 2022
Available online: 11 May 2022

Keywords:
New cultivars
Plant height
Spike
Warm regions
Yield

ABSTRACT

Bread wheat cultivars Chamran, Chamran2, and Sirvan are the dominant cultivars in Kerman province's warm regions. Due to their obsolescence and lack of purity, farmers are dissatisfied with the performance of common cultivars. Therefore, if the new cultivars outperform the conventional cultivars in terms of yield, they should be used to replace the conventional cultivars. The quantitative yield of 12 bread wheat cultivars was determined quantitatively in this experiment using a randomized complete block design with three replications. At a 5% probability level, the combined analysis of variance revealed that the year effect was significant for 1000-seed weight, plant height, and spike length. Additionally, at a 5% probability level, there is a significant difference between cultivars in terms of grain yield, 1000-seed weight, plant height, and spike length, indicating a genetic difference between cultivars. Sarang cultivar produced the most grain (7191.33) kg/ha, while the Chamran cultivar produced the least grain (6376.50 kg/ha). Sarang cultivar averaged 46.6 grams per 1000 seeds, while Shush cultivar averaged 35.1 grams per 1000 seeds. The Mehregan, Sirvan, and Tirgan cultivars, on the other hand, had the longest spikes at 10.16, 10.06, and 10 cm, respectively, while the Chamran2 cultivar had the shortest spikes at an average of 7.46 cm. The Chamran cultivar reached a height of 104.16 cm, while the Chamran2 and Aflac cultivars reached 94.33 and 94.16 cm, respectively. According to the findings of this study, Sarang, Shush, Khalil, and Tirgan wheat cultivars should be used in place of older and conventional cultivars in warm areas of Kerman province, depending on available facilities.

Highlights

- This experiment used a randomized complete block design with three replications to quantify yield characteristics of 12 bread wheat cultivars.
- Grain yield, 1000-seed weight, plant height, and spike length differ significantly between cultivars, indicating genetic differences.
- The longest spikes were 10.16 cm for the Mehregan, Sirvan, and Tirgan cultivars, while the shortest spikes were 7.46 cm for the Chamran2 cultivar.
- Sarang, Shush, Khalil, and Tirgan should be used in place of older conventional cultivars in warm areas of Kerman province.

1. Introduction

Wheat (*Triticum aestivum*) is one of the most important grains in the world, which accounts for about 31% of total grain consumption in the world (Yousefi Moghadam et al., 2018). Iran ranked seventh in the world in terms of the high volume of wheat consumption. Increasing the production of this plant will help reduce food prices and the poverty ratio (Chen and Ravallion, 2007). According to the latest statistics in the country, wheat production is 14,592,003 tons of seeds per 5,928,728 ha, of which about 97% of the wheat is used for bread (Anonymous, 2018). The most important agronomic species of wheat include bread wheat (Triticum aestivum) and durum wheat (Triticum turgidum var. Durum). The durum species, which are divided into two growth groups based on growth type, account for only about 8% of the

* Corresponding author
Email: javaheri310@yahoo.com (M.A. Javaheri)
http://dx.doi.org/10.22034/aes.2022.338177.1032

total area of wheat cultivation in the world. In areas where conditions are not suitable for producing bread wheat, the durum species are considered important crops (Srivastava, 1984; Fabriani and Lintas, 1988).

Considering the importance of wheat in the country and the importance of productivity more than the existing agronomic and environmental capabilities, modified and productive cultivars must be found to be replaced by the current cultivars. It is hoped that this method will allow the potential capabilities to be used. On the other hand, wheat is a strategic product and is considered the basic food of the country. In addition to the necessity for self-sufficiency in the production of this plant, the following issues are worth considering: increasing the need for more production of this product; the importance of increasing variation in existing cultivars in the country (which ultimately increases the power of production); the importance of replacing existing cultivars (due to the broken resistance of diseases, etc.). These items are necessary to achieve higher yields and adapt the findings of research to farm conditions (Esmaeilzadeh Moghaddam, 2013). In most international wheat research centers in the world, comparisons of performance and adaptation have been carried out to achieve new wheat cultivars and plan to transfer new findings to farmers. In Iran, for many years, such schemes have been carried out. The result of these studies has introduced new wheat cultivars, such as Chamran, Hamoon, Aflac, etc., into the country and the region. The implementation of research-promotion projects in the country has had very effective results in the introduction, development, and promotion of new cultivars (Esmaeilzadeh Moghaddam, 2013).

The first step in a genetic improvement program is the choice of parents. Success in plant breeding projects mainly depends on factors such as the ability to recognize parents, combining desirable traits through the hybrid, identification, and effective choice among the differentiating masses. Following that, the next goal is the high and sustainable performance of these programs (Baker, 2020; Knott, 1987; Stoskopf et al., 1993). In this regard, extensive experiments were performed to compare performance to determine the differences between specific lines and cultivars and their performance potential (Austin, 1982; Stoskopf et al., 1993; Yazdansepas, 1997). Studies conducted in the tropics on the comparison of yields of different cultivars showed that cultivars S-90-3, S-90-4, S-90-5, S-90-6, and S-90-7 in terms of yield and characteristics optimal crops are in better conditions than the dominant cultivar of the region (Chamran). Bread wheat of Sirvan cultivar with PRL / 2 * PASTOR pedigree with high yield, tolerant of late water shortage, and good bakery-quality in 2012, for planting in the conditions of moisture stress at the end of the season in temperate regions of the country was introduced. Sirvan wheat has a high grain weight of 1000 grains, very high tillering power, and suitable resistance to plant lodging is relatively early and adapted to warm to temperate climates. Due to the tolerance of this cultivar to yellow rust, it is a suitable alternative to the Chamran cultivar (Najafian et al., 2012).

The Mehregan cultivar is one of the second international treasures received from the Corn and Wheat Research Center (CIMMYT). This cultivar was evaluated in Karaj in the 2007-2008 crop year. This cultivar was studied in the adaptation test to the hot and dry climate of the south, which was carried out for two cropping years (2008-2009) in six stations in the hot and dry climate of the south of the country. The results showed that this cultivar had a stable grain yield in all the evaluated stations. High yield potential, relatively good tolerance to late-season heat, relative maturity, acceptable resistance to yellow, brown, and black rust diseases, and good bakery quality are important features of this cultivar (Esmaeilzadeh Moghaddam et al., 2017).To study the compatibility of Omidbakhsh wheat lines, 16 lines along with two commercial cultivars (Chamran and Aflac) were studied for two crop years (2012–2014) in six research stations (Zabol, Ahvaz, Darab, Dezful, Iranshahr, and Khorramabad). The results of the experiment showed that the lines S-91-6, S-91-13, and S-91-15 with average grain yields of 6262, 6251, and 6315 kg/ha, respectively, with average yield ranks (7.4, 7, and 6.5, respectively) and standard deviation had lower ranks (3.8, 3.84, and 3.48, respectively) and higher performance ratio index (104, 104, and 105, respectively) than the control. These lines were concurrent with the control in terms of processing time. They also had better general adaptability and, consequently, grain yield stability (Esmaeilzadeh Moghaddam, 2013).

The Parsi cultivar (line) M-84-17 was produced from the cross of the irrigated wheat lines "S-Buc" / "S-Dove", as the mother plant, and the Darab wheat cultivar, as the father plant, in Zarghan Agricultural Research Station, in the crop year 1994-95. It should be noted that the irrigated wheat line ""S-Buc" / "S-Dove" is one of the improved lines at the Center for International Corn and Wheat Research (CIMMYT). In the 1995-96 crop year, the F1 generation was crossed with the Darab cultivar again. Generation F1 with "S-Buc" / "S-Dove" / 2 * t Darab pedigree was evaluated and its seeds were selected as the superior generation for planting, evaluation, and selection in the F2 generation at the Zarghan station during the 1996-1997 crop year. Due to its high yield potential, resistance to yellow rust, and the race of Ug99 of black rust disease, as well as very good bakery-quality and good agronomic characteristics, this cultivar was recommended for planting in irrigated farms in Iran (Najafian et al., 2010). Bread wheat of Aflac cultivar (S-80-18) is a mid-maturity, medium-sized cultivar, with medium height, sensitive to grain fall and plant dormancy, suitable for early planting dates, and adapted to warm regions. The Aflac cultivar is one of the heat tolerant cultivars (Esmaeilzadeh Moghaddam, 2011).

To study the phenological traits of commercial bread wheat cultivars, an experiment was conducted in the 2015-2016 crop year in a randomized complete block design with three replications in experimental farm number one of the Department of Agriculture and Plant Breeding of Shahid Chamran University of Ahvaz. The treatments included ten commercial bread wheat cultivars, namely Sistan, Dez, Chamran 2, Kavir, Roshan, Pishtaz, Mehregan, Shush, Verinak, and Chamran. The Mehregan cultivar, with 7680 kg/ha, had the highest yield among cultivars and showed a better yield than the control cultivar, Chamran (6346.7 kg/ha) (Mousavi et al., 2016). The contribution of each yield component in justifying grain yield can also be indirectly affected by other components (Mehmet and Tetal, 2006). The advantage of path analysis over correlation coefficients is that, through causal analysis, the indirect effect of each performance component can be separated from the direct effect of that particular component on performance. In fact, the interrelationship between components creates an indirect effect (Mehmet and Tetal, 2006). Plaut et al. (2004) also noted a negative relationship between 1000-seed weight and the number of seeds per spike.

Wheat is a major crop in the warm region, where it contributes significantly to food production. Due to the critical role of improved seeds in increasing yield and area under wheat cultivation in the region, which is the primary source of income for farmers, and the requirement for self-sufficiency in wheat production in accordance with national policies, new cultivars with higher yields and desirable agronomic properties should be reviewed on a continuous basis, and existing cultivars should be replaced. Thus, to achieve the desired cultivars, such schemes are necessary and critical. As a result, new cultivars or lines must be introduced to farmers in cases of superiority. Over 90% of the area under irrigated wheat cultivation in the Kerman Research Center's work area is located in warm areas. Around 500 hectares of land in this area are affected by salinity. It is critical to obtain and introduce more productive cultivars than cultivars in hot areas such as Vakilabad and Baft city. Utilizing existing wheat production potential effectively requires the use of appropriate cultivars.

2. Materials and methods

In this experiment, the yield and some agronomic characteristics of 12 bread wheat cultivars were determined, including the Chamran cultivar as a control, as well as Shush, Parsi, Sivand, Sirvan, Chamran 2, Aflak, Mehregan, Khalil, Sarang, Tirgan, and Talaei cultivars in the warm Vakilabad area of Kerman province's Baft city. They were calibrated using a four-replication randomized complete block design.

2.1. Experimental area

The Vakilabad hot region is located one hundred kilometers southwest of Baft county in Kerman, Iran. It is located at 25.0° and 65.6° east longitude and 29° and 28° north latitude. It is an average of 1150 meters above sea level. According to the Amberje climate classification, this region has a mild to warm desert climate. The county has mild and relatively humid winters and hot and dry summers. The average annual maximum temperature is 31.7 °C, the average annual minimum temperature is 15.49 °C, and the annual rainfall is 160 mm. Its absolute minimum temperature is -11.4 °C.

2.2. Experimental layout and treatments

The experiment was planted in the cropping years 2019-2020 and 2020-2021, and in both years in a field that was the fallow year. The number of seeds of each cultivar was determined based on 400 seeds per square meter and considering the weight of 1000 seeds. Each cultivar was planted manually in six six-meter rows with 20 cm line spacing. Therefore, the area of each experimental plot was 7.2 square meters, and a margin of one meter was considered between each replication. According to the experiments performed and according to the needs of the farm soil, the amount of fertilizer used was based on the recommendations of the colleagues of the Water and Soil Department (Table 1).

Table 1. Result of soil analysis of experimental site

Year	Soil texture	O.C. (%)	P (mg.kg^{-1})	K (mg.kg^{-1})	pH	EC (dS.m^{-1})
2019	Loamy clay	0.48	10.2	198	7.9	2.8
2020	Loamy clay	0.51	11	219	7.8	2.6

All phosphorus and potash fertilizers, microelements, and one-third of the nitrogen fertilizer were applied simultaneously with planting. The rest of the nitrogen fertilizer was applied as Sarak (fertilizer to the soil after planting) at the appropriate time, which is usually between tillering and flowering stages. Field weeds were chemically controlled during the growing season based on the recommendations of plant protection colleagues. Irrigation was done according to the conventional method of the region, and after the physiological maturity of the cultivars, harvesting was done in each plot from the four middle lines and after removing half a meter from both sides of each line.

Necessary notes such as planting date, frost damage, plant height, cluster length, dormancy percentage, and yield were taken. Plant height at the time of physiological maturation of genotypes (fading of green from glume and glume) was obtained by measuring the height of 10 randomly selected stems from the soil surface to the end of the spike. Finally, simple and compound analyses of variance and mean comparison are performed by the Duncan method, and the best cultivars will be introduced for research-extension projects or recommendations to farmers and the province's agricultural management.

3. Results and discussion

3.1. Results of combined analysis of variance

The results of the combined analysis of variance are shown in Table 2, and the mean comparison of the studied traits during the two years of the experiment is given in Table 3. The results of the combined analysis of variance showed that the year effect was significant for 1000-seed weight, plant height, and spike length at a 5% probability level. Also, there is a significant difference among cultivars in terms of grain yield, 1000-seed weight, plant height, and spike length at the 1% probability level, which indicates a genetic difference among cultivars. Among different treatments, the Sarang cultivar with a yield equal to 7191.33 kg/ha had the highest, and the Chamran cultivar with a yield equal to 6376.50 kg/ha had the lowest grain yield. Also, the Sarang cultivar with a weight of one thousand seeds had the highest weight of equal to 46.6 g, and the Shush cultivar with an average 1000 seed weight had a minimum weight of 35.1 g. The Chamran cultivar with 104.16 cm had the highest plant height, and the Chamran 2 and Aflak cultivars with 94.33 and 94.16 cm had the lowest plant height. Also, Sirvan, Mehregan, and Tirgan cultivars had the highest spike length, and the Chamran 2 cultivar had the lowest spike length among the tested cultivars (Table 3). Varga et al. (2001) also showed that there is a significant difference between different wheat cultivars in terms of grain yield.

Table 2. Combined analysis of variance results of studied traits

		Sum of squares			
S.O.V	**df**	**Grain yield**	**1000 seed weight**	**Plant height**	**Spike length**
Year	1	5.24	4.60 *	8.64 *	35.83 *
Error 1	4	1.76	1.37	0.58	2.10
Cultivar	11	37.17 **	27.07 **	32.52 **	16.38 **
Year×Cultivar	11	1.30	0.83	1.18	2.29 *
Error 2	44	1106.40	2.48	2.02	0.33
CV%	-	16.13	10.06	12.13	9.24

* and ** are significant at P=0.05 and P=0.01, respectively

Table 3. Comparison of two-year mean of studied traits for different cultivars

Cultivar	**Cultivar Number**	**Grain yield (Kg/ha)**	**1000 seed weight (g)**	**Plant height (cm)**	**Spike length (cm)**
Sivand	1	6499.83 f	38.8 de	97.66 c	9.25 bc
Sirvan	2	6955.67 cde	37.1 e	97.33 c	10.06 a
Tirgan	3	7064.67 bc	43.4 b	100.50 b	10 a
Aflak	4	6552.83 f	38.6 de	94.16 d	8.44 d
Khalil	5	7094.33 ab	40.5 cd	98.25 c	9.66 ab
Talaeei	6	6902 de	40.8 c	97.50 c	8.66 dc
Parsi	7	6842.17 e	41 c	98.66 c	8.25 d
Mehregan	8	6996 bcd	44.5 b	97.50 c	10.16 a
Shush	9	7107.33 ab	35.1 f	90.83 e	9.65 b
Chamran2	10	6870.67 e	43.8 b	94.33 d	7.46 f
Chamran	11	6359.83 g	43.5 b	104.16 a	8.36 de
Sarang	12	7191.33 a	46.6 a	97.50 c	7.93 f

Means in each column, followed by similar letter(s), are not significantly different at 5% probability level using LSD Test

The year-genotype interaction effect is given in Table 4 the year-genotype interaction effect was not significant for the measured traits. Although the Sarang cultivar in the second year with a yield equal to 7265.66 kg/ha had the highest yield, the Chamran cultivar in the second year with a yield equal to 6470 kg/ha had the lowest grain yield (Table 4). In terms of 1000-seed weight, the Sarang cultivar in the second year and the Shush cultivar in the first year, with 47 g and 36 g, respectively, had the highest and lowest 1000-seed weight. The highest and lowest plant heights were Chamran cultivars in the second year and Shush in the first year, with 104.66 cm and 90.66 cm, respectively. Mehregan and Tirgan cultivars with 10.83 cm in the second year had the highest spike height, and Chamran 2 cultivars with 7.43 cm had the lowest spike height in the second year (Table 4).

3.2. Correlation coefficients of the studied traits

The correlation coefficients for the traits examined are shown in Table 5. As can be seen, the weight of 1000 seeds has no discernible relationship with the spike's length. These findings corroborate the research of Plott et al. (2004). Additionally, there is a positive and statistically significant correlation between grain yield and 1000-grain weight at a 5% probability level (Table 5). In another study, the relationship between traits affecting wheat grain yield was investigated using Zarrin, Alvand cultivars, and promising lines on planting dates of 20 October, 10 November, and 30 November. The results indicated that grain yield with day to spike, day to maturity, plant height, number of spikes per square meter, and 1000-seed weight had a positive and significant correlation in both conditions of no stress and moisture stress. Using the aforementioned traits, path analysis revealed that the number of spikes per square meter and the day to maturity had the greatest direct and indirect effects on grain yield in both conditions (Mohammadi, 2014). On the other hand, there is a slight negative correlation between the weight of 1000 seeds and the length of the plant, as well as between the weight of 1000 seeds and the length of the spike. This correlation, however, is not statistically significant.

Table 4. Mean Comparison of studied traits under the influence of year interaction in cultivar

Year×Cultivar	Grain yield (ton/ha)	1000 seed weight (g)	Plant height (cm)	Spike length (cm)
Y1× V1	6444	38	97.66	8.33
Y1× V2	6913.33	36.66	97.66	9.66
Y1× V3	7006	43.06	100.33	9.16
Y1×V4	6403	38.33	92.33	8.06
Y1× V5	7110	40	97.50	9
Y1×V6	6864	40.33	97	8
Y1× V7	6813	41	97.66	8.33
Y1× V8	6977.33	42.93	96.33	9.50
Y1×V9	7098.33	36	90.66	9.50
Y1× V10	6916.66	44	94.66	7.50
Y1×V11	6283	42.66	103.66	8.40
Y1×V12	7117	46.33	97	8.63
Y2× V1	6555.66	39.66	97.66	10.16
Y2× V2	6998	37.66	97	10.66
Y2× V3	7123.33	43.83	100.66	10.83
Y2×V4	6702.66	39	96	8.80
Y2× V5	7078.66	41	99	10.33
Y2×V6	6940	41.33	98	9.33
Y2× V7	6871.33	41	99.66	8.16
Y2× V8	7014.66	46.06	98.66	10.83
Y2×V9	7116.33	34.33	91	9.80
Y2× V10	6824.66	43.66	94	7.43
Y2×V11	6470	44.33	104.66	8.33
Y2×V12	7265.66	47	98	8.73

Y1: First year, Y2: Second year, V1: Sivand, V2: Sirvan, V3: Tirgan, V4: Aflak, V5: Khalil, V6: Talaeei, V7: Parsi, V8: Mehregan, V9: Shush, V10: Chamran2, V11: Chamran, V12: Sarang

Table 5- Correlation coefficients between grain yield and some agronomic characteristics

Agronomic traits	Grain yield	1000 Grain weight	Plant height
1000 Grain weight	0.218*		
Plant height	-0.339	-0.301	
Spike length	0.011	-0.236	-0.209

* and ** are significant at P=0.05 and P=0.01, respectively

4. Conclusion

Chamran, Chamran 2, and Sirvan cultivars are the dominant cultivars of bread wheat in warm regions of Kerman province. Due to the obsolescence and lack of purity of common cultivars, farmers are not satisfied with the performance of these cultivars. Therefore, according to the results of this study, it is recommended that due to the stability of grain yield in Sarang, Shush, Khalil, and Tirgan cultivars in warm regions of Kerman province, and according to the existing facilities for seed production, Sarang, Shush, Khalil, and Tirgan should replace the old and conventional cultivars, respectively.

References

Anonymous., 2018. Statistics. Available at Web site http://amar,mja.ira. Accessed February, 2019.

Austin, R.B., 1982. Crop characteristics and the potential yield of wheat. The Journal of Agricultural Science, 98(2), 447-453.

Baker, R.J., 2020. Use of selection indices and related techniques for evaluating parental material. In Selection Indices in Plant Breeding (pp. 75-82). CRC Press.

Chen, S., Ravallion, M., 2007. Absolute poverty measures for developing world. 1984-2004. PNAS, 104(43): 1657 -1662.

Esmaeilzadeh Moghaddam, M., Jalal Kamali, M. R., Saidi, A., Sofi, A., Akbari Moghaddam, H., Abedini Esfahlani, M., Bahari, M., Nikzad, A.R., Radmehr, M., Tabib Ghaffari, S.M., 2011. Aflak, A New Bread Wheat Cultivar, Resistant to Yellow and Leaf Rusts and Terminal Heat Stress for Cultivation under irrigated conditions in southern warm and dry areas of Iran. Seed and Plant Journal. 27(2). 275-281.

Esmaeilzadeh Moghaddam, M., 2013. Report on the introduction of the new bread wheat cultivar (S-83-3) for warm southern regions. Institute for Seed and Plant Improvement. Karaj Annual reports of the department of grain research for 2013-2014.

Esmaeilzadeh Moghaddam, M., Khodarahmi, M., Shahbaz Pour Shahbazi, A., Akbari Moghaddam, H., Sayahfar, M., Tahmasebi, S., Afshari, F., Dalvand, M., Tabatabaei, N.A., Roohparvar, R., Kia, S., 2017. Mehreghan, A New Bread Wheat Cultivar, Resistant to Yellow, leaf and stem rust and high bread making quality for cultivation in agricultural systems in Southern Warm and Dry Zone of Iran. Research Achievements for Field and Horticulture Crops Journal, 6(1), 71-77.

Fabriani, G., Lintas, C., 1988. Durum chemistry and technology. American. Association of cereal chemistry. Minessota. U.A.A.

Knott, D.R., 1987. The application of breeding procedures to wheat. Wheat and Wheat Improvement, 13, 419-427.

Mehmet, A., Tetal, Y., 2006. Path coefficient analysis of yield and yield components in bread wheat (Triticumaestivum L.) genotypes. Pakistan Journal of Botany, 38(2), 417-424.

Osman, A.M., Mahmoud, Z.M., 1981. Yield and yield components of wheat (Triticum aestivum L.) and their interrelationships as influenced by nitrogen and seed rate in the Sudan. The Journal of Agricultural Science, 97(3), 611-618.

Mohammadi, M., 2014. Evolution of grain yield and its components relationships in bread wheat genotypes under full irrigation and terminal water stress conditions using multivariate statistical analysis. Iranian Journal of Field Crops Research, 12(1), 99-109.

Mousavi, S.F., Siahpoosh, M.R., Sorkhe, K., 2016. Variation in phenological traits of 10 cultivars of bread wheat in Ahwaz. The Second International Congress and the Fourteenth National Congress of Agricultural Sciences and Plant Breeding of Iran. Aug. 30-Sep. 1, 2016. University of Gilan, Rasht, Iran.

