University of Zabol

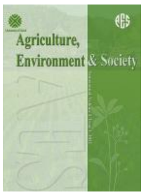
Agriculture, Environment & Society

Biannual, Volume 3, Issue 2, December 2023

Agriculture, Environment & Society (AES)

Volume 3, Issue 2, December 2023

Publisher: University of Zabol



Editorial Office: ***Faculty of Agriculture, University of Zabol, Zabol, Iran, P.O. Box 538-98615***

Tel: +98-54-31232102

Website: http://aes.uoz.ac.ir

Email: aes@uoz.ac.ir, aes.uoz.journal@gmail.com

Aims and Scopes

Agriculture, 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.

Agriculture, 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 *Agriculture, Environment and Society:*

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

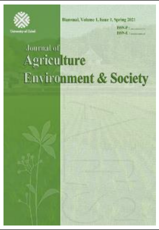
Agriculture, Environment and Society (AES)

Volume 3, Issue 2, December 2023

Contents

Agriculture, Environment & Society

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



The assessment of suitable lands for rain-fed safflower (*Carthamus tinctorius* L.) cultivation in Kermanshah province using the Geographic Information System and Analytical Hierarchy Process model

Alireza Bagheri [*a], Bita Abbasi [a], Sadegh Jalilian [b]

[a] Department of Plant Production and Genetics, Razi University, Kermanshah, Iran
[b] Department of Plant Production and Genetics, University of Zabol, Zabol, Iran

ARTICLE INFO

Article history:
Received: 12 September 2022
Accepted: 16 February 2023
Available online: 18 June 2023

Keywords:
Climatic factors
Digital map
Suitable areas
Topography

ABSTRACT

Recognizing potential areas based on agricultural potentials and determining the suitability of land for specific productivity allows for the planning of increased production and sustainable land use, and provides a suitable foundation for human activities and land development. Using the Geographical Information System (GIS) and the Analytical Hierarchy Process (AHP), this study was conducted to identify areas susceptible to autumn safflower cultivation in Kermanshah province. Altitude, maximum, average, and minimum temperature, precipitation, slope, and slope direction were used as parameters. The ecological needs of safflower were extracted from scientific sources in order to determine the areas suitable for safflower cultivation based on the desired parameters. Then, the measurements-related maps were prepared and classified. Using hierarchical analysis, the weight of each variable was determined in the subsequent step. Finally, the safflower zoning map was extracted from the GIS environment by overlapping and combining the obtained maps. The rainfall gauge and then the maximum temperature had the highest coefficients based on the results of the hierarchical analysis procedure (0.295 and 0.219). 52%, 33%, 13%, and 2% of the total arable land in the Kermanshah province are classified as highly suitable, suitable, semi-suitable, and unsuitable, respectively. Based on the investigated climatic and topographical variables, 85% of the cultivated land in the Kermanshah province is suitable for safflower cultivation. They are predominantly regions with moderate and tropical climates, demonstrating the high potential of Kermanshah province for safflower cultivation as a suitable plant for crop rotation.

Highlights

- Recognizing potential agricultural areas and determining land suitability for specific productivity allows for increased production, sustainable land use, and human activities.
- This study identified autumn safflower cultivation areas in Kermanshah province using GIS and AHP.
- The rainfall gauge and maximum temperature had the highest coefficients in hierarchical analysis.
- 52%, 33%, 13%, and 2% of Kermanshah's arable land is highly suitable, suitable, semi-suitable, or unsuitable for safflower.
- As a crop rotation-friendly plant, safflower is well-suited to Kermanshah's temperate and tropical climates.

1. Introduction

Oilseeds are the most important source of edible oil production. The consumption of edible oil in our country is more than one million tons per year. About 90 to 95 percent of this amount is provided through imports, and for this purpose, more than one billion dollars of foreign currency is taken out of the country every year. Safflower (*Carthamus tinctorius* L.) is an annual plant of the citrus family (Asretaceae) with a nut-shaped fruit that stores oil in its cotyledons (Weiss, 2000). It ranks eighth among

* Corresponding author.
E-mail address: a.bagheri@razi.ac.ir
https://doi.org/10.22034/aes.2023.360749.1044

oilseeds (Yari et al., 2004). The content of seed oil in most cultivars is about 30%, and in some cultivars, it reaches 40% under suitable conditions (Yaghobian and Yaghobian, 2016). Having 73-85% of linoleic fatty acid, safflower oil plays an essential role in reducing blood cholesterol and is considered one of the best vegetable oils in terms of quality (Lotfi et al., 2012). In recent years, the area under safflower cultivation has increased in Iran. In this regard, research on this oil plant is expanding to achieve thornless, high-yielding, oil-rich and cold-resistant cultivars.

Safflower is cultivated in more than 60 countries. In Iran, its cultivation started in 1957 (Baghkhani and Farahbakhsh, 2008). This plant is a native plant of Iran (Zeinali, 2008). Due to its adaptability to a wide range of weather conditions, resistance to drought and salinity stresses, early ripening, and the presence of desirable oil with more than 90% of unsaturated linoleic and oleic fatty acids, it has high industrial and food value (Dwivedi et al., 2005). It grows successfully in areas with low temperatures and soils with low fertility (Koutroubas and Papakosta, 2005). Due to its tolerance to cold, drought and salinity, it can be cultivated in the dry Anatolian regions of Turkey and its surroundings that do not have enough rainfall (FAO, 2019).

Optimal use of agricultural lands requires careful assessment of ecological resources. In ecological zoning, a set of environmental information (climate, topography, soil conditions) is examined to determine land use (Bagheri and Asadi, 2019). Identifying suitable areas based on agricultural potential and determining land suitability for specific productivity makes it possible to plan for increased production and sustainable land use (Sokoti-Oskooei, 2001). The diversity of information and the dynamics of natural resources on the one hand and the need for timely information, on the other hand, have caused geoscience experts to abandon manual and traditional data collection, storage, analysis, and processing, and modern systems including geographic information system (GIS = Geographic information system) to replace it. Appropriate spatial analysis, determination of land capabilities, various modelings such as soil erosion, water and air pollution, and preparation of digital maps with appropriate scale are among the facilities of the geographic information system (Bayat et al., 2001; Cengiz and Akbulak, 2009).

Researchers in the Domerk Plain of Turkey conducted a study with the aim of evaluating the appropriateness of land use for agriculture, forest, and pasture with a geographic information system and analytical hierarchy process (AHP). Finally, based on the assigned weights, the western part of the plain was suitable for agriculture, the eastern part for the forest, and the northern and southern parts for pasture (Bobade et al., 2010).

In India, the land use of the Soni Madhya region was investigated using a geographic information system. The results indicated that out of the total 57% of arable land, 24% for sorghum-soybean, 15% for sorghum-cotton, and 18% for rice, citrus fruits, corn, sunflower, and vegetables were suitable (Yasari et al., 2013).

In another study, Isfahan province was zoned in terms of spring safflower planting date using 48-year temperature data of 51 synoptic and climatology stations. Based on the results, Isfahan province was divided into three temperature zones, and in each zone, suitable planting dates were determined, and maps were drawn. Considering the heat requirement of safflower, if this plant is cultivated in different areas on the suggested planting dates, it will not face restrictive temperatures during the growth period (Rafiei et al., 2015). In another study that examined the climatic zoning of Ilam province for safflower cultivation, the researchers stated that the agricultural lands located in the west and southwest of the province (Dahlran county) have more favorable conditions for safflower cultivation than other regions of the province (Dashti et al., 2012).

Other researchers in East Azerbaijan investigated the quantitative and spatial potential of safflower. In terms of planting safflower, Jolfa and Marand regions (1.6%) were found to be very suitable, and East Tabriz and Warzghan (16.4%) were relatively suitable for safflower cultivation (Seyed Shahivandi et al., 2013). In Lorestan province, grain corn climate zoning was done using a geographic information system by hierarchical analysis method. The zoning map of the land suitable for grain corn cultivation was obtained. Based on the results of the role of each of the climatic and land elements in different regions of the province and by combining the effective layers in the GIS environment, it was possible to identify the areas prone to seed corn cultivation. Finally, 299,521 hectares of the province's lands were found to be very suitable for grain corn cultivation, 809,956 hectares were suitable, 1040,944 hectares were of medium capability, 529,535 hectares were unsuitable, and 95,930 hectares were very unsuitable (Kazemi et al., 2012).

As a result of the research in this field, in the zoning of agricultural lands in Golestan province for rapeseed and soybean production, it was found that 21.3% and 27.4% of agricultural lands are highly suitable and semi-suitable for soybeans, respectively. 27.6% and 27.4% of agricultural lands are located in highly suitable and suitable areas (Kazemi et al., 2014). The researchers zoned the lands of Gorgan using the process of hierarchical analysis in terms of the ability to plant sunflowers. After assigning weight to each of the digital layers of environmental factors, the layers were superimposed and combined. The results showed that 71.4% of the agricultural lands of Gorgan County are located in a highly suitable zone for sunflower production (Borna and Alizadeh, 2016).

In research conducted in Khuzestan province, the agroclimatic zoning of citrus cultivation was investigated in the GIS environment using the Hierarchical Analysis Process method. Based on the results, the northern and eastern regions of the province have good to excellent conditions for citrus cultivation. The limited areas of the province with weak potential include the southern, central, and western parts (Alavi Zadeh et al., 2013; Mohammadi et al., 2011). In research on the feasibility of saffron cultivation in different regions of South Khorasan province, according to the results, the northern and northeastern regions of the province had the best position for saffron cultivation in terms of rainfall and relative humidity. The central regions were reported as semi-suitable and the south of the province as non-suitable (Kouzegaran et al., 2013).

Despite the annual rainfall of more than 300 mm in many areas of Kermanshah province, the production of rainfed crops is limited. The safflower plant has high adaptability to growing in different conditions in a dry state. Identifying areas prone to safflower cultivation in Kermanshah province can provide the basis for the development of safflower cultivation in rainfed lands. In addition, it will create product diversity and increase income in the dry farming sector. Therefore, this study was conducted in order to zoning the rainfed lands of Kermanshah province in terms of safflower cultivation capability using a geographic information system and hierarchical analysis.

2. Materials and methods

2.1. Area of study

Kermanshah province, with an area of about 24435 square kilometers, is located in the middle of the western side of the country between 33 degrees 36 minutes to 35 degrees 15 minutes north latitude and 45 degrees 24 minutes and 48 degrees 30 minutes east longitude from the Greenwich meridian. Kermanshah is one of the western provinces of Iran that share a border with Iraq. This province is bordered by Kurdistan province from the north, Lorestan and Ilam provinces from the south, Hamedan province from the east, and Iraq from the west. Kermanshah city is the capital of Kermanshah province (Figure 1).

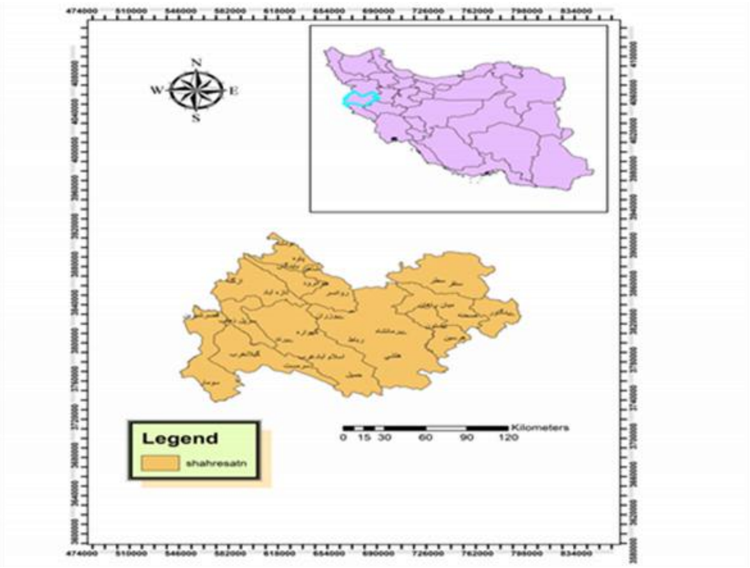


Figure 1. Location of the study area (Kermanshah province)

Kermanshah province has 14 cities, most land belongs to Kermanshah County, with 271,273 hectares, and Paveh County has 874 hectares and the least amount of land. This province with an altitude of 1400 meters above sea level, has an average rainfall of 400 to 500 mm (Eini et al., 2013). The research conducted on the portal of Kermanshah Governorate indicates that more than 1.5 million hectares of natural resource areas of Kermanshah province include forests and pastures, and 942,077 hectares are agricultural lands, of which 210,447 hectares are irrigated lands, and the rest are rainfed. Of course, some statistics indicate that this number is lower than what was mentioned, and they add it to the level of water lands. Because water depends on the amount of annual rainfall, seasonal rivers, and dams in the province and outside the province, so they do not have reliable water and are classified as dry lands.

2.2. Determining the coefficients of the layers using the hierarchical analysis process

The zoning of areas prone to safflower cultivation requires the adaptation of the characteristics and ecological needs of this plant to the environmental conditions of the region. For this purpose, the ecological needs of safflower were determined and graded using available resources (Table 1).

In this way, climatic (rainfall and temperature) and topographical (height, slope and slope direction) requirements of safflower were used as criteria in this experiment.

In order to prepare digital maps, measurements used in the research, plant growth period temperatures and annual rainfall, daily statistics and information from meteorological stations in Kermanshah province were used in the long-term period (10 years). This study was carried out with the assumption of autumn cultivation of safflower.

Since most of the climatic parameters, especially temperature and precipitation, are affected by the geographical conditions of the region (Fatemi Gheiry and Yazdan Panah, 2000). Therefore, in the preparation of maps related to temperature and precipitation, the relationships between these criteria and the geographical features of the region (altitude, longitude and latitude) were used. Therefore, in order to create a multivariable linear relationship, the altitude, longitude, and latitude of meteorological stations were considered independent variables, and temperature and precipitation as dependent

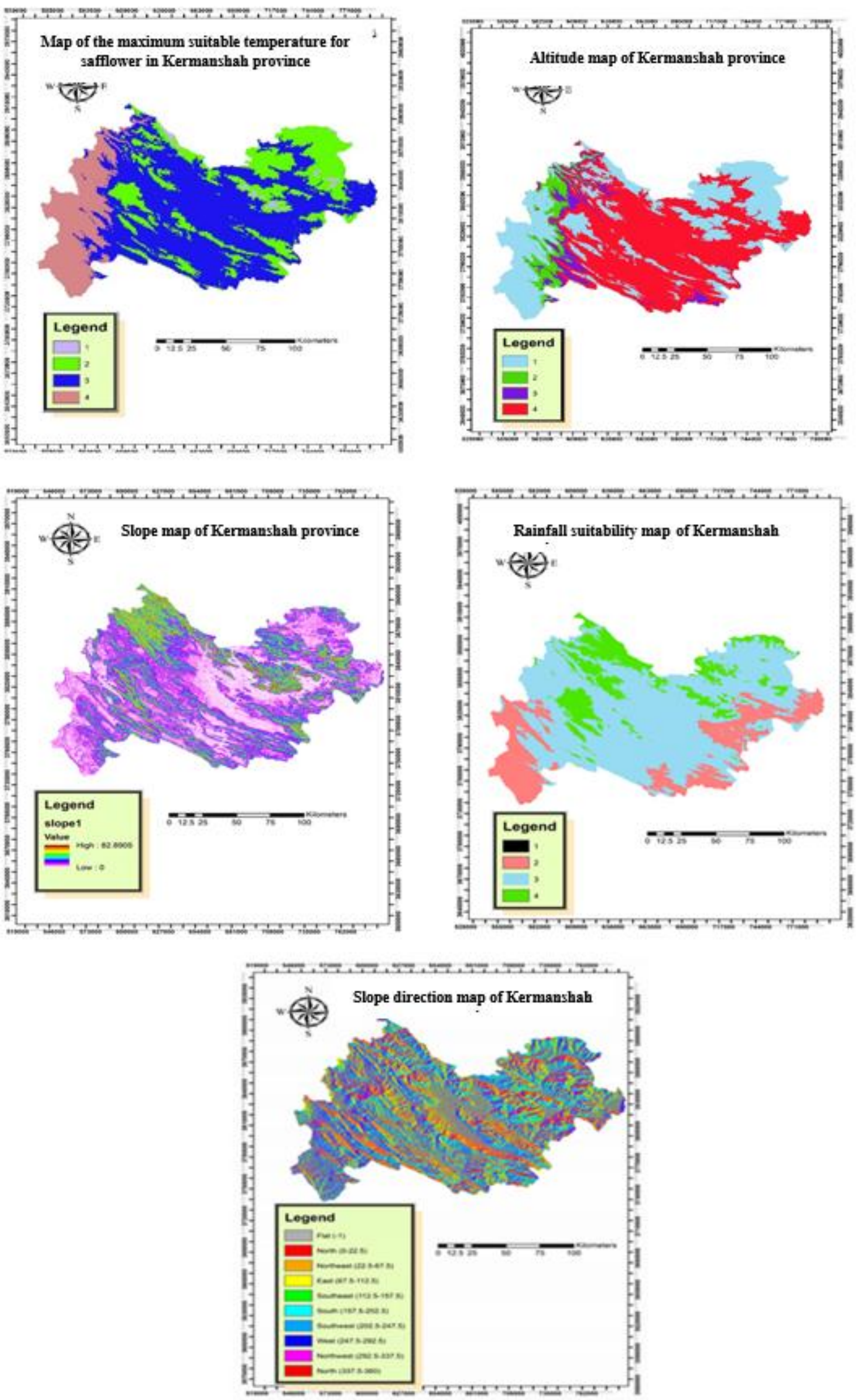


Figure 2. Land suitability map of Kermanshah province based on each of the studied micro-criteria: minimum temperature (a), average temperature (b), maximum temperature (c), altitude (d), rainfall (e), slope (f) and slope direction (g)

variables. In this way, the linear relationship between the height above sea level as well as longitude and latitude as independent variables with temperature (minimum, average and maximum temperatures) and annual precipitation as dependent variables was obtained using SPSS v.20 software. By entering these relations in ArcMap software and using the possibility of Raster Calculator, the same temperature and rainfall raster layers of the studied

area were created. In order to prepare the layers related to the slope measurements and the directions of slope and height, the digital elevation model of Kermanshah province with a spatial accuracy of 30 meters was used in the ArcMap environment (Digital elevation models).
After preparing the layers (raster), classification of the layers (raster classification) was done based on the table of ecological requirements (Table 1), in four classes: high suitable (4), suitable (3), semi-suitable (2), and non-suitable (1) (Figure 2).

2.3. Combine layers

Each of the measures has a different effect on the growth of safflower. A hierarchical analysis process was used to determine the coefficient related to the importance of these measures. Based on the opinions of experts and scientific sources, the gauges were compared in pairs. Then, using Expert Choice software, their importance coefficients were extracted. Moreover, the obtained coefficients were used in the geographic information system to superimpose the raster layers related to each of the gauges (Fathi and Nazari, 2017).

The classified rasters related to each measure were combined using the weighted overlay method in the geographic information system based on the calculated importance coefficient. After combining the layers, the final raster related to all the lands of the province was prepared with four classes: high suitable (4), suitable (3), semi-suitable (2), and non-suitable (1). In order to determine the agricultural lands suitable for the growth of safflower, the final zoning map was cut based on the land use grid related to farms, and all the residential parts, mountains, forests, pastures, and barren lands were removed from the final map. Finally, the area of highly suitable, suitable, semi-suitable and non-suitable for safflower cultivation in agricultural lands was calculated for the province, and important cities were identified.

3. Results and discussion

The results of AHP data analysis showed that according to the weight value and importance of criteria and sub-criteria related to the safflower plant, the importance of climatic variables (rainfall and temperature) was more than other studied variables. Based on the results of the hierarchical process, the rainfall gauge with a coefficient of 0.295, and then the maximum temperature with a coefficient of 0.219 had the highest coefficients (Table 2). After rainfall and maximum temperature, the highest relative importance was observed in slope (0.142), minimum temperature (0.126), height above sea level (0.098), average temperature (0.063), and slope direction (0.057). In research conducted under the title of the effect of temperature and day length on vegetative growth and seed yield in safflower genotypes, the results showed that the maximum temperature, more than any other factor, could affect the growth rate. Moreover, the growth rate in safflower showed a greater response than the maximum temperatures, which can be attributed to the occurrence of moisture and thermal stresses and the reduction in the length of the growth period. (Heydarizadeh et al., 2008). In the study on safflower, the growth rate in the greening to emergence stage was interpreted by the maximum temperature more than other atmospheric variables. The researchers stated that with the increase in temperature, the plant is subjected to thermal and moisture stress, and its growth rate increases greatly (Dadashi and Khajehpour, 2004).

In another study, in field conditions, the growth rate of sunflower cultivars from planting to emergence showed a linear relationship with temperature (Goyne et al., 1990). In autumn safflower planting, planting is done in the cold season, so after the rainfall factor, the temperature gauge is important to ensure the required growth rate. In another study that was conducted among the effective climatic factors of saffron growing in Torbet-Haydriya, rainfall followed by average, maximum, and minimum temperatures were the most important (Sorkh abadi et al., 2015). In Golestan province, the weight of climatic factors was expressed as 0.433 for rapeseed cultivation and 0.269 for soybean cultivation (Kazemi et al., 2012).

In this research, the inconsistency coefficient of the judgments made was less than 0.01, which indicates the coordination of the judgments regarding the criteria and sub-criteria and shows that the comparisons have a very favorable and acceptable consistency. One of the advantages of the hierarchical analysis process is the possibility of evaluating the judgments made in determining the importance coefficients related to criteria and sub-criteria. Thus, by using this method, the possibility of the inconsistency of reviewed judgments and the degree of inconsistency of judgments are shown (Ishizaka and Labib, 2009).

3.1. The potential of safflower cultivation in Kermanshah province by different cities

Highly prone areas (group 4) for safflower cultivation in the province include the cities located in the central region of the province, including Kermanshah (199,273 hectares), Islamabad West (52,825 hectares), Ravansar (42,919 hectares), Dalahu (38,564 hectares), and GilanGharb (33,962 hectares), which includes the plains of Mahidasht, Mian-Darband, and Islamabad. The conditions of the plain, suitable altitude and moderate weather of these areas have provided the necessary conditions for autumn and dry season cultivation of safflower. According to the weather conditions of the province, it is as a suitable cultivar for planting in dry areas such as Faraman thornless red flower variety and Sinai thorny yellow flower variety for these areas (Jabari et al., 2019). According to the results obtained from the long-term study of meteorological data in cold temperate regions, as well as the results of the study in seven provinces, it was shown: Sina cultivar (average yield equal to 1347.2 kg per hectare) has better yield conditions than other safflower cultivars in terms of compatibility. (Poordad, 2017). The best time for autumn sowing of Sina variety is the first decade of November, before the first rain (Pasban Eslam, 2018). According to unreported observations, farmers tend to cultivate thornless cultivars, which can be one of the reasons for the compatibility and proper performance of these cultivars.

According to the report, the Faraman variety, with an average yield of 1079.2 kg per hectare, has a higher yield than the other rainfed safflower varieties after the Sina variety (Poordad, 2017).

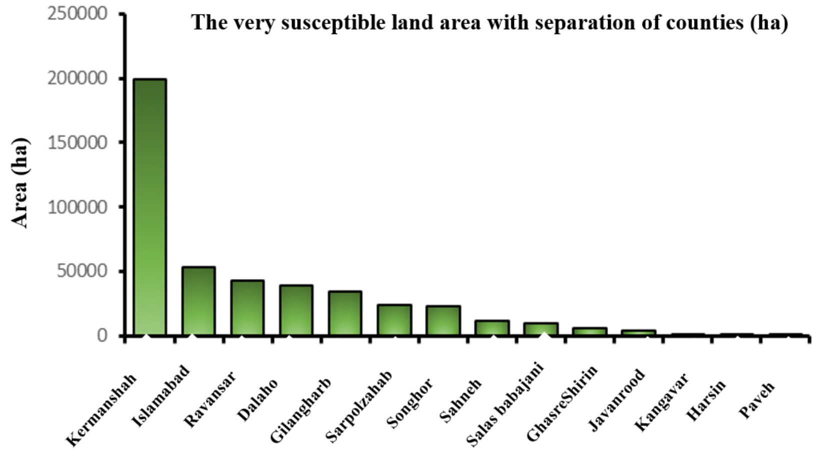


Figure 3. Area and share of highly suitable lands for autumn safflower cultivation in each of the cities

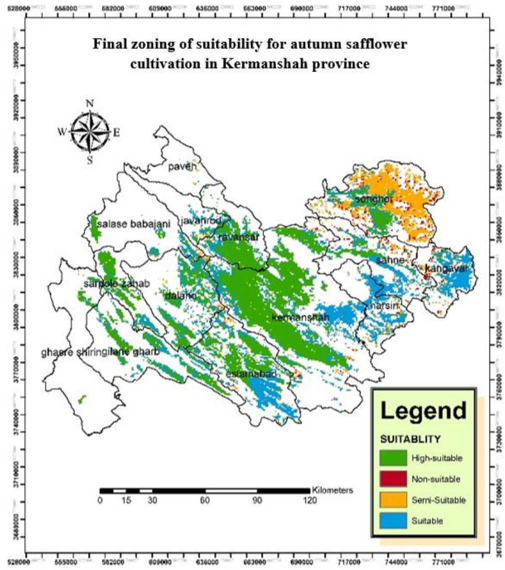


Figure 4. Land suitability map of Kermanshah province for autumn safflower cultivation

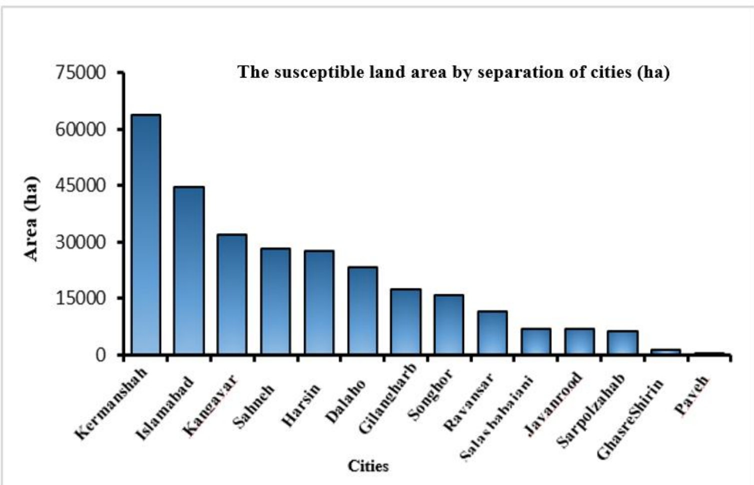


Figure 5. Area and share of suitable lands to autumn safflower cultivation in each of cities

Faraman safflower is a variety resistant to drought stress, early, with an intermediate growth type, thornless, large seeds, with red flowers, with an average plant height of 90 cm and a weight of 1000 seeds of 48 grams, which can be recommended to farmers in these areas. The lowest land classified in the high suitable group of the province was related to Paveh county. Due to its mountainous location, the county of Paveh has a very small amount of total arable land, of which a very small amount is very suitable for safflower cultivation (Figures 3, 4, 5).

Suitable areas (group 3), has a total of 285 thousand hectares of agricultural land in Kermanshah province. Also, it includes the cities located in the center of the province, including the cities of Javanrood, Islamabad and Hamil, Halshi, Bistun, Mian-Rahan, Parts of Kangavar and Dalaho cities, and lands located in the west of Sahne county. In general, 22.5% of the lands of Kermanshah, 15.5% of Islamabad, 11% of Kangavar, 10% of Sahne, 9.5% of Harsin, 8% of Dalahu, and 6.5% of Gilan Gharb were the most suitable areas. Due to having suitable climatic conditions during the safflower growth period, these areas have high performance and can be suitable places to meet the environmental and agricultural requirements of safflower. Similar to the highly suitable group, Paveh County has the least suitable land (1%). As mentioned, due to its mountainous nature, this region has a less cultivated area for agriculture, and its mountainous nature is mostly used for horticulture. After Paveh, Qasr Shirin County has the lowest area of safflower cultivation areas with 2%, which can be attributed to the high air temperature and dryness of the area in the conditions of rainfed cultivation (Figure 6).

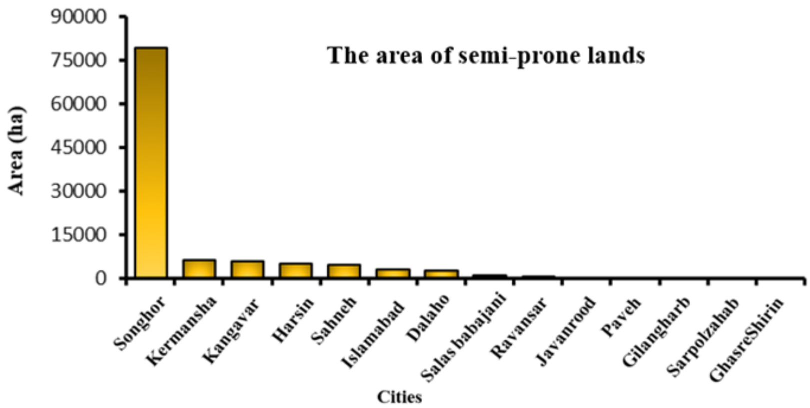


Figure 6. Area and share of semi-suitable lands for autumn safflower cultivation in each county

The semi-suitable areas (group 2) cover about 109 thousand hectares of the province's lands. The most important of which, respectively, included Sanghar counties (72 percent), about 6 percent of the lands of Kermanshah county, and 5 percent of the lands in the west of Kangavar county. The low air temperature in the months of March and April, at the same time as the beginning of the plant's growth period, can lead to a decrease in the proper growth and development of safflower in these areas. On the other hand, the area of this group of lands is small in Qasrshirin Safar county and Sarpol Zahab county (Figure 7). In terms of having suitable ecological conditions, including temperature for safflower cultivation, these areas have weaker conditions than suitable areas.

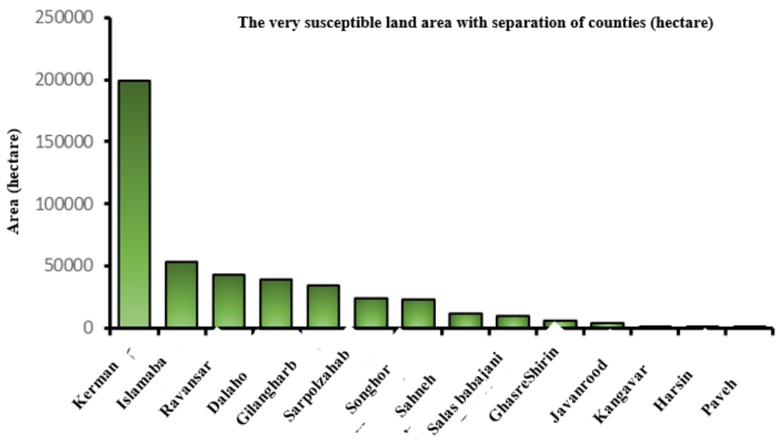


Figure 7. Area and share of semi-suitable lands for autumn safflower cultivation in each county

Regarding the group of non-suitable areas (group 1), 17,885 hectares of the total arable lands of the province are not suitable for safflower cultivation, which includes (2.08) percent of the agricultural lands of the province. Among the cities of the province, Sanghar has the largest area (9849 hectares) of non-suitable areas. Also, 33 hectares of the land area of Bakhsh-Shahu located in Ravansar county, Setr district located in Sanghar Keliai county, and parts of Nodsheh and Baingan and east of Paveh county were assessed as not suitable for safflower cultivation (Figure 7). As explained in the previous sections, in addition to rainfall and temperature, the slope and direction of slope and height were also examined and evaluated as important. In some areas, the non-standard slope of the land, inappropriate height (the height gauge can affect other gauges such as the maximum, minimum, and average temperature), and the mountainous nature (areas such as Paveh and Bayingan) can be the cause of non-susceptibility. He stated that there is a small amount of land in these cities.

According to the obtained results, 52% of the total agricultural lands of Kermanshah province are highly suitable, and 33% are suitable. Likewise, about 13% of the arable land in the province was identified as semi-suitable and 2% as non-suitable (Figure 8). Therefore, based on the investigated climatic and topographical variables, there are suitable conditions for the cultivation of this crop in 85% of the agricultural lands of the province (areas with moderate and cold weather). These results show the high potential of Kermanshah province in safflower cultivation as a suitable plant in crop rotation.

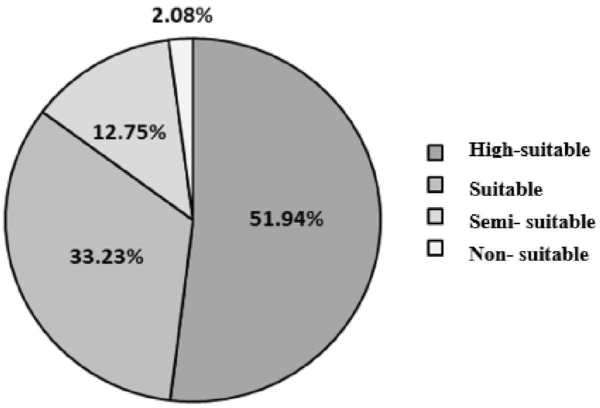


Figure 8. The share of lands in Kermanshah province in terms of ability to autumn safflower cultivation

4. Conclusion

The results of this research showed that by identifying the seven effective environmental layers in the process of safflower cultivation in a GIS environment, it is possible to identify the areas prone to cultivation for this crop in Kermanshah province. The results obtained from the hierarchical process indicated that the rainfall rate is the most important factor in the autumn rainfed cultivation of safflower. The results indicate that Kermanshah province has a high potential for safflower cultivation in terms of climatic and environmental potential and can be included in the periodic program of rainfed crops. This can lead to increasing the variety of rainfed farming systems in the province and benefiting from its benefits. In general, the agroecological zoning method is a suitable method for the qualitative assessment of land suitability in different regions and the quantitative assessment of crop yield. Due to the high potential of this method, it will be possible to evaluate and modify agricultural systems for different crops on a wide scale. This can lead to increasing the productivity of resources and reducing costs in the production of agricultural products.

References

Alavi Zadeh, S., Monazzam Esmaeel Pour, A., & Hossein Zadeh Kermani, M. (2013). Possibility study of areas with potential cultivation of safflower in Kashmar plain using GIS. *Saffron Agronomy and Technology*, *1*, 71-95. [In Persian].

Bagheri, A., & Asadi, S. (2019). Determination of suitable areas to cultivating annual alfalfa (*Medicagio scutellatu* L.) using the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) in the province of Kermanshah. *Agroecology*, *11*, 467-482. [In Persian]. **doi:10.22067/jag.v11i2.67180**

Baghkhani, F., & Farahbakhsh, H. (2008). Effects of drought stress on yield and some physiological characters of three spring safflower (*Carthamus tinctorius*) varieties. *Agricultural Research*, *9*(3), 45-58. [In Persian].

Bayat, R., Rafahi, H., Darvishsefat, A. A., & Sarmadian, F. (2001). An investigation of EPM and MPSIAC model efficiencies in estimating erosion and sediment yield of Taleghan sediment yield of Taleghan watershed using GIS. *Iranian Journal of Agriculture Science*, *32*, 203-217. [In Persian].

Bobade, S. V., Bhaskar, B. P., Gaikwad, M. S., Raja, P., Gaikwad, S. S., Anantwar, S. G., et al. (2010). A GIS-based land use suitability assessment in Seoni district, Madhya Pradesh, India. *Tropical Ecology*, *51*, 41-54.

Borna, R., & Alizadeh, A. (2016). Agroclimatic zoning of citrus cultivation in Khuzestan province using AHP method. *Journal of Agricultural Meteorology*, *4,* 12-21. [In Persian]

Cengiz, T., & Akbulak, C. (2009). Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: a case study of Dümrek village (Çanakkale, Turkey). International

Journal of Sustainable Development & World Ecology, *16*, 286-294. **doi:10.1080/13504500903106634**

Dadashi, N., & Khajehpour, M. R. (2004). Effects of planting date and cultivar on growth, yield components and seed yield of safflower in Isfahan. JWSS-Isfahan University of Technology, 8, 95-112. [In Persian].

Dajue, L., & Mundel, H. (1996). Safflower. Carthamus tinctorius L. Promoting the conservation and use of neglected and underutilized crops (No. 7 ed.). IPK and IPGRI.

Dashti, S., Alahdadi, I., Behbahani, M. R., & Nazarifar, M. H. (2012). Zoning and quantitative evaluation for safflower. *Asian Journal of Agricultural Sciences*, *4*, 373-378.

Dwivedi, S. L., Upadhyaya, H. D., & Hegde, D. M. (2005). Development of core collection using geographic information and morphological descriptors in safflower (*Carthamus tinctorius* L.) germplasm. *Genetic Resources and Crop Evolution*, *52*, 821-830. **doi:10.1007/s10722-003-6111-8**

Eini, H., Sadeghi, S., & Hosseinzadeh, S. R. (2013). Zonation of topoclimatic potentials of rain-fed wheat cultivation in Kermanshah Province. *Journal of Geography and Regional Development*, *10*(2), 21-45. [In Persian]. **doi: 10.22067/geography.v0i0.23233**

FAO. (2019). Agricultural data. Available at food and agricultural organization of the United Nation.

Fatemi Gheiry, S., & Yazdan Panah, H. (2000). Evaluation of different methods of interlinking to estimate precipitation data in Isfahan province. *Geographic Space*, *12*, 46-63. [In Persian]

Fathi, M., & Nazari, H. (2017). Investigation the effect of total quality management on financial performance of companies of Alborz industrial park in Qazvin province: the mediator role of organizational learning capability and innovation. *Commercial Surveys*, *14*, 43-62. **doi:10.1001.1.26767562.1395.14.81.4.1**

Goyne, P. J., Schneiter, A. A., & Cleary, K. C. (1990). Prediction of time to anthesis of a selection of sunflower genotypes. *Agronomy Journal*, *82*, 501-505. **doi:10.2134/agronj1990.00021962008200030012x**

Heydarizadeh, P., Sabzalian, M., & Khajehpour, M. R. (2008). Effect of temperature and day length on vegetative growth and yield of safflower genotypes. *Journal of Science and Technology of Agriculture and Natural Resources*, *12*(45), 365-376. [In Persian]

Ishizaka, A., & Labib, A. (2009). Analytic hierarchy process and expert choice: Benefits and limitations. *Or Insight*, *22*, 201-220. **doi: 10.1057/ori.2009.10**

Jabari, H., Omidi, A. H., Nazari, M. R., Sadeghi-Garmaroodi, & Sharifnasab, H. (2019). Technical and practical instructions for safflower production in different climates of the country. Ministry of Jehad-Agriculture. Agricultural Research, Education and Extension Organization. [In Persian]

Kazemi, H., Tahmasebi Sarvestani, Z., Kamkar, B., Shataee, S., & Sadeghi, S. (2012). Agroecological zoning of agricultural lands in Golestan province for canola cultivation by Geographic Information System (GIS) and Analytical Hierarchy Process (AHP). *Electronic Journal of Crop Production*, *5*(1), 123-139. [In Persian].

Kazemi, H., Tahmasebi Sarvestani, Z., Kamkar, B., Shataei, S., & Sadeghi, S. (2014). Agro-ecological zoning of golestan province lands for soybean cultivation using geographical information system (GIS). *Journal of Agricultural Science and Sustainable Production*, *23*, 21-40. [In Persian]

Koutroubas, S. D., & Papakosta, D. K. (2005). Adaptation, grain yield and oil content of safflower in Greece. In Proceedings of the VIth International Safflower Conference Engin Maatbacilik Ltd. Scedilla˜ ti, İstanbul-Turkey (pp. 3-166).

Kouzegaran, S., Mousavi Baygi, M., Sanaeinejad, H., & Behdani, M. A. (2013). Identification relevant areas for saffron cultivation according to precipitation and relative humidity in South Khorasan using GIS. *Journal of Saffron Research*, *1*, 85-96**.** **doi:10.22077/jsr.2013.436**

Lotfi, P., Mohammadi-Nejad, G., & Golkar, P. (2012). Evaluation of drought tolerance in different genotypes of the Safflower (*Carthamus tinctorius* L.). *Crop Science*, *5*, 1-14. [In Persian]

Mohammadi, H. (2006). Applied Meteorology. Tehran University Press. [In Persian]

Mohammadi, H., Ranjbar, F., & Soltani, M. (2011). Climatic Potentials Assessment for Saffron Cultivation in Marvdasht. *Geography and Environmental Planning*, *22*(3), 143-154. [In Persian].

Mündel, H. H., blackshaw, R., byers, R., huang, H., & Johnson, D. (2004). Safflower production on the Canadian prairies: revisited in 2004. Lethbridge, Alta.: Lethbridge Research Station, Agriculture and Agri-Food Canada.

Pasban Eslam, B. (2018). Effect of Planting Date on Reducing Growth Period of Spring Safflower Cultivars in Tabriz Cold and Semi-arid Climate. *Iranian Journal of Field Crops Research*, *15*(4), 851-860. **doi:0.22067/gsc.v15i4.55365**

Poordad, S. (2017). Safflower cultivar Sina is suitable for cultivation in cold and temperate dry areas of the country. National Rainfed Agricultural Research Institute.

Rafiei, J., Nassiri, B., Kiani, M., & Jahanian, M. (2015). Bioclimatic zoning of safflower in Ilam province. First national conference on agricultural and environmental sciences. [In Persian]

Seyed Shahivandi, M., Khaledi, S., Shakiba, A. R., & Mirbagheri, B. (2013). The agroclimatic zoning of grainy maize using GIS techniques in Lorestan province. *Journal of Applied Researches in Geographical Sciences*, *13*, 195-214. [In Persian]

Sorkh Abadi, M., Shahidi, A., & Khashei, A. (2015). Spatial zoning of saffron (*Crocus sativus* L.) cultivation based on climatic factors using hierarchical analysis process method (Case study: Torbate Hydariyeh city). *Agroecology*, *7*(2), 225-236.

Weiss, E. (2000). Oilseed crops. Blackwell Science, London, UK.

Yaghobian, I., & Yaghobian, Y. (2016). Physiological changes of safflower (*Carthamus tinctorus* L.) in response to water deficit. In 2nd International Conference on New Findings of Science and Technology. [In Persian].

Yari, L., Modares Sanavi, S. A. M., & Soroushzadeh, A. (2004). Effect of foliar application of zinc and manganese on quality traits of five safflower cultivars. *Soil and Water Sciences*, *18*, 143-151.

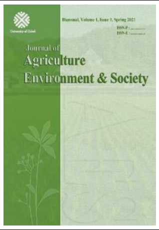
Yasari, T., Khoshhal, J., & Shahsavari, M. R. (2013). Planting dates zoning of safflower varieties in Esfahan province. *Geography and Environmental Planning*, *24*, 171-182. [In Persian]

Zeinali, E. (2008). Safflower (characteris, production and utilization). Gorgan University of Agricultural Sciences and Natural Resources Publications, Gorgan.

Agriculture, Environment & Society (2023) Volume 3, Issue 2, P. 77-92

Agriculture, Environment & Society

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



The effects of planting date on quantitative and qualitative yield of sunflower in Iran and the world: A meta–analysis

Mohsen Rezaei [*a], Mohammad Nabi Ilkaee [b], Saeed Souphizadeh [c], Faiyaz Aghayari [b], Abdolmajid Mahdavi Damghani [c]

[a] Department of Agronomy, Fasa Branch, Islamic Azad University, Fasa, Iran
[b] Department of Agronomy, Karaj Branch, Islamic Azad University, Karaj, Iran
[C] Department of Environmental of Sciences, Shahid Beheshti University, Tehran, Iran

ARTICLE INFO

Article history:
Received: 09 March 2023
Accepted: 20 June 2023
Available online: 28 June 2023

Keywords:
Gain oil percentage
Meta-analysis
Planting date
Seed yield
Sunflower

ABSTRACT

The science of meta-analysis provides a comprehensive summary of a set of researches whose results are more stable. Meta-analysis study of the planting date effects on sunflower grain yield quality and quantity were very important in obtaining of perdition results and improving of the economical yield. In this study, using meta-analysis, we want to investigate the effects of planting date on grain yield (GY), number of seeds per head (NS/H) and head diameter (HD) using 40 articles published in Iran and the world (between 1995 and 2018). According to the results, the correlation coefficient except for GY (R=0.2462), NS/H (R=0.2462) was not significant for HD trait. According to the table of average traits, the highest amount of GY (5173 kg. ha^{-1}), NS/H (1818.35), HD (23.9 cm) was in basis of Julian days (JD) with planting date 1-170 JD range. The highest GY in the range of sowing date 80-170 JD, the highest NS/H under 1-80 JD, the highest HD in 17-180 JD, the highest of grain oil percentage (GOP) (52.16%) in 171-262 JD and the highest 1000-seed weight (TSW) (82.11 g) was observed in the treatment of 177-387 JD. According to the results of regression, except for TGW and GOP, other traits showed a negative slope by changing the planting date. Correlation coefficient was significant for GY (R=0.2462) and NS/H (R=0.364). Based on the intensity model of the effect of sowing date on NS/H, GY and TSW under 1-80 JD, the SOP in the range of 176-387 JD and HD in the range of 81-1701 JD were significant. According to the results of bias in the experiment based on funnel diagram, due to the large range of planting date, positive and negative effects of planting date on traits were observed. Based on the accumulation diagram and review of each study, the general results of meta-analysis show it based on the accumulation diagram and review of each study, the general results of meta-analysis show that the best spring planting time identified under mid-May to mid-June (80-170 JD) and under subtropical to tropical regions from mid-February to mid-march (1-80 JD). In these 25 studies, considering the results of meta–regression no negative correlation was seen in the traits of the NS/H and GY. But for other traits no correlation was seen. On the other hand, the results of the accumulation chart also showed that the minimum and the maximum effect size were related to the studies that in addition to the cultivation date had studied the cultivar and cultivation methods including density. So, it is recommended that meta-analysis be done on the other factors.

Highlights

- Meta-analysis provides a comprehensive summary of research results, offering more stable conclusions.
- Highest GY (5173 kg/ha), NS/H (1818.35), and HD (23.9 cm) were observed with planting dates in the range of 1-170 Julian days (JD).
- Correlation Coefficients was significant for GY (R=0.2462) and NS/H (R=0.364), but not for HD.
- Temperature is a crucial factor affecting growth stages and yield.

[*] Corresponding author.
E-mail address: mohagro@gmail.com
https://doi.org/10.22034/jelsa.2024.460430.1070

• Early Planting are beneficial for GY, TGW, and GN/H, especially in saline soils.
• Delayed Planting can reduce yield due to high temperatures during the growing season, affecting traits like HD and PH.

1. Introduction

Sunflower is one of the most important oilseeds that have a strategical role in oil supplying in the country. Sunflower is cultivated in a wide range of months of the year and due to the difference in cultivar characteristics compared to the planting date in order to adapt the important physiological stages of growth, it is necessary to study the effect of planting date on important traits (De lavega et al., 2002).

Climate differences have different effects on plant growth and development, in other words, it regulates the temperature and humidity of plant growth and development stages. Geographical and morphological diversity with the habit of diverse growth in tolerance to high and low temperatures is a sign of optimal adaptation of the sunflower plant (Khalifa et al., 2000). Every year, many studies are conducted on the effects of different planting dates on the quantitative and qualitative traits of sunflower oil. Existence of different soil, climate and crop management conditions often do not show the same GY and biomass (B). For example, sometimes planting date delays have negative and positive effects on GY. Therefore, most researchers are looking for valid results based on scientific principles to adjust their management plans to achieve the desired performance. Since planting date is one of the most important factors in yield production and the results of research on different planting dates in Iran and over the world on the characteristics of sunflower oil are contradictory, so a comprehensive study that can provide reliable results with more data to reach a final conclusion, seems necessary. The purpose of this study is to summarize the effects of planting date and in fact different temperature changes in important phenological stages of plant growth using meta-analysis of yield and yield components of sunflower seeds and oil in Iran and the world.

2. Materials and Methods

2.1. Search Strategy

Data were obtained from long-term studies (1972-2019) on yield and yield component and percentage of oil in grain sunflower in Iran and some other countries were obtained from refereed journals and peer-reviewed conference proceedings through online searches. Our search was comprehensive including the following keywords: sunflower, date of planting, grain yield, meta-analysis, and percentage of grain oil. And our combinations: date of planting (0-80, 81-170,171-262,263-387 in basis Julian day (JD) range. We collected information on date of planting, altitude, location of experiment, agronomic management as reported by the primary authors.

2.2. Data Preparation and Descriptive Statistics

Data required for the meta-analysis were in the form of treatment mean (X), its standard deviation (SD) and the number of replicates (n) mentioned in the experimental design. Several authors presented statistical data in different formats such as standard error (SE) and coefficient of variation (CV %). These forms were converted to standard deviation (SD) using the Eq. 1.

SD= ¼ SE (1)

To overcome these challenges, our searches were carried out online in order to get results from some of the world. We identified the factors in our analysis such the 1000-grain weight (TGW), the number of grain per head (NG/H), the grain oil percentage (SOP), the height of the plants (HP), head diameter (HD), and the grain yield (GY) input which could affect the effect sizes and employed the random effects model. In this research different agricultural studies published in authentic academic journals, information and quotation databases of Islamic world, Jahad Daneshgahi, and mag Iran have been used, as well as conferences, scientific reply of research centers, thesis, and articles presented on Google Scholar, CABI and Scopus. After compiling articles, the ones which could be used in meta-analysis were separated and encoded 26 articles were chosen among 40 articles under study, and processed by meta-analysis. These groups were included in. (0-80, 81-170, 171-262, 263-387 JD range). Then the following important parameters were extracted separately from articles: By using meta-analysis, the data gathered was analyzed and the graphs were drawn. The complete description of the statistical calculation method of meta-analyses is introduced by Hedges et al., 1999. The first step of the meta-analysis is the calculation of average standard deviation of control treatment and experimental treatments under planting date scenarios (Eq. 2).

$$d = \frac{\overline{X}_t - \overline{X}_c}{S_P} \times J \quad (2)$$

Therefore, for every 36 independent experiment which are surveyed in this meta-analysis an amount of (d) according to Eq. 1 calculated. It must be mentioned that the effects of the planting date were calculated separately (Hedges et al., 1999).