Najafian, G., Amin, H., Afshari, F., Pazhomand, M.E., Dadaeen, M., Zakeri, M., Yasaie, A., Rajaie, S., Nikzad, A.R., Nikooseresht, R., 2010. Parsi, A new bread wheat cultivar, resistant to stem rust (Race Ug99) with good bread making quality for cultivation under irrigated conditions of temperate regions of Iran. Seed and Plant Journal, 26(2), 289-292.

Najafian, G., Nikooseresht, R., Khodarahmi, M., Kafashi, A.K., Amini, A., Afshari, F., Malihipour, A., Sadeghi, N., 2012. Sirvan, new bread wheat cultivar, tolerant to terminal drought with good bread making quality adapted to irrigate conditions of temperate regions of Iran. Research Achievements for Field and Horticulture Crops Journal, 1(1), 1-10.

Plaut, Z., Butow, B.J., Blumenthal, C.S., Wrigley, C.W., 2004. Transport of dry matter into developing wheat kernels and its contribution to grain yield under post-anthesis water deficit and elevated temperature. Field Crops Research, 86, 185-198.

Srivastava, J.P., 1984. Durum wheat, its word status and potential in the Middle East and North Africa. Rachis, 3, 1-8.

Stoskopf, N. C., Tomes, D. T., Christie, B. R., 1993. Plant breeding theory and practice Westview Press. Inc. Colorado.

Varga, B., Svecngak, I., Pospisil, I., 2001. Winter wheat cultivars performance as affected by production systems in Croatia. Agronomy journal, 93(5), 961-966.

Yazdansepas, A., 1997. Studies of the stability, heritability, components and subcomponents of harvest index in wheat. Ph.D. thesis, University of Guelph, Canada.

Yousefi Moghadam, R., Khoramdel, S., Banayanaval, M., Nasirimahallati, M., 2018. Comparison of old and new dryland wheat cultivars in response to different planting dates. Applied Agricultural Research, 31 (2), 46-72.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 77-84

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Providing a model for predicting and status of aquifer depth changes through tree and clustering algorithms

Seyed Hassan Mirhashemi [*a], Mehdi Panahi [b]

[a] M.Sc Graduate of Water Engineering, Faculty of agriculture, University of Zanjan, Zanjan, Iran
[b] Department of Water Engineering, Faculty of Agriculture, University of Zanjan, Zanjan, Iran

ARTICLE INFO

Article history:
Received: 25 March 2022
Accepted: 27 April 2022
Available online: 5 May 2022

Keywords:
Accuracy
Human and natural factors
Irrigation network
Temperature

ABSTRACT

The need for a model for effective planning and management of water resources, particularly groundwater, is especially critical in light of water scarcity and aquifers. Given the importance of various factors in determining the amount of drop, this study used human and natural factors to predict the amount of aquifer drop in Qazvin. To accomplish this, the K-Means clustering algorithm was used first, followed by the tree algorithms CART, CHAID, C5.0, and QUEST to determine the optimal ratio between different fields. Accuracy values of 0.90, 0.96, 0.94, and 0.92 were obtained for the aforementioned tree algorithms. The values obtained for the CHAID algorithm's sensitivity, transparency, accuracy, precision, false-positive rate, false-negative rate, F-measure, geometric mean, and error rate demonstrate that this algorithm outperforms other algorithms. The amount of water in the irrigation network is the most influential human factor in model production, while the amount of temperature is the most influential natural factor. The proposed model enables more accurate prediction of aquifer changes and can be used by managers and farmers to improve aquifer management.

Highlights

- Given water scarcity and aquifers, a model for effective water planning and management is critical.
- Given the importance of various factors in determining aquifer drop, this study used both human and natural factors in Qazvin.
- CHAID algorithm outperforms other algorithms in terms of sensitivity, transparency, accuracy and precision, geometric mean and error rate.
- The irrigation network's water supply is the most important human factor, while temperature is the most important natural factor.

1. Introduction

The development and progress of agriculture, as well as population growth, which led to an increasing need for water resources, created instabilities in traditional water resource management. A major part of the imbalance in water resources is due to the natural limitations of water resources. Managers in this sector are also faced with complex relationships and very diverse characteristics of the vast amount of data collected, which are difficult to analyze and manage by experimental and statistical methods, and in many basins, practically impossible.

In recent years, researchers have conducted various studies related to spatial variation and groundwater level estimation (Jang et al., 2013). The Standardized Precipitation Index (SPI) was used to investigate the effects of drought and rainfall on groundwater levels in three irrigated areas in the Marie-Darlin Basin, Australia. Their results showed a good correlation between the SPI index and groundwater level fluctuations in the region, and it can be used to determine the pattern of major droughts in Australia (Khan et al., 2008).

Prediction results showed that the CART data analysis tree model can provide a correlation between variables and can increase the accuracy of prediction by reducing additional information. By comparing the CART model with the PSO-SVR model, the CART model with better fit and better forecasting ability can be used to predict groundwater level drops (Zhao et al., 2016). The results showed that groundwater managers and decision-makers could support the implementation of programs to protect

* Corresponding author
Email: hassan.mirhashemi@yahoo.com (S.H. Mirhashemi)
http://dx.doi.org/10.22034/aes.2022.335733.1028

groundwater resources by using general and detailed information from the data analysis decision tree (Stumpp et al., 2016). Using data analysis and data of old aquifers in the Toluca valley, it was determined that data analysis of these aquifers is able to produce new knowledge. Using the data analysis algorithm, it is determined that water management underground is affected by social and economic factors such as GDP and population structure (Corona et al., 2016). Data analysis classification methods were used to classify water quality improvement factors. Cluster analysis tends to be categorized based on groundwater quality and pollution characteristics (Oorkavalan et al., 2016).

It was identified areas of high potential groundwater using a CART1 data analysis algorithm method and RF and BRT methods, and in mapping the springs of the Koohrang basin using BRT, CART, and RF models, the accuracy of the models was 0.8103, 0.7870, and 0.7119, respectively. Therefore, the BRT model had the best performance in mapping groundwater resources, followed by the CART and RF models in the second and third ranks. According to the results, the accuracy of all three models is more than 70%. Therefore, all three models can be used by planners and engineers in water and land resource management and planning in the study area (Naqbi et al., 2016). Using data from the Meteorological Station of the Laboratory of Energy and Environmental Physics, the Department of Physics at Patrice University in Greece, data analysis techniques were used to estimate maximum, minimum, and average temperatures. It was concluded that the data analysis regression algorithm makes it possible to predict the maximum, minimum, and average temperatures with satisfactory accuracy. Also, a hybrid data analysis technique was developed for estimating daily values of mean temperature and achieved the same result (Kotsiantis et al., 2008). In India, groundwater resources are declining (Bonsour et al., 2017). Improper use of alluvial aquifers is one of the main causes of subsidence (Novinpour, 2017). Natural factors affect water access (Konapala et al., 2020). Mirhashemi et al., Used data mining methods to predict aquifer depth changes (Mirhashemi et al., 2020).

In the field of water resources management, we are faced with a huge amount of spatial and temporal data such that it is practically impossible to use experimental and statistical methods for converting such data into applied knowledge. Data analysis is a powerful technique for managing and organizing information as well as extracting useful knowledge from a large amount of data. In this paper, it was assumed that this method could be used for better aquifer management. Therefore, due to the need for a strong and appropriate algorithm in this field and the capabilities of data analysis algorithms regarding aquifer management, it is necessary to use this method. Data analysis is the process of recognizing valid, new, inherently useful, and understandable patterns of data, as well as automatically searching large data sources for patterns and dependencies that simple, routine statistical analysis cannot perform.

2. Materials and methods

2.1. Study area

The Qazvin plain, with an area of about 450,000 hectares, is located in the range of longitudes of 49 degrees and 25 minutes to 50 degrees and 35 minutes east and latitudes of 35 degrees and 25 minutes to 36 degrees and 25 minutes north. This plain is composed of a wide alluvial plain composed of sediments from surface currents of the surrounding mountains (Mohammadi et al., 2011). The total aquifer nutrition of the Qazvin plain is 1259.46 million cubic meters. The total discharge factor of the Qazvin plain aquifer is 1458.66 million cubic meters. Accordingly, the share of discharge in the agricultural sector is about 1352.92 million cubic meters, of which about 857.3 million hectares is the share of the agricultural sector. Due to the limited surface water resources and the seasonality of these resources, most of the irrigation water is extracted from groundwater sources. In the current situation, the harvest has caused an annual drop of 1.5 meters in the surface of the aquifers and up to about 25 centimeters per year of subsidence in this area. Considering the importance of the Qazvin plain as a potential agricultural area, on the one hand, and the problem of severe water drop in this area, on the other hand, it seems necessary to pay attention to the sustainability of groundwater resources in the production of agricultural products and the choice of cultivation pattern in this area. (Barikani et al., 2011). The Qazvin province has six counties: Abik, Avaj, Alborz, Buinzahra, Takestan, and Qazvin. Of these six counties, parts of Abik, Alborz, Buinzahra, Takestan, and Qazvin are in the Qazvin plain. Due to the different behavior of the Qazvin plain aquifer in different parts of the plain, in this study, only part of the Qazvin plain aquifer, which is within the agricultural area of Qazvin County, was studied (Figure 1).

Figure 2 shows the location of the irrigation network in the agricultural area of Qazvin County. According to Figure 2, the area outside the irrigation network is about 757.7587 hectares, and the area within the irrigation network is about 19908.908 hectares.

Out of 174 authorized wells used in the agricultural area of Qazvin city, 138 wells are of the agricultural exploitation type, 23 wells are of the integrated exploitation type, and 13 wells are of the multi-purpose exploitation type. Of the 174 wells available, 134 are within the irrigation network. The average depth of wells is 123 meters, the maximum depth of wells is 200 meters, and the average discharge of wells is 36 liters per second, and the maximum discharge of wells is 90 liters per second (Figure 3).

2.2. Models and data used

The method of work in this study was predictive data analysis. Clustering is the non-regulatory process of grouping similar elements into clusters. Classification can be performed based on clustering if category or class information is used to evaluate the obtained clusters. This approach is based on the "cluster to batch" evaluation procedure and finds a mapping with minimal error from clusters to classes (Lopez et al., 2012).

In this research, first, the K-Means clustering algorithm was used to obtain the best ratio between different variables. Then the decision tree algorithms were used to obtain the best ratio between different clusters resulting from the implementation of the K-Means algorithm.

To train a decision tree, a class of variables must have an output field and one or more input variables. Input fields, human and natural variables affecting aquifer depth changes were selected, and the result of clustering with the K-Means algorithm was considered as the output variable and prediction target.

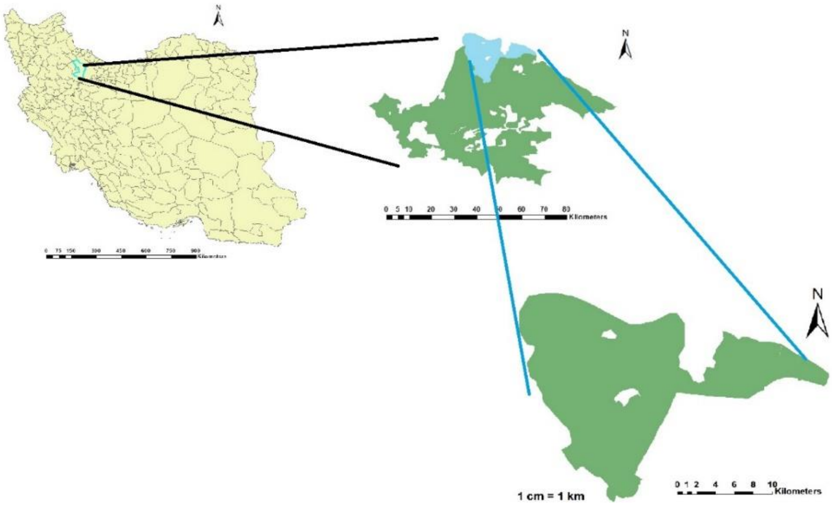


Figure 1. A- Location of Qazvin plain among the plains of Iran B- Location of Qazvin cities in Qazvin plain C- Agricultural area of Qazvin city

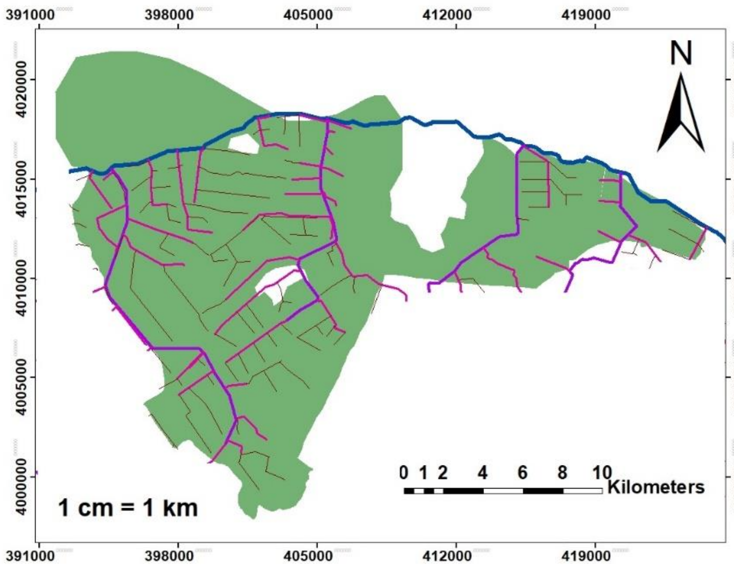


Figure 2. Location of irrigation network in the agricultural area of Qazvin County

In prediction algorithms, the goal is to predict a particular attribute based on another attribute. The predictable property is called a dependent variable, and the rest of the variables are called independent (Tavousi et al., 2015). Decision tree algorithms were used for modeling. In order to validate the models, the data was divided into two parts: training and test data. Models were constructed using training data, and the models were tested on test data. The percentage of samples of test data whose objective feature was correctly identified by the model expresses the accuracy of the model (Gupta, 2011). For all models used, 70% of the data was randomly selected as training data and the remaining 30% was tested as test data. For modeling, CART, CHAID, C5.0, and QUEST tree algorithms were used for modeling. The CHAID and QUEST decision trees solve classification problems, while the CART and C4.5 trees are used to solve both regression and classification problems (Pham, 2006). The C5.0 algorithm is a new version of the C4.5 algorithm that uses less memory than C4.5 when generating a set of rules (Pandya and Pandya, 2015). The experimental option chosen for the tree algorithms was the Cross-Validation decision with ten repetitions (10-Fold Cross Validation) because experiments have shown that the best choice for obtaining the most accurate estimate is section validation of the ten sectors (Ameri et al., 2013). There are various indicators, such as transparency, sensitivity, accuracy, and precision, for evaluating classification methods. It is also possible to calculate the error rate or incorrect classification based on the accuracy index. The criterion of classification error, or error rate, is exactly the opposite of the criterion of accuracy, and its minimum value (zero) is when the best performance is achieved. Also, its highest value (one) is when the lowest efficiency is achieved (Alizadeh et al., 2014; Han and Kamber, 2006). To evaluate the models and select the best model, the indicators of sensitivity or True Positive Rate (TPR), transparency (TNR), accuracy (ACC), positive predictive value or precision (PPV), false-positive rate (FPR), false-negative rate (FNR), F-measure (FM), geometric mean (GM), and error rate (ER) were used. The mentioned indicators are defined in equations (1) to (9), respectively.

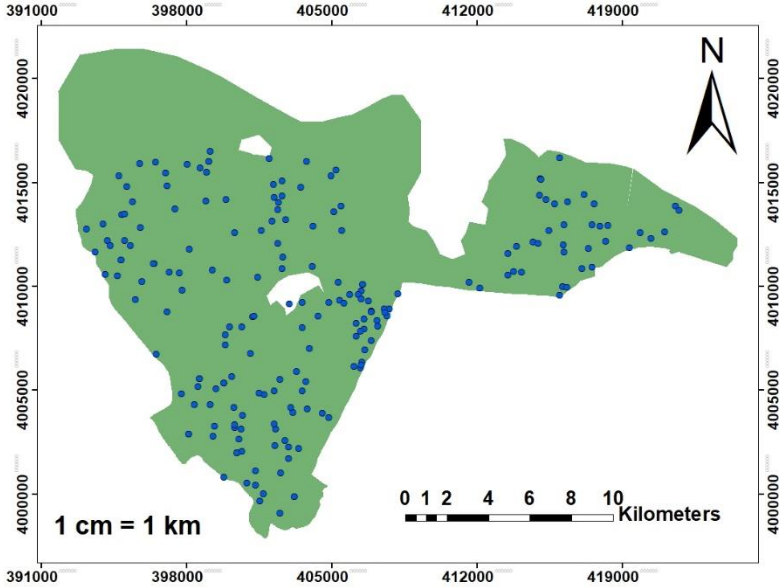


Figure 3 - Location of agricultural wells within the irrigation network of Qazvin County

In real problems, the classification accuracy criterion is by no means a good criterion for evaluating the performance of classification algorithms because, in relation to classification accuracy, the value of records in different categories is considered to be the same. Therefore, other criteria are used when dealing with unbalanced categories or when the value of a category is different from that of another category. In real problems, other criteria such as sensitivity and false positive rate are of particular importance. These criteria, which pay more attention to positive categorization, explain the classifier's ability to recognize a positive category. The sensitivity criterion shows how accurate the positive category is, and the false positive rate criterion expresses the false alarm rate with respect to the negative category (Seliya and Khoshgoftaar, 2011). The desired indices are calculated according to relations (1) to (9) (Han, 2000).

We have

$$TPR = \frac{TP}{TP + FN} \tag{1}$$

$$TNR = \frac{TN}{FP + TN} \tag{2}$$

$$ACC = \frac{TP + TN}{TP + FN + FP + TN} \tag{3}$$

$$PPV = \frac{TP}{TP + FP} \tag{4}$$

$$FPR = \frac{FP}{FP + TN} = 1 - TNR \tag{5}$$

$$FNR = \frac{FN}{TP + FN} = 1 - TPR \tag{6}$$

$$FM = \frac{2 \times TP}{TP + FP + FN} \tag{7}$$

$$\mathrm{GM} = \sqrt{\mathrm{TPR} \times \mathrm{TNR}} \tag{8}$$

$$ER = \frac{FP + FN}{TP + FN + FP + TN} = 1 - Accuracy \tag{9}$$

where TP is the number of positively labeled data correctly classified, FP is the number of negatively labeled data positively classified as positive, FN is the number of positively labeled data classified as incorrectly negative, and TN is the number of negatively labeled data that is properly categorized.

The data set used in this research is information about the plain of Qazvin County during the period of 2001-2005 on a monthly basis. The independent variables used, including human and natural factors, were selected. The amount of water output from agricultural wells (million cubic meters), the volume of irrigation network water (million cubic meters), the amount of agricultural water consumption (million cubic meters) as human factors, and the amount of rainfall (million cubic meters), temperature (Celsius), humidity (percentage) and evapotranspiration (mm / day) as natural factors were selected. Data from the amount of change in aquifer depth (meters) was also introduced to the K-Means algorithm as target data.CART, CHAID, C5.0, and QUEST tree algorithms were selected as the target variables to determine the best ratio between different clusters resulting from the output of the K-Means algorithm.

Qazvin county has 34 piezometers within the Qazvin plain. Considering the distribution of piezometers in different parts of the aquifer, to approximate the amount of utilization and effect of each piezometer from different parameters such as rainfall, water supply, and consumption, the Thyssen method was calculated to determine the range of effect of each piezometer. To achieve this, ArcGIS 10 software was used. In this regard, using GIS software, the first piezometer information layers and borders of Qazvin County in the Qazvin plain were prepared.

Table 1 contains a summary of monthly statistical characteristics related to the aquifer data of the agricultural area of Qazvin County within the irrigation network for a period of 15 years from 2001 to 2015.

Table 1. Statistical specifications related to groundwater depth within the irrigation network of Qazvin County

Scope of Study	Average Total (M)	Average Drop Values (M)	Average Rise Values (M)	Maximum Drop (M)	Maximum Rise (M)
Inside The Network	-0.16	-0.59	0.51	-4.61	3.3
Number	3780	2309	1471	1	1

3. Results and discussion

According to the results, it was found that the highest amount of aquifer loss occurs in the growing season and peak months of agricultural water consumption, with a temperature above 25 degrees and a moisture content of about 40%. The amount of water output from wells is directly related to the amount of drop, and with the monthly volume of more than one million cubic meters of agricultural wells, the probability of an aquifer drop will be higher. The clustering algorithm divided the studied data into 6 clusters.

Table 2. Results of clustering

Variables	First Cluster	Second Cluster	Third Cluster	Fourth Cluster	Fifth Cluster	Sixth Cluster
Volume of well outlet water	0.3±0.1	1.02±0.05	0.02	0.5±1	0.03	0.3±0.61
Evaporation and transpiration	0.62±2.8	0.9±4.9	0.31±1	0.13±5	0.1±1.1	0.1±3.79
Vol. of water in the whole net.	0.1±0.2	0.3±0.61	0.01	0.3±0.4	0.03±0.05	0.3±0.65
Temperature	3.5±17	1±24	2±4	0.6±26	2.5±6	1±18.31
Humidity	6±47	3±41	7±66	3±40	7±63	6±52
Agricultural water volume	0.18±0.32	0.6±1.08	0.03	0.5±1.01	0.03	0.3±0.65
Rainfall volume	0.1±0.3	0.1±0.58	0.2±0.47	0.03±0.06	0.3±0.06	0.3±0.57
Aquifer depth changes	0.01±0.2	0.01±0.1	0.01±0.2	0.2±0.1	0.2±0.5	0.1±0.15
Month						
October	33	25	0	0	0	0
June	0	100	0	0	0	40.3
January	0	0	25.5	0	35.5	0
July	0	0		49.7	0	0
November	35.6	0	0	0	51.6	0
May	0	85.8	0	0	0	100

Quantitative variables as "standard deviation ± mean" and nominal variables as "percentage" are reported

Table 3. Value of indicators for the models produced

	CART	CHAID	C5.0	QUEST
Sensitivity	0.90	0.96	0.93	0.90
Transparency	0.92	0.98	0.95	0.93
False-Positive Rate	0.03	0.02	0.03	0.08
False-Negative Rate	0.08	0.07	0.14	0.17
Precision	0.89	0.98	0.91	0.94
Accuracy	0.90	0.96	0.94	0.92
F-Measure	1.7	1.9	1.8	1.7
Error Rate	0.07	0.05	0.06	0.07
Geometric Mean	0.89	0.95	0.92	0.90

Table 2 shows the frequency of variables in clustering. Each cluster determines the amount of changes in the aquifer drop so that the first cluster (a drop of about 0.2 m), the second cluster (a drop of about 0.1 m), the third cluster (a rise of about 0.2 m), the fourth cluster (a drop of about 0.5 meters), the fifth cluster (a rise of about 0.5 meters), and the sixth cluster (a drop of about 0.15 meters). Also, we calculate the amount of water output from the well, the amount of network water, agricultural water, and rainfall in millions of cubic meters, the temperature in degrees Celsius, humidity in percent, evapotranspiration in millimeters per day, and the amount of aquifer depth changes in meters (the amount of drop with a negative sign).