In which X_u and X_t are the averages of control treatments and planting date consecutively, Sp is combined standard deviation of averages, and J is the correction coefficient for the declination of the averages' criterion. The amounts of J and Sp were calculated from Eqs. 2 and 3 consecutively.

$$S_p = \sqrt{\frac{df_c(S_c{}^2) + df_t(S_t{}^2)}{df_c + df_t}} \quad (3)$$

In which Sc and St are average standard deviation of the treatment a planting date d treatment, df_c and df_t are the degree of voluntary control and planting date. If the amounts of the standard deviation of the averages are not mentioned in the articles, we can calculate the amount of Sp according to mean squared error (MSE) which is present in the tables of variance analysis of articles (Eq. 4) (Hedges et al., 1999).

$$S_p = \sqrt{\left(\frac{n_c + n_t - 2}{n_c + n_t}\right) MSE} \quad (4)$$

In which n_c and n_t are the number of repetitions of control and treatment (Hedges et al., 1999).

No doubt all the experiments do not enjoy the same degree of precision. Therefore, it is necessary to measure the precision of each experiment and then synchronize them according to the effect size. To do this the variance of the effect size for each experiment (V_d) was calculated (Eq. 5).

$$V_d = \left[\frac{n_c + n_t}{n_c \times n_t}\right] + \left[\frac{d^2}{2n(n_c + n_t)}\right] \quad (5)$$

The opposite of this variance is the weight related to that experiment, so each experiment which has a smaller variance, will be heavier (Hedges et al., 1999).

Finally, a total effect size (d) is calculated which it is in fact the standardized variation between control and planting date treatments for all the experiments surveyed (Eq. 6).

$$d^* = \frac{\sum w_i d_i}{\sum w_i} \quad (6)$$

Standard deviation is calculated by Eq. 7 Hedges et al., 1999).

$$S_{d*} = \sqrt{\frac{1}{\sum w_i}} \quad (7)$$

The last stage of meta-analysis is meaningfulness experience of d. If you know S_d you can calculate confidence interval of d. If this confidence interval overlaps zero, then the size of the synchronized cumulative effect (d)

Will not be meaningful and is different from control treatment, otherwise the difference between treatment and control will be significantly more than zero. All the calculations and drawing of graphs was done by excel. Meta-analysis allows quantitative analyses of experimental results reported by other authors and the estimation of effect sizes (Borenstein et al., 2009). The analysis increases the statistical power available to test hypotheses and differences in response between treatments under different environments (Borenstein et al., 2009). The effect size found in each individual study can be considered an independent estimate of the underlying true effect size, subject to random variation. All studies contribute to the overall estimate of the treatment effect whether the result of each study is statistically significant or not. Data from studies with more precise measurements are given more weight, so they have a greater influence on the overall estimate. However, meta-analysis has potential weaknesses due to publication bias and other biases that may be introduced in the process of locating, selecting and combining studies. Publication bias is the tendency on the part of investigators, reviewers and editors to submit or caccept manuscripts for publication based on the direction or strength of the study findings.

2.3. Meta-analysis

There are several metrics that have been thoroughly examined for use in meta-analysis. We chose the two methods that are most widely used in ecology: Hedges'd, a standardized difference-based method, and the log response ratio, ln R, a transformed ratio-based method (Eq. 1) estimates the standardized mean difference in a manner similar to original effect size measurement, and is the most widely accepted measure of effect size used in the social sciences (Hedges and Olkin, 1985). d = [(Ye – Yc)/s] J(m) where Ye and Yc are the means of the treatment (e) and control (c) groups, s is the pooled standard deviation, and J(m) is a correction factor to remove small sample bias.

The difference between the mean of the treatment group (Ye) and the mean of the control group (Yc) is divided by the pooled standard deviation s, providing effect size, a dimensionless statistic. The variance of Hedges'd permits the calculation of confidence intervals around the effect size. Equation 2 is the variance of Hedges'd, Variance of d=s2 (d) = [(n_c + n_e)/n_c n_e] + d2/2(n_c + n_e) (2) where n_c and n_e are the total number of samples (Σnij) in the control and treatment group, respectively (Hedges and Olkin, 1985). Equations 3 and 4 are for the pooled standard deviation and correction factor, respectively: s = [(n_e – 1) (se) 2 + (n_c – 1) (sc) 2]/ (n_e + n_c – 2) where se and sc are the standard deviations of the individual samples, and J (m) = 1 – (3/ (4m – 1) where m ≈ n_c + n_e – 2 .There are potential problems with Hedges' d pointed out that d is sensitive to the differences in sample standard deviations, rather than the actual strength of the process. For example, in two studies measuring the effect of different predators on the same prey, one predator may appear to have a larger effect size, but in reality, d is larger because the studies compiled for that predator had smaller s values than studies compiled for the other. Log response ratio although no single metric of effect size is optimal for all cases, the use of the log response ratio and its variance (Eqs. 5 and 6) is currently favored in the meta-analyses of ecological data (Hedges et al., 1999). InR = In (Ye/Yc) Variance of In R = [(se) 2/n_e (Ye) 2] + [(sc) 2/n_c (Yc) 2] where the notation is consistent with that used for Hedges'd. The log response ratio estimates the proportional change between the treatment and control groups (Rosenberg et al., 2000), thus allowing the fuel reduction effect to be derived from the back-transformed log response ratio. Hedges et al. (1999) presented the statistical properties of the log response ratio and exemplified its appropriate usage in meta-analysis. The log response ratio can only be used for data that can be expressed as a ratio, and where the denominator (mean of the control) is not zero or opposite of the overall effect. CMA version 3.0 software was used to draw the funnel diagram and bias.

2.4. Statistical Analysis

In the first step of the analysis, the test of homogeneity as the amount of p-value in different characteristics was more than 5 % null hypothesis is not rejected (Table 1).

Since the study surveys are different, there will definitely be differences in experiments, there for statistical measurement is not a reason for the heterogeneity of studies, as a result, according to the studied data, assortment was done (Tables 2-5). In the second step the between-studies variance was calculated the between-group homogeneity analysis was conducted. Planting of date was considered as a categorical variable and was coded in four levels JD range (1–80, 81–170, 171-262, 262-387) the results of the assortment showed that the dispersion of the coefficient of changes in some traits of the TGW, NG/H, GOP, HD and PH was high (Tables 2-5), therefore to continuation of meta–analysis seems necessary.

Table 1. Homogeneity analysis

Traits	Df	d	p-valve
Grain yield (kg. ha^{-1})	25	-1.52	0.3749
Plant height (cm)	19	-0.53	0.4652
Number of seed per head	18	-0.75	0.4457
Grain oil (%)	22	0.07	0.4947
Head diameter (cm)	22	-0.25	0.4861
1000-grain weight (g)	21	-0.41	0.4695

Table 2. Mean trails of sunflower and homogeneity analysis (1-80 after Julian Days)

Traits	Planting date (max)	Planting date (min)	cv (%)	Means of control	Means of treatment	df	d	p-valve
Grain yield (kg.ha^{-1})	4882.58	316.2	3.7	2811.872	3109.016	5	3.42	0.0162
Plant height (cm)	210.33	137.6	2.2	173.95	163.85	2	1.61	0.1712
Number of grain per head	1818.25	940.9	19.2	1422.1452	1380.32	4	1.26	0.2026
Grain oil (%)	49.57	29.9	29.1	40.51	38.47	4	-1.62	0.1470
Head diameter (cm)	18.93	10.6	16.07	14.91	16.91	4	2.3	0.1418
1000-grain weight (g)	60.96	41.93	1.39	48.56	53.79	4	2.28	0.0957*

Table 3. Mean traits and homogeneity analysis (81-170 after Julian Days)

Traits	Planting date (max)	Planting date (min)	cv %	Means of control	Means of treatment	df	d	p-valve
Grain yield (kg.ha^{-1})	5173	811.1	6.68	2964.3536	2426.1655	9	-2.86	0.0804*
Plant height (cm)	205.5	123.1	27.4	167.501	154.428	7	-1.27	0.3324
Number of grain/heads	1773	4.4	22.6	1017.07	901.99	7	-1.15	0.3369
Grain oil (%)	48.3	25.8	4.48	41.28	39.75	9	-1.08	0.3326
Head diameter (cm)	23.9	9.73	4.39	15.215	12.865	2	-2.96	0.0725*
1000-grain weight (g)	76.84	19.34	2.75	54.047	50.502	7	-0.52	0.4192

Table 4. Mean traits and homogeneity analysis (171-262 JD range)

Traits	Planting date (max)	Planting date (min)	cv %)	Means of control	Means of treatment	df	d	p-valve
Grain yield (kg.ha^{-1})	4414.3	216.05	11.38	2735.1758	2113.46	12	-1.48	0.3044
Plant height (cm)	166.7	112.5	17.51	147.126	135.43	8	-0.65	0.4244
Grain number/head	12.1	337.8	7.8	892.85	813.37	9	-0.99	0.3807
Grain oil (%)	52.16	21.1	14.8	40.054	40.1	3	1.46	0.1771
Head diameter (cm)	20.73	4.92	7.84	14.99	15.23	13	-0.03	0.4974
1000-Grain weight (g)	76	36	33.13	57.85	54.1	10	-0.28	0.4531

Table 5. Mean traits and homogeneity analysis (263-387JD)

Traits	Planting date (max)	Planting date (min)	cv (%)	Means of control	Means of treatment	Df	d	p-valve
Grain yield (kg.ha^{-1})	2500	.403.2	3	1946.16	2056.81	6	0.02	0.4964
Plant height (cm)	184.1	117.1	2.56	163.67	161.19	7	0.02	0.49692
Grain number/head	935	565.6	0.95	750.3	746.19	2	-0.22	0.4545
Grain oil (%)	51	32	1.97	40.29	42.41	5	0.59	0.3930
Head diameter (cm)	18.4	10.8	6.57	15.42	14.28	5	-0.3	0.45
1000-Grain weight (g)	82.11	31	6.54	62.10	53.24	4	-0.5	0.4135

3. Results

3.1. Sizes Effect

There was no change in weighted mean differences in plant height (PH), therefore planting date had no positive effect on PH compared with control (Figure 1). The results of the intensity of the effect of PH showed that this trait was not affected by planting dates and was not significant in any of the planting dates (Figure 1). In the intensity chart, the effect of number of seeds per head (NS/H) was significantly affected by the range of planting date 1-80 JD range. The intensity of the effect of this trait in the range of planting date 80-170 JD, despite the observed changes, but was not statistically significant (Figure 2). According to the intensity chart, the diameter of the head (HD) was significantly affected by the range of planting date 170-181 JD. (Figure 3). The intensity of grain yield was significantly affected by the range of planting date 1-80 days JD (Figure 4) in the graph, the intensity of the effect of 1000-grain weight (TGW) was significant under the influence of the range of planting date 1-80 JD. But in other domains of planting date, no significant increase was observed (Figure 5). The intensity of the effect was significant in the range of sowing date 263-387 on the percentage of grain oil (GOP) (Figure 6).

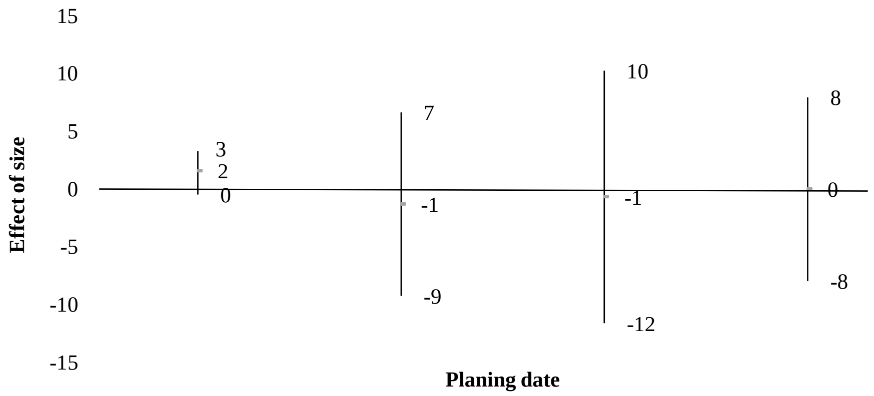


Figure 1. Comparison of different planting dates on PH. Error bars represent 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect

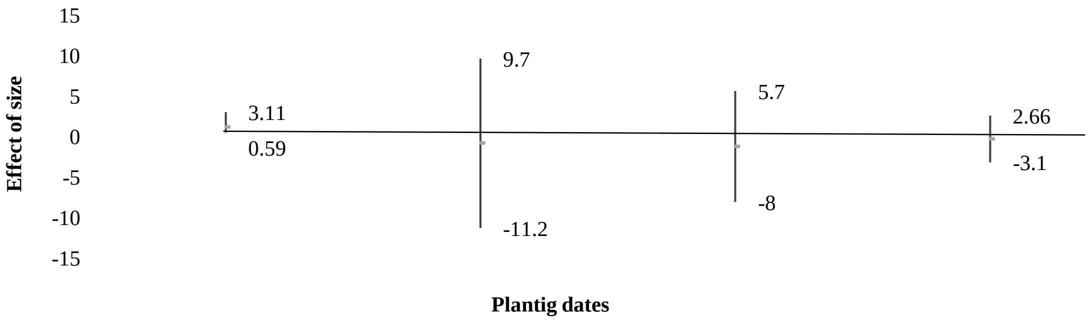


Figure 2. Comparison of different planting dates on GN/H. Error bars represents 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect

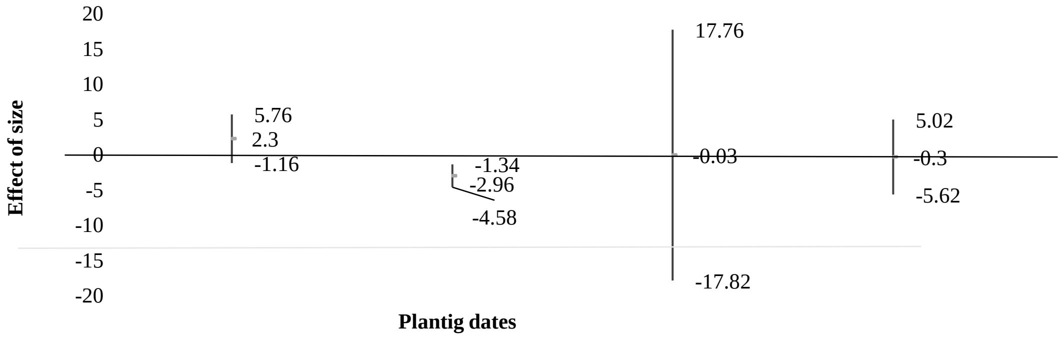


Figure 3. Comparison of different planting dates on HD. Error bars represent 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect

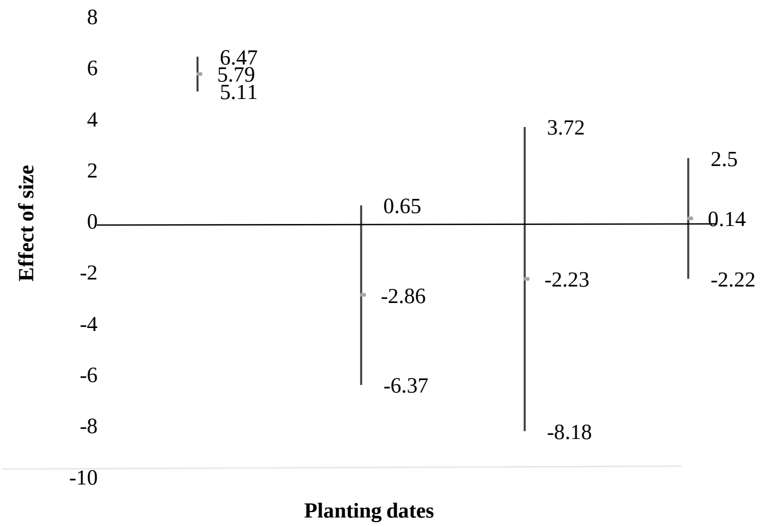


Figure 4. Comparison of different planting dates on GY. Error bars represent 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect

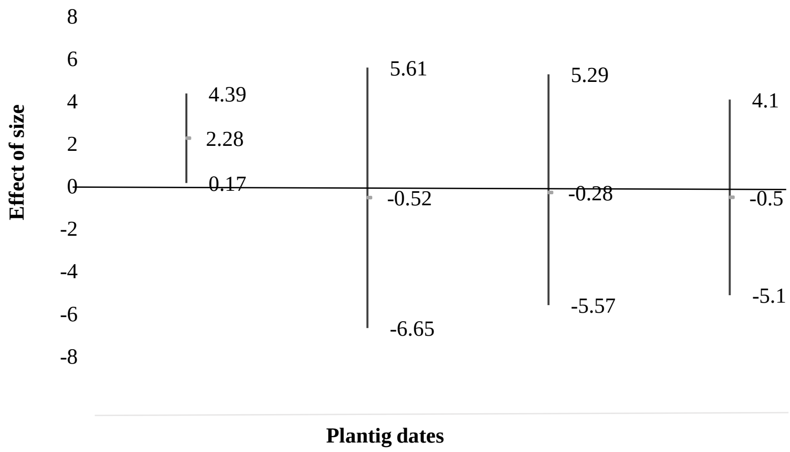


Figure 5. Comparison of different planting dates on TGW. Error bars represent 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect

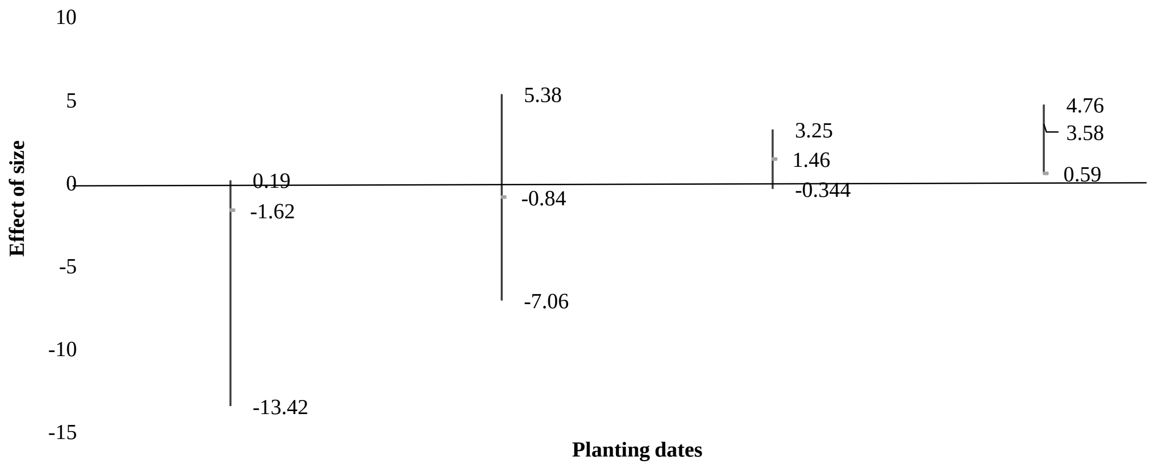


Figure 6. Comparison of different planting dates on GOP. Error bars represent 95% confidence intervals. Vertical lines are the confidence interval size of weighted cumulative effect.

3.2. Meta-regression

Correlation coefficient was not significant, except for GY (R=0.2462) (Figure 7) and NG/H (R=0.364) (8) among other traits, so mentioning these coefficients in the diagrams has been avoided. According to the regression diagram of TGW trait (Figure 9). By changing the planting date, an increasing trend can be seen in this trait. In the regression diagram, the trend of changes in GOP trait under the influence of planting date was fixed (Figure 10). From the meta-analysis presented in Figures 3, 4, 5 and 6, it seems that the response to important economic traits of sunflower oil relate to the range of changes in planting dates is different. Giving the process of trait changes except for TGW and GOP, other traits had a negative slope under the influence of planting date, which shows the negative effect of planting date on these traits (Figures 7-12).

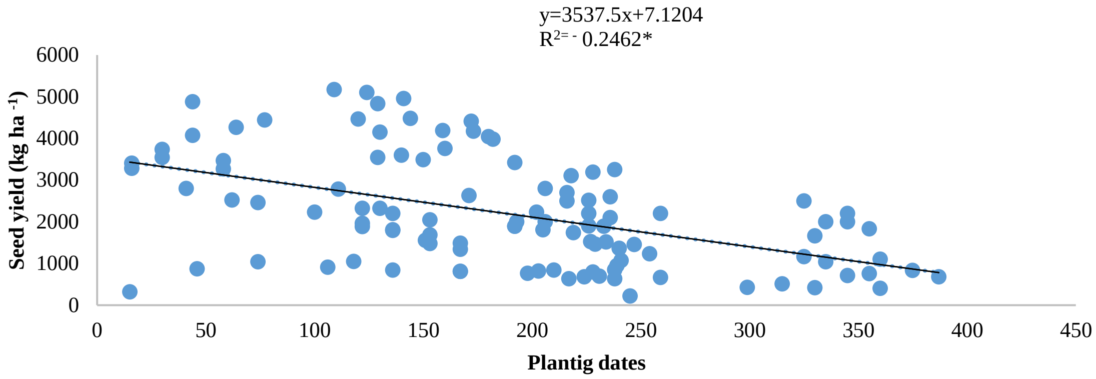


Figure 7. Response of GY to planting dates (p-value= 0.3749, N = 110)

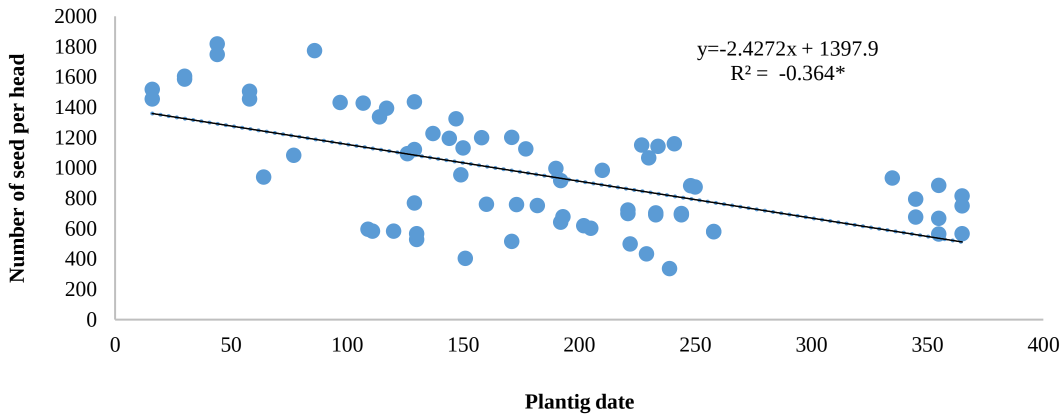


Figure 8. Response of NG/H to planting dates (p-value=0.4457, N =70)

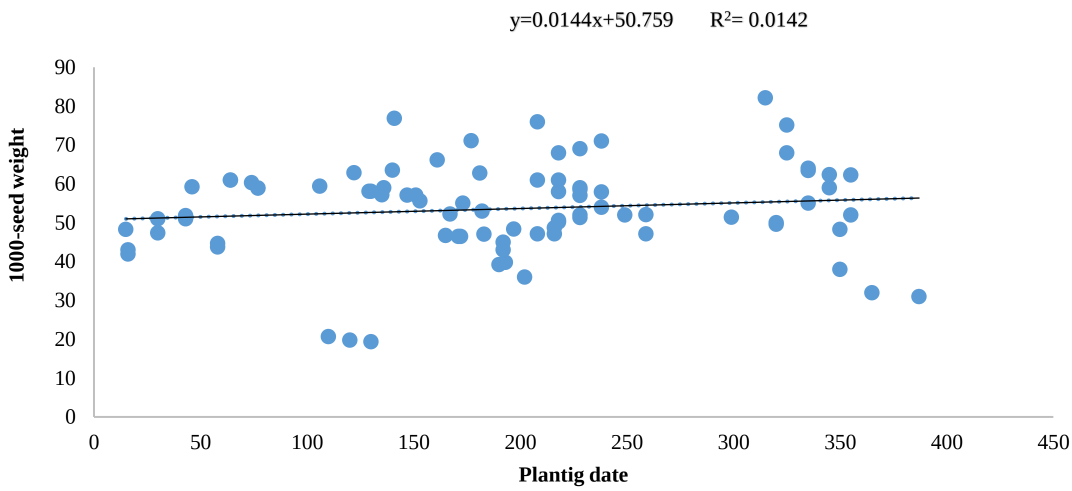


Figure 9. Response of TGW to planting dates (p-value=0.4695, N =84

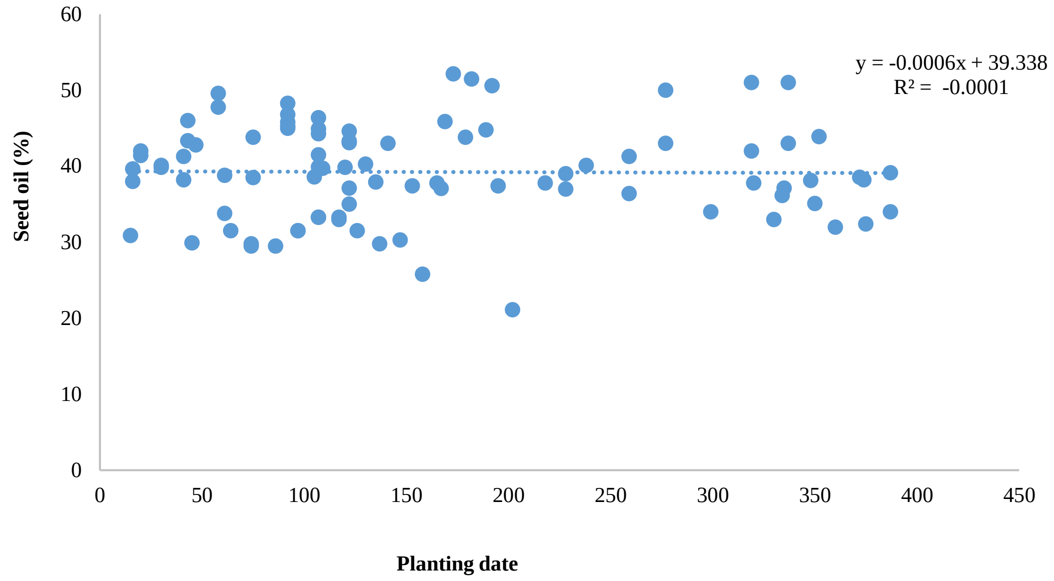


Figure 10. Response of GOP to planting dates (p-value=0.4947, N =91)

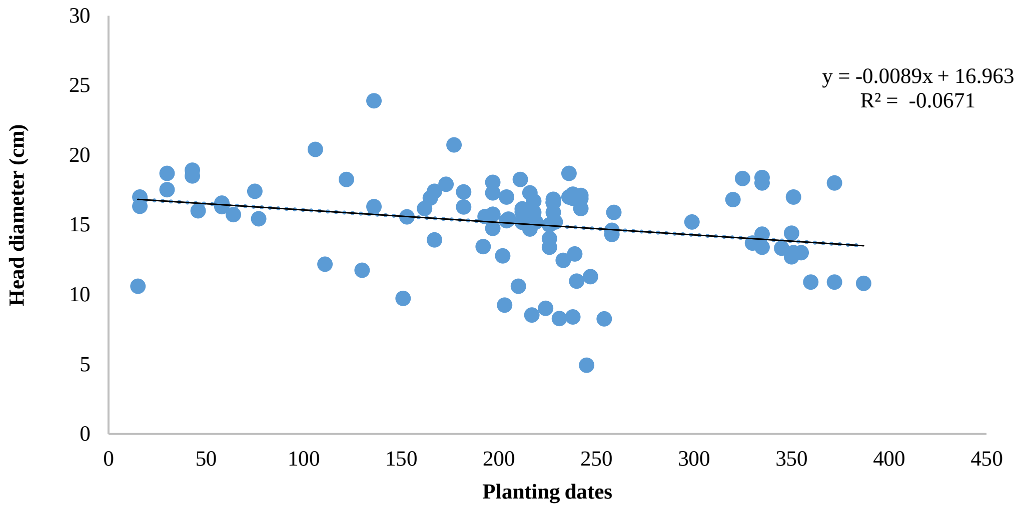


Figure 11. Response of HD to planting dates (p-value=0.4861, N =99)

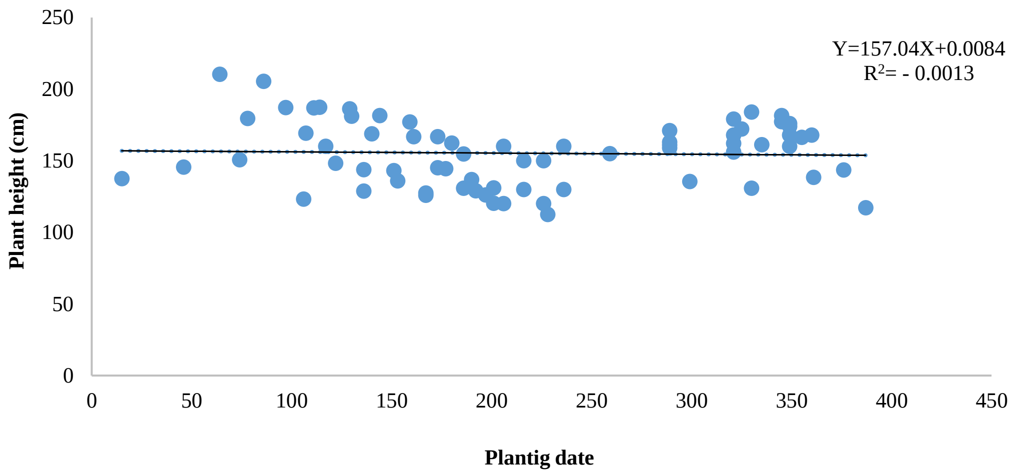


Figure 12. Response of PH to planting dates (p-value=0.4652, R^2= 0. 0013, N =70)

Studies	Effect size
Osuonda et al., 2014	-4.49
Salim et al., 2007	-7.41
Hendei ,2015	-6.71
Hendei , 2015	-6.51
Hendei , 2015	-7.54
Akhtar et al., 2005	-1.71
Akhtar et al., 2005	5.91
Duta, 2011	-2.29
Mirchekaariet al., 2001	-13.4
Gholipoor et al., 2011	-68
Ahmad et al., 2015	-2.07
Qadiret al., 2007	-10.56
Rajabi et al., 2013	-0.47
Dadashian et al., 2007	-27.26
Elsir et al., 2017	-0.34
Elsir et al , 2017	4.62
Mazaheri laghab et al., 2010	-12.59
Moradiaghdam et al., 2010	0.3
Ahmad et al., 2015	5.72
Qadir et al., 2007	-75.36
Haerinejad et al .,2010	1.67
lawel et al .,2011	-4.57
lawel et al.,2011	-5.78
Zamani et al.,2001	-4.45

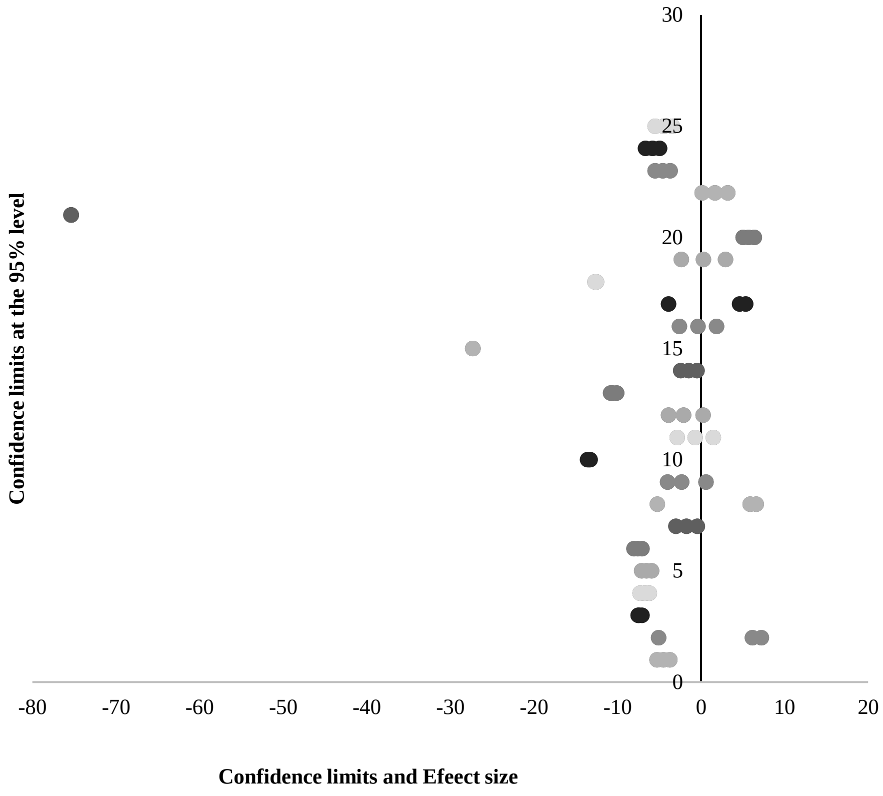


Figure 13. Accumulation chart displaying an inverse-variance weighed random effect meta-analysis of the effect of GY under planting dates

Studies	Effect size
Oshinduia et al., 201	-1.75
Salim et al., 2007	-3.28
salim et al.,2007	-3.11
Akhtar et al., 2005	3.25
Akhtar et al., 2005	9.47
Moradiaghdam et al.,	-0.32
Mirshekari et al., 20	-4.26
Golipour et a., 2010	-0.6
Baboul et al., 2015	-1.49
Baboul et al., 2015	0.66
Qadir et al., 2007	-46.2
Haerinejad et al., 201	4.48
Rajabi et al., 2013	-0.65
Reo et al., 2012	0.25
Zamani et al ,2001	-1.55
Mazaherilaghab et al., 2012	-0.73
Kiliy et al., 2005	-4.27
Daneshyan et al., 20	-2.99

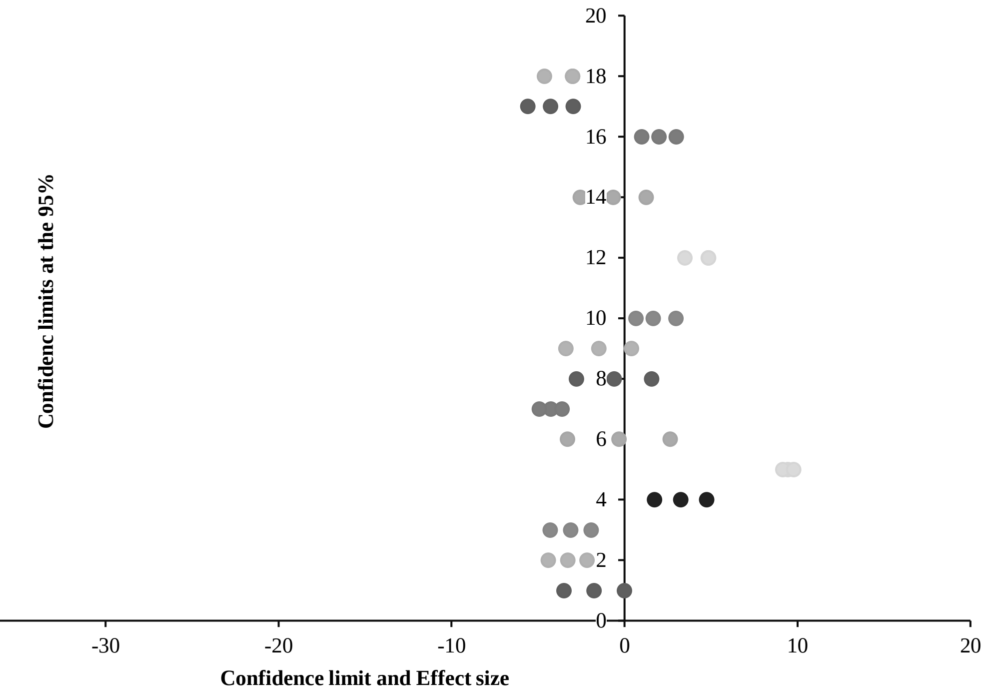


Figure 14. Accumulation chart displaying an inverse-variance weighed random effect meta-analysis of the effect of GN/H under planting dates

Studies	Effect size
Hamza et al., 2014	4.11
Salim et al., 2007	-7.95
Salim et al., 2007	-2.47
Hendei et al., 2015	-9.79
Akhtar et al., 2005	9.73
Akhtar et al., 2005	8.72
Moradiaghdam et al., 2010	-1.68
Elsir et al., 2017	-19.56
Mirshekari et al., 2012	-4.21
Gholipour et al., 2010	-0.66
Ahmad et al., 2015	-2.2
Haerinejad et al., 2012	-1.1
Rajabi et al., 2013	-2.42
Mazaheri laghab et al., 2010	-1.32
ahmad et al., 2015	-15.71
Khalil et al., 2005	-1.83
Salim et al., 2015	-1.92
Salim et al., 2015	9.76
Dadashian et al., 2008	5.16

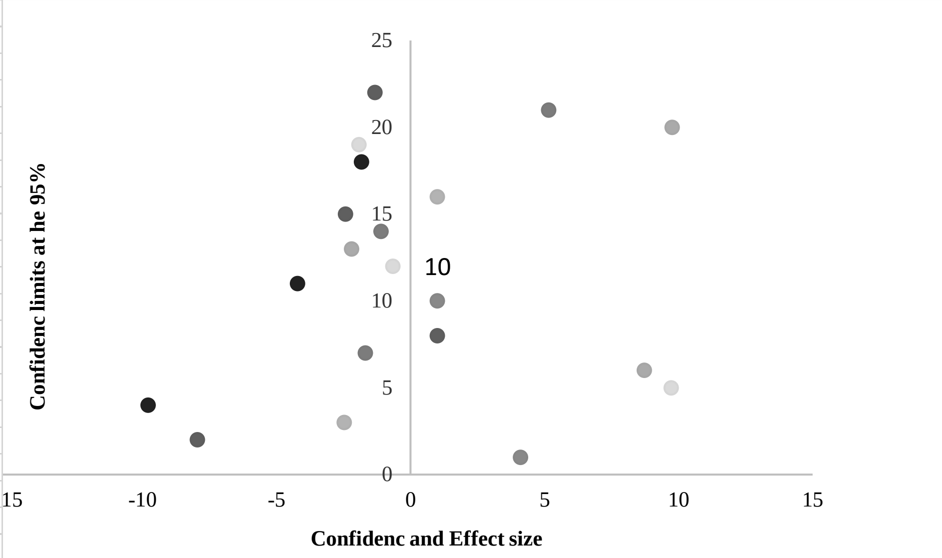


Figure 15. Accumulation chart displaying an inverse-variance weighed random effect meta-analysis of the effect of TGW under planting dates

Studies	Effect size
Eschie , 1995	0.61
Eschie, 1995	-0.3
Hamzeh et al., 2013	1.01
Radoji et al., 2013	10.75
Salim et al., 2007	3.77
Hendei, 2001	-10.29
Akhtaret al., 2005	7.51
Akhtar et al., 2005	-0.63
Golipour et al., 2010	0.12
Mazaheri laghab et al., 2001	14.63
Khalil et al., 2005	-1.83
Dikkion et al., 2107	-3.94
Petco et al., 2012	-2.11
Dikkion et al., 2107	-9.41
Petko et al., 2012	0.43
Petko et al., 2012	-9.57
Salim et al., 2007	-3.29
Salim et al., 2007	16.09
Dikkion et al., 2107	0.3
Petko et al., 2012	-10.61

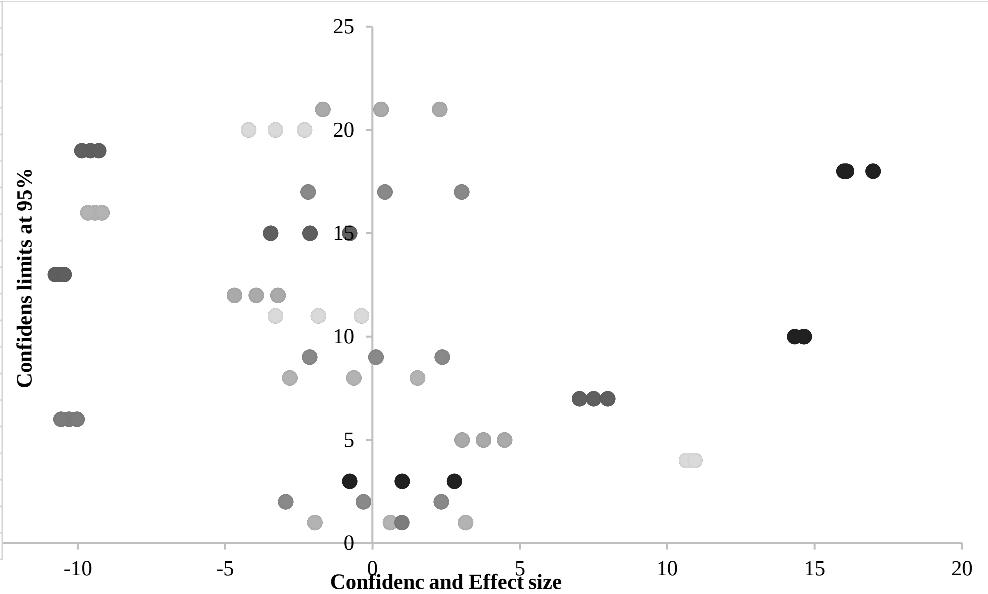


Figure 16. Accumulation chart displaying an inverse-variance weighed random effect meta-analysis of the effect of GOP under planting dates

Studies	Effect size
Bagherpour et al., 2013	0.06
Radoji et al., 2015	-1.05
Radoji et al., 2015	-0.28
Salim et al., 2007	0.04
Salim et al., 2007	-0.46
Hendei , 2015	-1.6
Akhtar et al., 2005	0.74
Akhtar et al., 2005	0.83
Elsir et al., 2017	0.63
Elsir et al., 2017	-0.76
Duta , 2011	-2.07
Mirshekari et al., 2012	-0.71
Gholipour et al., 2011	0.04
Ahmad et al., 2015	-1.84
Ahmad et al., 2015	-1.74
Haerinejad et al., 2009	0.64
Rajabi et al., 2015	-0.17
Lawel et al., 2011	-1.04
Lawel et al., 2011	-1.36
Hamza et al., 2014	-0.31
Bagherpoor et al., 2013	5.77
Bagherpoor et al., 2013	0.04
Radoje et al., 2016	0.53

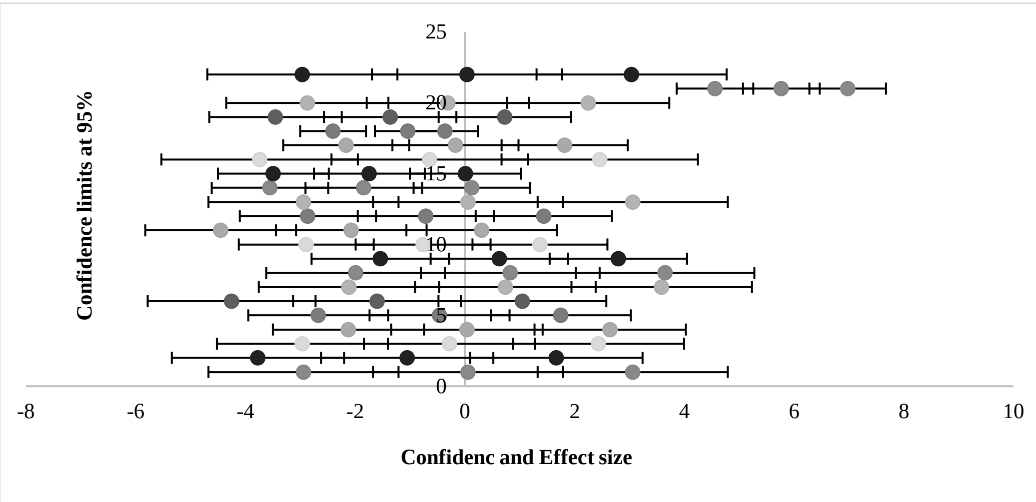


Figure 17. Accumulation chart displaying an inverse-variance weight random effect meta-analysis of the effect HD under planting dates

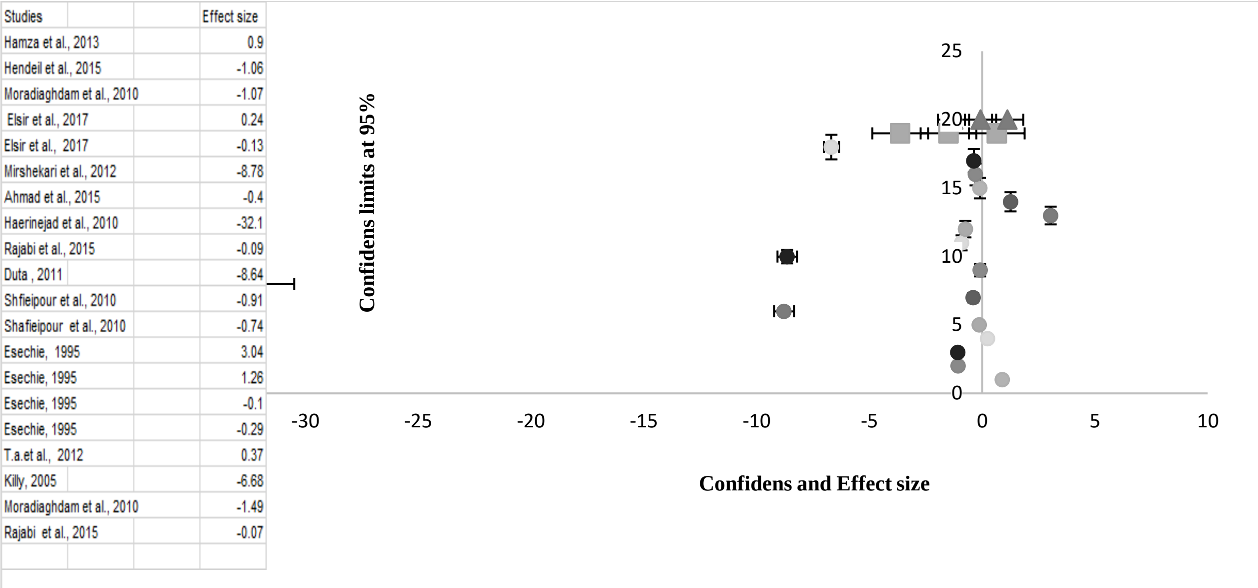


Figure 18. Accumulation chart displaying an inverse-variance weighed random effect meta-analysis of the effect of PH under planting dates

3.3. Accumulation diagrams

With the mean weight of articles and 95% confidence interval -1.14 (23.55, -25.83) for equal grain yield, it was shown that the highest additive effect of planting date (+6.15 with increase 800 kg) to the study Ahmad et al. (2015), and had the least negative effect of reduction (-75.36 with increase 250 kg) according to the study of Gadir et al. (2007) among 25 studies, 21 studies had a positive charge and 4 articles had a negative charge (Figure 13). were placed out of funnel, it can be showed according the validity of the funnel diagrams 9 and 4 that they had a lower reference rate.

In the accumulation diagram for the GN/H according to the mean effect size and 95% confidence interval -0.75 (28.66, -30.16) in the head also the most positive incremental effect of planting date (+4.48) to study Haaerinejad et al. (2010) and the least negative reduction effect -46.2) was related to the study of Ghadir et al. (2007). Out of 18 articles, 17 articles had a positive charge and 1 article had a negative charge (Figure 14). Had a low validity and the funnel1 and 24 of the funnel diagrams showed that they were out of reference studies.

According to the results of the accumulation diagram of 22 studies out of 40 studies for TGW, mean effect size and 95% confidence interval -2.22 (19.9, -24.34) The least negative effect of planting date (-15.71 with increase 6 g) to study Mazaherilaghab et al. (2011) and the highest positive effect (9.76 with increase 6 g) and the lowest confidence interval of the study Salim et al. (2015), among 22 articles, 16 articles had a positive charge and 6 articles had a negative charge. (Figure 15). According to the accumulation diagram of grain oil, mean effect size and 95% confidence interval 0.07 (26.51, -26.37), highest positive incremental effect (+16.09), date of planting to study Salim et al. (2015) and lowest negative effect of planting date (-10.61) belonged to the study Gheorghe and Elena. (2012), among 22, 18 articles have a positive charge and 4 articles have a negative charge (Figure 16). HD trait with mean effect size and confidence interval of -0.32 (55.68, -56.32) 95% had the highest incremental effect of planting date (+6.98) and the lowest confidence interval in the study Akhtar et al. (2005) and the lowest negative effect of planting date (-4.45) belonged to the study Duta. (2011) Among 24 studies, 10 articles had a positive charge and 14 articles had a negative charge (Figure 17). For PH trait, mean effect size and 95% confidence interval -0.51 (36.03, -37.05) the least decreasing effect of planting date (-8.78 lowest confidence interval belonged to the study of Mirshekari et al .2012 (1995) highest incremental effect of planting date (+1.26) belonged to the study of Esechie (1995). Out of 20studies, 16 articles had a positive charge and 4 articles had a negative charge (Figure 18).