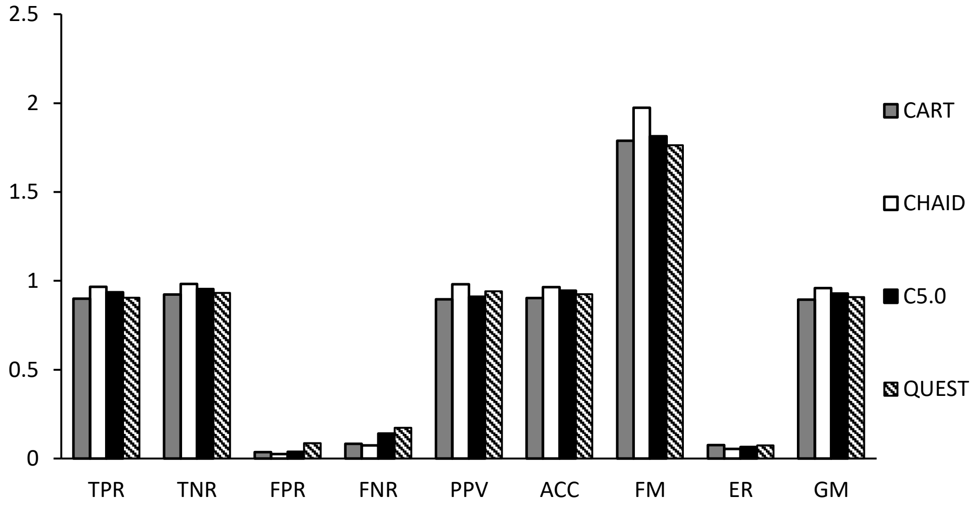


Figure 4. Chart of indicators for generated models

Table 3 shows the values obtained for the sensitivity, transparency, accuracy, precision, false-positive rate, false-negative rate, F-measure, geometric mean, and error rate for the four tree algorithms.

The values of the indicators presented in Table 3 show that the CHAID algorithm has produced the best model. Sensitivity, transparency, accuracy, positive predictive value, F-measure, and geometric mean index are the highest values for this model. The higher the value of these indicators, the more classifications are used in the right place. The false-positive rate, false-negative rate, and error rate have the lowest values for this model. Low values of these indicators confirm the occurrence of fewer errors in the classification of samples. Figure 4 shows a better comparison of the model index. Among the algorithms used, the best results are related to the CHAID algorithm, with an accuracy of 0.98 and a precision of 0.96. Table 4 shows the rules created by the CHAID tree algorithm.

Table 4. Some rules extracted from the CHAID tree algorithm

Number	Rules
1	If in April and October, the percentage of humidity is less than 60%, then, in the label of the "first cluster" category, the drop in the aquifer will be about 0.2 meters.
2	If in September, the total monthly volume of water, in the irrigation network is less than 0.76 million cubic meters, then, in the label of the "first cluster" category, the drop in the aquifer will be about 0.2 meters.
3	If the temperature is more than 14.6 in June, then, in the label of the "second cluster" category, the drop in the aquifer will be about 0.1 meters.
4	If the temperature is less than 14.6 in December, January and February, then, in the label of the "third cluster", the elevation in the aquifer will be about 0.2 meters above.
5	If the amount of evapotranspiration is more than 2 mm per day in July and August, then, in the "Cluster Four" category, the drop in the aquifer will be about 0.5 meters.
6	If in March the total monthly volume of water in the irrigation network is more than 0.07 million cubic meters and the amount of evapotranspiration is more than one millimeter per day, then, in the label of the category "fifth cluster", the rise in the aquifer will be about 0.5 meters.
7	If the amount of evapotranspiration is more than 2 mm per day in May, then, in the label of the "sixth cluster" category, the drop in the aquifer will be about 0.15 meters.

4. Conclusion

According to Rule One in Table 4, the percentage of moisture has the opposite effect on the amount of drop. That is, if the amount of moisture increases, the amount of moisture decreases. In the second rule, it is specified that in September, the amount of water in the network has the opposite effect on the amount of drop and that the more water in the network, the amount of drop decreases. If the temperature in June is higher than 14.6, then in the label of the category "second cluster," a drop in the aquifer is of about 0.1 meters. Also, in December, January, and February, if the temperature is less than 14.6, then, in the "third cluster" category, the elevation in the aquifer will be about 0.2 meters. As it is clear from the third and fourth rules, the amount of temperature is directly related to the amount of drop in the aquifer, and as the temperature increases, the amount of drop decreases more, and as the temperature decreases, the amount of drop decreases. In rules 4 and 5, it was found that the amount of evapotranspiration is directly related to the amount of drop, and the amount of drop decreases and increases with more or less the amount of evaporation and transpiration, respectively. According to rule 6, it is clear that the effect of the monthly volume of the total water in the irrigation network is greater than the effect of evaporation and transpiration on the drop. According to the results, it is clear that the most influential human factor on the amount of changes in aquifer depth is the amount of monthly volume of total water in the irrigation network, and the most natural factor on the amount of changes in aquifer depth is the amount of temperature.

References

Alizadeh, S., Teymourpour, B., Ghazanfari, M., 2014. Data mining and knowledge discovery. Iran University of Science and Technology (In Persian).

Ameri, H., Alizade, S., Barzegari, A., 2013. Knowledge extraction of diabetics' data by decision tree method. Journal of Health Administration, 16(53), 58-72.

Barikani, A., Ahmadian, M., Khalilian, S., 2011. Sustainable optimal utilization of groundwater resources in agriculture: a case study of qazvin plain agriculture. Journal of Economics and Agricultural Development (Agricultural Science and Technology), 25, 262-253 (In Persian).

Bonsor, H.C., MacDonald, A.M., Ahmed, K.M., Burgess, W.G., Basharat, M., Calow, R.C., Dixit, A., Foster, S.S.D., Gopal, K., Lapworth, D.J., Moench, M., 2017. Hydrogeological typologies of the Indo-Gangetic basin alluvial aquifer, South Asia. Hydrogeology Journal, 25(5), 1377-1406.

López-Corona, O., Fuentes, O.E., Morales-Casique, E., Longoria, P.P., Moran, T.G., 2016. Data Mining of Historic Hydrogeological and Socioeconomic Data Bases of the Toluca Valley, Mexico. Journal of Water Resource and Protection, 8(4), p.522.

Gupta, G.K., 2011. Introduction to Data Mining with Case Studies. (2nd ed) Prentice Hall of India

Han, J., Kamber, M., 2006. Data Mining: Concepts and Techniques. 2nd ed.Morgan Kaufman.

Jang, C.S., Chen, S.K., Kuo, Y.M., 2013. Applying indicator-based geostatistical approaches to determine potential zones of groundwater recharge based on borehole data. Catena, 101, 178-187.

Khan, S., Gabriel, H.F., Rana, T., 2008. Standard precipitation index to track drought and assess impact of rainfall on watertables in irrigation areas. Irrigation and Drainage Systems, 22(2), 159-177.

Konapala, G., Mishra, A.K., Wada, Y., Mann, M.E., 2020. Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. Nature Communications, 11(1), 1-10.

Kotsiantis, S., Kostoulas, A., Lykoudis, S., Argiriou, A., Menagias, K., 2008. Using data mining techniques for estimating minimum, maximum and average daily temperature values. International Journal of Mathematical, Physical and Engineering Sciences, 1(1), 16-20.

Lopez, M.I., Luna, J.M., Romero, C., Ventura, S., 2012. Classification via clustering for predicting final marks based on student participation in forums. International Educational Data Mining Society.

Mirhashemi, S.H., Haghighat jou, P., Mirzaei, F., Panahi, M., 2020. The study of environmental and human factors affecting aquifer depth changes using tree algorithm. International Journal of Environmental Science and Technology, 17(3), 1825-1834.

Mohammadi, M., Mohammadi Qalehuni, M., Ebrahimi, K., 2011. Temporal and spatial changes of groundwater quality in Qazvin plain. Iranian Journal of Water Research, 8, 52-41. (In Persian).

Novinpour, E.A., 2017. A study of the relationship between the exploitation and subsidence of Salmas. Urban Management, 15(45), 319-326.

Oorkavalan, G., Chidambaram, S.M., Mariappan, V., Kandaswamy, G., Natarajan, S., 2016. RETRACTED: Cluster analysis to assess groundwater quality in Erode District, Tamil Nadu, India. Circuits and Systems, 7(6), 877-890.

Pandya, R., Pandya, J., 2015. C5. 0 algorithm to improved decision tree with feature selection and reduced error pruning. International Journal of Computer Applications, 117(16), 18-21.

Pham H, editor., 2006. Springer Handbook of Engineering Statistics. Germany: Springer.

Seliya, N., Khoshgoftaar, T.M., 2011. The use of decision trees for cost-sensitive classification: an empirical study in software quality prediction. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 1(5), 448-459.

Sotoudehnia, A., Sotoudehnia, S., 2016. Investigating the role of taleghan reservoir dam construction on sedimentation of Qazvin plain irrigation network, 15th Iran hydraulic conference, Faculty of Engineering, Imam Khomeini International University, Qazvin December 15-17, 2016 (In Persian).

Stumpp, C., Żurek, A.J., Wachniew, P., Gargini, A., Gemitzi, A., Filippini, M., Witczak, S., 2016. A decision tree tool supporting the assessment of groundwater vulnerability. Environmental Earth Sciences, 75(13), 1-7.

Tavousi, A., Sepehri, M.M., Malakoutian, T., Khatibi, T., 2015. Data mining approach in prediction of erythropoietin dosage in hemodialysis patients. Journal of Mazandaran University of Medical Sciences, 25(129), 26-35.

Zhao, Y., Li, Y., Zhang, L., Wang, Q., 2016. Groundwater level prediction of landslide based on classification and regression tree. Geodesy and Geodynamics, 7(5), 348-355.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 85-94

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Analysis of reasonability for producing main crops using TOPSIS (case study: Azna, Lorestan province, Iran)

Zahra Marzban [*a], Shahram Torabian [b], Elham Faryabi [a]

[a] Department of Agriculture, Payame Noor University, Tehran, Iran
[b] Hermiston Agricultural Research and Extension Center, Oregon State University, Hermiston, USA

ARTICLE INFO

Article history:
Received: 26 April 2022
Accepted: 36 May 2022
Available online: 5 June 2022

Keywords:
Economic indicators
Energy efficiency
Global warming potential
Greenhouse gases emission
Input-output energy

ABSTRACT

Non-renewable energy consumption in agriculture increased greenhouse gases (GHGs) emissions and global warming. The present study aimed to look at energy use, GHGs emissions and economic indicators in Azna, a city in Iran's Lorestan Province in 2019. For this purpose, data were collected applying questionnaires via face-to-face interviews. The TOPSIS method was used to find the most energy efficient and environmentally friendly crop. Investigated crops were irrigated and rain-fed wheat and barley, rapeseed, bean, potato, and sugar beet. The results revealed that sugar beet cultivation is not efficient in terms of energy consumption and global warming potential (GWP). The highest share of the total energy input was recorded for diesel fuel, N and P fertilizer with at least 80% for all crops. The maximum GHGs emission and GWP was observed in sugar beet and bean at 0.019 and 0.02, however, the lowest was recorded in rain-fed barely at 0.005. The highest relative proximity to the ideal and the shortest distance from the ideal were observed in rain-fed barley and wheat. In general, wheat and barley, especially when cultivated under rain-fed condition, had the highest cultivation priorities in the region, which can reduce environmental problems.

Highlights

- The TOPSIS method, which is a technique for establishing order priority by similarity to ideal, was used for determination of suitable cultivation pattern.
- Production of sugar beet and potato in the Azna, Lorestan province, Iran is not reasonable because of the high energy input, greenhouse gases emission and global warming potential.
- The highest relative closeness to ideal and the shortest distance from the ideal were rain-fed barley and wheat; however, the farthest distance from ideal was recorded in sugar beet and potato.

1. Introduction

Energy plays a decisive role in the economic growth of countries, and its importance is increasing continuously. Scientific forecasts and energy consumption analysis will be of great importance for the planning of energy strategies and policies (Liang et al., 2007). Agriculture is one of the most important consumers of energy resources. The increase in energy inputs in agriculture has led to numerous environmental problems, such as high consumption of non-renewable energy resources, loss of biodiversity and pollution (Nemecek et al., 2011). Non-renewable energies include diesel fuel, machinery, chemicals, and chemical fertilizers, while renewable energies consist of human labor, seeds, and animal manure (Mohammadi et al., 2008). The additional use of non-renewable energy sources to boost agricultural production in developing countries with low levels of technological knowledge not only results in environmental deterioration but also causes the depletion of energy resources (Fadai., 2007). The analysis of energy in agricultural systems seems to be a hopeful advance when considering energy use efficiency and environmental problems (Giampietro et al., 1992). The increase in the consumption of renewable energy resources and energy use efficiency could be a valuable part of meeting the objectives of sustainable energy consumption (Streimikiene et al., 2007). The patterns of energy use and the amount of energy input depend on agricultural systems, growing seasons, and growing conditions (Hatirli et al., 2006). The efficient use of energy is one of the main requirements of sustainable agriculture, and its improvement will minimize

[*] Corresponding author
Email: marzban_zahra1986@yahoo.com (Z. Marzban)
http://dx.doi.org/10.22034/aes.2022.340379.1035

environmental problems, the destruction of natural resources, and promote sustainable agriculture (Erdal et al., 2007). Energy input-output analysis is generally used to estimate the efficiency and environmental impacts of production systems. The energy consumption of agriculture can be classified into direct and indirect energy use; energy consumed directly as fuel and electricity, and indirectly outside the farm to produce chemical fertilizers, seed, machinery, and chemicals (Uhlin., 1998; Ozkan et al., 2004).

Global warming is one of the most important problems of recent times. Agricultural activities contribute a large percentage of GHGs emission (Guo et al., 2007). Over the past 100 years, the global mean temperature has increased (Pimentel et al., 1996). The use of fossil fuels for crop production emits carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), which have a greenhouse effect and cause global warming. Therefore, improving energy efficiency not only helps improve competitiveness by reducing costs, but also decreases GHGs emission (Alluvione et al., 2011). Proper coordination of issues in agriculture by the administration and the design of an appropriate crop pattern in the regions can be a solution for energy consumption and the reduction of GHGs emission. There are several studies, which focused on GHGs emission, energy and economic indicators for crops in a specific location (Mohammadi et al., 2014; Yousefi et al., 2016; Tzilivakis et al., 2005), but for the first time we evaluated the shortest distance of a crop from the ideal by using TOPSIS methodology. This study aimed to determine the energy efficiency, the GHGs emission, GWP and economic indicators of some important crops in Azna, Lorestan province, Iran, including rain-fed barley and wheat, irrigated barley and wheat, rapeseed, bean, sugar beet, and potato.

2. Materials and methods

2.1. Region and data collection

In this study, rain-fed agroecosystems of wheat and barley and irrigated agroecosystems of wheat, barley, rapeseed, bean, potato, and sugar beet were studied in Azna, Lorestan province, Iran. Azna is located at 33°27' N, 49°27' E and 1870 m above sea level in the west of Iran. The climate of the region is characterized by an annual average rainfall of 300 mm, distributed mainly in winter and spring; an annual average temperature of 12.3 °C, with a monthly maximum of 25 °C in July and a minimum of -0.8 °C in January. The economy of Azna depends on agriculture, and a large part of the city's population is engaged in the agricultural sector. The total farm of Azna is 62,000 ha, of which 29,000 ha is irrigated and another 33,000 ha is rain-fed. The quantity of crops obtained from irrigated and rain-fed farms is 275,000 and 25,000 metric tons, respectively (Marzban et al., 2021).

The study data were gathered using two methods: the first was obtained through interviews and face-to-face conversations with the farmers, and the second was obtained by completing questionnaires between September and August 2015 and 2016. The second set was composed of statistics acquired from the Agricultural Jihad Organization. The farms were randomly selected from the villages in the study area. The size of each sample was determined using the Neyman technique using relation. 1 (Yamane., 1967).

$$n = (\sum N_h S_h)^2 / (N^2 D^2 + \sum N_h S_h^2) \quad (1)$$

where n is the required sample size, N is the number of total holdings in the target population, N_h is the number of the population in the h stratification, S_h is the standard deviation in the h stratification, S_h^2 is the variance in the h stratification, D^2 is equal to d^2/z^2; d is the precision, where ($\bar{x}$-$\bar{X}$) (5%) is the permissible error and z is the reliability coefficient (1.96, which represents 95% reliability). The permissible error in the sample size was defined to be 5% for 95% confidence.

Wheat, barley, potato, sugar beet, and bean were the substantial products grown in the region (Table 1). The growing season for wheat and barley was from mid-September to the end of July, for sugar beet and potato was from the beginning of April to the middle of October and for bean from the beginning of June to the end of May.

Table 1. The area of cultivation for different crop in Azna

Crop	Area under cultivation (ha)	
	Irrigated	Rain-fed
Wheat	13000	15000
Potato	2000	-
Bean	8000	-
Sugar beet	450	-
Barley	1000	2000
Canola	400	-
Others	4150	-

2.2. Energy indicators

Human labor, machinery, diesel fuel, chemical fertilizer, pesticides, herbicides, fungicides, irrigation water, seed as a farm input and economic and biological yields of crops as farm output have been used to estimate the energy efficiency ratio. The energy equivalents for different inputs and outputs are presented in Table 2. The energy input and energy output were calculated by multiplying the input and output quantities by their respective energy equivalents. In this study, total energy input, total energy output, energy use efficiency, energy productivity, net energy and specific energy were calculated using Eqs. 2-5 (Zangeneh et al., 2010; Mandal et al., 2002).

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Plant performance (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad (3)$$

$$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Plant performance (kg ha}^{-1})} \quad (4)$$

$$\text{Net Energy (MJ.ha}^{-1}) = \text{Energy out} - \text{Energy in} \quad (5)$$

2.3. GHGs emission and GWP

The amount of GHGs emission from inputs was estimated using CO_2, N_2O, and CH_4 emission coefficients of the inputs presented in Table 3. We did not estimate N_2O and CH_4 for the chemicals due to the unavailability of emission coefficients (Yousefi et al., 2016). Emissions are measured in terms of a reference gas, CO_2 At a time span of 100 years, the GWP of CO_2, CH_4, and N_2O are 1, 21, and 310, respectively (Demircan et al., 2006).

Table 2. Energy equivalent of inputs and output in agricultural production

Particulars	Unit	Energy equivalent (MJ Unit^{-1})	Sources
Inputs			
Human labor	h	1.96	(Mohammadi et al., 2008; Mohammadi et al., 2014; Yousefi et al., 2016)
Machinery	h	62.7	(Samavatean et al., 2011; Yousefi et al., 2016)
Diesel fuel	L	56.31	(Samavatean et al., 2011; Yousefi et al., 2016)
Chemical fertilizer			
Nitrogen (N)	kg	64.4	(Esengun et al., 2007; Mohammadi et al., 2008; Mohammadi et al., 2014)
Phosphate (P_2O_5)	kg	12.44	(Erdal et al., 2007; Yousefi et al., 2016)
Potassium (K_2O)	kg	11.15	(Erdal et al., 2007; Yousefi et al., 2016)
Micro-Fertilizers	kg	120	(Asgharipour et al., 2012; Banaeian et al., 2011)
Chemicals			
Herbicide	kg	238	(Rathke and Diepenbrock, 2006; Asgharipour et al., 2012)
Fungicide	kg	216	(Rathke and Diepenbrock, 2006; Asgharipour et al., 2012)
Pesticide	kg	101.2	(Rathke and Diepenbrock, 2006; Asgharipour et al., 2012)
Water for irrigation	M^3	1.02	(Mohammadi et al., 2008; Samavatean et al., 2011; Mohammadi et al., 2014; Yousefi et al., 2016)
Seeds			
Wheat	kg	20.1	(Ghorbani et al., 2011)
Barley	kg	14.7	(Mobtaker et al., 2010)
Bean	kg	25	(Mohammadi et al., 2014)
Sugar beet	kg	50	(Erdal et al., 2007; Asgharipour et al., 2012)
Potato	kg	3.6	(Mohammadi et al., 2008; Zangeneh et al., 2010)
Output (Seed)			
Wheat	kg	14.48	(Ghorbani et al., 2011)
Barley	kg	14.7	(Mobtaker et al., 2010)
Bean	kg	14.7	(Ozkan et al., 2004)
Sugar beet	kg	16.8	(Erdal et al., 2007; Asgharipour et al., 2012)
Potato	kg	3.6	(Ozkan et al., 2004; Mohammadi et al., 2008; Mohammadi et al., 2014)
Straw			
Wheat	kg	9.25	(Ghorbani et al., 2011)
Barley	kg	11.7	(Mobtaker et al., 2010)
Bean	kg	12.5	(Ozkan et al., 2004)

Table 3. Greenhouse gas (GHG) emission per unit of chemical sources and their global warming potential (GWP) in crops production (ha)

Inputs	Unit	CO_2	N_2O	CH_4	Sources
Diesel fuel	L	3560	0.70	5.20	(Kramer et al., 1999; Yousefi et al., 2016)
Chemicals					
Nitrogen (N)	kg	3100	0.03	3.70	(Mohammadi et al., 2014; Yousefi et al., 2016)
Phosphate (P_2O_5)	kg	1000	1.25	1.80	(Mohammadi et al., 2014; Yousefi et al., 2016)
Potassium (K_2O)	kg	700	0.01	1.00	(Mohammadi et al., 2014; Yousefi et al., 2016)
Herbicide	kg	6300	-	-	(Mohammadi et al., 2014; Yousefi et al., 2016)
Fungicide	kg	5100	-	-	(Mohammadi et al., 2014; Yousefi et al., 2016)
Insecticide	kg	3900	-	-	(Mohammadi et al., 2014; Yousefi et al., 2016)
GWP CO_2 equvalent factor		1	310	21	(Tzilivakis et al., 2005; Yousefi et al., 2016)

2.4. Economic indicators

The economic output of crops was calculated according to market prices. The basic unit for cost analysis was one hectare of experimental field. The investigated economic indicators are gross value of production, net return, and benefit to cost ratio. Economic indicators were calculated using Eqs. 6–8 (Simanaviciene et al., 2010).

$$\text{Gross prod. Value} = \text{Yield (kg.ha}^{-1}) \times \text{Price (\$.kg}^{-1}) \quad (6)$$

$$\text{Net return} = \text{Gross value of production (\$ ha}^{-1}) - \text{Total cost of production (\$ ha}^{-1}) \quad (7)$$

$$\text{Benefit to cost ratio} = \frac{\text{Gross value of production (\$ ha}^{-1})}{\text{Total cost of production (\$ ha}^{-1})} \quad (8)$$

2.5. TOPSIS evaluation method

Decision-making is the study of identifying and selecting alternatives based on the values and preferences of the decision maker. The reason for the problem is the high ability and capability for modeling real-world issues, as well as the simplicity and understandability for the majority of users. Some of these methods can be pointed to order preference by similarity to the ideal solution (Ansarifar et al., 2015). TOPSIS is a strong technique to prioritize options because of their similarities to the ideal solution. In this method, the selected option must have the shortest distance from the ideal response and the farthest distance from the most inefficient response (Dymova et al., 2013). One advantage of this method is that the scales and the indices applied for comparison are expressed in different assessment units and are therefore positive and negative in their nature. In other words, the positive and negative indices can be used in combination with this technique (Mohammadi et al., 2010);

Stage 1: Forming the raw data matrix according to Eq. (9).

$$X = \begin{bmatrix} X_{11} & X_{12} & X_{1n} \\ . & . & . \\ X_{m1} & X_{m2} & X_{mn} \end{bmatrix} \quad (9)$$

Stage 2: Forming a normalized matrix according to relation (10):

$$Vij = \frac{Xij}{\left[\sum_{i=1}^{m} Xij^2\right]^{1/2}} \quad (10)$$

i=(1, 2, …, n)

vij: normalized matrix

Stage 3: forming a weighted matrix: decision matrix is, in fact, parametric and it has to be parametrized. To do so, the decision maker specifies a weight for every index, according to relation (11):

$$V = N_D \times W_{n\times n} \quad (11)$$

A diagonal Matrix is obtained from the weights acquired for each of the indices. Based on the above relation, *W* is the balanced scaleless matrix and *V* is the balanced matrix. One of the important issues in decision-making is assigning a weight value to each of the scales that are carried out in various and different ways. The weight of each of the scales indicates how important each of the scales is and to what extent it influences the decision-making.