3.4. Drawing funnel plots and bias studies

By the test, we can observe that the symmetry hypothesis is rejected. It cannot be excluded that there was a certain publication bias within the results. In order to find out whether there was a publication bias in the meta-analysis “funnel plots” were used to detect a possible publication and location bias in this study we didn't have access to the authors and it was too time consuming. we could not gather the articles which had not been published in valid journal. In the other hand, as some of the resources had been published for a short time, we didn't have access it the details of the studies. The reason why the diagrams are asymmetrical in different characteristics is that most of the articles had a low effect size. There were few articles with high effect size. Our meta-analysis was based on local and foreign studies, so we had to use the studies published in scientific research journals and reliable scientific conferences.

CMA version 3.0 software was used to draw the funnel diagram and bias**.** The program is looking for missing studies based on a fixed effect model, and is looking for missing studies only to the right side of the mean effect (these parameters are set by the user). he method is known as 'Trim and Fill' as the method initially trims the asymmetric studies from the left-hand side to locate the unbiased effect (in an iterative procedure), and then fills the plot by re-inserting the trimmed studies on the left as well as their imputed counterparts to the right the mean effect. In the drawn funnel charts, the filled circles are filled with studies that are statistically significant at the 5% level, their p-value is less than 5%**.** Funnel diagram of GY of 22 articles, the seed yield bias showed that 4 studies were out of the funnel, which is not statistically significant at the 5% level (open circles) (Figure 19). In biasing the attribute number of seeds in 6 studies from the right side had a significant p-value at the 5% level, and with the trim test, only one study left the funnel (filled circle) (Figure 20).

In the trait bias of seed oil percentage, it was shown that 4 studies were statistically significant at the 5% level, and 3 studies were excluded from the funnel (filled circle) (Figure 21). Also, two studies were excluded that were not statistically significant at the 5% level (Your circle is empty)**.** In the bias of 1000 seed weight trait, 6 studies are statistically significant at the 5% level, and out of these 6 studies, two studies were out of the funnel (filled circle), which do not have good statistical validity. The number of 3 studies was not statistically significant at the 5% level (open circles) (Figure 22). According to the bias of the diameter attribute, the studies that were outside the funnel were not statistically significant at the 5% level (open circles) (Figure 23). The height trait bias showed that 5 studies were statistically significant at the 5% level, and 3 studies were out of the funnel (filled circles). 5 studies were

out of the funnel, which is statistically significant at the level of 5%, their p-values are not significant (open circles) (Figure 24).

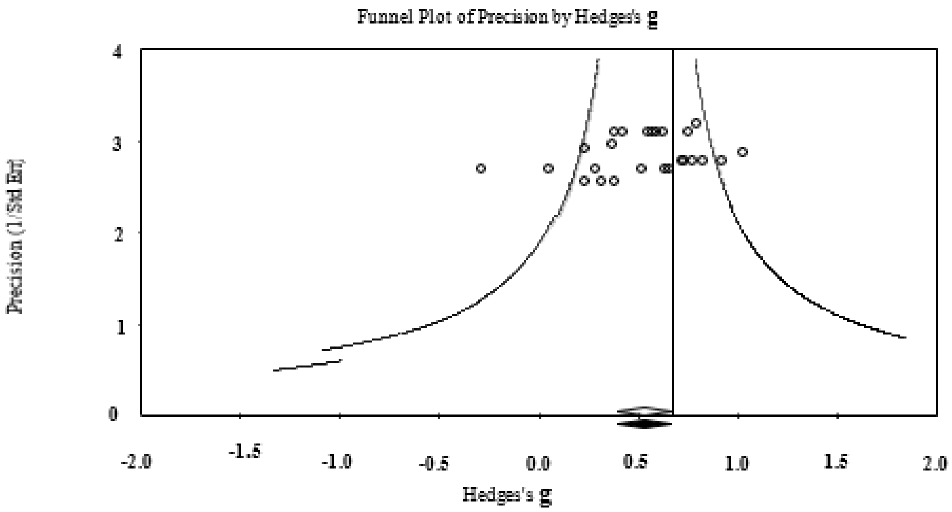


Figure 19. Funnel plot for GY (kg. ha^{-1}). Plot observed studies only Plot observed and imputed (○) Plot observed and imputed (●)

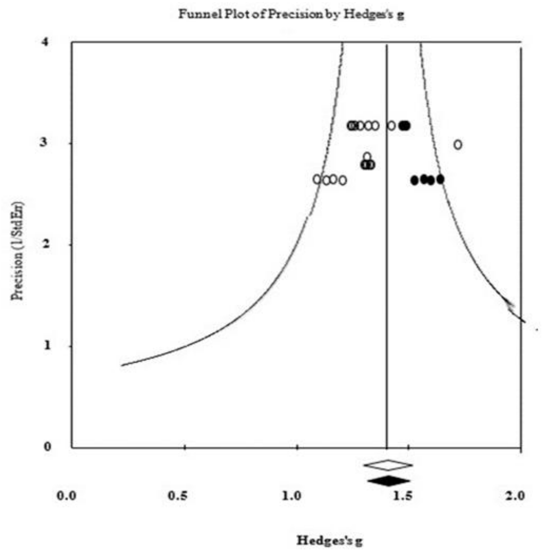


Figure 20. Funnel plot for GN/H. Plot observed studies only Plot observed and imputed (○) Plot observed and imputed (●)

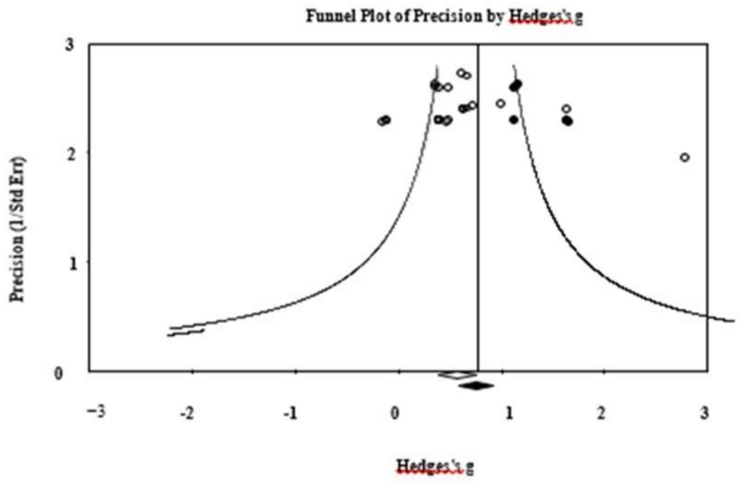


Figure 21. Funnel plot for GOP (%). Plot observed studies only Plot observed and imputed (○) Plot observed and imputed (●)

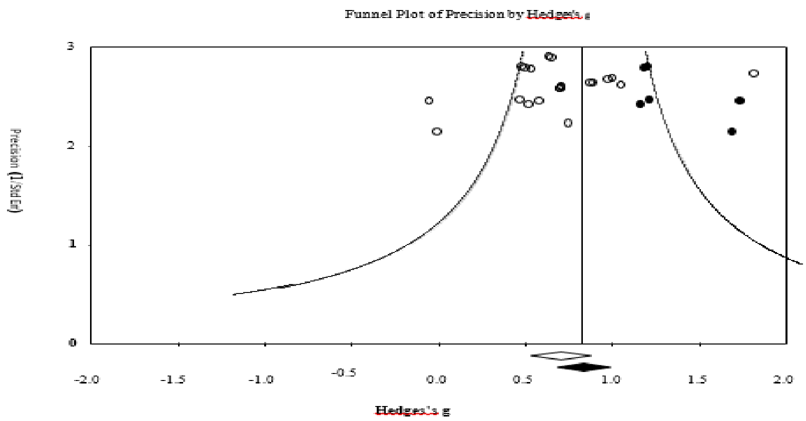


Figure 22. Funnel plot for TGW (g). Plot observed studies only Plot observed and imputed (○) Plot observed and imputed (●)

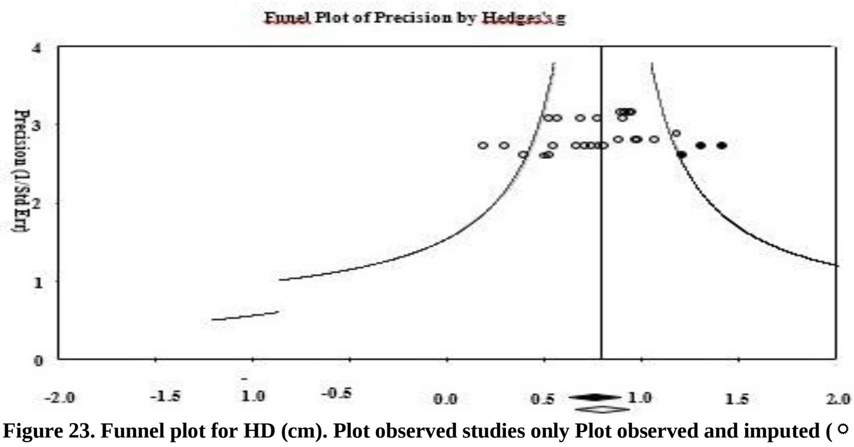


Figure 23. Funnel plot for HD (cm). Plot observed studies only Plot observed and imputed (○) Plot observed and imputed (●)

4. Discussion

In this study, we seek to investigate the effects of planting date on yield and yield components and some morphological traits and qualitative yield such as GOP in sunflower oil. Planting sunflower oil among 40 articles has been done in spring in cold to semi-cold regions and winter planting in semi-warm to warm regions. Given that the physiological zero of the plant is 7-10° C (Zamani et al. 2005; Ghadir et al. 2007; Qadir et al. 2013). Therefore, the best time to plant oil sunflowers in Iran and the world for spring planting in mid-May to mid-June (80-170 JD), and in subtropical to tropical regions from mid-February to mid-March (1-80 JD). The results of this study showed that the planting date range is 1-170 JD, significantly affected on GY, TGW, HD, GN/H (Figures 2, 3, 4 and 5). The mentioned traits had an increasing trend under the influence of planting date (Figures 7, 8, 9, 11). The effect of planting date on the GOP in the range of 263-387 JD range was significant (Figure 6). According to the regression diagram, the GOP under the influence of planting date was associated with a decreasing trend (Figure 10). Environmental factors have affected the growth of hazelnut, GOP, oil yield and its quality. Among environmental factors, temperature is considered as the most important factor and changes in planting date change the temperature of each of the phenological stages. The growth and development of the plant is effective, so the appropriate planting date, while affecting the rate of vegetative growth and increasing plant vigor for the more developed reproductive part, increases the number of flowers and seeds in plant. Early sowing of sunflower due to the temperature below zero is physiologically suitable, causes no seed germination and seed contamination at the time of germination. Early planting in saline soil has been effective in improving GY, TGW, GN/H (Kochehbaghi et al., 2009).

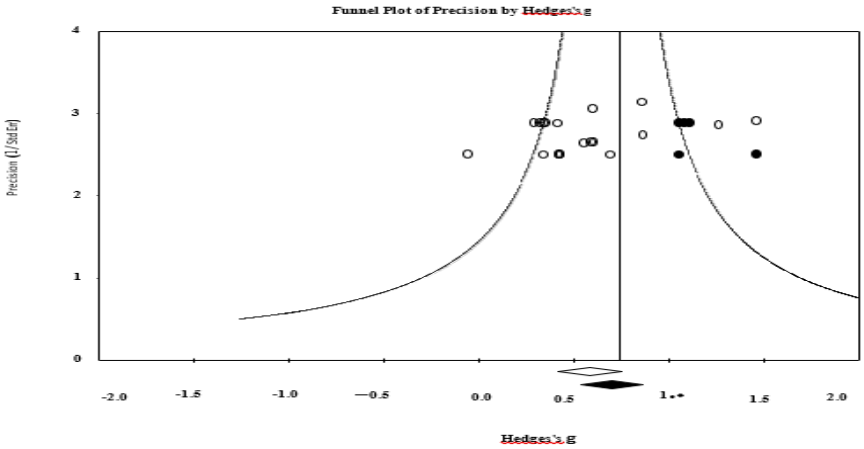


Figure 24. Funnel plot for PH (cm). Plot observed studies only Plot observed and imputed (○)
Plot observed and imputed (●)

According to Figure 6, GY and grain oil yield traits are obtained in early spring planting dates and the amount of these traits will be reduced with planting delay. Early planting date does not have much effect on increasing yield, but due to increasing the length of the plant growth period, it will delay the next planting and increase costs and thus reduce the farmer's income. Matching delayed planting in many cases, the plant faces high temperatures during the growing season, which in turn increases the initial growth of the stem and reduces the length of the flowering period. Various studies by Johnson et al., (1972), Andrade (1995), Uger and Thomson (1982) showed that high GY in sunflower when the grain development stages are at moderate temperatures, is achieved. Environmental factors affect the HD trait according to sunflower more than genotype so that with delay in planting and facing unfavorable environmental conditions, especially high temperatures, the growth period of the plant is shortened and the average HD per plant is reduced (Figure 2). For this reason, the longer the growth period of the plant delay of planting date to temperature above zero is physiological germination in the region reduces germination power and reduces the growth and delay of seedling emergence and thus reduces PH. The PH depends on the selected genotype and other factors such as nitrogen fertilizer application rate, soil type, soil salinity, planting density (Figure 1). Delay of sowing from the optimal time significantly reduces GY by reducing the number of grains produced per square meter and lack of late planting date also not only reduces yield due to reduced growth period and consequently reduces the efficiency of using environmental resources air and soil (Figure 4) but also due to the time of harvest with autumn rainfall, causes Obstacles to be created for the next crop planting time in rotation. According to José et al. (2004) planting dates 101, 103, 110 and 125 JD, for four consecutive years, no suitable trend and relationship was observed between planting date and TGW, but a significant relationship was observed between planting date and increase in the number of grains per square meter (Figure 5). Meta-analysis of each study showed that the highest TGW gain (9.76) on planting date is in mid-August (228 JD), the highest PH by weight (3.04) on planting date is 2 December (347 JDD), the highest performance increase with weight (41.64) is on March 15 (74 JD), The highest increase in the GN/H, by weight (9.79) on the date of sowing February 13 (44 JD), the highest increase in the GOP by weight (21.71) on the date of sowing is in mid-September (259 JD). The largest increase in the HD with weight (4.35) on planting date is August 29 (242 JD), d among the 40 meta-analytic studies were associated. Therefore, according to the final goal in this study, the best sowing date in terms of GY can be obtained in the planting date of 1-80 JD due to the increase in the GN/H. Also, the best treatment for planting date was achieved to the maximum yield of grain oil in the range of 171-263 JD. The purpose of investigating changes in planting date in 40 studies based on meta-analysis was to achieve the desired temperature for all important phenological stages of the plant that face the desired temperature and are safe from temperature stress, which can be based on latitude and longitude for similar areas from these favorable planting dates to achieve more economic production.

5. Conclusion

In this meta-analysis, we found that delay in sowing date reduced traits such as GY, GN/H, GOP, PH, HD, but had a positive effect on TGW and an increasing trend was observed. Also, for the GOP, there were very few changes at the same time as the planting date changes. Due to the dispersion of the studied sites in 40 articles, the contradictory results confirm that the effects of planting date are not the main reason for the changes in the measured traits and should be due to other variables such as plant cultivar, crop input management and geographic coordinates. The geographical location of the farm should be considered in meta-analysis. The increasing trend of the studied traits was observed according to the effect intensity diagrams and the mean of the traits in the range of planting date 1-117 JD. According to the results of funnel diagrams, the selected articles were heterogeneous in such a way that the negative and positive effects of planting date were observed and the range of planting date was varied and the contradictory results were not unexpected. According to the accumulation diagrams, changes in the studied traits are not dependent on planting dates, so planting date is not considered as the main factor affecting the GY and its GY components in oil sunflower. The best time for spring planting is in mid-may to mid-June (80-170 JD) and in subtropical to tropical regions, from mid-February to mid-March (1-80 JD). The present results support such a relationship. Based on the present results and due to the homogeneity. In these 25 articles, considering the results of meta–regression no negative correlation was seen in the traits of the number of seeds in plate and the yield. But for other traits no correlation was seen. In the other hand the results of the accumulation chart also showed that the minimum and the maximum effect size were related to the studies that in addition to the cultivation date had studied the cultivar and cultivation methods including Cultivation density. The differences of the studies based on the funnel diagram in the three characteristics of GOP, GN/H, HD and TGW showed that in these studies, differences can be seen both between studies and within studies. Therefore, meta-analysis of other factors is also necessary.

References

Ahmed, B., Sultana, M., Zaman, J., Kumar, S. P., Mokhlesur Rahman, M. D., Rezaul Islam, M. D., & Majumdar, F. (2015). Effect of sowing dates on the yield of sunflower. *Bangladesh Agronomy Journal*, *18*(1), 1-5. **doi: 10.3329/baj.v18i1.25561**

Ahmad, S., & Hassan, F. U. (2000). Oil yield and fatty acid composition of spring sunflower. *Pakistan Journal of Biological Sciences*, *3*, 2063-2064. **doi: 10.3923/pjbs.2000.2063.2064**

Abdu, S. M. M., Abd El-Latif, K. M., Farrag, R. M. F., & Yousef, K. M. R. (2011). Response of sunflower yield and water relations to sowing dates and irrigation scheduling under Middle Egypt condition. *Advance Applied Science Research*, *2*(3), 141-150.

Akhtar, N., & Malik, M. A. (2005). Effect of planting dates and irrigation levels on achene yield and oil contents of spring sunflower. *Journal of Agriculture Research*, *43*(2), 145-154.

Ashley, R. O., Carr, P. M., Martin, G., Whitney, B., & Peterson, H. (2001). Sunflower date of planting study in western North Dakota. Annual Report 2001, Dickinson Research Extension Center, Dickinson, ND, 187-198.

Andria, R., Chiaranda, F. Q., Maglivlo, V., & Mori, M. (1995). Yield and soil water uptake of sunflower sown in spring and summer. *Agronomy Journal*, *87*, 1122-1128. **doi: 10.2134/agronj1995.00021962008700060014x**

Awais, M., Wajid, A., Ahmad, A., Farrukh Saleem, M., Usman Bashir, M., Saeed, U., Hussain, J., Ur-Rahman, M., & Habib, M. (2015). Nitrogen fertilization and narrow plant spacing stimulated sunflower productivity. *Turkish Journal of Field Crops*, *20*(1), 99-108. **doi: 10.17557/.17374**

Bagheripour, M., Asad Abadi, A., & Akbarian, M. M. (2013). Study the effect of varieties and planting date on sunflower production (*Helianthus annuus* L). *Annals of Biological Research*, *4*(7), 41-46.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). Introduction to meta-analysis (1st ed.). West Sussex, UK: Wiley and Sons.

El Sir, A. I., Abdallah Adlan, A. A., Ezeldeen, M., Banaga, A., & Omima, B. H. (2017). Effects of sowing date on sunflower (*Helianthus annuus* L.) yield and yield components under rainfed conditions in Blue Nile State, Sudan. *Merit Research Journal of Agricultural Science and Soil Sciences*, *5*(3), 060-063.

El-Saied, S. K. H., El-Ahmer, B. A., El-Sergei, D. Z., & Guirguis, N. R. (1989). Response of sunflower varieties to different sowing dates. *Minia Agricultural Research*, *11*(3), 1485-1504.

Esechie, H. A. (1995). Effect of planting date on the growth and yield of irrigated sunflower (*Helianthus annuus* L). *Journal of Agronomy and Crop Science*, *175*, 41-49. **doi: 10.1111/j.1439-037X.1995.tb01127.x**

Darby, H., Harwood, C., Cummings, E., Madden, R., & Monahan, S. (2012). Sunflower planting date trial. University of Vermont Crops and Soils Technicians Technical Report, 524-6501.

De La Vega, A. J., & Hall, A. J. (2002). Effects of Planting Date, Genotype, and Their Interactions on Sunflower Yield: I. Determinants of Oil-Corrected Grain Yield. *Crop Science*, *42*(4), 1191-1201. **doi: 10.2135/cropsci2002.1202**

Dutta, A. (2011). Effects of sowing dates on yield and yield components of hybrid sunflower (Helianthus annuus L) in nontraditional areas of West Bengal. *Journal of Crop and Weed*, *7*(2), 226-228.

Johnson, B. J., & Jellum, M. D. (1972). Effect of planting date on sunflower yield, oil, and plant characteristics. *Agronomy Journal*, *64*, 747-748.

Jose, F. C., Barrosa, B., Mario de Carvalhoa, B., & Gottlieb, B. (2004). Response of sunflower (Helianthus annuus L.) to sowing date and plant density under Mediterranean conditions. *European Journal of Agronomy*, *21*, 347-356. **doi: 10.1016/j.eja.2003.10.005**

Gheorghe, S., & Elena, P. (2012). Effect of sowing date and plant density on sunflower yield and its main components. National Agricultural Research and Development Institute Funduleano, 29(44), 135-144. **doi: 10.2298/hel0644135p**

Golipoor, H., Siyadat, A., & Mojadam, M. (2010). The effect of different planting dates on yield and yield components of sunflower seeds in Shahinshahr, Isfahan. *Journal of Crop Physiology*, *3*(9), 3-13.

Hamza, M., & Safina, S. A. (2015). Performance of sunflower cultivation in sandy soil at a wide range of planting dates in Egypt. *Iranian Journal of Field Crops Research*, *14*(4), 686-698. **doi: 10.21608/jpp.2015.49782**

Hedges, L., Gurevitch, J., & Curtis, P. (1999). The meta-analysis of response ratios in experimental ecology. *Ecology*, *80*, 1150-1156.

Hedges, L. V., & Olkin, I. (1985). Statistical methods for meta-analysis. New York: Academic Press.

Henedi, M. M. (2015). Evaluating the correlation between yield and yield components in sunflower under different planting dates. *International Journal of Agricultural Sciences*, *5*(3), 541-550.

Haerinejad, S., Madani, H., & Sadeghzadeh, S. (2010). Effect of planting date on yield and components and oil seed sunflower in Rodab-Iran. *Journal of New Agriculture*, *6*(2), 119-126.

Killi, F. A. T. I. H., & Altunbay, S. G. (2005). Seed yield, oil content and yield components of confection and oilseed sunflower (*Helianthus annuus* L.) cultivars planted in different dates. *International Journal of Agriculture and Biology*, *7*(1), 21-24.

Khalifa, F. M., Schneiter, A. A., & Eltayeb, E. I. (2000). Temperature-germination responses of sunflower (*Helianthus annuus* L.) genotypes. *Helia*, *23*, 97-104. **doi: 10.1515/helia.2000.23.33.97**

Khalil, L. A., Shah, F., Yasmeen, & Mumtaz, M. A. (2000). Seed yield and fatty acid profile of sunflower hybrids. *Sarhad Journal of Agriculture*, *16*, 601-604.

Lawal, B. A., Obigbesan, G. O., Akanbi, W. B., & Kolawole, G. O. (2011). Effect of planting time on sunflower (Helianthus annuus L.) productivity in Ibadan, Nigeria. *African Journal of Agricultural Research*, *6*(13), 3049-3054.

Qadir, G., Ul-Hassan, F., & Azim Malek, M. (2007). Growing degree days and yield relationship in sunflower (*Helianthus annuus* L). *International Journal of Agriculture and Biology*, *11*(2), 135-123.

Rahimzadeh, R., & Najafi Mirak, T. (2009). Effect of planting method and plant density on yield and agronomic traits of sunflower in rainfed conditions. *Iranian Journal of Crop Sciences*, *2*(11), 123-135.

Radooji, A., Sayedi, N., & Neamati, M. (2015). Possibility of planting new sunflower cultivars in autumn in Gonbad rainfed conditions. *Iranian Journal of Rainfed Agriculture*, *4*(2), 189-227. **doi: 10.22092/idaj.2016.106101**

Rajabi, M., Faraji Arman, M. H., & Ghatari, M. (2013). Effect of normal and late planting date on yield and yield components of sunflower cultivars in hamadan climatic conditions. *Journal of Modern Knowledge of Sustainable Agriculture*, *2*, 21-30.

Salim, S. F. Hassan, I. Mahmood, M. R. Ullah, A. & Ahmad, M. (2011). Response of sunflower to environmental disparity. *Nature and Science Journal*, *9*(2): 73-81.

Sharief, A.E. (1998). Productivity of some introduced sunflower cultivars as affected by planting date and plant population density. *Zigzag Journal and Agricultural Research*, *25*(6): 895-909.

Shafeiepoor, H., Saeedisar, S., Nadali, F., & Mohammadi, A. (2010). Effect of planting date and seed pretreatment on phenological stages, morphological characteristics and yield of sunflower seeds. *Journal of agricultural research*, *3*(1), 103-131.

Mazaheri Laghab, H. F., Noori Zare Abyaneh, H., & Vafaie, H. M. (2001). Effects supplemental irrigation on traits of three cultivars of sunflower in dry farming. *Journal of Agricultural Research*, *3*(1), 31-44.

Mirshekari, B., Koucebagh S. B., Valizadeh, N., & Roudsari, A. M. (2010). Interference of redroot pigweed in sunflower hybrids. *Journal Food, Agriculture and Environment*, *8* (3 and 4), 810-814.

Moradi Aghdam, A., Dashain, J., Zakirin, H., Ghafari, M., Haji Hosni Asl, N., Moradi Aghdam, M., & Valinejad, H. (2010). The effect of planting date on phenology and some agronomic characteristics of oil sunflower cultivars in Khoi, *Ecophysiology of Agricultural Plants*, *3*(3),Pp:205-215

Zakerin, G., Ghafari, J., Hajhossini, M., Asl N., Moradiagdam, M., & Valinegad, H. (2010). The effect of planting date on phenology and some agronomic characteristics of oil sunflower cultivars in Khoi. *Journal of Crop Plants Ecophysiology*, *3*(3), 205-215.

Oyinlola, E. Y., Ogunwole, J. O., & Amapu, I. Y. (2010), Response of sunflower to nitrogen application in *Asavanna alfisol*. *Helia*, *33*(52), 115-126. **doi: 10.2298/hel1052115o**

Zamani, A., & Fourozesh, P. (2001). Effect of date of plant on phenology and yield and component yield in sunflower. *Agronomy Journal and Village Development*, *4*, 53-64.

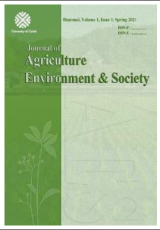
Oshundiya, F. O., Olowe, V. I. O., Sowemimo, F. A., & Odedina, J. N. (2014). Seed yield and quality of sunflower (*Helianthus annuus* L.) as influenced by staggered sowing and organic fertilizer application in the humid tropics. *Helia*, *37*(61), 237-255. **doi: 10.1515/helia-2014-0012**

Uger, P. W., & Thomson, T. G. (1982). Planting date effect on sunflower in the Texas plains. *Agronomy journal*, *78*, 507-515. **doi: 10.1080/01904167.2012.724138**

Agriculture, Environment & Society (2023) Volume 3, Issue 2, P. 93-100

Agriculture, Environment & Society

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



Evaluation of the sustainability of wheat production systems in the Sistan using emergy analysis

Shirali Kohkan *[a], Seyed Ahmad Ghanbari [b], Mohammad Reza Asgharipour [b], Barat Ali Fakheri [c]

[a] Department of Sistan Agricultural and Natural Resources Research and Education Center, AREEO, Zabol, Iran
[b] Department of Agronomy, College of Agriculture, University of Zabol, Zabol, Iran
[c] Department of Plant Breeding and Biotechnology, College of Agriculture, Zabol, Zabol, Iran

ARTICLE INFO

Article history:
Received: 12 November 2022
Accepted: 06 March 2023
Available online: 07 March 2023

Keywords:
Emergy analysis
Environmental pressure
Sustainability index
Wheat emergy

ABSTRACT

This study was conducted using the emergy analysis approach in wheat production systems in order to plan and manage the major challenges facing the Sistan region's wheat production. All inputs for wheat production, the most important crop in the region, were assessed in this study. These inputs include renewable inputs, such as sunlight, wind, and rain; nonrenewable inputs, such as soil erosion; and purchased inputs and services, such as machinery, fossil fuels, electricity, labor, nitrogen, potassium, phosphorus, and chemical fertilizers. According to the results of the study, the total emergy production of wheat was 1.061016 sej ha^{-1}. The irrigation water consumed the most energy at 28.96%, followed by nitrogen and phosphorus fertilizers at 20.75 and 16.5%, respectively. The emergy yield ratio index was 1.41, the emergy investment ratio index was 2.4, the environmental loading ratio was 2.41, and the emergy sustainability index was 0.585, which indicates the average sustainability and environmental load of this system relative to other researchers' reports. By increasing input efficiency by optimizing the consumption of irrigation water, nitrogen fertilizer, and phosphorus fertilizer, this production system can be made more sustainable and less taxing on the environment.

Highlights

- This study used emergy analysis to manage Sistan's wheat production challenges.
- Irrigation water consumed 28.96% of the emergy, followed by nitrogen and phosphorus fertilizers.
- The EYR was 1.41, the EIR was 2.4, the ELR was 2.41, and the ESI was 0.585, indicating the system's average sustainability and environmental load.
- By optimizing irrigation water, nitrogen fertilizer, and phosphorus fertilizer use, this production system can be made more environmentally friendly.

1. Introduction

Today, the agricultural industry relies heavily on energy consumption in order to meet the rising food demands of the world's expanding population. Due to limited natural resources and the negative effects of improper use of various energy sources on human health and the environment, it is necessary to study agricultural energy consumption patterns (Wang et al., 2014).

Emergy analysis is one of the new methods of evaluating sustainability based on energy and precise estimations of energy quantity and quality (Odum, 2007). Emergy is the direct or indirect use of available solar energy to provide a service or product. Emergy, also known as embodied energy or "energy memory," is measured in solar emJoule (sej) (Odum, 2000). Every available energy in agriculture has a specific unit of emergy, such as sej, coal emJoule, and electric emJoule. As solar energy is the direct and indirect source of all biosphere energy, solar energy (emJoule) is the unit of measurement (Fallahinejad and Armin, 2022; Shahhoseini and Kazemi, 2022). Consequently, the radiation emergy per unit of energy can be calculated using the appropriate conversion factor. The

* Corresponding author.
E-mail address: koohkan182@gmail.com
https://doi.org/10.22034/aes.2022.346800.1039

greater the conversion ratio, the greater the requirement for solar energy to generate and conserve resources, goods, or services (Brown, 2004).

Over the past several decades, emergy has proven to be an efficient and potent tool that can be utilized to support the flow of natural ecosystem resources and macroeconomic systems. After about 30 years of development and application, this analysis has become a common and valid method for assessing the transformation of ecological-economic systems and processes, with a particular focus on the agricultural sector (Brown, 2004). By converting all currents, natural resources, and economic resources into solar energy units, the emergy methodology enables a comprehensive review of system stability. Emergy experts believe that using the emergy approach to guide policymaking can result in a more remarkable coexistence between humans and the natural world (Wang et al., 2014). The natural input valuation system serves as the foundation for emergy methods. It is based on the flow of available energy, which has the potential to do more work individually or in the form of conversion forms (Asgharipour et al., 2020; Amiri et al., 2021).

Energy flow alone is insufficient for valuing ecological goods and services because it disregards the work performed by the environment and economy in the past to produce a good or service. EmJoule calculates the energy used directly and indirectly in the past to produce a good or service, as opposed to the joule, which measures the amount of available energy used in the present. The modified solar coefficients represent the amount of solar energy utilized in the past to produce one joule of current energy. Consequently, the use of emergency indicators to evaluate the system's sustainability provides valuable insight into the sustainability of present and future policies (Brown, 2004).

Numerous studies have demonstrated that conventional agriculture is less productive and more energy inefficient than agriculture based on natural inputs. Using the emergy yield ratio, environmental loading ratio, and emergy sustainability index, a number of researchers compared the organic and conventional red-orange production in Sicily, Italy. Their research confirmed that organic orange production utilized less nonrenewable energy sources than conventional agriculture (La Rosa et al., 2008). Using emergy based indices, Brazilian researchers evaluated soybean cultivation in Brazil. They demonstrated that soybean production is not profitable due to the commodity's market price and the high cost of production inputs (Cavalett and Ortega, 2009). Four common types of agriculture in the Vichy region of China were evaluated based on emergy indices. The results demonstrated that corn cultivation is more sustainable than that of other crops (Zhang et al., 2012). A study of three types of ecosystems in the United States, including corn cultivation systems, blackberry cultivation, and the traditional production of several intermittent crops, revealed that corn cultivation systems are the most environmentally friendly and have the least impact on the environment compared to conventional agriculture. Additionally, corn cultivation was related to the lowest stability and highest ecological load (Martin, 2006). A group of researchers demonstrated that integrated cultures are significantly more justifiable than single cultures (Wang et al., 2014). Using emergy, energy, and economic indicators, the study evaluated the rice cultivation and vegetable cultivation systems. The results demonstrated that although the short-term profitability of continuous rice and vegetable cultivation is greater, the stability of intermittent rice and vegetable cultivation is greater (Lu, 2010).

Small-scale (smallholder) farming systems traditionally practiced in northern China were compared to large-scale farming systems using emergy indicators. The results indicated that the emergy efficiency of corn production on large-scale farms was 88% greater than on small-scale farms. In addition, the emergy efficiency of wheat production in large farms was 41% greater than that of conventional farms. They hypothesized that this model could boost resource productivity for grain production in northern China (Wang et al., 2014).

Undoubtedly, resource efficiency is one of the primary objectives of sustainable agriculture. Therefore, emergy efficiency in agriculture is one of the prerequisites for sustainable agriculture (Ghaley and Porter, 2013). This highlights the need to revise agroecosystem management and consumption practices. In this regard, it appears necessary to examine energy consumption patterns in order to identify energy-intensive areas in agricultural systems and evaluate energy consumption efficiency, environmental issues, and their connection to agricultural sustainability. Therefore, agroecosystems must be analyzed in terms of inputs and outputs in order to implement new solutions (Martin et al., 2006). Thus, studying the emergy budget of various crops will assist in identifying the available potential in Iran. In addition, comparing the energy productivity of different crops is one of the methods that will assist in prioritizing the cultivation of different crops in each region (Beheshti Tabar et al., 2010).

The Sistan wheat production system contributes the most to the regional cropping pattern. Consequently, this region has become the province's principal wheat-producing region. This study's objective was to evaluate the Sistan wheat production system using emergy indicators to precisely plot energy flow, calculate environmental load, and determine the system's sustainability.

2. Materials and Methods

2.1. Study area

In Sistan, more than 120,000 ha are devoted to crop cultivation. Wheat, barley, summer crops, alfalfa, fodder corn, Yaghuti grapes, and greenhouse crops are the primary crops in this region. the wheat production system in Sistan was examined and analyzed in this study using data from a one-hectare farm at the Zahak Agricultural Research Station (which is the average representative of agricultural lands in the Sistan region). Zahak Agricultural Research Station is located 20 km south of Zabol city and north of Zahak city with a latitude of 30° 154′, a longitude of 41° 61′, and an altitude of 483 m above sea level. This region has an arid agricultural climate with long, sweltering summers. This field has loamy soil with a conductivity of 3.3 dS/m and an acidity of 8, and irrigation water with a conductivity of 2-3 dS/m and an acidity of 8.

Wheat is cultivated in the study area in November and harvested in June. Most of the agricultural operations for wheat cultivation on this farm, including land preparation, planting, irrigation, weed control, fertilization, and harvesting, were performed using agricultural machinery. Chemical fertilizers were used to stimulate crop growth, and herbicides were used to control weeds.

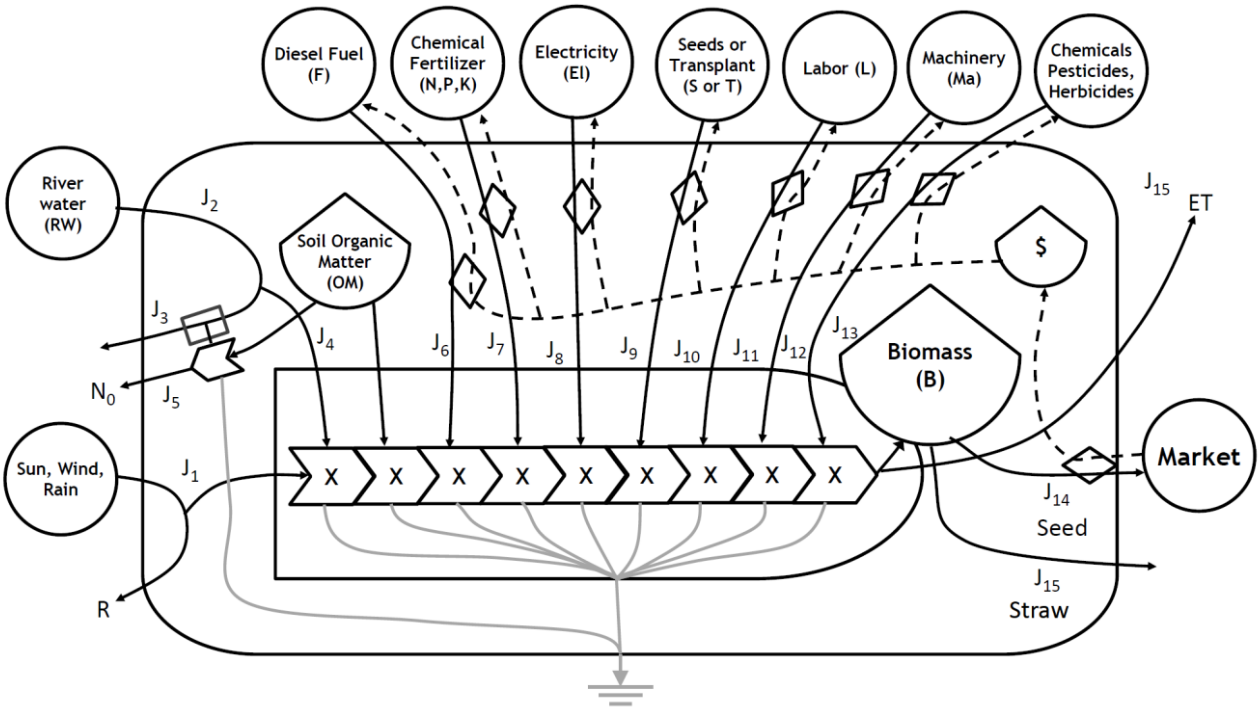


Figure 1. Emergy diagram of wheat cultivation system

2.2. Emergy analysis method

The first step in emergy analysis is to determine the spatial and temporal boundaries of the systems under study and draw an emergy flow chart. It is essential to classify the system's inputs under investigation into renewable or non-renewable, local, or imported sources. In addition, the emergy flow chart is used to show the inputs and outputs of the culture system clearly. This work is essential for managing the relationships between key components and processes of a profitable strategy. It also demonstrates the environmental foundations of ecologists and their relationship to the larger economy (Odum, 2007). The emergy diagram of the Sistan wheat production system is shown in Figure 1.

2.3. Data collection

The first step in emergy analysis is drawing energy flow diagram of the system. The second step in emergy analysis is to draw emergy evaluation tables. To obtain the emergy value of each input, the raw data of each input was multiplied by their conversion coefficients in joules, grams, or Dollars. Total emergy is the sum of emergy from all independent inputs (Odum et al., 2000).

In the wheat production system in the Sistan, free renewable resources, including sunlight, rain, and wind, were considered. Also, renewable sources purchased included seeds, irrigation water, and labor. Surface soil erosion was considered a non-renewable source of environment, and machinery, fossil fuels, chemical fertilizers, herbicides, and electricity were considered as purchased non-renewable sources. Services were considered as input, and the product of grain, and stubble produced was considered as output.

2.4. Method of calculating and measuring emergy inputs

The formula for converting energy to emergy is calculated according to Eq. 1:

Emergy (sej)= available energy (J) × conversion factor (sej/J) (1)

Where the emergy unit is the sej and the unit of transfer conversion of emergy is the sej factor per joules (sej/J) (Brown and Ulgiati, 2004).

Specific emergy is defined as emergy per unit of output mass and is usually expressed as solar emergy per gram (sej/g).

Emergy per currency is considered emergy supporting an economical product unit (currency) production. This unit converts paid money into emergy units (Odum, 2007).

Solar radiation energy was calculated based on Eq. 2:

Solar rad. energy (joules)= A (m^2) × I ($W\ m^{-2}$) × F_{ab} (2)

Where A is the land area, I is the average solar radiation in the Zabol region during the growing season of different crops, and Fab is the percentage of radiation absorption. The radiation absorption percentage of albedo coefficient for the wheat production system was considered to be 20%.

The solar to emergy conversion factor is defined as 1 sej per joule (Odum, 2007). The chemical energy potential of rainwater and irrigation water was calculated based on Eq. 3:

Chemical energy Water potential (joules)= A (m^2) × p (mm yr^{-1}) × d (g m^{-3}) × G (J gr^{-1}) (3)

Where A is the area of land, p is the amount of annual rainfall + water entering through irrigation (mm / year), d is the density of water (1×10^6 g/m^3), and the Gibbs free energy for water is 4.94 joules in gram (Odum and Odum, 1983).

The solar conversion coefficient of chemical energy of rainwater potential to emergy was considered as 18199sej/j.

Wind kinetic energy was calculated based on Eq. 4.

Wind kinetic energy (joules)= A (m^2) × r (kg m^{-3}) × c × $(vg)^3$ (4)

Where A is the area of the earth, r is the density of air (1.23 kg/m^3), and c is the drag constant (a dimensionless quantity to calculate the drag force on a moving object), vg is a geostrophic wind. A geostrophic wind is a theoretical wind due to the equilibrium between the Coriolis effect and the pressure gradient force; the value of this wind is defined as 1.67 times the average wind speed.

The solar conversion factor of wind energy to emergy is considered to be 1496 sej per joule.

The amount of wasted soil energy was calculated using Eq. 5.

Waste soil energy =A (m^2) × ErodSoil (g m^{-2} yr^{-1}) × OM (%) × EOM (kcal gr^{-1}) × 4186 J $kcal^{-1}$ (5)

Where A is land area, ErodSoil is the amount of soil eroded per square meter per year, OM is the percentage of soil organic matter, and EOM is the energy content of soil organic matter, which is 5.4 kcal/g (Odum, 2007). Soil erosion was measured by a sediment sampling device installed in the field.

The solar conversion coefficient of net surface soil losses is 1.24×10^5 sej/J (Odum, 2007). Emergy human resources are considered based on the solar conversion factor of 4.5 $\times10^6$ sej/J (La Rosa et al., 2008). A coefficient of 15.7 × 10^6 sej/kg was used to calculate the seed content. The solar conversion factor was used to calculate the seed emergy of 1.11×10^5 sej/J (Ghaley and Porter, 2013). To calculate the energy content of diesel, a coefficient of 56.31×10^6 J/l was used. Also, to estimate the emergy of diesel, the solar conversion coefficient of 1.11 $\times10^5$ sej/J was used (Odum, 2007). Emergy Machines were considered based on a solar conversion factor of 3 × 10^{12} sej/kg (La Rosa et al., 2008).

To calculate the energy content of electricity, a coefficient of 3.6 × 10^6 J/kWh of electricity was used. The solar conversion factor was calculated to estimate the emergy of the electricity equal to 2.69 $\times10^5$ sej/J (Odum, 2007). The energy content of herbicide is 9.6 $\times10^6$ sej/kg (Asgharipour et al., 2012). To calculate the emergy of pesticides, the solar conversion factor was considered to be 2.49×10^{10} sej/J (Brown and Ulgiati, 2004). To calculate nitrogen emergy, the solar conversion factor was considered equal to 4×10^{10} sej/g of nitrogen (Brandt-Williams, 2002). To calculate phosphorus emergy, the solar conversion factor was considered equal to 3.69×10^{10} sej/g of phosphorus (Brandt-Williams, 2002). To calculate potassium emergy, the solar conversion factor equivalent to K_2O is 3×10^9 sej/g of potassium was considered (Odum, 2007). To calculate the irrigation of irrigation water, the average solar conversion coefficient is 4.34×10^{12} sej/m^3 of water (Buenfil, 2001). The energy content of the wheat grain is 14.7×10^6 J/kg, and straw is 9.25×10^6 J/kg (Ghaley and Porter, 2013).

2.5. Emergy indicators

The indicators used in the wheat production system in Sistan are as follows (La Rosa et al., 2008).

2.5.1. Emergy Yield Ratio

This index is derived from Eq. 6 by dividing emergy output by purchased emergy inputs.

$$(EYR) = \frac{Y}{NP+RP} \quad (6)$$

Where EYR represents the yield ratio of emergy, Y represents the output of emergy, NP represents non-renewable purchased inputs, and RP represents renewable purchased inputs. A greater value for this index indicates a greater return per unit of invested emergy.

2.5.2. Emergy Investment Ratio

This index is derived from Eq. 7 by dividing economic inputs (purchased) by accessible environmental inputs.

$$(EIR) = \frac{NP+RP}{RR+NR} \quad (7)$$

Where EIR represents the investment ratio, NP represents the emergence of non-renewable purchased inputs, RP represents renewable purchased inputs, NR represents non-renewable natural inputs, and RR represents renewable natural inputs. The lower the value, the lower the economic cost, and consequently, such systems tend to compete in the market. The greater the transaction, the greater the economic development.

Index of the environmental loading ratio This index is the ratio of total non-renewable environmental inputs and non-renewable purchased inputs to total renewable environmental inputs and purchased inputs, as determined by Eq. 8.

$$(ELR) = \frac{NP+NR}{RR+RP} \quad (8)$$

This index determines the pressure ratio on the environment and the system pressure on the environment. A lower percentage of this index indicates less environmental stress. NP represents non-renewable purchased inputs, NR represents non-renewable natural inputs, RP represents renewable purchased inputs, and RR represents natural renewable inputs.

2.5.3. Emergy self-supporting ratio

This ratio is calculated by dividing the emergy of all environmental inputs by the emergy of product performance derived from Eq. 9.

$$(ESR) = \frac{RR+NR}{Y} \quad (9)$$

Where ESR is the self-sustaining ratio, NR is the emergy of non-renewable natural inputs, RR is the natural renewable input, and Y is the emergy of product performance. The greater this index's value, the greater the system's dependence on free environmental resources. This system has greater potential to increase economic productivity and economic investment.

2.5.4. Environmental Sustainability Index

The index of environmental sustainability is obtained from Eq. 10.

$$(ESI) = \frac{EYR}{ELR} \quad (10)$$

Where ESI represents the environmental sustainability index, EYR represents the energy yield ratio, and ELR represents the environmental loading ratio. This metric indicates whether it is possible to find a process that, while performing well, has a smaller environmental impact. In calculation of ESI the degree of compatibility between the economy and the environment is considered. A high value for this index indicates a stable crop system (Brown and Ulgiati, 2004). Reducing feedback and increasing the proportion of renewable inputs relative to feedback results in an increase in this index's rate, leading to an increase in this ratio.

The average annual long-term weather data for solar radiation, precipitation, and wind speed were collected from Zahak Agricultural Meteorological Research Station. In this investigation, to determine the price of inputs and wheat crops, we consulted with the Jihad Agricultural Office, farmers, and region traders.

3. Results and discussion

Table 1 contains information on the inputs and outputs of wheat production in Sistan, as well as their equivalent emergy values.

According to Table 1, irrigation water has the highest emergy in the Sistan wheat production system at 3.07×10^{15} sej ha^{-1}. The highest amount of emergy consumption is associated with nitrogen fertilizer at 2.15×10^{15} sej ha^{-1}, followed by phosphate fertilizer at 1.77×10^{15} sej ha^{-1}.

A study to evaluate the emergy of a wheat field in Denmark found that the highest emergy application was for nitrogen fertilizer at 7.7×10^{15} sej ha^{-1} (Ghaley and Porter, 2013). In the emergy analysis of the corn and wheat production system in China, it was found that the emergy of irrigation water consumption for corn and electricity for wheat is 9.005×10^{14} and 5.95×10^{15} sej ha^{-1}, respectively (Wang et a., 2014).

Table 1. The Assessment of the Emergy of wheat production system in Sistan

Note	Item	Unit	Data	Transformity (sej/unit)	Emergy (sej ha^{-1} yr^{-1})	%
			Renewable natural resources			
1	sunlight	J	3.41×10^{13}	1	3.41×10^{13}	0.321
2	wind	J	5.5×10^{6}	1496	8.2×10^{9}	0.0004
3	rain	J	2.47×10^{8}	18199	4.49×10^{12}	0.04
4	water	J	5650	5.43×10^{11}	3.07×10^{15}	28.96
	total	J			3.11×10^{15}	29.33
			Nonrenewable natural resources			
5	Topsoil	J	4.65×10^{7}	1.24×10^{5}	5.76×10^{12}	0.054
			Renewable purchased resources			
6	Labor	J	3.66×10^{8}	4.5×10^{6}	1.65×10^{15}	15.56
7	Seed	J	2.83×10^{9}	1.11×10^{5}	3.14×10^{14}	2.96
	Total				1.96×10^{15}	18.49
			Nonrenewable purchased resources			
8	Fuel	J	3.3×10^{9}	1.11×10^{5}	3.66×10^{14}	3.45
9	Machinery	kg	3.59	3.00×10^{12}	1.08×10^{13}	0.1
10	Electricity	J	1.84×10^{9}	2.69×10^{5}	4.95×10^{14}	4.67
11	Nitrogen	g	5.50×10^{4}	4.00×10^{10}	2.2×10^{15}	20.75
12	Phosphate	g	4.8×10^{4}	3.69×10^{10}	1.77×10^{15}	16.7
13	Potash	g	6.00×10^{4}	3.00×10^{9}	1.84×10^{14}	1.73
14	Herbicide	g	1640	2.49×10^{10}	4.08×10^{13}	0.38
15	Services	$	150	3.12×10^{12}	4.68×10^{14}	4.41
	total	J			5.53×10^{15}	52.17
	Emergy yield				1.06×10^{16}	100
			Output			
16	Grain yield	kg	3850			
17	energy	J	5.56×10^{10}	1.87×10^{5}	1.04×10^{16}	
18	Specific emergy	sej g^{-1}	2.75×10^{9}			
19	Straw yield	kg	4200			
20	Straw energy	J	3.88×10^{10}	2.73×10^{5}	1.06×10^{16}	

Irrigation of irrigation water, nitrogen fertilizers, and phosphorus fertilizers are due to the high consumption of these inputs in traditional cultivation systems. The general classification results of different emergy sources involved in the Sistan wheat production system are shown in Table 2. Based on the above results, the share of natural resources (R + N) of total emergy consumption was 29.38%, and the percentage of purchased resources (P) was 70.62%. Total renewable resources (R + RP) accounted for 47.8% and total non-renewable resources for 52.2% of the total emergy. The total emergy yield of Sistan wheat production was 1.06×10^{16} sej ha^{-1}, and the grain conversion coefficient of wheat, straw, and stubble was 1.87×10^{5} and 2.73×10^{5} sej/J, respectively.