In the present study, Shanon's entropy technique can be used for weighting the indices. Basically, the method considers the idea that the more scattering in the amounts on every scale, the more important the scale.

Stage 4: calculating the positive ideal solution and negative ideal solution according to the below relations (12) and (13):

A^+ and A^- are indicative of the option with the highest priority (positive ideal response) and the option with the least priority (the worst response), respectively:

$$A^+ = \{(max, v_{ij} \mid j \in j_1), (Min, v_{ij} \mid j \in j_2)/i = 1,2, \dots n\} \quad (12)$$

$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$

i=(1, 2, …, n)

$$A^- = \{(min, v_{ij} \mid j \in j_1), (max, v_{ij} \mid j \in j_2)/i = 1,2, \dots m\} \quad (13)$$

$A^- = \{v_1^-, v_2^-, \dots, v_m^-\}$

i=(1, 2, …, m)

Stage 5: Computing the distance size (d) to the next option n by the use of the Euclidean method. For every negative ideal solution and positive option, and similarly, for every positive ideal solution and negative option, corresponding to relations (14) and (15),

$$d_j^+ = \left\{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2\right\}^{1/2} \quad (14)$$

i=(1, 2, …, n)

Stage 6: calculating the relative closeness of *Ai* to the positive ideal solution based on relation (15):

$$Ci = \frac{d_i^-}{(d_i^- + d_i^+)} \qquad 0 < Ci < 1 \quad (15)$$

Ci = relative closeness to the ideal solution

It is evident that the shorter the option *Ai*'s distance to the ideal solution, the closer the relative closeness to unity.

Stage 7: Options Ranking:

Finally, the options are ranked in descending order. Every *Ai* option found closer to the ideal solution will have a *Ci* value closer to unity. Based on the descending order of the *Ci*, the existing options can be ranked based on their highest importance (Dymova et al., 2013). Finally, mathematical algorithms of the analysis of reasonability for producing main cropsusing, were used in the BT TopSis Solver software.

3. Results and discussion

3.1. Energy indicators

In the current cropping pattern of Azna, the total energy input in irrigated farms is 67% higher than on rainfed farms (Table 4). The lowest energy input was observed in rain-fed agroecosystems of barley and wheat. Energy input for potato and sugar beet agroecosystems was 5.8 and 4.5 times more than rain-fed barley (Table 4). The increase in the consumption of chemicals and machinery and the consequent increase in the use of non-renewable energies decrease the agro-ecosystem's sustainability. As a result, the lowest total energy input (direct and indirect energies, renewable and non-renewable energies) was observed in rain-fed barley and wheat (Table 4). In all agroecosystems, indirect energy was greater than direct energy. Researchers have indicated that the proportion of indirect energy is greater than that of direct energy in different agroecosystems (Rafiee et al., 2010; Kazemi et al., 2015). Interestingly, non-renewable energy in bean, barley, and wheat (rain-fed and irrigated) was more than renewable energy. however, an inverse trend was observed in sugar beet and potato (Table 4). The total energy output was 0.17, 0.039, 0.036, 0.026, 0.022, 0.018, 0.014, and 0.011 for sugar beet, irrigated wheat, potato, irrigated barley, bean, rapeseed, rain-fed barley, and rain-fed wheat, respectively (Table 4). Rain-fed practice can significantly reduce chemical fertilizers and energy output.

Table 4. Energy indicators and different form of energy in crops production using TOPSIS method

Crop	Energy input	Energy output	Direct energy	Indirect energy	Renewable energy	Non-renewable energy
Sugar beet	0.032	0.17	0.074	0.011	0.018	0.026
Potato	0.041	0.036	0.074	0.009	0.017	0.024
Bean	0.019	0.022	0.035	0.008	0.03	0.014
Irrigated barley	0.013	0.026	0.019	0.008	0.03	0.011
Irrigated wheat	0.021	0.039	0.024	0.012	0.054	0.015
Canola	0.012	0.018	0.006	0.008	0.002	0.01
Rain-fed barley	0.007	0.014	0.014	0.003	0.015	0.006
Rain-fed wheat	0.008	0.011	0.01	0.006	0.02	0.007

Table 4 continued.

Crop	Energy use efficiency	Energy productivity	Specific energy	Net energy
Sugar beet	0.051	0.073	0.004	0.261
Potato	0.009	0.057	0.006	0.023
Bean	0.011	0.009	0.034	0.018
Irrigated barley	0.019	0.017	0.018	0.031
Irrigated wheat	0.018	0.018	0.018	0.046
Canola	0.015	0.014	0.022	0.019
Rain-fed barley	0.019	0.019	0.017	0.016
Rain-fed wheat	0.013	0.016	0.02	0.011

The data provided in Table 4 demonstrated that the amount of input energy for sugar beet is higher than that of other crops in the region. Erdal et al (2006) reported that energy efficiency, energy productivity, and net energy in sugar beet were higher than the other products. Among other crops, sugar beet and potato had the highest and lowest energy use efficiency, respectively (Table 4). Energy use efficiency increases in two ways: one by an increase in crop yield and two by a reduction in the consumption of energy inputs (Pahlavan et al., 2012).

The efficient use of energy resources is essential to increasing the production, productivity, and competitiveness of agriculture and the sustainability (Hatirli et al., 2006) of rural production systems. Pahlavan et al. (2014) reported that sustainable agricultural production is closely related to the efficiency of energy use due to financial savings, the protection of fossil resources, and the reduction of air pollution. The highest energy productivity and net energy belonged to sugar beet at 0.073 and 0.261, respectively. However, the lowest amounts of energy productivity and net energy were recorded in bean and rain-fed wheat, respectively. For crops such as cereals whose economic yield is a proportion of biological yield, energy productivity is low, but this indicator seems to be higher in root crops and forage crops due to the greater denominator (Hulsbergen et al., 2001).

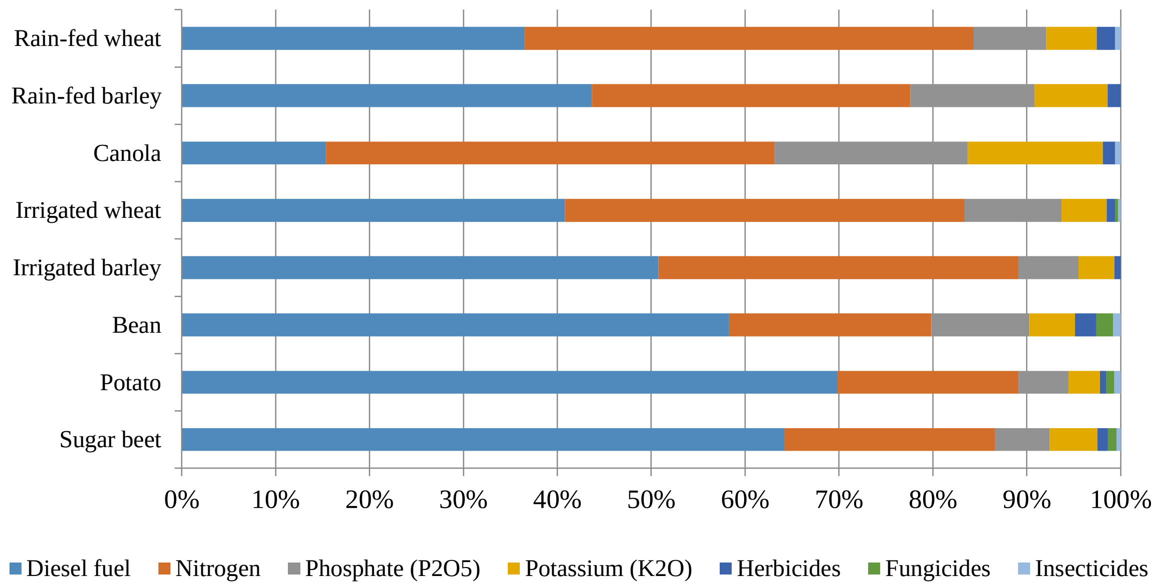


Figure 1. The share of different inputs of total energy in crops

In the case of specific energy, the highest and lowest values were recorded in bean (0.034) and sugar beet (0.004), respectively. Specific energy (energy intensity) is a measure of the environmental effects associated with crop production. From an ecological point of view, this parameter can be used to determine the best intensity of land and crop management from an ecological point of view (Alimagham et al., 2017).

Figure 1 shows the percentage distribution of energy associated with the inputs. The highest share of total input energy was recorded for diesel fuel, N and P fertilizers, with at least 80% for all crops. The maximum and minimum share of diesel fuel consumption was observed in potato and rapeseed with 70 and 16%, respectively. Recently, the mechanized agricultural system in Iran caused an increase in fuel consumption by 10% (Beheshti et al., 2010; Ozkan et al., 2004). In a study in Turkey, the cultivation of tomato, pepper, cucumber and eggplant made with fuel and fertilizers (mainly N) accounted for most of the total energy contribution (Börjesson et al., 2011). Börjesson and Tufvesson (Yuan et al., 2016) concluded that fertilizers and diesel fuel were the main energy inputs in the production of wheat, sugar beet, rapeseed, ley crops, maize, and willow. In all crops, the share of herbicides, fungicides, and pesticides was not more than 5% (Figure 1). In summary, the results of the classification based on the TOPSIS methodlogy in terms of energy indicators showed that the cultivation patterns of rapeseed, rain-fed barley, and wheat were ranked with higher priority compared to sugar beet and potato (Figure 2). Therefore, it seems that the current cultivation method used in Azna is not optimal. However, wheat, bean, and potato are cultivated in the largest farm area in the county. Given a higher growth rate and the production of high-value and low-energy crops versus low-value and high-energy crops, the economic performance of energy use increased while energy use efficiency decreased (Lal., 2004).

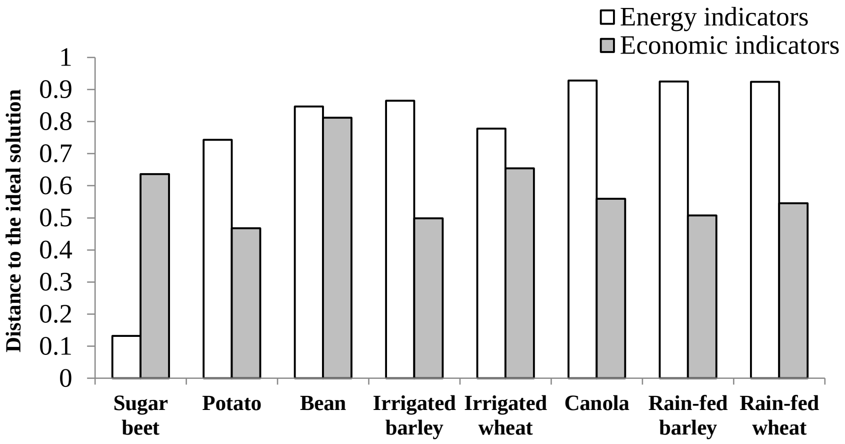


Figure 2. Ranking the options based on closeness to the ideal option in terms of energy and economic indicators

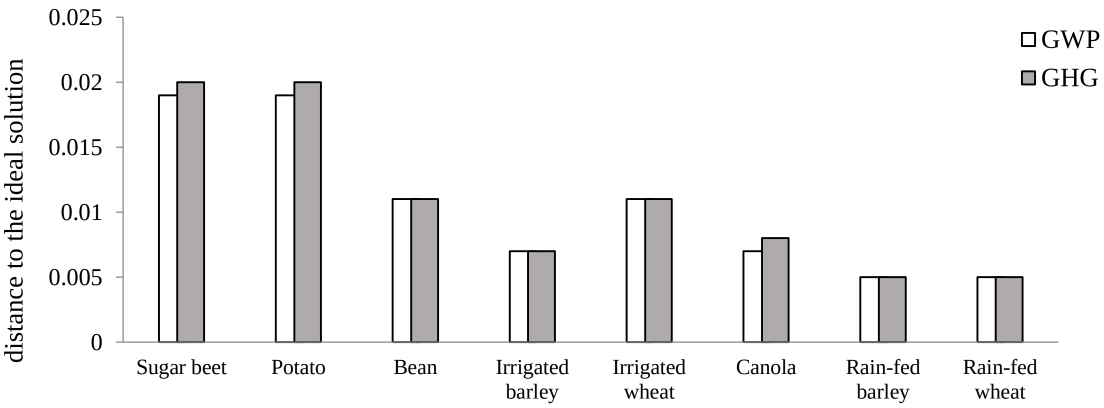


Figure 3. GWP (global warming potential) and greenhouse gas (GHG) emissions for crops using TOPSIS method

3.2. GWP and GHGs emission

According to Figure 3, the highest GWP was 0.019 for sugar beet and potato, while the lowest was 0.005 for rain-fed wheat and barley. Increased herbicide use for weed control has the potential to increase global warming (Khakbazan et al., 2009). According to Figure 3, GHGs emission for sugar beet, potato, bean, irrigated wheat, rapeseed, irrigated barley, rain-fed wheat, and barley were 0.02, 0.02, 0.011, 0.011, 0.008, 0.007, 0.005 and 0.005, respectively. Khan et al (2009) found that GHGs emission from wheat production are due to the fertilization rate, location, and planting system. The extreme application of the energy contribution of chemical fertilizers in agriculture can have drastic environmental effects (Lin et al., 2017). Fertilizer and diesel fuel consumption were the main sources of GHGs emission (Lu et al., 2017), with N fertilizer being the most important factor in terms of energy use and GHGs emission (Ghorbani et al., 2011). In addition, it should be mentioned that energy consumption in agriculture causes an increase in GHGs emission worldwide. So, determining a sustainable cultivation pattern is one of the most effective strategies to reduce climate change. The results indicated that the GHGs emission in the irrigated system is three times greater than that in the rain-fed system. Therefore, the use of the rain-fed system can play an effective role in reducing GHGs emission, which was also observed in the TOPSIS methodology. As a result, a larger area of land should be allocated to the cultivation of rain-fed barley and wheat, irrigated barley and rapeseed (Figure 3).

3.3. Economic indicators

The cost of production is a key factor in the cropping pattern. In the current study, the production costs of potato, sugar beet, bean, irrigated wheat, rapeseed, irrigated barley, rainfed wheat, and barley agroecosystems were 2293, 997, 562, 397, 392, 371, 239, and 235 \$ ha^{-1} (data not shown), respectively. According to the TOPSIS methodlogy, the highest and lowest total production costs were for potato and rainfed barley, at 0.283 and 0.028, respectively (Figure 4). The total cost of production in rainfed farms was lower than in irrigated systems, and the difference is due to the lower consumption of chemicals, chemical fertilizers, and machinery in rainfed farms.

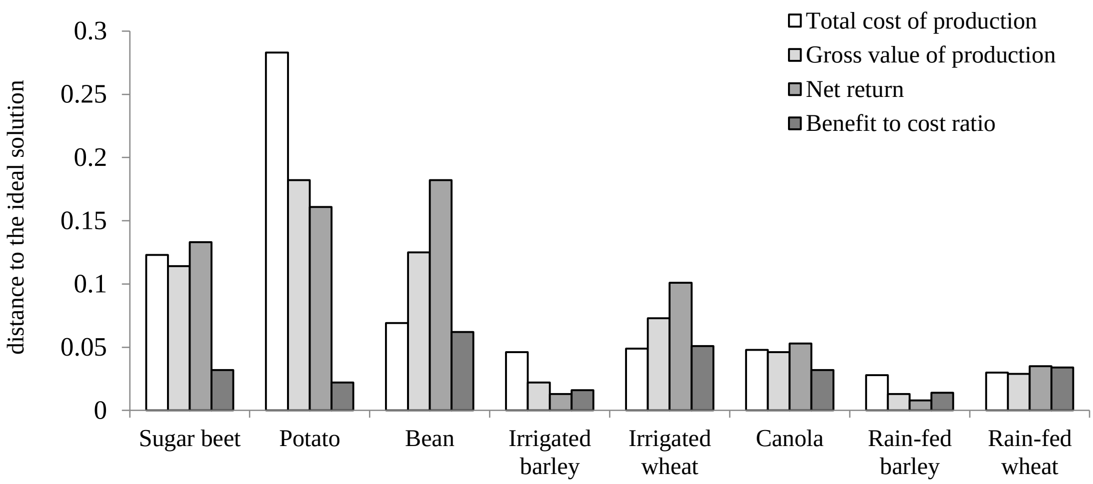


Figure 4. Economic parameters for crops production using TOPSIS method

In addition, the production of the highest gross value and the net return were obtained in potato and bean by 0.182, respectively (Figure 4). Furthermore, had the highest benefit to cost ratio (0.062), followed by irrigated wheat (0.051), and rainfed barley had the lowest (0.014) (Figure 4). Ghorbani et al (2016) reported that the benefit-to-cost ratio for rain-fed wheat was higher than irrigated wheat. The TOPSIS model classified the crops according to economic indices as bean, irrigated wheat, sugar beet, rapeseed, rainfed wheat, barley, irrigated barley, and potato (Figure 1). Our results showed that the current cropping pattern exerted in Azna is not acceptable in terms of economic indicators. The objectives of the producers play an important role in the selection of the crop and the cultivated area (Dalgaard et al., 2001).

Table 5. The effect and the weight of the energy indicators, economic factors, GHG emission and GWP on the cultivation pattern determination

	Energy input	Energy output	Direct energy	Indirect energy	Renewable energy	Non-renewable energy	Energy efficiency	Energy productivity
Scales weights (entropy)	0.042	0.122	0.077	0.016	0.051	0.03	0.043	0.067
Each scale's effect	-	+	-	-	-	-	+	-

Table 5 continued.

	Specific energy	Net energy	Total cost of production	Production gross value	Net return	Benefit to cost ratio	GHG	GWP
Scales weights (entropy)	0.037	0.18	0.088	0.071	0.081	0.028	0.035	0.033
Each scale's effect	-	+	+	+	+	+	-	

GWP: Global warming potential; GHG: Greenhouse gas emission

3.4. Evaluation of the sectors in crop production by TOPSIS

In the current study, the TOPSIS methodology was used for group decision-making to address multi-criteria decision problems. This methodology allows us to find the best alternatives for crop production in Azna. The effects of each of these scales (energy and economic indicators, GHGs, and GWP) were indicated according to their weight in the TOPSIS model. As the results are presented in Table 5, the highest effect was on net energy, followed by energy output. In other words, the mental priorities of the farmers were net energy and output energy, and after these costs of production and net return. New researches in agriculture are looking for solutions that minimize input energy in favor of producing and maximizing output energy (Payraudeau et al., 2007). In addition, the development of agricultural systems with lower input energies can help GHGs emission and GWP reduction (Samavatean et al., 2011).

The relative proximity to the ideal for each crop is shown in Table 6 by the TOPSIS model. The relative proximity to the ideal for rain-fed barley and wheat, rapeseed, irrigated barley and wheat, bean, potato and sugar beet were 0.931, 0.924, 0.906, 0.872, 0.759, 0.752, 0.623, and 0.21, respectively. In other words, the highest relative proximity to the ideal and the lowest distance to the positive ideal were observed in rain-fed barley at 0.931 and 0.017, respectively. In contrast, the lowest relative proximity to the ideal and the highest distance to the positive ideal were for sugar beet at 0.21 and 0.218, respectively. It can be concluded that rain-fed barley is the first/highest priority. Rain-fed wheat and rapeseed came as the second and third highest priority.

Table 6. Fuzzy TOPSIS results.

Crop	Relative closenes to ideal	Distance to positive ideal	Ranking of crops
Sugar beet	0.21	0.218	8
Potato	0.623	0.114	7
Bean	0.752	0.069	6
Irrigated barley	0.872	0.031	4
Irrigated wheat	0.759	0.061	5
Canola	0.906	0.023	3
Rain-fed barley	0.931	0.017	1
Rain-fed wheat	0.924	0.019	2

4. Conclusion

The objective of this study was to analyze the energy and economic indicators, GHGs emission and GWP of some crops in Azna, Lorestan Province, Iran. Energy management is the main part in terms of efficient and sustainable use of energy. Minimizing of energy inputs is essential, but it is not adequate to obtain an economic benefit, as well as the sustainability of these production systems and reduce GHGs emission. Although the net return in rain-fed was lower than that of the irrigated farms, the relative proximity to the ideal in rain-fed was much greater than in the irrigated systems. It can be inferred from the results that the cultivation of sugar beet and potato in the studied region is not reasonable. However, rain-fed barley and wheat, and rapeseed are suitable crops for this region. Although the new system offered by the TOPSIS model decreases farmer's incomes, it could sustain the environment and agriculture. Low energy input is not acceptable for farmers of the Azna who prefer economic benefits instead of sustainable agriculture. We believe that government support can provide incentives for farmers to grow the crops offered, which increases the stability of farmers' incomes. Rain-fed systems can be used to reduce the rate of non-renewable energy inputs, chemical synthetic fertilizers and, consequently, GHGs emission and GWP. Therefore, the cultivation of rain-fed barley and wheat, and rapeseed propose to reduce fossil fuel consumption and improve the environmental profile of agricultural systems in the region.

References

Alimagham, S.M., Soltani, A., Zeinali, E., Kazemi, H., 2017. Energy flow analysis and estimation of greenhouse gases (GHG) emissions in different scenarios of soybean production (Case study: Gorgan region, Iran). Journal of Cleaner Production, 149, 621-628.

Alluvione, F., Moretti, B., Sacco, D., Grignani, C., 2011. EUE (energy use efficiency) of cropping systems for a sustainable agriculture. Energy, 36, 4468-4481.

Ansarifar, E., Shahidi, F., and Mohebbi, M., 2015. Razavi SM, Ansarifar J. A new technique to evaluate the effect of chitosan on properties of deep-fried Kurdish cheese nuggets by TOPSIS. LWT - Food Science and Technology, 62, 1209-1211.

Asgharipour, M.R., Mondani, F., Riahinia, S., 2012. Energy use efficiency and economic analysis of sugar beet production system in Iran: A case study in Khorasan Razavi province. Energy, 44, 1078-1084.

Banaeian, N., Omid, M., Ahmadi, H., 2011. Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran. Energy Conversion and Management, 52, 1020-1025.

Beheshti Tabar, I., Keyhani, A., Rafiee, S., 2010. Energy balance in Iran's agronomy (1990–2006). Renewable & Sustainable Energy Reviews, 14, 849–855.