Table 2. The General Categorization of Different Emergy Resources of wheat production system in the Sistan

Note	Item	Emergy (sej ha^{-1} yr^{-1})	%
	Natural resources		
1	Renewable natural resources	3.11×10^{15}	29.33
2	Nonrenewable natural resources	5.76×10^{12}	0.05
3	Sub-total	3.115×10^{15}	29.38
	Purchased resources		
4	Renewable purchased resources	1.96×10^{15}	18.47
5	Nonrenewable purchased resources	5.53×10^{15}	52.15
6	Sub-total	7.49×10^{15}	70.62
7	Total	1.06×10^{16}	100
8	Wheat transformity	1.87×10^{5}	
9	Straw transformity	2.73×10^{15}	

3.1. Emergy indicators in the Sistan wheat production system

Indicators related to wheat production are shown in Table 3. Based on the results, the renewability percentage index (R%) equals to 47.83. This index shows the share of renewable resources in total production resources, and its low means low renewable canvas cultivation and poor sustainability (Amiri et al., 2021).

Emergy Yield Ratio (EYR): This index in Sistan wheat was 1.41. A higher value of this index is more desirable because it shows the ratio of emergy performance for invested emergy. In the estimate of potato emergy in Florida, the emergy yield ratio was 1.24 (Brandt-Williams, 2002). Italian researchers in the study of orange emergy in Italy reported the value of this index as 1.5 (La Rosa et al., 2008). In another survey of grapes in southwest China, the grape emergy yield ratio was 1.07 (Feng et al., 2013).

Table 3. Emergy Indices for wheat production system in the Sistan

Indices	Data
Renewability (R %)	47.83
Emergy yield ratio (EYR)	1.41
Emergy investment ratio (EIR)	2.4
Environmental loading ratio (ELR)	2.41
Emergy self-sufficiency ratio (ESR)	0.294
Emergy sustainability index (ESI)	0.585

Emergy Investment Ratio (EIR): This index indicates the economic capital consumed in the system, so its higher value indicates the greater share of purchased resources. The lower the value of this index, the more desirable it is. The value of this index in Sistan wheat production was equal to 2.4, which suggests that the system relies more on purchased resources than free environmental resources. In the evaluation of soybean emergy in Brazil, the emergy investment ratio was 1.25 (Cavalett and Ortega, 2009). In a study on grapes in southwest China, several researchers reported a grape emergy investment ratio of 14.08 (Feng et al., 2013).

Environmental Loading Ratio (ELR): This indicator shows the amount of pressure a cultivation system imposes on the environment. Its value in this study was equal to 2.41, which indicates the average pressure of this system on the environment. Researchers reported an environmental loading for grapes in southwest China of 2.78 (Feng et al., 2013). In the emergy study of the rice cultivation system in China, the above index was 0.62 (Lu et al., 2010). In the assessment of barley emergy in Washington state, this index was declared 2.94 (Haden, 2002).

Emergy Self-Sufficiency Index (ESR): This indicator indicates the degree to which the system relies on its internal resources, and the higher the value, the better. The value of the above index in this study was 0.294. In an emergy study performed on protected grapes in China, the emergy self-sufficiency index was 0.66 for southwest China and 0.11 for north China (Feng et al., 2013).

Emergy Stability Index (ESI): This indicator shows the sustainability of a cultivation system. The higher the share of renewable resources than non-renewable resources, the higher the value of this index and the more desirable it is. The value of this index in the present study was 0.585. An American researcher evaluating the emergy of different cropping systems in the state of Florida reported a sustainability index of 0.68 for oats and 0.16 for potatoes (Brandt-Williams, 2002). Other researchers in evaluating the emergy of the rice cultivation system in China obtained that the value of this index is 1.83 (Lu et al., 2010).

4. Conclusion

In this study, different sources of energy supply and essential indicators of sustainability and environmental burden of the Sistan wheat production system were analyzed using the emergy evaluation method. The results showed that among all inputs involved in wheat production, three variables of irrigation water, nitrogen fertilizer, and phosphate fertilizer, 28.96%, 20.75%, and 16.7% had the highest share in emergy consumption, respectively. If energy efficiency is to be considered, the main priority must be to optimize these three sources. Also, the analysis of emergy indices showed that R% is equal to 47.83, EYR is 1.41, EIR is 2.4, ELR is 2.41, ESR is 0.294, and ESI is 0.555. The results obtained compared with many similar studies show that the emergy indices of Sistan wheat are moderate. The environmental load is essential, and the lower the value, the less pressure on the environment.

The value obtained for this index is the average of similar studies, which indicates the relative pressure of this cultivation system on the environment. Although the environmental sustainability index in this study is higher than the average of similar studies, its value is not desirable and shows the relative sustainability of this system.

Acknowledgments

This research was carried out in the Agricultural Research and Training Center of Sistan and Natural Resources. We sincerely thank the officials of the center and all the staff who have contributed to this research.

References

Amiri, Z., Asgharipour, M. R., Campbell, D. E., Azizi, K., Kakolvand, E., & Moghadam, E. H. (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. **doi:10.1016/j.jclepro.2021.126000**

Amiri, Z., Maghsoudi, A., Asgharipour, M. R., Nejati-Javaremi, A., & Campbell, D. E. (2022). The semi-intensive production model: A strategy based on emergy and economic analyses to realize sustainability in the ecosystem of Sistani beef cattle raising in Iran. *Journal of Cleaner Production*, *362*, 132304. **doi:10.1016/j.jclepro.2022.132304**

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. **doi:10.1016/j.ecolmodel.2020.109021**

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. **doi:10.1016/j.energy.2012.04.023**

Beheshti Tabar, I., Keyhani, A., & Rafiee, S. H. (2010). Energy balance in Iran's agronomy (1990-2006). *Renewable and Sustainable Energy Reviews*, *14*, 849–855. **doi:10.1016/j.rser.2009.10.024**

Brandt-Williams, S. (2002). Handbook of emergy evaluation: A compendium of data for emergy computation issued in a series of folios. Folio 4. Emergy of Florida agriculture. Gainesville, Florida, USA: Center for Environmental Policy. University of Florida.

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. **doi:10.1007/978-3-642-15479-9_5**

Buenfil, A. A. (2001). Emergy evaluation of water (Doctoral dissertation). University of Florida.

Cavalett, O., & Ortega, E. (2009). Emergy, nutrients balance, and economic assessment of soybean production and industrialization in Brazil. *Journal of Cleaner Production*, *17*, 762–771. **doi:10.1111/hex.12487/965-23**

Fallahinejad, S., & Armin, M. (2022). Role of mechanization on the sustainability of sugar beet production using emergy approach. *Journal of Emergy, Life Cycle and System Analysis in Agriculture*, *2*(1), 15-24. **doi:10.22034/aes.2022.327793.1019**

Feng, J., Lu, S., Fu, Z., & Tian, D. (2013). Emergy analysis of protected grape production system in China. *Advanced Materials Research*, 726-731, 3938–3942. **doi:10.1080/02626667.2018.1560449**

Ghaley, B., & Porter, J. R. (2013). Emergy synthesis of a combined food and energy production system compared to conventional wheat (Triticum aestivum L.) production system. *Ecological Indicators*, *24*, 534–542. **doi:10.1016/j.jpsychires.2017.11.014**

Haden, A. (2002). Emergy analysis of food production at S&S Homestead Farm. S&S Center for Sustainable Agriculture.

Higgins, J. B. (2003). Emergy analysis of the Oak Openings region. *Ecological Engineering*, *21*, 75–109. **doi:10.1016/j.ecoleng.2003.09.007**

La Rosa, A. D., Siracusa, G., & Cavallaro, R. (2008). Emergy evaluation of Sicilian red orange production. A comparison between organic and conventional farming. *Journal of Cleaner Production*, *16*, 1907–1914. **doi:10.1016/j.copsyc.2015.09.005**

Lu, H. F., Bai, Y., Ren, H., & Campbell, D. (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. **doi:10.1016/j.jenvman.2010.07.025**

Martin, J. F., Diemont, S. A. W., Powel, A., 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. **doi:10.1016/j.agee.2005.12.016**

Odum, H. T., & Odum, E. C. (1983). Energy analysis overview of nations: Concepts and methods. Working Paper. International Institute of Applied Systems Analysis, Laxenburg, Austria.

Odum, H. (2007). Environment, power, and society for the twenty-first century. The hierarchy of energy. Columbia University Press.

Odum, H., Brown, M. T., & Williams, S. B. (2000). Handbook of emergy evaluation. Environmental

Engineering Sciences, University of Florida, Gainesville.

Shahhoseini, H. R., & Kazemi, H., (2022). Evaluation of sustainability of rainfed rapeseed production in Gorgan County using Emergy analysis. *Journal of Emergy, Life Cycle and System Analysis in Agriculture*, *2*(1), 61-70**. doi: 10.22034/aes.2022.337172.1031**

Ulgiati, S., Odum, H. T., Bastianoni, S. (1994). Emergy use, environmental loading and sustainability. An emergy analysis of Italy. *Ecological Modelling*, *73*, 215–268. **doi:10.1016/0304-3800(94)90064-7**

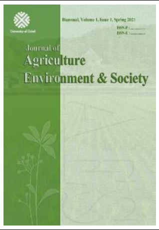
Wang, X., Chen, Y., Gao, W., Qin, J., Zhang, F., & Wu, X. (2014). Emergy analysis of grain production systems on large-scale farms in the North China Plain based on LCA. *Agricultural Systems*, *128*, 66–78. **doi:10.1016/j.agsy.2014.03.005**

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. **doi:10.1016/j.jclepro.2011.10.042**

Agriculture, Environment & Society (2023) Volume 3, Issue 2, P. 101-106

Agriculture, Environment & Society

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



Effect of cytokinin on the number of capsules per leaf node in sesame under field conditions

Seyyed Fazel Fazeli Kakhki [*a], Nasser Beikzadeh [a]

[a] Khorasan Razavi Agricultural and Natural Resources Research and Education Center, AREEO, Mashhad, Iran

ARTICLE INFO

Article history:
Received: 04 April 2023
Accepted: 16 June 2023
Available online: 24 June 2023

Keywords:
Capsule per plant
Fresh and dry weight
Hormone
Sesamum indicum

ABSTRACT

Sesame has valuable oil which is beneficial for human health. This plant has one capsule in each leaf node (the place where the leaf joins the stem), and by manipulating plant hormones, the number of capsules in each leaf node can increase, which leads to an increase in yield. To increase the number of capsules per leaf node, a factorial experiment was carried out in a randomized complete block design. The first factor was two types of seeds [seeds from one capsule per leaf node (CAP1) and seeds from triple capsule per leaf node (CAP2)], and the second factor was three concentrations of cytokinin (CK) (zero, 50, 100 ppm). The results showed that the maximum plant length (83.5 cm) was obtained from the 50 ppm CK treatment. The application of 50 ppm CK in CAP1 was increased the number of single capsule nodes about 48%. Compared with the control and 100 ppm treatments, the 50 ppm CK treatment had the greatest effect on the number of nodes with triple capsules (7.71), with increases of 38.6 and 72.8%, respectively. The greatest number of triple capsule nodes per plant (10.3) was obtained in the CAP2 treatment by using 50 ppm CK. The greatest amount of fresh and dry weight (84.5 and 30.7 g per plant, respectively) was obtained from the 50 ppm CK treatment group. The maximum number of capsules per plant and number of seeds per capsule were obtained from the 50 ppm CK×CAP2 treatment. Other results showed that the application of 50 ppm CK led to the highest number of seeds produced per plant (6.75 grams). In addition, the exogenous application of cytokinin to plants has the greatest effect on the areas to which it moves or the areas where cytokinin is synthesized, but to improve the effectiveness of this hormone and obtain an economic crop, it is necessary to use an appropriate ratio of other plant growth regulators.

Highlights

- Cytokinin increased sesame yield by boosting capsule production.
- 50 ppm cytokinin was optimal for growth and yield.
- Combining cytokinin with superior seeds maximized yield.
- Cytokinin application can enhance sesame yield.
- Balancing cytokinin with other hormones is crucial for optimal results.

1. Introduction

Sesame (*Sesamum indicum* L.) is an important oil crop because its seeds contain valuable substances, such as oil (50-60%), protein (20%), and carbohydrates (14-20%), and because they contain endogenous antioxidants, such as sesamol, sesaminol and tocopherol, which have remarkable stability (Ball et al., 2000). Compared to other crops, this plant has a low yield capacity due to its low harvest index (HI), capsule shattering, susceptibility to disease, and indeterminate habitat. One of the main components of yield is the number of capsules per leaf node (node: is place that leaf join to stem or branch). In natural ecotypes, there is one capsule in each leaf node. Studies have shown that some ecotypes have three or more capsules per leaf node. This trait is controlled by a single gene, and the recessive allele produces triple capsules. In a few ecotypes, three capsules

* Corresponding author.
E-mail address: sf_fazeli@yahoo.com
https://doi.org/10.22034/jelsa.2024.463230.1077

are produced in all leaf nodes of the plant (three capsules in each node). Most three-capsule lines have single capsules at the bottom and top of the plant (Langham and Wiemers, 2002). Yield enhancement, especially for oil crops, is the main issue in our agricultural agenda. Yield is a complex trait, and yield components such as the number of seeds per capsule, the number of capsules per plant, and the weight of 1000 seeds are significantly positively correlated with the number of capsules per plant (Fazeli Kakhki et al., 2014). Based on these findings, it seems that cytokinin regulates the growth of reproductive meristems that can produce more than one capsule per leaf node and is effective in determining sesame yield.

Cytokinins (CKs) was discovered in 1955. Since kinetin was isolated from autoclaved products of herring sperm DNA as a cell division-promoting factor (Amasino, 2005; Sakakibara, 2006), several compounds with CK activity have been identified, including zeatin (Z), a natural CK substance (Sakakibara, 2006). Other CK synthetic compounds include kinitin, benzyladenine (BA), tetrahydropyranylbenzyladenin (PBA) and ethoxyethyl adenine, as well as several natural CKs with aromatic side chains (Vylíčilová et al., 2020). Our knowledge of CKs is incomplete, but based on the available data, CKs occur not only as free bases and ribonucleosides and ribonucleotids but also as constituents of particular tRNA species (Marquez-lopez et al., 2019). CK was synthesized in the roots. It moves acropetally through the transpiration system in the xylem and promotes bud growth and plant growth by inducing cell division. Cytokinin is involved in lateral branching and has indirect effects, unlike auxin (Nordstrom et al., 2004; Nagarathna et al., 2010). The results have shown that hormones are synthesized and act at various sites in the plant body, although the physiological differentiation and mechanisms of the dual signaling system have not been fully elucidated (Sakakibara, 2006). Researchers have shown that the effect of CK in the physiological stage is dissimilar due to the differences between the concentrations used and the plant growth stage. The results of study showed that reduced cytokinin content was decreases the size and the activity of the shoot apical meristem (SAM), demonstrating that cytokinin is a positive regulator of the SAM, in contrast, enhancing the cytokinin content was increases SAM activity that led to formation of more flowers by reproductive meristems (Schwarz et al., 2020). One of the functions of CK is to increase the activity of the meristematic zone. In this regard, Giulini et al. (2004) reported an increase in the size of the meristem in a maize mutant. Studies have shown that simultaneous mutation of two CKX genes in Arabidopsis delays the differentiation of cells in reproductive meristems; as a result, the flowers are formed more and larger, and subsequently, more seeds are produced. A study by Bartrina et al. (2011) showed that an increase in cytokinin content caused an approximately 50% increase in seed yield; they suggested that cytokinin has a major role in reproductive development. Cytokinin plays a central role in the induction and regulation of buds and nodes in plants (Bartrina et al., 2011; Li and Tang, 2002). Based on the research conducted, the aim of this research was to investigate different concentrations of cytokinin in the production of more than one capsule at the node of each leaf in sesame plant.

2. Materials and methods

The field trial was conducted in the spring of 2023 at Khorasan Razavi Agricultural and Natural Resources Research and Education Center, Mashhad, Iran. Geographical experimental site: Longitude 59.6 degrees east and latitude 36.2 degrees north and an altitude of 985 meters. The average rainfall of the region is 255 mm and the maximum and minimum annual absolute temperature is 42 and -27.7 degrees Celsius, respectively. The climate of the region is determined based on the Amberozheh method, cold and dry (IRIMO, 2016). The experiment was performed in a factorial arrangement based on a randomized complete block design with three replications. The first factor was two types of seeds obtained from three consecutive years. First, 13 sesame seed accessions were prepared from the oilseed section of the center in 2009 and then tested for morphological components and yield at the research farm of the Faculty of Agriculture of Ferdowsi University of Mashhad (Nezami et al., 2014). In this year, seeds were collected from plants that produced three capsules per leaf node, and to obtain pure seeds of three capsules per leaf node, these seeds were planted in pots for three consecutive years. For the plants that produced three capsules per leaf node, seeds with three capsules per leaf node (CAP2) and one capsule per leaf node (CAP1) were prepared separately and considered as the first factor for the two types of seeds. The second factor was three concentrations of cytokinin (CK) (zero, 50, and 100 ppm) applied during the life cycle of sesame plants (seed priming and foliar spraying at 55 and 80 days after planting: DAP), so the total treatments were zero, 50, and 100 ppm for T1, T2, and T3, respectively.

Table 1. Physical and chemical characteristics of the experimental (0 – 30 cm depth)

Sand %	Silt %	Clay %	EC $dS.m^{-1}$	pH -	OC %	TNV %	SP %	NT %	P_{ave} ppm	K_{ave} ppm
31	49	20	1.08	7.6	0.61	15.5	36.4	0.076	227	12.8

TNV: (Total Neutralising Value), this is a quality index system used to express the effectiveness of the material to reduce or neutralise soil acidity
SP: (The Saturation Percentage), equals the weight of water required to saturate the pore space divided by the weight of the dry soil.
NT: (Total Nitrogen Content)

To prepare for hormonal treatments, 0.1 g of cytokinin powder was mixed with 10 ml of a 1 N solution of NaOH, and after stirring for 5 minutes on a shaker, 10 ml of 1 N hydrochloric acid (HCl) was added to the mixture. The resulting solution was stirred well until the NaOH was completely neutralized in the solution. Finally, 980 ml of distilled water was added. This solution was 100 ppm of cytokinin stock solution. The same procedure was used to prepare 50 ppm cytokinin solution. The seeds were disinfected with fungicides and planted on 20 May. Land preparation and planting operations were carried out according to the custom of the region. In order to ensure uniformity of nutrition, before planting, soil samples were prepared from five points of land and sent to the laboratory (Table 1). After the plants were established and reached the four-leaf stage, they were thinned until the distance between two plants in a row reached seven centimeters.

Irrigation was done every week. After elimination of the marginal effects in each plot, and the plants ripened, 10 plants were selected, and several morphological traits (such as plant length, number of branches per plant, branch length, number of nodes with one capsule, number of nodes with three capsules, number of capsules per plant, number of seeds per capsule, 1000 seed weight, and fresh and dry weight) and yield components were measured in the laboratory.

The data were analyzed with Mstat-C software, and the means were compared with the least significant difference (LSD) test at five percent probability.

3. Results

3.1. Morphological traits

Analysis of variance revealed that cytokinin (CK) significantly affected the length and number of plant branches (Table 2). The maximum plant length (83.5 cm) was obtained from the 50 ppm CK treatment, which increased by 4 and 31% compared to those in the zero and 100 ppm CK treatments, respectively (Table 4). The greatest plant lengths in CAP2 and CAP1 under 50 ppm CK were 97.2 and 68.7 cm, respectively (Table 5). The number of branches per plant was obtained after the application of 100 ppm CK in the CAP1 treatment (6.66), and the other interaction treatments did not significantly affect this trait. The lowest number of branches per plant was recorded in the T3×CAP2 treatment (1.00), which was a decrease of 84.9% compared to the greatest reduction (Table 5). There was no significant difference in branch length between the zero and 50 ppm CK treatments (42.8 and 45.8 cm, respectively), but as the CK concentration increased to 100 ppm, the branch length decreased (Table 4). The length of the branches in the T2×CAP1 and T2×CAP2 treatments were 34.4 and 46.0 cm, respectively. The maximum length of this trait was obtained in the 50 ppm CK treatment (T2) in CAP2 treatment (57.2 cm), which was 42% greater than effect it in the CAP1 treatment (Table 5).

3.2. Comparison of CAP1 and CAP2 treatments

Table 2 shows that plants grown from the seeds of one-capsule plants (CAP1) differed significantly from those grown from the seeds of three-capsule plants (CAP2) in terms of traits such as the number of one-capsule nodes and the number of three-capsule nodes. In the CAP1 and CAP2 treatments, the number of one-capsule nodes per plant was 25.1 and 15.5, respectively. In CAP2, the number of three capsule nodes per plant was greater than that in CAP1 (Table 3). Compared with the use of 100 ppm CK, the use of 50 ppm CK in CAP1 increased the number of one-capsule nodes by 48% (Table 5). With the application of 50 ppm CK, the maximum number of three-capsule nodes was approximately 7.71, which was 38.6 and 72.8% greater than that in the control and 100 ppm CK treatments, respectively (Table 4). The interaction results of treatments showed that the maximum and minimum number of one-capsule nodes were in T2×CAP1 (32.2) and T3×CAP2 (9.33), respectively. The highest and lowest number of three-capsule nodes in CAP2 were 10.3 and 2.02, respectively, which were obtained from the application of 50 and 100 ppm CK, respectively (Table 5). The number of one-capsule nodes in CAP2 was much lower than that in CAP1. The lowest number of three-capsule nodes was obtained for T1×CAP1 (1.01) treatment (Table 5).

Table 2. Results of variance analysis of morphological and yield components traits of sesame plants affected by different concentrations of cytokines under field conditions.

S.O.V	df	Plant length	No. of branches per plant	Branch length	No. of one-capsule nodes per plant	No. of three-capsule nodes per plant	No. of capsules per plant	No. of seeds per capsule	1000 seed weight	seed weight per plant	Plant fresh weight	Plant dry weight
Block	2	499*	18.4	16.8	47.1	5.52	1394	42.5	96.4	12.2	3109	231
Capsule (CAP)	1	640**	290**	2.51ns	420**	0.907*	354*	530**	9.46ns	0.27ns	351ns	2.56ns
cytokinin	2	1010**	282**	1001**	290**	46.7**	1540*	269*	171ns	39.3	1940ns	181*
Capsule×cytokinin	2	448*	124**	733**	35.3*	96.1**	488*	8.37*	30.1ns	0.45*	3234*	134ns
Error	10	6025	7.41	34.2	18.6	2.03	503	40.4	70.5	12.1	1002	61.5

ns, * and ** are nonsignificant and significant at the 5% and 1% probability levels, respectively.

Table 3. Mean comparison of morphological and yield components traits of in two sesame plant. sesame plant.

Treatment	Plant length (cm)	No. of branches per plant	Branch length (cm)	No. of one-capsule nodes per plant	No. of three-capsule nodes per plant	No. of capsules per plant	No. of seeds per capsule	1000 seed weight (g)	seed weight per plant (g)	Plant fresh weight (g)	Plant dry weight (g)
CAP1	65.8 b	11.8 a	35.6 a	25.1 a	4.6 b	49.8 b	30.64 b	3.84 a	3.59 a	72.8 a	17.2a
CAP2	78.2 a	3.77 b	36.4 a	15.5 b	5.05 a	55.9 a	41.4 a	3.59 a	4.12 a	83.9 a	19.4a

CAP1: plants grown from one-capsule plant seeds; CAP2: plants grown from three-capsule plant seeds.

Table 4. Mean comparison different concentrations of cytokinin on morphological and yield components traits of sesame plant.

Treatment	Plant length (cm)	No. of branches per plant	Branch length (cm)	No. of one-capsule nodes per plant	No. of three-capsule nodes per plant	No. of capsules per plant	No. of seeds per capsule	1000 seed weight (g)	seed weight per plant (g)	Plant fresh weight (g)	Plant dry weight (g)
T1	79.5 a	14.7 a	42.8 a	23.1 a	4.73 b	49.3 b	28.7 c	1.78 a	3.16 b	79.7 a	20.4 b
T2	83.5 a	4.16 b	45.8 a	24.1 a	7.71 a	56.7 a	47.1 a	2.45 a	6.75 a	84.5 a	30.7 a
T3	57.4 b	3.83 b	21.1 b	12.4 b	2.09 c	28.0 c	33.7 b	2.30 a	1.48 c	49.9 b	11.1 c

Means with common letters are not significantly different from each other based on the least significant difference (LSD) test at the 5% probability level.
* T1: zero of cytokinin (CK), T2: 50 ppm prime with CK, T3: 100 ppm prime with CK.