Börjesson, P., Tufvesson, L.M., 2011. Agricultural crop-based biofuels–resource efficiency and environmental performance including direct land use changes. Journal of Cleaner Production, 19, 108-120.

Dalgaard, T., Halberg, N., Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems and Environment, 87, 51-65.

Demircan, V., Ekinci, K., Keener, H.M., Akbolat, D., Ekinci, C., 2006. Energy and economic analysis of sweet cherry production in Turkey: a case study from Isparta province. Energy Conversion and Management, 47, 1761-1769.

Dymova, L., Sevastjanov, P., and Tikhonenko, A., 2013. An approach to generalization of fuzzy TOPSIS method. Information Sciences, 238, 149-162.

Erdal, G., Esengün, K., Erdal, H., and Gündüz, O., 2007. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. Energy, 32, 35-41.

Esengun, K., Gündüz, O., Erdal, G., 2007. Input–output energy analysis in dry apricot production of Turkey. Energy Conversion and Management, 48, 592-598.

Fadai, D., 2007. Utilization of renewable energy sources for power generation in Iran. Renewable and Sustainable Energy Reviews, 11(1), 173-181.

Ghorbani, R., Mondani, F., Amirmoradi, S., Feizi, H., Khorramdel, S., Teimouri, M., Sanjani, S., Anvarkhah, S., Aghel, H. A., 2011. case study of energy use and economical analysis of irrigated and dryland wheat production systems. Applied Energy, 88, 283-288.

Giampietro, M., Cerretelli, G., Pimentel, D. 1992. Energy analysis of agricultural ecosystem management: human return and sustainability. Agriculture, Ecosystems and Environment, 38, 219-244.

Guo, J., Zhou, C., 2007. Greenhouse gas emissions and mitigation measures in Chinese agroecosystems. Agricultural and Forest Meteorology, 142, 270–277.

Hatirli, S., Ozkan, B., Fert C., 2006. Input energy crop yield relationship in greenhouse tomato production. Renew Energy, 31, 427-438.

Hulsbergen, K.J., Feil, B., Biermann, S., Rathke G.W., Kalk, W.D., Diepenbrock W. A., 2001. method of energy balancing in crop production and its application in a longterm fertilizer trial. Agriculture, Ecosystems and Environment, 86, 303–321.

IPCC, 2006. Guidelines for national greenhouse gas inventories. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan 2006.

Kazemi, H., Shahbyki., M, Baghbani S., 2015. Energy analysis for faba bean production: A case study in Golestan province, Iran. Sustainable Production and Consumption, 3, 15-20.

Khakbazan, M., Mohr, R.M., Derksen D.A., Monreal, M.A., Grant, C.A., Zentner, R.P., et al., 2009. Effects of alternative management practices on the economics energy and GHG emissions of a wheat–pea cropping system in the Canadian prairies. Soil Tillage Research, 104., 30–38.

Khan, S., Khan, M.A., Hanjra, M.A., Mu. J., 2009. Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy, 34, 141-149.

Kramer, K.J., Moll, H.C., Nonhebel, S. 1999. Total greenhouse gas emissions related to the Dutch crop production system. Agriculture, Ecosystems & Environment, 72, 9-16.

Lal, R., 2004. Carbon emission from farm operations. Environment international, 30(7), 981-990.

Liang, Q.M., Fan, Y., Wei, Y.M., 2007. Multi-regional input–output model for regional energy requirements and CO_2 emissions in China. Energy policy, 35(3), 1685-1700.

Lin, H.C., Huber, J.A., Gerl, G., Hülsbergen, K.J., 2017. Effects of changing farm management and farm structure on energy balance and energy-use efficiency—A case study of organic and conventional farming systems in southern Germany. European Journal of Agronomy, 31, 242-253.

Lu, X., Lu, X., 2017. Tillage and crop residue effects on the energy consumption, input–output costs and greenhouse gas emissions of maize crops. Nutrient Cycling in Agroecosystems, 108, 323-337.

Mandal, K.G., Saha, K.P., Ghosh, P.K., Hati, K.M., Bandyopadhyay, K.K., 2002. Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass Bioenergy, 23, 337–345.

Marzban, Z., Asgharipour, M.R., Ghanbari, A., Ramroudi, M., Seyedabadi, E., 2021. Evaluation of environmental consequences affecting human health in the current and optimal cropping patterns in the eastern Lorestan Province, Iran. Environmental Science and Pollution Research, 28(5), 6146-6161.

Mobtaker, H.G., Keyhani, A., Mohammadi, A., Rafiee, S., Akram, A., 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agriculture, Ecosystems & Environment, 137, 367-372.

Mohammadi, A., Omid, M., 2010. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Applied Energy, 87, 191-196.

Mohammadi, A., Rafiee, S., Jafari, A., Keyhani, A., Mousavi-Avval, S.H., Nonhebel, S., 2014. Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. Renewable & Sustainable Energy Reviews, 30, 724-733.

Mohammadi, A., Tabatabaeefar, A., Shahin, S., Rafiee, S., Kyhani, A., 2008. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. Energy Conversion and Management, 49, 3566-3570.

Nemecek, T., Dubois, D., Huguenin-Elie, O., Gaillard, G., 2011. Life cycle assessment of Swiss farming systems: integrated and organic farming. Agricultural Systems, 104, 217-232.

Niu, G., Li, Y.P., Huang G.H., Liu, J., Fan, Y.R., 2016. Crop planning and water resource allocation for sustainable development of an irrigation region in

China under multiple uncertainties. Agricultural Water Management, 166, 53-69.

Ozkan, B., Akcaoz, H., Fert, C., 2004. Input energy–output analysis in Turkish agriculture. Renewable Energy, 29, 39-51.

Ozkan, B., Kurklu, A., Akcaoz, H., 2004. An input–output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. Biomass and Bioenergy, 26, 89-95.

Pahlavan, R., Omid, M., Rafiee, S., Mousavi-Avval, S.H., 2012. Optimization of energy consumption for rose production in Iran. Energy for Sustainable Development. 16, 236–241.

Payraudeau, S., Van der Werf, H.M., Vertès, F., 2007. Analysis of the uncertainty associated with the estimation of nitrogen losses from farming systems. Agricultural Research, 94, 416-430.

Pimentel, D., Hurd, L.E., Belloti, A.C., Forster M.J., and Oka I.N. 1990. Scholes OD, Salway AG.. UK Greenhouse Gas Emission Inventory 1990–1994. AEA Technology and Department of the Environment. AEA/200920011996.

Rafiee, S., Mousavi Avval, S.H., Mohammadi, A., 2010, Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy., 35, 3301-3306.

Rathke, G.W., Diepenbrock W., 2006. Energy balance of winter oilseed rape (*Brassica napus* L.) cropping as related to nitrogen supply and preceding crop. European Journal of Agronomy, 24, 35-44.

Samavatean, N., Rafiee, S., Mobli, H., Mohammadi, A., 2011. An analysis of energy use and relation between energy inputs and yield, costs and income of garlic production in Iran. Renewable Energy, 36, 1808-1813.

Simanaviciene, R., Ustinovichius, L., 2010. Sensitivity analysis for multiple criteria decision making methods: TOPSIS and SAW. Procedia Social and Behavioral Sciences, 2, 7743-7744.

Streimikiene, D., Klevas, V., Bubeliene, J., 2007. Use of EU structural funds for sustainable energy development in new EU member states. Renewable and Sustainable Energy Reviews, 116, 1167–1187.

Tzilivakis, J., Warner, D.J., May, M., Lewis, K.A., Jaggard, K., 2005. An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris L) production in the UK. Agricultural Systems, 85.

Uhlin, H. 1998. Why energy productivity is increasing: an I–O analysis of Swedish agriculture. *Agricultural Systems*, 56, 443–465.

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2000. The art of writing a scientific article. Journal of Science Communication, 163(2), 51-59.

Yamane, T. 1967. Elementary sampling theory. Prentice Hall Englewood Cliffs, N.J., USA.

Yousefi, M., Damghani, A.M., Khoramivafa, M, 2016. Comparison greenhouse gas (GHG) emissions and global warming potential (GWP) effect of energy use in different wheat agroecosystems in Iran. Environmental Science and Pollution Research, 23, 7390-7397.

Yousefi, M., Damghani, A.M., Khoramivafa, M., 2014. Energy consumption, greenhouse gas emissions and assessment of sustainability index in corn agroecosystems of Iran. Science of the Total Environment, 493, 330-335.

Yuan, S., Peng, S., 2016. Trends in the economic return on energy use and energy use efficiency in China's crop production. Renewable and Sustainable Energy Reviews, 70, 836–844.

Zangeneh, M., Omid, M., Akram, A. A., 2010. comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. Energy, 35, 2927–2933.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 95-102

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Population changes of *Pulvinaria aurantii* and its predatory ladybird *Cryptolaemus montrouzieri* in Tonekabon citrus groves

Maryam Bozorg-Amirkalaee [*a], Seyed Ali Asghar Fathi [a], Ali Golizadeh [a], Seyed Esmaeil Mahdavian [b]

[a] Department of Plant Protection, University of Mohaghegh Ardabili, Ardabil, Iran
[b] Plant Protection Research Station of Khoshkdaran, Agricultural and Natural Resources Research Center of Mazandaran, Tonekabon, Iran

ARTICLE INFO

Article history:
Received: 24 April 2022
Accepted: 29 May 2022
Available online: 1 June 2022

Keywords:
Blood orange
Lady beetle
Orange pulvinaria scale
Overlap
Population dynamics

ABSTRACT

The orange pulvinaria scale, *Pulvinaria aurantii* Cockerell (Hemiptera: Coccidae), is one of the most significant citrus orchard pests in northern Iran. To assess the population fluctuations of this pest and its predator *Cryptolaemus montrouzieri* Mulsant in Tonekabon blood orange orchards, 80 leaves from 20 trees were randomly selected at each sampling time (with a maximum relative variation of 15%) and the number of each biological stage of the *P. aurantii* and its predatory ladybird were recorded per leaf. The average population of all biological stages of *P. aurantii* (ovisac, nymphal stages, and adult female insect) peaked on June 29 (30.05 per leaf) and September 14 (29.55 per leaf) in 2011, and on June 21 (30.09 per leaf) and September 6 (22.6 per leaf) in 2012. Similarly, the average population of all *C. montrouzieri* biological stages peaked on June 29 (0.34 per leaf), September 7 and 14 (0.45 per leaf), and June 21 (0.65 per leaf) and September 6 (1.00 per leaf) in 2011 and 2012, respectively. The population change curves indicated that increasing the population of ovisacs, 1st and 2nd instar nymphs of the pest attracted and increased the population of *C. montrouzieri* on infected trees, possibly due to the desirability of these biological stages of the pest to the predator. The present study revealed that in both years, the second generation of the pest is characterized by greater concordance and overlap between the populations of scale ovisacs and ladybird eggs. In 2011, *C. montrouzieri* prevented an increase in the population of *P. aurantii* second generation, and in 2012, due to a higher population density, it was able to significantly reduce the second generation population of this soft scale. Additionally, the regression between prey and predator populations was statistically significant, indicating a density-dependent response of the predator to the prey population.

Highlights

- *Pulvinaria aurantii* Cockerell is a major citrus orchard pest in northern Iran.
- The average population of *P. aurantii* peaked on June 29 (30.05 per leaf) and September 14 (29.55 per leaf) in 2011, and on June 21 (30.09 per leaf) and September 6 (22.6 per leaf) in 2012.
- In both years, the second generation of the pest has increased concordance and overlap between scale ovisacs and ladybird eggs.
- In 2011, *C. montrouzieri* prevented a growth in *P. aurantii* second-generation population, and in 2012, it substantially decreased this soft scale's second-generation population.

1. Introduction

Iran is one of the countries where citrus fruits are produced economically. According to FAO statistics, in 2020 the country was ranked 9th in the world in terms of citrus production (Anonymous, 2020). The orange pulvinaria scale, *Pulvinaria aurantii* Cockerell (Hemiptera: Coccidae), is one of the most important pests in the north of Iran (Moghaddam, 2010) that weakens the citrus trees by sucking plant sap and causes the growth of sooty mold (*Capnodium citri* Penz.) by the secretion of honeydew, which reduces the quality and marketability of fruits. This insect causes leaf and fruit fall and plant

[*] Corresponding author
Email: m.amirkalaee@gmail.com
http://dx.doi.org/10.22034/aes.2022.339021.1033

drying in outbreak conditions. (Hallaji Sani, 1999; Damavandian et al., 2014).

The *P. aurantii* female has different life stages, including eggs, nymphs (1st, 2nd, and 3rd instar), and adult insects. In the male insect, the 2nd instar nymph becomes pre-pupae and then pupae. Male insects live for one or two days, and adult female insects live for 12 to 15 days. The oviposition period lasts about 10 days, and the number of eggs in an ovisac of *P. aurantii* on different hosts varies from 350 to 500 (Hallaji Sani, 1999).

The population density of scale insects is affected by temperature, relative humidity, climatic conditions, pesticide application, and biological agents (Ullah, 1992; Hallaji Sani, 1999; Abdel-Moniem, 2003). At present, insecticides are mostly used in the north of Iran to control this pest, as well as other scale insects (Hallaji Sani et al., 2021). Insecticides, in addition to adverse environmental effects, are not always effective and may be washed away by unpredictable rainfall or may not be able to control the pest at all stages (McDowell et al., 1984). In contrast, biological control agents are more stable and reduce the cost of reusing insecticides (van Driesche, 1994; Kimberling, 2004).

Among the natural enemies of this pest, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) is a polyphage and native Australian insect that has a higher relative abundance (Bozorg-Amirkalaee et al., 2017) and is widely used in biological control programs of different species of scale insects in the world (Hodek and Honěk, 2009; Kairo et al., 2013; Pérez-Rodrígueza et al., 2019; Ferreira et al., 2021). In Azerbaijan in 1982, researchers released 5,000 *Cryptolaemus* in a three-hectare garden and prevented the spread of *Chloropulvinaria* (Prokopenko et al., 1982).

Wax filaments produced by scale insects stimulate the oviposition of *C. montrouzieri* (Gharizadeh Gelsefidi et al., 2004; Merlin et al., 1996a). The female ladybird usually lays their eggs individually or in groups in the mass of prey eggs, so that the larvae of early ages can easily find their prey (Gharizadeh Gelsefidi et al., 2004). The development time from egg to adult insect of this ladybird is 27.7 days by feeding on *P. aurantii* ovisacs on blood orange, and its oviposition period has been reported to be 70 days (Bozorg-Amirkalaee et al., 2015). The average and maximum number of ladybird eggs per day on *P. aurantii* were 12.5 and 25 eggs, respectively (Gharizadeh Gelsefidi et al., 2004). Feeding of *Cryptolaemus* eggs by conspecific larvae has also been observed in low prey densities (Merlin et al., 1996b).

Population density changes of *P. aurantii* have been studied by Hallaji Sani (1999), Rajabpour (2006), and Damavandian et al. (2014), but no comprehensive research has been done on the population fluctuations of the *Cryptolaemus* predatory ladybird by feeding on different stages of this pest. Therefore, information about population fluctuations of the biological stages of this pest during the growing season as well as its predominant natural enemy, *C. montrouzieri*, will play an effective role in designing integrated pest management.

2. Methods and Materials

This study was conducted in the blood orange orchards of the Tonekabon region, Iran (latitude 36 ° 70 North and longitude 51 ° 10 East) in 2011 and 2012.

In the assessment of population changes and in order to reduce the sampling error, the sampling program and the number of samples were first determined. In this study, the statistical population in the field sampling was the orange pulvinaria scale population. Based on the initial studies, blood orange leaves were selected as the sampling unit. To determine the sample size, an initial sampling of 30 leaves was performed on April 25 (2011) by nymphs present at the time. Using the data from the initial sampling, the relative variation (RV), which indicates the accuracy of sampling, was obtained using the Eq. 1:

$$RV = (SE/m)\ 100 \quad (1)$$

where m and SE are the mean density and standard error of the primary sampling data, respectively. Then the sample size (N) was obtained through the Eq. 2:

$$N = [ts/dm]^{2} \quad (2)$$

where m and S are the mean density and standard deviation of the initial sampling data, respectively, d (RV) is the range of accuracy, and t is the numerical value of the student table in terms of the degree of freedom of the sample (Pedigo and Buntin, 1994).

In this study, the number of samples required for the sampling program with a maximum relative variation of 15% was equal to 77 leaves, of which 80 leaves were used as the number of samples required for field studies. With the advent of other stages of *P. aurantii* as well as *C. montrouzieri* ladybird, the RV value was examined for the different biological stages of the pest and its predator (N = 80 leaves) in each season of both studied years during the sampling period. Because the RV value was within the acceptable range, sampling was done with the same number of samples (80 leaves).

To study the population changes of *P. aurantii* and its predominant natural enemy, *C. montrouzieri* ladybird, four gardens approximately two kilometers apart were selected in this area. No spraying operations have been carried out in these gardens since September 2008. Sampling was done weekly from late April to mid-November. It should be noted that no sampling was done from the margins of the gardens. At each sampling time, 80 leaves from all four geographical directions of trees at the height of 1 to 1.8 meters above the ground were randomly selected, and the number of larvae, pupae, and adult insects of *C. montrouzieri* was counted per leaf. In addition, these leaves were numbered and transferred to the laboratory with the date of sampling in plastic bags. The leaves were examined in the laboratory under a stereomicroscope, and the numbers of each biological stage of the soft scale, as well as the ladybird eggs, were counted and recorded. The data was used to draw the graphs of pest and predator population changes in Excel software.

An analysis of linear regression was done between prey and predator densities in SPSS software to evaluate the type of interaction between *P. aurantii* and *C. montrouzieri*. If P-value > 0.05 or b = 0, the predation would be density-independent, but if P-value< 0.05 and b > 0 or b< 0, the predator could act as density-dependent and inverse density-dependent, respectively (Kidd and Jervis, 1996).

3. Results

The population fluctuations of the orange pulvinaria scale and its predatory ladybird, *C. montrouzieri,* in 2011 and 2012 are shown in Figures 1-5. The population of soft scale ovisacs was observed in the first generation from mid-May to late June and in the second generation from mid-August to mid-October (Figure 1). The mean population of scale ovisacs in the first and second generation peaked on June 8 (1.88 ovisacs per leaf) and September 7 (1.8 ovisacs per leaf) in 2011 and also on May 31 (2.04 ovisacs per leaf) and August 30 (1.59 ovisacs per leaf) in 2012 (Figure 1).

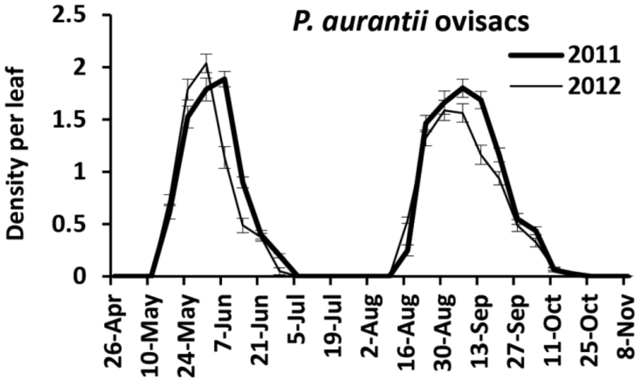


Figure 1. Fluctuations in ovisac population of *P. aurantii* in citrus orchards of Tonekabon region in 2011 and 2012.

The population of 1st instar nymphs of *P. aurantii* was observed in the first generation from late May to late July and in the second generation from the third decade of August to late October (Figure 2). The mean population of 1st instar nymphs of this pest in the first and second generations peaked on June 29 (28.65 nymphs per leaf) and September 14 (27.81 nymphs per leaf) 2011, and on June 21 (29.11 nymphs per leaf) and September 6 (21.00 nymphs per leaf) 2012 (Figure 2).

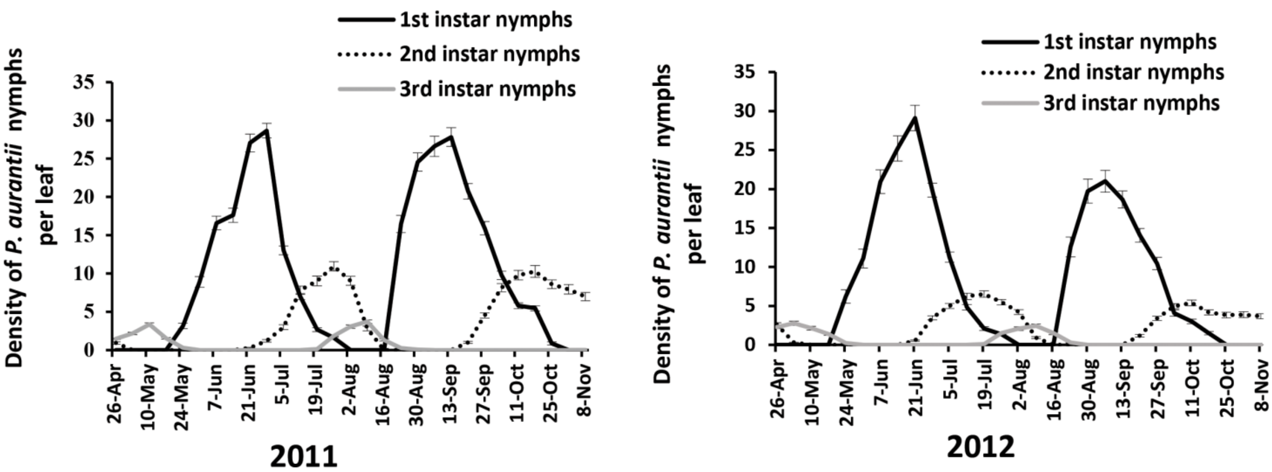


Figure 2. Population fluctuations of different nymph instars of *P. aurantii* in citrus orchards of Tonekabon region in 2011 and 2012.

The population of 2nd instar nymphs of *P. aurantii* was present in the first generation from the third decade of June to mid-August (Figure 2). The emergence of the 2nd instar nymph in the second generation began on September 20, and overwintering of the pest also passed into the 2nd instar nymph. In addition, a small population density was present from early spring to late April. The mean population of 2nd instar nymphs of *P. aurantii* in the first and second generations peaked on 2011, July 27 (10.95 nymphs per leaf) and October 19 (10.27 nymphs per leaf) and on 2012, July 19, (6.53 nymphs per leaf) and October 11 (5.4 nymphs per leaf) (Figure 2).

The population of 3rd instar nymphs from the winter generation of *P. aurantii* was observed from spring to late May (Figure 2). The 3rd instar nymphs of this pest were also present in nature from mid-July to late August. Adult females of *P. aurantii* were also found on plants from early May to June 22, and from early August to mid-September (Figure 3). In 2011, the peak population of 3rd instar nymphs was on May 11 (3.36 nymphs per leaf) and August 10 (3.71 nymphs per leaf), and the peak population of adult female insects was on June 1 (1.8 nymphs per leaf) and August 24 (1.88 nymphs per leaf) (Figure 2). In 2012, the peak population of 3rd instar nymphs was on May 3 (2.79 nymphs per leaf) and August 9 (2.45 nymphs per leaf), and the peak population of adult female insects was observed on May 24 (2.00 adult insects per leaf) and August 16 (1.53 adult insects per leaf) (Figure 3).

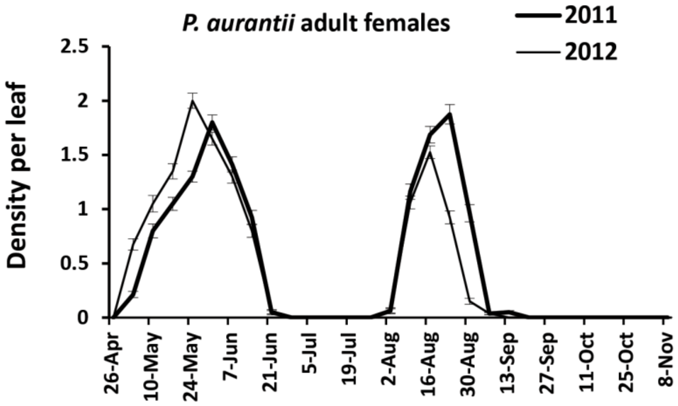


Figure 3. Population fluctuations of *P. aurantii* adult females in citrus orchards of Tonekabon region in 2011 and 2012.

In both years, the activity of ladybirds began in citrus orchards in May (Figure 4). In 2011, the peak population of *C. montrouzieri* eggs in the first and second generation of the orange pulvinaria scale was on June 15 (0.14 eggs per leaf) and September 7 (0.19 eggs per leaf), respectively (Figure 4).

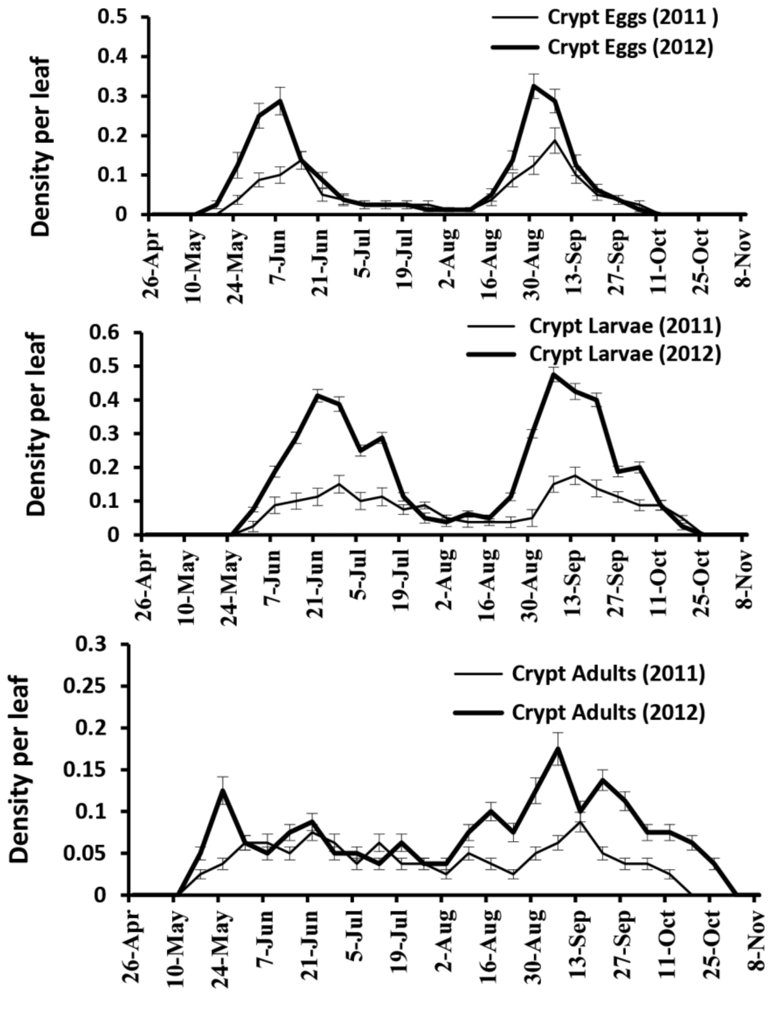


Figure 4. Population fluctuations of eggs, larvae and adult insects of *C. montrouzieri* in citrus orchards of Tonekabon region in 2011 and 2012. Crypt; *C. montrouzieri*.

The peak population of ladybird larvae in two generations of the pest was on June 29 (0.15 larvae per leaf) and September 14 (0.18 larvae per leaf), respectively (Figure 4). In 2012, the peak population of *C. montrouzieri* eggs was in the first and second generation of the soft scale on June 7 (0.29 eggs per leaf) and August 30 (0.33 eggs per leaf), respectively. The peak population of larvae of this ladybird during two generations of pests was on June 21 (0.41 larvae per leaf) and September 6 (0.47 larvae per leaf). The population density of *C. montrouzieri* also ranged from 0.03 to 0.09 per leaf in 2011 and 0.03 to 0.18 per leaf in 2012.

In general, in 2011, the peak of the average population of all biological stages of *P. aurantii* (ovisac, nymph instars, and adult female insects) was on June 29 (30.05 per leaf) and September 14 (29.55 per leaf), and the peak of the average population of all biological stages of *C. montrouzieri* was on June 29 (0.34 per leaf) and also on September 7 and 14 (0.45 per leaf) (Figure 5). In 2012, the peak of the average population of all biological stages of this soft scale was on June 21 (30.09 per leaf) and also on September 6 (22.6 per leaf), and the peak of the average population of all biological stages of predator ladybird was on June 21 (0.65 per leaf) and September 6 (1.00 per leaf).

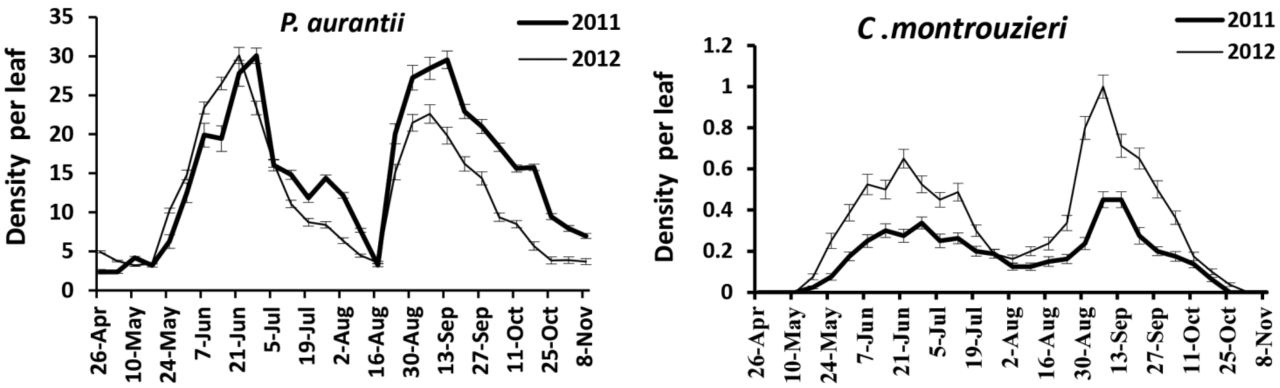


Figure 5. Population fluctuations of *P. aurantii* and *C. montrouzieri* in citrus orchards of Tonekabon region in 2011 and 2012.

Regression between population densities of *P. aurantii* ovisacs and *C. montrouzieri* eggs was significant (P-value < 0.001; Table 1), indicating that increasing the prey ovisacs increased the population density of predator eggs. Further, the P-value of the regression between prey and predator populations was less than 0.01 (b > 0; Table 1), showing a density-dependent reaction of the predator to the prey population (Figure 6).

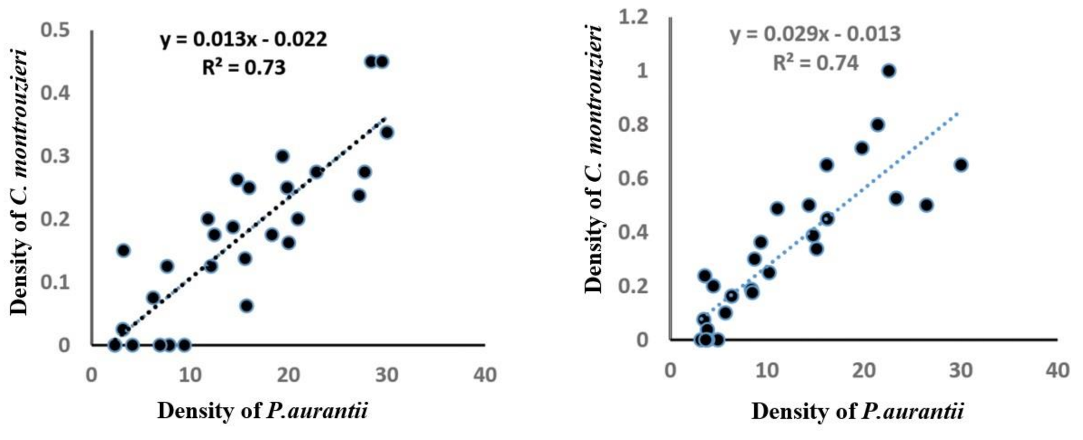


Figure 6. Regression showing the relationship between mean population densities of *P. aurantii* and *C. montrouzieri* in 2011 (left) and 2012 (right).

Table 1. Statistics of the linear regression between the mean population densities of *P. aurantii* and *C. montrouzieri* in 2011 and 2012.

X-Y[a]		a	b	r	r^2	P_{value}
***P. aurantii* Ovisacs– *C. montrouzieri* Eggs**	**2011**	0.01	0.06	0.82	0.68	0.001[b]
	2012	0.01	0.13	0.85	0.72	0.001[b]
P. aurantii* – *C. montrouzieri	**2011**	-0.02	0.01	0.85	0.73	0.001[b]
	2012	-0.01	0.03	0.86	0.74	0.001[b]

[a] Y and X are dependent and independent parameters, respectively.
[b] The regression between X and Y is significant at 0.01 level.

4. Discussion

In the process of population changes of the orange pulvinaria scale on the blood orange in the Tonekabon region, two distinct peaks were observed, which indicate the existence of two generations of this pest per year. This result is consistent with the results of Hallaji Sani (1999), Rajabpour (2006), and Damavandian et al. (2014) that this pest has two generations. The first generation of *P. aurantii* was observed from May to September, and the second generation of this pest was found from late August to the following June. The present study showed that *P. aurantii* has a high density in June and September. Also, the peak points of the pest population occur due to the sudden increase in population following the emergence of 1st instar nymphs. In the present study, during 2011 and 2012, different biological stages of *P. aurantii* were present in nature at almost the same time, but the peak points of this pest were observed in 2011 with a one-week delay compared to 2012, which can be related to changes in weather conditions in these two years. According to meteorological reports, in 2011, there were more rainy days and a decrease in temperature compared to 2012. Abdel-Moniem (2003) showed that the population density of *Pulvinaria tenuivalvata* (Newstead) was positively related to temperature and relative humidity. In addition to climatic conditions, orange pulvinaria scale activity and population growth can be very closely related to its contamination rate in the previous year.

According to the results of this study, in 2011, there was no significant difference in *P. aurantii* population density between the two generations, but in 2012 this difference was more evident, and the pest population in the second generation decreased considerably. This could be associated with an increase in the population density of the *C. montrouzieri* as an important contributor to changes in the soft scale population (Moore, 1988). The curves of *P. aurantii* and *C. montrouzieri* population changes in this study show that increasing the population of ovisacs, 1st and 2nd instar nymphs of pests, increased predator ladybird populations on infected trees. It can result that these biological stages of *P. aurantii* are favorable for *C. Montrouzieri*.

In this study, the population growth of predator ladybirds in 2012 was faster than in 2011 due to the higher temperature in May 2012 (19 ° C) compared to 2011 (16 ° C) and also the decrease in the number of rainy days in 2012. Hennekam et al. (1987) reported that *Cryptolaemus* ladybird was unable to be active at temperatures below 17 °C. Besides, it has been reported that the population of *Cryptolaemus* ladybird on rainy days is lower due to a decrease in suitable prey (Rao et al., 1971). In the experimental gardens, it should be noted that the orange pulvinaria scale was the predominant pest of blood orange trees, and other pests were rarely observed. Thus, the population changes of *C. montrouzieri* are largely related to the population changes of *P. aurantii*. In this research, the regression between prey and predator densities (Figure 6) was significant (Table 1), suggesting density-dependent predation. On the other hand, this ladybird feeds more on soft scale eggs than nymphs (Gharizadeh Gelsefidi et al., 2004), hence the co-occurrence of predator ladybird populations with scale ovisacs will play an important role in controlling this pest. Our results showed that the regression between densities of prey ovisacs and predator eggs was significant, indicating the effect of the presence of soft-scale ovisacs on the increase in the number of eggs laid by predators (Table 1). Further, in the second generation of this pest, more synchronicity was observed between the population of scale ovisacs and ladybird eggs ($b > 0$). Thus, the peak density of *C. montrouzieri* eggs coincided with the peak density of citrus *P. aurantii* ovisacs. Also, the peak of the average population of total biological stages of this ladybird in the first and second generations was observed three weeks and one week later than the peak population of scale ovisacs, respectively. Therefore, in the first generation, when the population of this predator increased, there were not enough *P. aurantii* ovisacs in which the ladybird could lay their eggs. Consequently, the population density and growth of this predator in this generation were lower compared to the second generation. As a result, *C. montrouzieri* in 2011 prevented the increase in the *P. aurantii* population in the second generation. In 2012, due to higher population density, this predator was able to significantly reduce the pest population in the second generation.

In this study, the population density of *C. montrouzieri* decreased in August in both 2011 and 2012. Solangi et al. (2012) reported that as the temperature rises above 33 °C, reproduction, oviposition, and, consequently, the population of *Cryptolaemus* ladybird decrease. In our study, every two years, the average temperature in August was 27–28 °C. Therefore, the reduction in the population of *C. montrouzieri* this month can probably be attributed to the decrease in the favorable stage density of *P. aurantii* for the predatory ladybird. In September, with the increase of scale ovisacs, the ladybird population also increased. Ullah (1992) studied the population fluctuations of *Pulvinaria psidii* Maskell and *Pulvinaria floccifera* Westwood in Bangladesh and mentioned that abiotic factors such as temperature, relative humidity, and rainfall were the main causes of their population changes. Aghajanzadeh and Taheri (2017) showed that the pathogenic fungus *Lecanicillium muscarium* has an important role in the population reduction of *P. aurantii* in citrus orchards. In a study of population changes of *P. pyriformis* on the laurel in Greece by Stathas et al. (2009), it was reported that other natural enemies of the pest, such as *Chilocorus bipustulatus* L. and the parasitoid wasp *Metaphycus helvolus* (Compere), could not significantly reduce the pest population.

The results of the present study showed that the *C. montrouzieri* ladybird has been able to increase its population well over time and settle in citrus orchards, so it plays an important role in *P. aurantii* population changes. In our study, as mentioned before, the ladybird population in the first generation of the pest was less than in the second generation in both years. According to Hagen (1962), the *Cryptolaemus* ladybird does not tolerate temperatures below 10 °C, and a very large population of them perishes in cold winters. On the Black Sea coast, relatively large heat cages are placed around trees for ladybirds, which increase predator survival compared to laboratory breeding and reduce spring release rates (Hodek, 1967). In Azerbaijan, researchers managed to prevent soft-scale outbreaks by releasing 5,000 *C.*

montrouzieri into three hectares of orchards (Prokopenko et al., 1982). Therefore, it is recommended that when we face cold winters in the previous year, the release of this ladybird in citrus orchards should be done at the right time to strengthen its population in order to control this pest effectively.

Acknowledgments

The Research Council of Mohaghegh Ardabili University (Iran) is gratefully acknowledged for their financial support of this research. Also, we are grateful to the Agricultural and Natural Resources Research Center of Mazandaran (Iran) for supporting this study.

References

Abdel-Moniem, A.S.H., 2003. Ecological studies on the red-striped sugarcane soft scale, *Pulvinaria tenuivalvata* (newstead) (hemiptera: coccidae) in upper Egypt. Archives of Phytopathology and Plant Protection, 36, 161-172.

Aghajanzadeh, S., Taheri, H., 2017. Study on efficiency of different isolates of *Lecanicillium muscarium* against *Pulvinaria aurantii*. Biological control of pests and plant diseases, 6(2), 257-260.

Anonymous, 2020. Iranian agriculture statistics. The ministry of Jihad-e-Agriculture, Tehran, Iran.

Bozorg-Amirkalaee, M., Fathi, S., Golizadeh, A., Mahdavian, S., 2015. Performance of *Cryptolaemus montrouzieri* feeding on *Pulvinaria aurantii* ovisacs on citrus plants. Biocontrol science and technology, 25(2), 207–222.

Bozorg AmirKalaee, M., Fathi, S., Golizadeh, A., Mahdavian, S., 2017. Species diversity of natural enemies of the orange pulvinaria scale, *Pulvinaria aurantii* (Hem.: Coccidae) on different citrus species of Tonekabon region, Northern Iran, Plant Protection (Scientific Journal of Agriculture), 39(4), 1-12.

Damavandian, M.R., Hesami, Sh., Mohammadipour, A., 2014. The seasonal population changes of the citrus soft scale, *Pulvinaria aurantii* (Hemiptera: Coccidae), and its distribution pattern in citrus orchards. Journal of Entomological Research, 6(1), 1-12.

Ferreira, L., Silva-Torres, C., Torres, J., Venette, R., 2021. Potential displacement of the native *Tenuisvalvae notata* by the invasive *Cryptolaemus montrouzieri* in South America suggested by differences in climate suitability. Bulletin of Entomological Research, 111(5), 605-615.

Gharizadeh Gelsefidi, A., Hatami, B., Seidoleslami, H., 2004. Comparison of biological characteristics of *Cryptolaemus montrouzieri* (Col.: Coccinellidae) on citrus cottony scale, *Pulvinaria auranti* Cockerelli, and citrus mealybug, *Planococcus citri* in the laboratory. Journal of Science and Technology of Agriculture and Natural Resources, 8(2), 217–228.

Hagen, K.S., 1962. Biology and ecology of predaceous Coccinellidae. Annual Review of Entomology, 7, 289-326.

Hallaji Sani, M.F., 1999. Study on bioecology of pulvinaria scale, *Pulvinaria aurantii* Cockerell (Hom. Coccidae). MSc dissertation, University of Guilan, Guilan, Iran.

Hallaji Sani, M.F., Naseri, B., Rafiee-Dastjerdi, H,. Aghajanzadeh, S., Ghadamyari, M., 2021. Effects of three conventional insecticides on life table parameters and detoxifying enzymes activity of *Pulvinaria aurantii* Cockerell (Hemiptera: Coccidae), Toxin Reviews, 40(4), 1318-326.

Hennekam, M.M.B., Kole, M., Opzeeland, K.v, Alphen, J.J.M., 1987. Biological control of citrus mealybug in a commercial crop of ornamental plants in the Netherlands. Mededelingen van de Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent, 52, 329-338.

Hodek, I., 1967. Bionomics and ecology of predaceous Coccinellidae. Annual Review of Entomology, 12, 79-104.

Hodek, I., Honěk, A., 2009. Scale insects, mealybugs, whiteflies and psyllids (Hemiptera, Sternorrhyncha) as prey of ladybirds. Biological Control, 51(2), 232-243.

Kairo, M.T.K., Paraiso, O., Gautam, R.D., Peterkin, D.D., 2013. *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae): A review of biology, ecology, and use in biological control with particular reference to potential impact on non-target organisms. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 8, 1–20.

Kidd, N.A.C., Jervis, M.A., 1996. Population Dynamics. In: Jervis, M.A., Kidd, N.A.C. (Eds)., Insect Natural Enemies. Cardiff, UK. pp. 293-375.

Kimberling, D.N., 2004. Lessons from history: predicting successes and risks of international introductions for arthropod biological control. Biological Invasions, 6, 301-318.

McDowell, L.L., Willis, G.H., Southwick, L.M., Smith, S., 1984. Methyl parathion and EPN washoff from cotton plants by simulated rain. Environmental Science & Technology, 18(6), 423–427.

Merlin, J., Lemaitre, O., Gregoire, J.C., 1996a. Oviposition in *Cryptolaemus montrouzieri* stimulated by wax filaments of its prey. Entomologia Experimentalis et Applicata, 79, 141-146.

Merlin, J., Lemaitre, O., Gregoire, J.C., 1996b. Chemical cues produced by conspecific larvae deter oviposition by the coccidophagous ladybird beetle, *Cryptolaemus montrouzieri* mulsant. Entomologia Experimentalis et Applicata, 79, 147-151.

Moghaddam, M., 2010. Scale insect (Hemiptera: Coccoidea) fauna of the southern coast of Caspian Sea (Golestan, Mazandaran and Gilan provinces, Iran). Journal of Entomological Society of Iran, 29(2), 65-98.

Moore, D., 1988. Agents used for biological control of mealybugs (Pseudococcidae). Biocontrol News Information, 9, 209-225.

Pedigo, L.P., Buntin, G.D., 1994. Handbook of Sampling Methods for Arthropods in Agriculture. Boca Raton, FL, CRC Press. 689P.

Pérez-Rodrígueza, J., Miksanek, J. R., Selfa, J., Martínez-Blay, V., Soto, A., Urbaneja, A., Tena, A., 2019. Field evaluation of *Cryptolaemus montrouzieri* (Mulsant) (Coleoptera: Coccinellidae) as biological control agent of the mealybug *Delottococcus aberiae* De Lotto (Hemiptera: Pseudococcidae). Biological Control, 138, 104027.

Prokopenko, A.I., Bugayeva, L.N., Baklanova, Y.V., 1982. *Cryptolaemus* suppress *Chloropulvinaria.* zashchitz Rastenii, 3, 25.

Rajabpour, A., 2006. Investigation on population dynamics and spatial distribution determination of economic injury level of *Pulvinaria auranti* on Thompson Novel Orange in Sari and evaluation of two mineral of oils efficiency for its control. MSc dissertation, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

Rao, V.P., Ghani, M.A., Sankaran, T., Mathur, K.C., 1971. A Review of the Biological Control of Insects and Other Pests in South-East Asia and the Pacific Region. Trinidad, Technical Communication, Commonwealth Institute of Biological Control. 149P.

Solangi, G.S., Lohar, M.K., Abro, G.H., Buriro, A.S., 2012. Biology and release of exotic predator, *Cryptolaemus montrouzieri* Mulsant on mealybug, *Phenacoccus solenopsis* Tinsley at Tandojam. Sarhad Journal of Agriculture, 28(3), 429-435.

Stathas, G.J., Eliopoulos, P.A., Japoshvili, G., Kontodimas, D.C., 2009. Phenological and ecological aspects of *Protopulvinaria pyriformis* (Cockerell) (Hemiptera: Coccidae) in Greece. Journal of Pest Science, 82, 33–39.

Ullah, G.M.R., 1992. Seasonal effects on the rate of development and fecundity of scale insects, *Pulvinaria psidii* Maskell and *Pulvinaria floccifera* Westwood (Homoptera: Coccidae). Annals of Entomology, 10, 7-11.

Van Driesche, R.G., 1994. Classical biological control of environmental pests. Florida Entomologist, 77, 20-33.

Agriculture, Environment & Society (2022) Volume 2, Issue 1, P. 103-110

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

A fuzzy data envelopment analysis for assessing sustainability in potato farms of Kabodarahang village

Zahra Ghaffari Moghadam [*a], Seyed Mehdi Hosseiny [b], Somayyeh Mirshekari [a]

[a] Research Institute of Zabol, Zabol, Iran
[b] Department of Agricultural Economics, Management and Economic Faculty, University of Sistan and Baluchestan, Zahedan, Iran

ARTICLE INFO

Article history:
Received: 4 April 2022
Accepted: 10 May 2022
Available online: 1 June 2022

Keywords:
α- cut technique
Decision making units
Efficiency
Fuzzy context
Fuzzy DEA models

ABSTRACT

The disparity in agricultural production unit performance is a critical and fundamental issue that necessitates the implementation of required programs and policies to ensure an equilibrium in the distribution of resources and seeds in order to increase efficiency. Enhancing efficiency can result in economic growth and development in the agricultural sector, as well as rural development. In recent years, the potato has been regarded as the dominant crop in Kabodarahang; policy formulation based on production efficiency has become a necessity, given the importance of production and the rational use of seeds in potato production. Thus, the efficiency, effectiveness, and productivity of production units were determined under uncertain conditions using various level-cut and fuzzy data envelopment analysis methods for potato farms in Kabodarahang; the most efficient units were selected. The result indicates that 14% of producers are efficient or near-efficient. Additionally, 75% of producers operate at a level of efficiency between 70% and 100%. In total, unit 6 is the most productive and stable of the other units. As a result, this unit is chosen as the best producer. Efficiency analysis at various levels reveals that producers operate at a high level of efficiency. Therefore, to increase production, manufacturing technology should be enhanced. Thus, politicians and policymakers should take into account new technologies for planting, growing, and harvesting.

Highlights

- As a result of the disparity in agricultural production unit performance, programs and policies must be implemented to ensure an equilibrium in the distribution of resources and seeds.
- Increasing efficiency can lead to increased agricultural and rural economic growth.
- Given the importance of production and the rational use of seeds in potato production, policy formulation based on production efficiency has become necessary.
- 14% of potato farms in KabodarAhang are efficient or near-efficient, 75% of producers are between 70% and 100% efficient.
- Politicians and policymakers should consider new planting, growing, and harvesting technologies.

1. Introduction

Data Envelopment Analysis (DEA) can be considered a robust performance management tool to evaluate decision-making units (DMUs) capable of benchmarking the unit's performance against other competitors and deciding on a better future based on its outcomes. This tool measures the relative efficiency of DMUs with the same inputs and outputs and, accordingly, specifies efficient and inefficient units of performance (Alinezhad et al., 2018). In low-income countries, agricultural production, indirectly related to people's lives, is recognized as a strategic product. Several studies indicate the specific status of this product in the countries mentioned above (Mardani and Ziaee, 2016). Potato products are of particular importance because of their high nutritional value. Production of this

* Corresponding author
Email: zahraghafari@uoz.ac.ir
http://dx.doi.org/10.22034/aes.2022.336019.1029

product in developed countries is greater than in developing countries (Sepehrdoust and Emami, 2017).

Potato production in Iran is about 5 million tons, and its per capita consumption is about 45 kg (Ministry of Jahad Agriculture, 2011). With 23.5% of the country's potato production, Hamedan province has first place in the production of this crop. Besides, in the 2012-2013 crop year, 16.63% of the total potato croplands were allocated to Hamedan. This province ranked first with 21.72% of the Sepehrdoust and Emami, 2017). The Kabodarahang region in this province, whose farmers pay a lot of attention to the potato crops, is the leading producer of potatoes in the country and the exporter of this product to neighboring countries (Sepehrdoust and Emami, 2017). In this regard, rational planning to manage the production of this product and the way to use the production resources to increase production efficiency is inevitable.

DEA is a tool to measure the relative efficiency of units under evaluation that have multiple inputs and outputs. DEA was first described by Charnes et al. in 1978 and is widely used in Multi-Criteria Decision Making (MCDM). It considers a nonparametric linear programming technique to evaluate relative efficiency in decision-making units, using multiple inputs and outputs. Over the last three decades, various DEA models have been used to measure technical efficiency or effectiveness in different units. Most studies have compared the preference for technical efficiency with technical performance (Chiou et al., 2010). In many applications, they have encountered inaccurate or ambiguous data; our knowledge of the production process is inaccurate. This has led to combining the data envelopment analysis model with fuzzy set theory (Chiou et al., 2010). Bellman and Zadeh introduced the fuzzy concept to measure the efficiency based on inaccurate data in the decision-making process (Bellman and Zadeh, 1970).

Sengupta (1992) was the first to introduce a fuzzy programming method that was used in DEA models for multiple inputs. Cooper et al. (1999) proposed a model with the ability to consider inputs and outputs as either crisp or interval values. Guo and Tanaka (2001) considered data in the form of fuzzy Triangular and then, by applying the α-cut on constraint with comparison, determined the efficiency interval for each DMU. Hatami Marbini et al. (2017) proposed a novel fully fuzzy data envelopment analysis (FFDEA) approach, in which all the variables are considered fuzzy, including input and output data and efficiency scores. Moreover, a lexicographic multi-objective linear programming (MOLP) approach is suggested for solving the fuzzy models. Chiou et al. (2010) proposed two novel integrated data envelopment analysis (IDEA) approaches, comprising ICCR and IBCC, to jointly measure the technical efficiency and service effectiveness for bus transit services under constant and variable returns to scale technologies. It is demonstrated that the proposed novel IDEA approaches have higher benchmarking power than the conventional separate DEA. As Kumar et al. (2014) investigated, DEA provides a robust approach to supplier selection problems. Weber et al. (2000) proposed MOP and DEA to evaluate suppliers. Farzipoor Saen (2009) proposed a DEA model for supplier selection in the presence of both undesirable outputs and inaccurate data. Sengupta (1992) integrated fuzzy inputs and outputs in the DEA model by defining boundary levels in the objective function and constraining them. Hatami-Marbini et al. (2011) proposed a linear programming (LP) model with fuzzy parameters to measure the fuzzy efficiency of the DMUs. For different α levels, Esmaeili (2012) addressed an enhanced Russell measure (ERM) model with interval Data to evaluate the efficiency of the decision-making units. Azadi et al. (2015) used concept fuzzy in sustainable supply chain management to find the best supplier, and they created envelopment analysis using the Russell measure model. Qin and Liu (2010) developed a fuzzy random DEA (FRDEA) model, where randomness and fuzziness exist simultaneously. Many researchers have also proposed and applied various fuzzy DEA models (e.g., Nandy and Singh, 2021; Mardani et al., 2020; Dadmand and Naji Azimi, 2018; Hatami Marbini et al., 2012; Tlig and Hamed, 2017).

As mentioned above, several studies have examined performance using data envelopment analysis and fuzzy data envelopment analysis, and most of these studies have only obtained the concept of efficiency for decision units, but in this study, Using the proposed model, will obtain the efficiency, effectiveness, and productivity of the production units in conditions of uncertainty, using different levels of alpha for potato fields in Kaboudar Ahang, and the most efficient units will be selected.

Table 1. The nomenclatures.

Variable	Definition	Variable	Definition
j	The index of DMUs1,...,j n	ε_1 and ε_2	Predetermined acceptable levels of the possibility of objective function
r	The index of outputs1,...,r s	$\bar{\mathcal{G}}$	The maximum value denoting return function of effectiveness
i	The index of inputs1,...,i m	$\bar{\mathcal{F}}$	The maximum value denoting return function of efficiency
DMU_0	The DMU under evaluation	$\tau_1 \dots . \tau_5$	Predetermined acceptable levels of the possibility of constrains
y_{rj}	The rth output of jth DMU	v_i	The weight for the ith input
x_{ij}	The ith input of jth DMU	$\propto . \beta . \mu_i . f_r$	The dual variables
y_{ro}	The rth output of DMU_0	g_{to}	The tth goal of the DMU_0
x_{io}	The ith input of DMU_0	η_t	The weight of the tth goal
u_r	The weight for the rth output		

2. Material and method

In most studies that measure performance, efficiency can only be achieved using a fuzzy concept. The proposed model measures effectiveness, efficiency, and productivity in a fuzzy context. DEA can be considered as a method to determine the efficiency of a set of decision-making units (DMUs) based on the measure of outputs rather than inputs.

Although the typical method of DEA can be considered a powerful tool for measuring the efficiency of decision-making units, it also has some limitations. One of the most

important of these limitations may be the high sensitivity of this method to the value change in input and output data or the uncertainty associated with these data, So that the ranking and stimulation of unit efficiency level can be changed entirely with the slightest change in the values of input and output data (Kao and Liu, 2003). Due to the sampling errors or the use of the central tendency indexes, the uncertainty in the data for estimation of the DEA model in the agricultural sector is inevitable, and the necessity of using models that are capable of controlling the changes resulting from unreliable data (Toma et al. 2015).
The indices, parameters and variables that will be used in this study are described in Table 1.

The model used in the current study was developed by Azadi et al. (2015). Assumptions are evaluated by the Decision-making unit (DMU). Any DMU would consume different inputs and produce different outputs. Consider $x_{ij}(i = 1.2. \dots . m)$ and $y_{rj} = (1.2. \dots . s)$ demonstrating data fuzzy input and output ofDMU_j; u_r. v_i denote the rth output weight and ith input weight, respectively. N is the number of DUMs, (j=1, 2… n). Assuming all the inputs and outputs are positive, Esmaeili (2012) proposed the dual of ERM as follows:

$$\text{Max } E = \alpha - \beta \qquad (1)$$
$$\text{s.t } \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0. \qquad j = 1. \dots . n$$
$$v_i x_{io} - \mu_i \leq \frac{1}{m}. \qquad i = 1 \dots . m$$
$$\frac{\propto}{s} - u_r y_{ro} + f_r \leq 0. \qquad R = 1 \dots . s$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i \geq 0$$

The dual variable $\propto$ in the first constraint of the primal model implies the average output efficiency. The dual variables β and f_r associated with Equation (1) have no practical implications. They have only been developed to transform a non-linear model into a linear one. The $E = [0.1]$ denotes the efficiency score of DUM_o. If the objective function of the Equation (1) equals 1 known as theDUM_o, it is a relatively efficient unit. Otherwise, the DUM is a relatively inefficient unit. In many cases, measuring the effectiveness of each DUM can be as important as the efficiency measurement. Effectiveness refers to how much a company can meet its predetermined goals. The traditional DEA models fail to measure the effectiveness of DUMs. In this paper, we define the effectiveness of a DMU as the ratio of the output to the predetermined goals as follows (Azadi et al., 2015):

$$\text{Effectiveness} = \frac{\text{output}}{\text{goal}} \qquad (2)$$

To this end, a new model is proposed. To measure both the efficiency and effectiveness of the DMU_o the Equation (1) is converted as follows (Azadi et al. 2015):

$$Max\ \alpha - \beta + \left(\frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{t=1}^{T} \eta_t g_{to}}\right) \qquad (3)$$
$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0. \qquad j = 1 \dots . n$$
$$v_i x_{io} - \mu_i \leq \frac{1}{m}. \qquad i = 1 \dots . m$$
$$\frac{\propto}{s} - u_r y_{ro} + f_r \leq 0. \qquad R = 1 \dots . s$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{t=1}^{T} \eta_t g_{tj}} \leq 1. \qquad j = 1 \dots . n$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i . \eta_t \geq 0 \qquad \forall i. r. t.$$

Where the *t* goal of the DMU_o is denoted as g_{to}. The η_t is weight of the *t* goal. Equation (3) can be rewritten as follows:

$$\text{Max } P = \left[\sum_{t=1}^{T} \eta_t g_{to}(\alpha - \beta)\right] + \sum_{r=1}^{S} u_r y_{ro} \qquad (4)$$
s.t
$$\sum_{t=1}^{T} \eta_t g_{to} = 1$$
$$\sum_{r=1}^{S} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0. \qquad j = 1 \dots m$$
$$v_i x_{io} - \mu_i \leq \frac{1}{m}. \qquad i = 1 \dots . m$$
$$\frac{\propto}{S} - u_r y_{ro} + f_r \leq 0. \qquad R = 1 \dots . s$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{t=1}^{T} \eta_t g_{tj} \leq 0. \qquad j = 1 \dots n$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i . \eta_t \geq 0 \qquad \forall i. r. t.$$

The $P \in [0.2]$ shows the productivity score of DMU_o. If the optimal value of the Equation (4) equals 2, the $DMU_o$is relatively productive. Otherwise, the DMU is relatively unproductive. As addressed by Dittenhofer (2001), there are two reasons for measuring suppliers' productivity. One is because productivity is used to check whether or not a producer is performing satisfactorily. The second reason is that measuring productivity is a motivator for the producer. Productivity measurement may increase competition among producers (Azadi et al., 2015). Now, the fuzzy numbers are incorporated into Equation (4). Equation (4) can be developed to Equation (5) as follows:

$$\max P = \left[\sum_{t=1}^{T} \eta_t \tilde{g}_{to}(\alpha - \beta)\right] + \sum_{r=1}^{S} u_r \tilde{y}_{ro} \qquad (5)$$
$$\sum_{t=1}^{T} \eta_t \tilde{g}_{to} = 1$$
$$\sum_{r=1}^{S} u_r \tilde{y}_{rj} - \sum_{i=1}^{m} v_i \tilde{x}_{ij} \leq 0. \qquad j = 1 \dots m$$
$$v_i \tilde{x}_{io} - \mu_i \leq \frac{1}{m}. \qquad i = 1 \dots . m$$
$$\frac{\propto}{S} - u_r \tilde{y}_{ro} + f_r \leq 0. \qquad R = 1 \dots . s$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\sum_{r=1}^{s} u_r \tilde{y}_{rj} - \sum_{t=1}^{T} \eta_t \tilde{g}_{tj} \leq 0. \qquad j = 1 \dots n$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i . \eta_t \geq 0 \qquad \forall i. r. t.$$

Where $\tilde{x}_{ij}(i = 1 \dots . m)$,$\tilde{y}_{rj}(r = 1 \dots . s)$ and $\tilde{g}_{tj}(j = 1 \dots . T)$ are fuzzy input, output, and goals of DMUs.This fuzzy integrated DEA model cannot be solved as a crisp model. To solve this model, many methods have been proposed, one of which is α – cut technique (Puri and Yadav, 2014;

Azadi et al., 2015; Wen and Li, 2009; Lozano 2014a, 2014b). α – Cut technique is a method that inputs and outputs are shown by different α – cut and different confidence intervals and levels. Each fuzzy coefficient can be viewed as a fuzzy variable, and each constraint can be considered a fuzzy event. Given the proposed model and the concept of the possibility space of the fuzzy event, some constraints are known as crisp values, and *others* are defined as uncertain values. For this reason, the objective function of the fuzzy integrated model can be written as follows:

$$\max \bar{\mathcal{G}} + \bar{\mathcal{F}} \tag{6}$$
s.t:
$$\pi\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to}(\alpha-\beta) \geq \bar{\mathcal{G}}\right) \geq \varepsilon_1$$
$$\pi\left(\sum_{r=1}^{s} u_r \tilde{y}_{ro} \geq \bar{\mathcal{F}}\right) \geq \varepsilon_2$$

Where ε_1 and ε_2 are predetermined acceptable levels of possibility for the two sections of the objective function. Therefore, the objective value $\bar{\mathcal{G}}$ is the maximum value that the return function $\sum_{t=1}^{T} \eta_t \tilde{g}_{to}(\alpha-\beta)$can be achieved at possibility level ε_1 or higher. Moreover, the objective value $\bar{\mathcal{F}}$ is the maximum value that the return function $\sum_{r=1}^{s} u_r \tilde{y}_{ro}$ can reach at the possibility level ε_2 or higher and is subject to the possibility levels of other fuzzy and crisp constraints. By adding the other constraints, the fuzzy integrated model can be reformulated by the following expression:

$$\max \mathrm{P} = \bar{\mathcal{G}} + \bar{\mathcal{F}} \tag{7}$$
s.t:
$$\pi\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to}(\alpha-\beta) \geq \bar{\mathcal{G}}\right) \geq \varepsilon_1$$
$$\pi\left(\sum_{r=1}^{S} u_r \tilde{y}_{ro} \geq \bar{\mathcal{F}}\right) \geq \varepsilon_2$$
$$\pi\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to} = 1\right) \geq \tau_1$$
$$\pi\left(\sum_{r=1}^{S} u_r \tilde{y}_{rj} - \sum_{i=1}^{m} v_i \tilde{x}_{ij} \leq 0\right) \geq \tau_2 \qquad j = 1 \ldots m$$
$$\pi\left(v_i \tilde{x}_{io} - \mu_i \leq \frac{1}{m}\right) \geq \tau_3 \qquad i = 1 \ldots . m$$
$$\pi\left(\frac{\propto}{s} - u_r \tilde{y}_{ro} + f_r \leq 0\right) \geq \tau_4 \qquad \mathrm{R} = 1 \ldots . \mathrm{s}$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\pi\left(\sum_{r=1}^{s} u_r \tilde{y}_{rj} - \sum_{t=1}^{T} \eta_t \tilde{g}_{tj} \leq 0\right) \geq \tau_5 \qquad j = 1 \ldots n$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i . \eta_t \geq 0 \qquad \forall \mathrm{i.r.t.}$$

The related constraints should achieve the possible level where $\tau_1 \ldots \tau_5$ are the predefined levels. In the crisp condition, the DMU will be relatively productive if the optimal value of Equation (4) equals 2. Meanwhile, the objective value $[\sum_{t=1}^{T} \eta_t \tilde{g}_{to}(\alpha-\beta)] + \sum_{r=1}^{S} u_r \tilde{y}_{ro}$ is the productive criterion of the DMU. Also $\bar{\mathcal{G}}$ and $\bar{\mathcal{F}}$ in the fuzzy integrated model are used to determine if the DMU is relatively productive at the predetermined possibility level. A DMU is productive if its $\mathrm{P} = \bar{\mathcal{G}} + \bar{\mathcal{F}}$ value is greater than or equals 2, otherwise, it is nonproductive. This Equation can be rewritten as follows:

$$\max \mathrm{P} = \bar{\mathcal{G}} + \bar{\mathcal{F}} \tag{8}$$
s.t:
$$(\alpha-\beta)\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to}\right)_{\varepsilon_1}^{u} \geq \bar{\mathcal{G}}$$
$$\left(\sum_{r=1}^{S} u_r \tilde{y}_{ro}\right)_{\varepsilon_2}^{u} \geq \bar{\mathcal{F}}$$
$$\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to}\right)_{\tau_1}^{u} \geq 1$$
$$\left(\sum_{t=1}^{T} \eta_t \tilde{g}_{to}\right)_{\tau_1}^{u} \leq 1$$
$$\left(\sum_{r=1}^{S} u_r \tilde{y}_{rj} - \sum_{i=1}^{m} v_i \tilde{x}_{ij}\right)_{\tau_2}^{L} \leq 0 \qquad j = 1 \ldots m$$
$$(v_i \tilde{x}_{io} - \mu_i)_{\tau_3}^{L} \leq \frac{1}{m} \qquad i = 1 \ldots . m$$
$$\left(\frac{\propto}{s} - u_r \tilde{y}_{ro} + f_r\right)_{\tau_4}^{L} \leq 0 \qquad \mathrm{R} = 1 \ldots . \mathrm{s}$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$
$$\left(\sum_{r=1}^{s} u_r \tilde{y}_{rj} - \sum_{t=1}^{T} \eta_t \tilde{g}_{tj}\right)_{\tau_5}^{L} \leq 0 \qquad j = 1 \ldots n$$
$$\propto . \beta . \mu_i . f_r . u_r . v_i . \eta_t \geq 0 \qquad \forall \mathrm{i.r.t.}$$

In the present study, we use triangular fuzzy numbers. Consider $\tilde{g}_{tj} = (g_{tj}^a . g_{tj}^b . g_{tj}^c)$ is a fuzzy triangular number for the *t* goal of DMU_j; $\tilde{y}_{rj} = (y_{rj}^a . y_{rj}^b . y_{rj}^c)$ is a triangular fuzzy number for the rth output ofDMU_j, and $\tilde{x}_{ij} = (x_{ij}^a . x_{ij}^b . x_{ij}^c)$ is a triangular fuzzy number for the ith input of DMU_j. In this case, the linear programming model that transformed into the fuzzy model is presented as follows:

$$\max \mathrm{P} = \bar{\mathcal{G}} + \bar{\mathcal{F}} \tag{9}$$
$s.t$:
$$(\alpha-\beta)\sum_{t=1}^{T} \eta_t \left(g_{t1}^c - \varepsilon_1 (g_{ti}^c - g_{ti}^b)\right) \geq \bar{\mathcal{G}}$$
$$\sum_{r=1}^{S} u_r \left(y_{r1}^c - \varepsilon_2 (y_{r1}^c - y_{r1}^b)\right) \geq \bar{\mathcal{F}}$$
$$\sum_{t=1}^{T} \eta_t \left(g_{t1}^c - \tau_1 (g_{t1}^c - g_{t1}^b)\right) \geq 1$$
$$\sum_{t=1}^{T} \eta_t \left(g_{t1}^c - \tau_1 (g_{t1}^c - g_{t1}^b)\right) \leq 1$$
$$\sum_{r=1}^{S} u_r \left(y_{rj}^a + \tau_2 (y_{rj}^b - y_{rj}^a)\right) - \sum_{i=1}^{m} v_i \left(x_{ij}^a + \tau_2 (x_{ij}^b - x_{ij}^a)\right) \leq 0$$
$$v_i \left(x_{i1}^a + \tau_3 (x_{i1}^b - x_{i1}^a)\right) - \mu_i \leq \frac{1}{m}$$
$$\frac{\propto}{s} - u_r \left(y_{r1}^a + \tau_4 (y_{r1}^b - y_{r1}^a)\right) + f_r \leq 0$$
$$\sum_{r=1}^{S} u_r \left(y_{rj}^a + \tau_2 (y_{rj}^b - y_{rj}^a)\right) - \sum_{t=1}^{T} \eta_t \left(g_{tj}^a + \tau_5 (g_{tj}^b - g_{tj}^a)\right) \leq 0$$
$$\sum_{i=1}^{m} \mu_i - \sum_{r=1}^{s} f_r - \beta \leq 0$$

3. Result

This study used the model developed by Azadi et al. (2015) for ranking and measuring the efficiency of agricultural units in the region of Kabodarahang.

The required data was collected through a questionnaire in the villages of Kabodarahang in 2022–2021. To evaluate the validity and reliability of the questionnaire, Cronbach's alpha test was used after reviewing and confirming it with several subject matter experts. Its coefficient was estimated to be 0.81, which indicates the appropriate validity of the research tool. Then the data was analyzed using GAMS software.

The GAMS software has run this model. In this study, all the fuzzy constraints should be satisfied at the same possibility level. The results for five different possibility levels (0, 0.25, 0.5, 0.75, and 1) are presented in Table 2.

The results in Table 2 demonstrate that the three units of 3, 6, and 21 have the highest productivity at five probability levels. At the alpha level = 1, they have a productivity of 2 and are pretty efficient. Unit 22 has the lowest productivity rates of 0.67, 0.71, 0.75, 0.74, and 0.71 at five probability levels. By increasing the level of probabilities studied, the productivity of production units has also increased.

Table 2. Results of effectiveness, efficiency, and productivity indicators at different alpha levels

	Alpha=0			Alpha=0.25			Alpha=0.5		
No. DUMs	Effectiveness	Efficiency	Productivity	Effectiveness	Efficiency	Productivity	Effectiveness	Efficiency	Productivity
1	0.476	0.714	1.19	0.528	0.714	1.242	0.584	0.714	1.299
2	0.667	1	1.67	0.739	1	1.739	0.818	1	1.818
3	0.667	1	1.67	0.739	1	1.739	0.818	1	1.818
4	0.667	1	1.67	0.739	1	1.739	0.818	0.96	1.78
5	0.667	1	1.67	0.739	1	1.739	0.818	0.99	1.81
6	0.667	1	1.67	0.739	1	1.739	0.818	1	1.82
7	0.524	0.786	1.31	0.581	0.786	1.366	0.64	0.79	1.429
8	0.571	0.857	1.43	0.634	0.857	1.491	0.70	0.857	1.558
9	0.667	1	1.67	0.739	1	1.739	0.818	1	1.181
10	0.476	0.714	1.19	0.528	0.647	1.175	0.511	0.641	1.153
11	0.476	0.711	1.187	0.528	0.638	1.166	0.502	0.641	1.144
12	0.476	0.714	1.19	0.525	0.701	1.226	0.579	0.786	1.221
13	0.524	0.786	1.31	0.581	0.786	1.366	0.643	0.786	1.429
14	0.571	0.857	1.43	0.612	0.857	1.469	0.674	0.801	1.475
15	0.433	0.714	1.148	0.413	0.714	1.127	0.584	0.520	1.104
16	0.667	1	1.67	0.739	1	1.739	0.818	1	1.818
17	0.571	0.857	1.43	0.634	0.857	1.491	0.701	0.857	1.558
18	0.524	0.786	1.31	0.581	0.786	1.366	0.643	0.786	1.429
19	0.429	0.643	1.07	0.475	0.643	1.118	0.526	0.606	1.132
20	0.333	0.5	0.83	0.370	0.488	0.858	.409	0.409	0.818
21	0.667	1	1.67	0.739	1	1.739	0.818	1	1.818
22	0.286	0.429	0.714	0.317	0.429	0.745	0.336	0.411	0.746
23	0.571	0.857	1.43	0.634	0.824	1.458	0.589	0.857	1.446
24	0.476	0.714	1.19	0.528	0.654	1.182	0.446	0.714	1.160
25	0.550	0.857	1.41	0.634	0.754	1.387	0.511	0.857	1.368
26	0.554	0.857	1.401	0.634	0.757	1.390	0.522	0.857	1.379
27	0.407	0.714	1.12	0.528	0.572	1.10	0.363	0.714	1.077
28	0.381	0.571	0.95	0.422	0.571	0.994	0.468	0.571	1.039
29	0.571	0.857	1.43	0.634	0.857	1.491	0.639	0.857	1.496
30	0.381	0.571	0.95	0.422	0.513	0.935	0.330	0.571	0.901
31	0.667	0.955	1.62	0.79	0.882	1.622	0.697	0.924	1.622
32	0.381	0.558	0.94	0.422	0.485	0.907	0.378	0.496	0.874
33	0.571	0.827	1.40	0.531	0.857	1.388	0.520	0.857	1.377
34	0.476	0.714	1.19	0.480	0.714	1.194	0.457	0.714	1.171
35	0.381	0.558	0.94	0.336	0.571	0.907	0.302	0.571	0.874
36	0.604	1	1.60	0.604	1	1.604	0.604	1	1.604
37	0.619	0.929	1.55	0.686	0.929	1.615	0.760	0.929	1.688
38	0.571	0.857	1.43	0.634	0.857	1.491	0.701	0.857	1.558
39	0.619	0.929	1.55	0.686	0.929	1.615	0.760	0.929	1.668
40	0.571	0.929	1.55	0.686	0.929	1.615	0.760	0.929	1.688
41	0.619	0.857	1.43	0.634	0.857	1.491	0.701	0.857	1.558
42	0.524	0.786	1.31	0.581	0.786	1.366	0.643	0.786	1.429
43	0.524	0.786	1.31	0.581	0.786	1.366	0.643	0.786	1.429
44	0.476	0.714	1.19	0.528	0.672	1.20	0.584	0.593	1.178
45	0.571	0.857	1.43	0.634	0.851	10484	0.701	0.772	1.1473
46	0.381	0.571	0.95	0.422	0.571	0.994	0.468	0.571	1.039
47	0.476	0.714	1.19	0.528	0.714	1.242	0.584	0.714	1.299
48	0.571	0.857	1.43	0.634	0.587	1.491	0.701	0.857	1.558

Table 2 continued.

No. DUMs	Alpha=0.75			Alpha=1		
	Effectiveness	Efficiency	Productivity	Effectiveness	Efficiency	Productivity
1	0.646	0.714	1.409	0.714	0.694	1.361
2	0.889	1	1.889	1	0.889	1.889
3	0.905	1	2	1	1	1.905
4	0.771	1	1.766	1	0.766	1.771
5	0.818	1	1.822	1	0.822	1.818
6	0.905	1	2	1	1	1.905
7	0.711	0.786	1.57	0.786	0.786	1.497
8	0.776	0.857	1.70	0.857	0.845	1.633
9	0.853	1	1.86	1	0.860	1.853
10	0.414	0.714	1.10	0.714	0.387	1.128
11	0.405	0.714	1.09	0.714	0.377	1.119
12	0.496	0.714	1.19	0.714	0.473	1.210
13	0.711	0.786	1.57	0.786	0.786	1.497
14	0.743	0.732	1.47	0.821	0.650	1.475
15	0.614	0.466	1.05	0.672	0.381	1.080
16	0.895	1	1.90	0.957	0.947	1.895
17	0.776	0.857	1.71	0.857	0.857	1.633
18	0.711	0.786	1.57	0.786	0.786	1.497
19	0.582	0.531	1.08	0.643	0.439	1.113
20	0.452	0.322	0.727	0.5	0.227	0.775
21	0.905	1	2	1	1	1.905
22	0.336	0.371	0.67	0.336	0.336	0.707
23	0.577	0.857	1.42	0.563	0.857	1.434
24	0.421	0.714	1.11	0.394	0.714	1.135
25	0.491	0.857	1.33	0.471	0.857	1.348
26	0.510	0.857	1.35	0.496	0.857	1.367
27	0.338	0.714	1.026	0.311	0.714	1.053
28	0.479	0.571	1.03	0.458	0.571	1.05
29	0.639	0.857	1.49	0.636	0.857	1.497
30	0.293	0.571	0.82	0.252	0.571	0.864
31	0.697	0.924	1.62	0.688	0.934	1.622
32	0.265	0.571	0.796	0.224	0.571	0.836
33	0.507	0.857	1.35	0.494	0.857	1.364
34	0.432	0.714	1.12	0.405	0.714	1.147
35	0.265	0.571	0.80	0.224	0.571	0.836
36	0.604	1	1.604	0.604	1	1.604
37	0.840	0.929	1.86	0.929	0.929	1.769
38	0.776	0.857	1.71	0.857	0.857	1.633
39	0.840	0.929	1.86	0.929	0.929	1.769
40	0.840	0.929	1.86	0.929	0.929	1.769
41	0.776	0.857	1.71	0.857	0.857	1.633
42	0.711	0.786	1.57	0.786	0.786	1.497
43	0.711	0.786	1.54	0.773	0.771	1.497
44	0.646	0.507	1.13	0.701	0.424	1.153
45	0.776	0.685	1.45	0.844	0.603	1.461
46	0.517	0.536	1.03	0.571	0.462	1.053
47	0.646	0.695	1.33	0.714	0.620	1.342
48	0.768	0.857	1.62	0.767	0.857	1.626

According to Table 3, the maximum effectiveness value is 0.82, which is related to units (2, 3, 4, 5, and 6). The maximum efficiency value is 1 (for units 2, 3, and 6); the maximum productivity value among the production units under study is 1.82 (for unit 6). The minimum of these indicators is equal to 0.32, 0.41, and 0.72, and their average is equal to 0.61, 0.78, and 1.37, respectively. According to the results, 14% of production units are efficient. Units 2 to 6, 16, and 21 are superior to other units in terms of the effectiveness index. Units 2, 3, 6, 9, 16, 21, and 36 are efficient units. In total, unit 6 has the highest productivity and is the most stable unit among the other units. Therefore, this unit was selected as the best producer. Furthermore, units 35, 22, 32, and 20 have the lowest efficiencies.

The effectiveness of production units increases with increasing probability levels; in other words, production units get closer to their goals. Likewise, the productivity index increases with increasing probability level and efficiency decreases. The Table 3 shows that potato fields have an average efficiency of 0.80, 0.78, 0.79, 0.78, and 0.73% at different probability levels. In other words, potato production can be increased by using the same amount of input; efficiency will also increase by 20, 22, 21, 22, and 27% at different probability levels. The difference between the lowest and highest levels of efficiency shows that there are many differences between farmers in the region, which can be reduced by various methods, including the introduction of sample farmers. Table 4 show the result of Frequency distribution of effectiveness, efficiency and productivity of potato fields in different alpha level.

Table 3. Summary assessment result of effectiveness, efficiency and productivity for farms in sample in different levels.

	Effectiveness				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Average	0.53	0.58	0.61	0.64	0.70
Max	0.67	0.79	0.82	0.91	1.00
Min	0.29	0.32	0.30	0.27	0.22
Standard deviation	0.10	0.12	0.15	0.19	0.23
	Efficiency				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Average	0.80	0.78	0.79	0.78	0.73
Max	1.00	1.00	1.00	1.00	1.00
Min	0.43	0.43	0.41	0.32	0.23
Standard deviation	0.15	0.16	0.16	0.18	0.20
	Productivity				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Average	1.33	1.37	1.37	1.43	1.42
Max	1.67	1.74	1.82	2.00	1.91
Min	0.71	0.75	0.75	0.67	0.71
Standard deviation	0.25	0.27	0.29	0.37	0.33

Table 4. Frequency distribution of effectiveness, efficiency and productivity of potato fields

	Effectiveness				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Less than 50%	18	10	10	12	11
Between 50% to 60%	8	14	21	5	3
Between 60% to 70%	12	15	9	7	5
More than 70%	0	9	8	23	29
	Efficiency				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Less than 50%	8	14	12	12	17
Between 50% to 60%	15	12	12	13	9
Between 60% to 70%	11	10	11	10	13
More than 70%	13	12	13	13	9
	Productivity				
	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
Less than 1	7	7	5	5	5
Between 1 to 1.5	28	28	26	20	25
Between 1.5 to 2	13	13	17	23	18

4. Conclusion

Due to the importance of potato crops in Kabodarahang city, an attempt was made to measure potato fields' efficiency, effectiveness, and productivity. The presented fuzzy model in this paper is a method for dealing with fuzzy data. To solve the fuzzy model, the insoluble fuzzy model must be converted to a solvable linear model, for which the probability method is used. The findings indicate that the potato growers of Kabodarahang are in good condition in terms of efficiency. In addition, they can increase their efficiency by reducing the use of inputs without reducing the product to avoid wasting production inputs and be placed on the verge of production efficiency. The efficiency index shows that the efficiency values are different at different levels of α. As the probability level increases, the unit's effectiveness increases, the value of efficiency decreases, and the value of productivity increases. Increasing efficiency improves productivity and contributes to achieving the goals of the production unit. According to the results, 14% of the producers are efficient and the rest are on the verge of efficiency. In addition, 75% of the producers have an efficiency of between 70% and 100%. In total, unit 6 has the highest productivity and is the most stable unit among the other units. Thus, this unit was selected as the best producer. An examination of efficiency at different levels of alpha shows that producers are at a high level in terms of efficiency. Therefore, to increase production, production technology should be improved. Thus, politicians and policymakers should consider the new planting, growing, and harvesting technologies.

Reference

Alinezhad, A.R., Kakavand, H., Kazemi, A., Shakorloo, A. 2018. Presenting a hybrid model of data envelopment analysis and multi-objective decision making to achieve the efficiency score of decision making units in grey environment. Journal of Development Evolution Management, 31, 43-49. (In Persian).

Azadi, M., Jafarian, M., Farzinpooor Saen, k., Mirhedayatian, S.M., 2015. Anew fuzzy DEA model for evaluation of efficiency and effectiveness of suppliers in sustainable supply chain management context. Computer and Operation Research. 54, 274-285.

Bellman, R.E., Zadeh, L.A., 1970. Decision-making in a fuzzy environment. Management Science, 17(4), B-141.

Charnes, A., Cooper, W. W., Rhodes, E. 1978. Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444.

Chiou, Y.C., Lan, L.W., Yen, B.T., 2010. A joint measurement of efficiency and effectiveness for nonstorable commodities: Integrated data envelopment analysis approaches. European Journal of Operational Research, 201(2), 477-489.

Cooper, W.W., Park, K.S. and Yu, G., 1999. IDEA and AR-IDEA: models for dealing with imprecise data in DEA. Management Science, 45(4), 597-607.

Dadmand, F., Naji Azimi, Z., 2018. The application of fuzzy dea in evaluating the efficiency of wheat production case study: city of Torbate Hydarieh. Journal of Agricultural Economics Research, 10(1), 87-109. (In Persian).

Dittenhofer, M., 2001. Internal auditing effectiveness: an expansion of present methods. Managerial Auditing Journal, 16(8), 443-450.

Esmaeili, M., 2012. An enhanced Russell measure in DEA with interval data. Applied Mathematics and Computation, 219(4), 1589-1593.

Farzipoor Saen, R., 2009. A decision model for ranking suppliers in the presence of cardinal and ordinal data, weight restrictions, and nondiscretionary factors. Annals of Operations Research, 172(1), 177-192.

Guo, P., Tanaka, H., 2001. Fuzzy DEA: a perceptual evaluation method. Fuzzy Sets and Systems, 119(1), 149-160.

Hatami-Marbini, A., Ebrahimnejad, A., Lozano, S., 2017. Fuzzy efficiency measures in data envelopment analysis using lexicographic multi objective approach. Computers & Industrial Engineering, 105, 362-376.

Hatami-Marbini, A., Saati, S., Tavana, M., 2011. Data envelopment analysis with fuzzy parameters: an interactive approach. International Journal of Operations Research and Information Systems (IJORIS), 2(3), 39-53.

Hatami-Marbini, A., Tavana, M., Emrouznejad, A., Saati, S., 2012. Efficiency measurement in fuzzy additive data envelopment analysis. International Journal of Industrial and Systems Engineering, 10(1), 1-20.

Kao, C., Liu, S.T., 2003. A mathematical programming approach to fuzzy efficiency ranking. International Journal of Production Economics, 86(2), 145-154.

Kumar, A., Jain, V., Kumar, S., 2014. A comprehensive environment friendly approach for supplier selection. Omega, 42(1), 109-123.

Lozano, S., 2014a. Process efficiency of two-stage systems with fuzzy data. Fuzzy Sets and Systems, 234, 36-49.

Lozano, S., 2014b. Computing fuzzy process efficiency in parallel systems. Fuzzy Optimization and Decision Making, 13(1), 73-89.

Mardani, M., Mirzaei, A., Ohadi, N., 2020. Investigating the Rice Energy Efficiency Using Interval Fuzzy Data Envelopment Analysis Model (Case Study: Rice Farmers in Golestan Province). Iranian Journal of Agricultural Economic and Development, 51(4), 663-667. (In Persian).

Mardani, M., Ziaee, S., 2016. Determining the Efficiency of Irrigated Wheat Farms in Neyshabur County under Uncertainty. Journal of Agricultural Economics and Development, 3(2), 136-147. (In Persian).

Ministry of Jahad Agriculture, 2011. Agricultural Statistics of Crops, Deputy of Planning and Economy, Information and Communication Technology Center, (In Persian).

Nandy, A., Singh, P.K., 2021. Application of fuzzy DEA and machine learning algorithms in efficiency estimation of paddy producers of rural Eastern India. Benchmarking an International Journal, 28(1), 229-248.

Puri, J., Yadav, S.P., 2014. A fuzzy DEA model with undesirable fuzzy outputs and its application to the banking sector in India. Expert Systems with Applications, 41(14), 6419-6432.

Qin, R., Liu, Y.K., 2010. A new data envelopment analysis model with fuzzy random inputs and outputs. Journal of Applied Mathematics and Computing, 33(1), 327-356.

Sengupta, J.K., 1992. A fuzzy systems approach in data envelopment analysis. Computers and Mathematics with Applications, 24(8-9), 259-266.

Sepehrdoust, H., Emami, S.A.S., 2017. Comparative advantage of potato production and related government policies in Hamedan. Journal of Agricultural Economics Research, 33, 51-70. (In Persian).

Tlig, H., Hamed, A.B., 2017. Assessing the efficiency of commercial Tunisian banks using fuzzy data envelopment analysis. Journal of Data Envelopment Analysis and Decision Science, 2, 14-27.

Toma, E., Dobre, C., Dona, I., Cofas, E., 2015. DEA applicability in assessment of agriculture efficiency on areas with similar geographically patterns. Agriculture and Agricultural Science Procedia, 6, 704-711.

Weber, C.A., Current, J., Desai, A., 2000. An optimization approach to determining the number of vendors to employ. Supply Chain Management: An International Journal, 5(2), 90-98.

Wen, M., Li, H., 2009. Fuzzy data envelopment analysis (DEA): model and ranking method. Journal of Computational and Applied Mathematics, 223(2), 872-878.

Guide for Authors

Preface

The Journal of *Agriculture, Environment and Society (AES)* welcomes articles in various areas of agriculture from all over the world. Contributions must be original and have not previously been published elsewhere. Please be ensure that there are no conflicts between the authors before submitting. Before being published, manuscripts submitted to *Agriculture, Environment and Society (AES)* are critically reviewed. The purpose of the review is to reassure readers that the papers have been approved by competent and unbiased professionals. The manuscript should be submitted only via the *Agriculture, Environment and Society (AES)* Editorial System (www.aes.uoz.ac.ir). All papers are available free of charge at the Journal's webpage.

Types of article

The following types of contribution are published in Agriculture, Environment and Society (AES):

Original research article: It should describe novel and well validated findings, and experimental techniques should be described in sufficient detail to allow the study to be verified. Research papers of 6000-8000 words in length, with tables, illustrations and references, in which hypotheses are tested and results reported.

Review article: Review and perspective on current issues are accepted and encouraged. The format and length of review papers are more flexible than for a full paper. Typical reviews are less than 12000 words including references.

Short Communications: It is appropriate for recording the results of small-scale research or providing information on novel models or hypotheses, innovative methodologies, procedures, or apparatus. Research papers of 2500-3500 words in length, with tables, illustrations and references.

Structure of Articles

Text should be written in a succinct and cohesive manner, with an emphasis on significant points, conclusions, breakthroughs, or discoveries, as well as their broader relevance. All running text should be saved as a Word document. All writings should be written using Times New Roman font. Both American and British English format are accepted, but not their mixture. The font size for title is 14 point and for the main text is 12 point. The subtitles should be written in Bold and font size of 12 point. Figures and tables can be put within the text or at the bottom. Figures should have a high enough resolution to allow for refereeing.

The original research articles should contain the following sections:

Title

The title should be clear, intelligible to experts in different disciplines, and represent the substance of the article. There may be no abbreviations in the title. The title, authors, and affiliations should all be included on a title page as the first page of the manuscript file.

Name(s) of the author (s) not visible in the manuscript (Double Blind Reviews).

Abstract

The title's information does not need to be duplicated in the abstract. The abstract should not be more than 350 words long. It must include the study's goal, methods, findings, and conclusions. Abbreviations should be used sparingly and explained when first used. The abstract is presented separately from the article in a single paragraph after the title page in the manuscript file.

Keywords

Provide a maximum of six keywords appear immediately after the abstract with alphabetical order. Keywords should cover the most precise phrases in the article and should not be the same as the terms used in the title.

Introduction

The introduction should provide background that puts the manuscript into context and allows readers outside the field to understand the purpose and significance of the study. It should define the problem addressed and why it is important, with a brief review of the key literature and conclude with a brief statement of the overall aim of the work.

Material and methods
Provide sufficient details to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized, and indicated by a reference. If quoting directly from a previously published method, use quotation marks and also cite the source. Any modifications to existing methods should also be described.

Results
Results should be clear and concise.

Discussion
This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Together, these sections should describe the results of the experiments, the interpretation of these results, and the conclusions that can be drawn. Authors should explain how the results relate to the hypothesis presented as the basis of the study and provide a succinct explanation of the implications of the findings, particularly in relation to previous related studies and potential future directions for research.

Conclusions
The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

Appendices
If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Acknowledgements
Acknowledgements of persons, grants, money, and so forth should be included before the reference list in a distinct section.

References
Please ensure that every reference cited in the text is also present in the reference list (and vice versa). In the text, papers with more than two authors should be cited by the last name of the first author, followed by et al., (in italics), space, and the year of publication (example: Jones et al., 2020). If the cited manuscript has two authors, the citation should include both last names, space, and the publication year (example: Smith and Ebrahim, 2018).
In the Reference section, a maximum of ten authors of the cited paper may be given. All references cited in the text must be listed in the Reference section alphabetically by the last names of the author(s) and then chronologically.

Format for Periodical
Author, A.A., Author, B.B., Author, C.C., Year of publication. Title of article. Title of Periodical, volume number (issue number), pages.
Chen, H., Yu, C., Li, C., Xin, Q., Huang, X., Zhang, J., Yue, Y., Huang, G., Li, X., Wang, W., 2016. Modeling the impacts of water and fertilizer management on the ecosystem service of rice rotated cropping systems in China. Agriculture, Ecosystems & Environment, 219, 49-57.

Format for Books
Author, A.A., Year of publication. Title of work: Capital letter also for subtitle. Location: Publisher.
Strunk Jr., W., White, E.B., 2000. The Elements of Style, fourth ed. Longman, New York.

Chapter in an Edited Book
Author, A.A., Author, B.B., Year of publication. Title of chapter, in: Title of book (Eds.). Publisher, Location, pages of chapter.
Mettam, G.R., Adams, L.B., 2009. How to prepare an electronic version of your article, in: Jones, B.S., Smith, R.Z. (Eds.), Introduction to the Electronic Age. E-Publishing Inc., New York, pp. 281–304.

Tables and Figures
Please submit tables and figures as editable text and not as images. All figures and tables should be embedded while correctly positioned.

Tables
Please avoid using vertical lines in tables. Please use "Table" in both text and captions. Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article. The table caption appears above the table using Times New Roman font with font size of 10 points in bold. Use no border for the tables. Footnotes to tables should appear beneath the tables and should be designated by a lower-case superscript letter, †, or z, y, x, etc.

Figures
Ensure that each illustration has a caption. Supply captions separately, not attached to the figure. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used (preferably in the caption). The caption should allow the reader to understand the main elements of what is being shown without needing to refer to then main text. The figure caption appears below the figure and written using Times New Roman font with font size of 10 points in bold. Use no border for the figures. The font size within the figure should not smaller than 8 point and bigger than 10 point. Try to present the figures in gray scale instead of color illustration. Use (Figure) at the end of the sentence and captions and use Figure in text.

Math formulae
Present simple formulae in the line of normal text where possible. In principle, variables are to be presented in italics. Number consecutively any equations that have to be displayed separately from the text in the right margin (if referred to explicitly in the text).

Suggest Reviewers
With the manuscript, the author should include a list of three qualified, independent, prospective reviewers who could perform quality peer reviews of your document. Be sure to include their complete names, affiliations, and current e-mail addresses.

AES

University of Zabol

Agriculture, Environment & Society

Faculty of Agriculture, University of Zabol, Zabol, Iran
P.O. Box 538-98615, Tel: +98-54-31232102
Website: http://www.aes.uoz.ac.ir
Email: aes@uoz.ac.ir, aes.uoz.journal@gmail.com