Table 5. Mean comparison of the cytokinin×capsule interaction effect on morphological and yield components traits of sesame plant.

Interaction effect of treatments	Plant length (cm)	No. of branches per plant	Branch length (cm)	No. of one-capsule nodes per plant	No. of three-capsule nodes per plant	No. of capsules per plant	No. of seeds per capsule	1000 seed weight (g)	seed weight per plant (g)	Plant fresh weight (g)	Plant dry weight (g)
T1 × CAP1	68.3 b	4.01 ab	39.6 bc	28.9 a	1.01 c	48.8 b	26.0 c	1.81 a	3.28 c	57.4 d	15.3 cd
T2 × CAP1	68.7 b	4.00 ab	34.4 c	32.2 a	8.91 a	59.9 a	44.4 ab	2.31 a	6.91 b	93.6 a	25.5 b
T3 × CAP1	56.7 b	6.66 a	33.0 c	15.4 b	2.15 c	33.8 c	28.7 c	2.10 a	1.33 d	67.3 cd	13.3 cd
T1 × CAP2	89.3 a	4.66 ab	46.0 b	17.0 b	5.11 b	49.3 b	31.4 c	1.76 a	1.26 d	75.2 cd	19.3 bc
T2 × CAP2	97.2 a	4.33 ab	57.2 a	13.8 b	10.3 a	64.5 a	49.8 a	2.59 a	13.2 a	102 a	42.2 a
T3 × CAP2	58.0 b	1.00 b	9.33 d	9.33 c	2.02 c	22.1 d	39.4 b	2.50 a	3.08 c	31.2 e	8.69 d

Means with common letters are not significantly different from each other based on the least significant difference (LSD) test at the 5% probability level.
T1: zero of cytokinin (CK), T2: 50 ppm prime with CK, T3: 100 ppm prime with CK.
CAP1: plants grown from one-capsule plant seeds; CAP2: plants grown from three-capsule plant seeds

3.3. Yield components

The results of the analysis of variance showed that type of seed (CAP1 and CAP2), CK concentrations (T2, T3 and T4) and the interaction between them had significant effects on the number of capsules per plant and the number of seeds per capsule (Table 2). CAP2 had the greatest number of capsules per plant (Table 3), and with the application of 50 ppm CK, the greatest number of capsules per plant (56.7) and the greatest number of seeds per capsule (47.1) were obtained (Table 4). The minimum number of capsules per plant and the lowest number of seeds per capsule were recorded in the 100 ppm CK (T3) and control treatments, respectively (Table 4). The results of the interaction between the treatments showed that the maximum number of capsules per plant (64.5) and the maximum number of seeds per capsule (49.8) were recorded for T2×CAP2 (Table 5). The concentrations of CK, CAP treatment and their interaction had no significant effect on the 1000-seed weight (Tables 2, 3, 4 and 5). The results in Table 3 show that with the application of 50 ppm CK, the seed weight per plant was 6.75 g, which was 53 and 78% greater than that in application the zero and 100 ppm CK treatments, respectively. The highest (13.2 g) and lowest (1.26 g) seed weights per plant were obtained by application of 50 ppm CK and the control treatments in CAP2, respectively (Table 5). In CAP1, when 50 ppm CK was used, the maximum seed weight per plant (6.91 g) was recorded (Table 4). In compare of 50 ppm CK treatment (T2), the seed weight per plant was decreased by approximately 80% in the 100 ppm CK treatment (T3) (Table 5). There was a significant difference in the effect of CK and CAP on the fresh and dry weights of the plants (Table 2). The highest fresh and dry weights of the plants (84.5 and 30.7 g, respectively) were obtained from plants treated with 50 ppm Ck (Table 4). Similar results were recorded for the interaction between 50 ppm CK (T2) and CAP1 and CAP2, and the highest fresh weights of the plants were 93.6 and 102 g, respectively (Table 5). In Cap1, the lowest plant fresh weight was recorded for the zero Ck treatment, while in CAP2, the lowest plant fresh weight of 31.2 g was recorded in the 100 ppm CK (T3) treatment (Table 5). In the T2×CAP2 treatment, the greatest amount of plant dry weight (42.2 g) was recorded, and the lowest amount of this trait (8.69 g) was obtained in the T3×CAP2 treatment (Table 5). The lowest plant dry weight (13.3 g) was recorded in the T3×CAP1 treatment, (Table 5).

4. Discussion

Plant development and growth are affected by the activity of meristematic zones. Low-molecular-weight transcription factors, including plant hormones, regulate this region (Bartrina et al., 2011). In recent years, cytokinin metabolism and signal transduction have been elucidated (Werner and Schmulling, 2009), and it has been demonstrated that cytokinin positively regulation of seed germination, shoot elongation and proliferation, induction of flowering, fruiting, seed set, and senescence (Jameson and Song, 2015). The studies of Bartrina et al. (2011) also showed that the application of cytokinin in arabidobsis mutants caused the formation of a larger inflorescence meristem compared to that in wild type plants. In the present study, we observed an increase in the number of capsules per leaf node that originated from axillary buds in leaf nodes, and these results are consistent with the results of Bartrina et al. (2011). It seems that the division and differentiation of axillary bud cells in the presence of cytokinin increase the number of flower buds, and the synthesis of more photosynthates meets the needs of the growing auxiliary buds, and glucose is provided for their growth. In a research Akter et al. (2014) reported that application of CK at 150 $mg.l^{-1}$ was excellent resulting in a 106% yield advantage compared to drought stress and 79.9% increase relative to well-watered controls. Some researchers (Koprna et al., 2021; Yeh et al., 2015) reported that depending on the crop species, the exogenous application of cytokinin was increased reproductive tillers in winter wheat, and in rice plant, was increase in the number of tillers (34.7%), number of panicles (38.5%), and paddy yield (21.6%). The results of our study on these morphological traits are consistent with the results of these studies. In contrast, Leite et al. (2003) showed that the application of 30 mg. L^{-1} cytokinin during vegetative growth had no effect on the evaluated plant growth variables. Studies have shown that the efficacy of cytokinin depends on the amount of auxin; at lower levels of auxin, more cytokinin initiates bud break. Leite et al. (2003) reported that the application of GA3 and cytokinin increased plant height by 34% in compare of the control. In our study, plant height increased in response to 50 ppm CK. Importantly, in our study, the number of three capsule nodes increased with the use of 50 ppm CK. Increasing the concentration of CK was decreased the auxin/cytokinin ratio, and as a result, the effect of auxin was decreased in apical dominance, and the number of lateral buds increased. In this regard, Bartrina et al. (2011) showed that the levels of biologically active trans-zeatin and trans-zeatin riboside were approximately fourfold greater in the inflorescences of Arabidopsis mutants than in those of the wild type. In another study, increased chlorophyll contents were observed when plants were applied with BAP in 5 µM concentration under drought stress due to increased cell division, cell elongations and increased stay green foliage (Pandey et al., 2003). It seems that the appropriate concentration of CK causes a delay in leaf senescence, and as a result, by increasing photosynthesis, enough glucose is produced for the growth of other parts of the plant. In this regard, Hamdani et al. (2024) suggested that with foliar application cytokinin during the leaf development stage in potato plant led to accelerate growth in the early vegetative phase, resulting provided energy for formation and development of tubers. Thus, cytokinin present in the leaves stimulates the division and enlargement of young leaf cells to their normal size, which in turn increases the leaf area that leads to the increase of photosynthetic materials and the allocation of these materials to growth sites (Taiz and Zeiger, 2006). Therefore, cytokinin creates new source–sink relationships and preserves the synthesis of nucleic acid and protein in the leaf, thereby delaying leaf senescence.

5. Conclusion

The research findings of this research showed that the appropriate concentration of CK stimulates the division and enlargement of the meristic region, which in turn increases the morphological index (increasing the bud that produces leaves, stems, and flowers). In this regard, the use of 50 ppm external cytokinin in the CAP2 treatment has caused a significant increase in the number of multi-capsule nodes, the number of capsules per plant, the number of seeds per capsule and the weight of seeds per plant. However, for better efficiency, this hormone should be used with the appropriate growth ratio of other plant growth regulators to obtain an economic product.

References

Akter, N., Rafiqul Islam, M., Abdul Karim, M., & Hossain, T. (2014). Alleviation of drought stress in maize by exogenous application of gibberellic acid and cytokinin. *Journal of Crop Science and Biotechnology*, *17* (1), 41-48. **doi:10.1007/s12892-013-0117-3**

Amasino, R. (2005). 1955: kinetine arrives. The 50th anniversary of a new plant hormone. *Plant Physiology*, *138*(3), 1177-1184. **doi: 10.1104/pp.104.900160**

Ball, R. A., Purcell, L. C., & Vories, E. D. (2000). Short-season soybean yield compensation in response to population and water regime. *Crop Science*, *40*, 1070-1078. **doi: 10.2135/cropsci2000.4041070x**

Bartrina, I., Otto, E., Strnad, M., Werner, T., & Schmulling, T. (2011). Cytokinin regulates the activity of reproductive meristems, flower organ size, ovule formation, and thus seed yield in *Arabidopsis thaliana*. *The Plant Cell*, *23*, 69-80. **doi: 10.1105/tpc.110.079079**

Fazeli Kakhki, F. S., Nezami, A., Parsa, M., & Kafi M. (2014). Evaluation of yield and yield components of 43 sesame (*Sesamum indicum* L.) lines and ecotypes under irrigated with saline water. *Iranian Journal of Field Crops Research*, *12*, 378-386. [In Persian]. **doi: 10.22067/gsc.v12i3.42214**

Giulini, A., Wang, J., & Jackson, D. (2004). Control of phyllotaxy by the cytokinin-inducible response regulator homologue ABPHYL1. *Nature*, *430*, 1031-1034. **doi: 10.1038/nature02778**

Hamdani, S. (2024). Optimizing growth and yield of potato 'atlantic': effects of shading net and watering interval. *Journal of Applied Science and Social Science*, *14*(02), 01-06.

IRIMO. (2016). Applied meteorological development plan report, No. 1, Agricultural Meteorology.

Jameson, P.E., & Song, J. (2015). Cytokinin: A key driver of seed yield. *Journal of Experimental Boyany*, *67*, 593–606.

Koprna, R., Humplik, J. F., Spisek, Z., Bryksová, M., Zatloukal, M., Mike, V., Novák, O., Nisler, J., & Doležal, K. (2021). Improvement of tillering and grain yield by application of cytokinin derivatives in wheat and barley. *Agronomy*, *11*(67), 1-15.

Langham, D. R., & Wiemers, T. (2002). Progress in mechanizing sesame in the US through breeding. The Fifth National Symposium, Atlanta, USA.

Leite, V. M., Rosolem, C. A., & Rodrigues, J. D. (2003). Gibberlin and cytokinin effects on soybean growth. *Scientia Agricola*, *60*, 537-541. **doi: 10.1590/s0103-90162003000300019**

Li, J. Y., & Tang, Y. Q. (2002). Relation of change in content of plant endogenous cytokinin to germination and growth of ratooning buds in hybrid rice. *Hybrid Rice*, *17*, 50-52.

Marquez-lopez, R. E., Quintana-Escobar, A. O., & Loyola-Vargas, V. M. (2019). Cytokinins, the Cinderella of plant growth regulators. *Phytochemistry Reviews, 18*, 1387-1408. **doi: 10.1007/s11101-019-09656-6**

Nagarathna, T. K., Shadakshari, Y. G., Jagadish, K. S., & Sanjay, M. T. (2010). Interaction of auxin and cytokinins in regulating axillary bud formation in sunflower (*Helianthus annuus* L.). *Helia*, *33*, 85-94. **doi: 10.2298/hel1052085n**

Nezami, A., Fazeli Kakhki, F. S., Zarghami, H., Shabahang, J., & Gandomzadeh, M. R. (2014). Preliminary evaluation of yield and yield components of some Khorasanian sesame ecotypes (Sesamum *indicum L.*). *Iranian Journal of Field Crops Research*, *12*, 189-195. [In Persian]. **doi: 10.22067/gsc.v12i2.39144**

Nordstrom, A., Tarkowski, P., Tarkowska, D., Norbaek, R., Astot, C., Dolezal, K., & Sandberg, G. (2004). Auxin regulation of cytokinin biosynthesis in *Arabidopsis thaliana*: a factor of potential importance for auxin-cytokinin regulated development. *Proceedings of the National Academy of Sciences*, *101*, 8039-8044. **doi: 10.1073/pnas.0402504101.**

Pandey, D. M., goswami, C. L., & Kumar, B. (2003). Physiological effects of plant hormones in cotton under drought . *Biological Plantarum*, *47*(4): 535-540.

Sakakibara, H. (2006). Cytokinins: activity, biosynthesis, and translocation. *Annual Review of Plant Biology*, *57*, 431-449. **doi: 10.1146/annurev.arplant.57.032905.105231**

Schwarz, I., Scheirlinck, M. T., Otto, E., Bartrina, I., Schmidt, R. C., & Schmülling, T. (2020). Cytokinin regulates the activity of the inflorescence meristem and components of seed yield in oilseed rape. *Journal of Experimental Botany*, *71*(22), 7146-7159. **doi: 10.1093/jxb/eraa419**

Taiz, L., & Zeiger, E. (2006). Plant physiology, 4th ed. Sinauer Assoc, Inc., Publ. Sunderland MA, USA.

Vylíčilová, H., Bryksová, M., Matušková, V., Doležal, K., Plíhalová, L., & Strnad, M. (2020). Naturally occurring and artificial N9-cytokinin conjugates: From synthesis to biological activity and back. *Biomolecules*, *10*(6), 832. **doi:10.3390/biom10060832**

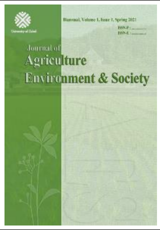
Werner, T., & Schmulling, T. (2009). Cytokinin action in plant development. Current Opinion in *Plant Biology*, *12*, 527-538. **doi: 10.1016/j.pbi.2009.07.002.**

Yeh, S. Y., Chen, H. W., Ng, C. Y., Lin, C. Y., Tseng, T. H., Li, W. H., & Ku, M. S. (2015). Down-regulation of cytokinin oxidase 2 expression increases tiller number and improves rice yield. *Rice*, *8*, 1-13. **doi: 10.1186/s12284-015-0070-5**

Agriculture, Environment & Society (2023) Volume 3, Issue 2, P. 107-113

Agriculture, Environment & Society

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



Water production by thermoelectric method and its effect on seed germination of wheat, foxtail millet, and radish

Sargol Hosseini [a], Hassan Heidari[*a]

[a] Department of Plant Production and Genetics Engineering, Faculty of Agricultural Science and Engineering, Razi University, Kermanshah, Iran

ARTICLE INFO

Article history:
Received: 24 February 2023
Accepted: 13 June 2023
Available online: 29 June 2023

Keywords:
Air-water vapor
Radicle
Seed vigor
Water supply

ABSTRACT

One of the sources of water is air-water vapor. To evaluate water supply with air-water vapor, a study was conducted as a factorial experiment in a completely randomized design with three replications. The studied factors included irrigation method (irrigation by thermoelectric module and control) and plant species (wheat, foxtail millet, and radish). Analysis of variance showed that the interaction effect of plant species and irrigation method on all seed germination characteristics was significant. The mean comparison showed that irrigation by thermoelectric module germinated wheat, foxtail millet, and radish seeds. So that all the seeds germinated. Irrigation by thermoelectric module increased seed germination, caulicle length, radicle length, caulicle weight, radicle weight, seed vigor based on length, seed vigor based on weight, and root to shoot ratio compared to the control (without irrigation). Overall, irrigation by the thermoelectric module can germinate the seeds of wheat, foxtail millet, and radish and can be considered as a new method of irrigation in arid and semi-arid regions where farmers do not have access to water for growing plants.

Highlights

- Thermoelectric module can germinate the seeds.
- Thermoelectric module increased caulicle length, radicle length, caulicle weight, radicle weight, seed vigor based on length, seed vigor based on weight, and root to shoot ratio.
- Irrigation by the thermoelectric module can be considered as a new method of irrigation.

1. Introduction

Drought is a natural phenomenon that occurs in all regions. Drought due to climate change has a negative effect on freshwater resources (Seo et al., 2022). Drought affects agriculture, the environment, and socio-economic issues. Climate change is increasing drought and reducing farmers' food security (Alahacoon and Amarnath, 2022).

Dew is one of the sources of water supply that is often neglected. To form dew, the air hits the cold surface and water vapor condenses into water droplets. Dew can wet the crop canopy and be used for evaporation and transpiration (Moratiel et al., 2016). Dew and hoar frost together account for 4.2-6% of the total annual rainfall in the alpine grassland. In drier months, dew and hoar frost make up 16.1% of the total monthly rainfall. Dew and hoar frost are of ecological importance. Dew and hoar are involved in the water budget of low-lying mountains and alpine grassland (Groh et al., 2018). In the arid valley of the Andes, the annual deposition of night dew is about 5-10 mm per year and acts as one of the water sources in meeting the water needs of natural vegetation, especially in dry seasons (Kalthoff et al., 2006). In the study of dew formation among *Haloxylon ammodendron* trees, it was found that air temperature, relative humidity, the difference between air temperature and dew point, and wind speed were effective on dew formation. The dew formation threshold was 50% air relative humidity and 4.27 m / s wind speed. With the increasing canopy of *H. ammodendron*, the amount of dew produced increased (Zhuang and Zhao, 2017). In the study of the amount of water produced in different condensers with different dimensions, it was found that passive dew condensers with a surface of 1 square meter provided enough water for the survival of tree seedlings during drought season (Snyder et al., 2018). Dew can be effective up to 3% in soil moisture. Collecting and storing dew with an area of 2 square meters in the amount

* Corresponding author.
E-mail address: heidari1383@gmail.com
https://doi.org/10.22034/jelsa.2024.458894.1068

of 4.5 liters per plant per month can easily meet the needs of a tree sapling (Tomaszkiewicz et al., 2017). Evaluation of dew formation characteristics in a semi-arid region in China showed that the dewfall was 1/18th rainfall, but the number of dew formation days was 2.6 times that of rainy days. Dew is therefore a vital source of water to reduce dry periods and support plants (Jia et al., 2019). The water-energy nexus is important in the production of atmospheric water. Today, hybrid atmospheric water production systems and problems of new atmospheric water production techniques are investigated (Raveesh et al., 2021). High quality water is produced by condensation. Factors such as climate and structure affect the quantity and quality of air condensation. There is a lot of interest in growing plants in closed water systems worldwide (Jurga et al., 2023). Sunlight is a cheap and available source of atmospheric water production. Nowadays, integrated systems are used because they use several methods to cool water vapor. This method increases productivity (Shafeian et al., 2022). In the study of the effect of factors such as temperature and relative humidity on the performance of the atmospheric water production system, it was seen that hot and humid air produced more water with less energy consumption. This study showed that the production of atmospheric water is a suitable method for India, which is prone to water scarcity (Raveesh et al., 2023).

Seed germination is one of the drought-sensitive stages. In the study of the drought effect of polyethylene glycol (PEG) on kenaf seed germination, it was observed that seed germination increased at 10% PEG concentration compared to control and 20% PEG concentration. Radicle growth was reduced at 10% PEG concentration (Tang et al., 2019). Drought induced by PEG reduced seed germination and seedling growth of wheat (Wang et al., 2020). PEG-induced drought decreased germination and seedling growth in *Vigna unguiculata* L. Walp. while increasing proline content (Carvalho et al., 2019). Drought induced by PEG reduced the percentage and rate of seed germination in Cantaloupe (*Cucumis melo* L.) and radish (*Raphanus sativus* L.) (Bakhshandeh and Gholamhosseini, 2019).

Production of water from water vapor in the air is one of the new sources of irrigation. Research on the use of air-water vapor for irrigation of plants is limited, so this study was conducted to determine the seed germination characteristics of wheat, foxtail millet, and radish using water produced by the thermoelectric method.

2. Materials and methods

To evaluate water production with thermoelectric module and its effect on seed germination of wheat (*Triticum aestivum* L.), foxtail millet (*Setaria italica* (L.) P. Beauv.), and radish (*Raphanus sativus* L.), a laboratory study was conducted as a factorial experiment in a completely randomized design with three replications in the Faculty of Agricultural Science and Engineering of Razi University in 2016. The studied factors included irrigation method (irrigation by thermoelectric module and control) and plant species (wheat, foxtail millet, and radish). Controls were intact seeds that were not irrigated. The control treatment was used to ensure that the air humidity did not affect the germination of seeds. The seeds were placed in a Petri dish containing a filter paper. Seeds of control treatment and seeds related to irrigation treatment with thermoelectric module were both placed in the relevant Petri dishes. In the irrigation treatment with the thermoelectric module, the device was first connected to electricity. The filter paper was then placed on the module until sufficient moisture was absorbed by the filter paper. The filter paper was then placed on the bottom of the Petri dish and the seeds were placed on it.

The thermoelectric module used had dimensions of 4 cm by 4 cm by 0.5 cm. The internal resistance of the device was 2.5 to 2.8 ohms. The voltage used was 12 volts. Cooling power was 60 to 72 watts. The device model was TEC1-12706.

After one week, seed germination characteristics including seed germination percentage, caulicle length, radicle length, caulicle weight, and radicle weight were calculated. The seed germination criterion was two millimeters of growth of the caulicle. Caulicle length and radicle length were measured with a ruler.

To measure caulicle and radicle weight, caulicle and radicle were first placed in a paper bag, and then transferred to an oven at 75 ° C. After 24 hours, caulicle dry weight and radicle dry weight was measured with a digital scale. Seed vigor based on length and seed vigor based on weight were obtained by the following equations (Eq. 1 and 2), respectively (Yosefi and Heidari, 2022).

Seed vigor based on length (%cm) = Seedling length (cm) × Seed germination (%) (1)

Seed vigor based on weight (%mg) = Seedling weight (mg) × Seed germination (%) (2)

Before data analysis, outliers were identified and deleted if necessary. First, the data were analyzed for a variance to determine significant effects. Then the means were compared. SAS software was used to analyze the data. Data were compared using Duncan's test at a 5% probability level.

3. Results

Analysis of variance showed that the interaction of irrigation method and plant species on germination percentage, caulicle length, radicle length, caulicle weight, radicle weight, seed vigor based on length, seed vigor based on weight, and root to shoot ratio was significant (Table 1).

Mean comparisons showed that irrigation with thermoelectric module resulted in 100% germination of wheat, foxtail millet, and radish, while in control (without irrigation) no seeds germinated (Figure 1A). Mean comparisons showed that the seeds irrigated with a thermoelectric module had a longer caulicle length than the control seeds. The caulicle length was the highest in wheat and the lowest in foxtail millet (Figure 1B). Mean comparisons showed that the seeds irrigated with a thermoelectric module had a longer radicle length than the control seeds. The radicle length in radish was longer than in foxtail millet and wheat (Figure 1C). Mean comparisons showed that the seeds irrigated with a thermoelectric module had higher caulicle weight than the control seeds.

The caulicle weight was the highest in radish and the lowest in foxtail millet (Figure 1D).

The mean comparison showed that the seeds irrigated with a thermoelectric module had higher radicle weight than the control seeds. Radicle weight was highest in wheat and lowest in foxtail millet (Figure 2A). The mean comparison showed that the seeds irrigated with a thermoelectric module had higher seed vigor based on length than the control seeds. Seed vigor based on length in wheat and radish was higher than foxtail millet (Figure 2B). The mean comparison showed that the seeds irrigated with a thermoelectric module had higher seed vigor based on weight than the control seeds. Seed vigor based on weight was highest in wheat and lowest in foxtail millet (Figure 2C). Mean comparisons showed that in wheat and foxtail millet, seeds irrigated with thermoelectric module had a higher root-to-shoot ratio than control. Root to shoot ratio was highest in foxtail millet and lowest in radish (Figure 2D).

Table 1. Analysis of variance of the effect of water production by thermoelectric method on seed germination traits of wheat, foxtail millet, and radish

Source of variation	df	Germination	Caulicle length	Radicle length	Caulicle weight	Radicle weight	Seed vigor based on length	Seed vigor based on weight	Root to shoot ratio
Irrigation (I)	1	45000**	69.38**	113.58**	96.56**	69.46**	44471156**	3373650**	1.62**
Plant species (P)	2	0**	2.25**	2.57**	20.01**	39.77**	66379**	823155**	0.42**
I×P	2	0**	2.94**	3.43**	22.94**	52.74**	66379**	997785**	0.51**
Error	12	0	0.02	0.23	0.01	0.05	2461	2333	0.01

** indicates significance at the probability level of 1%.

4. Discussion

Hosseini et al. (2020) reported that dew-irrigation resulted in seed germination and growth of flax, fenugreek, and fennel, which is consistent with the results of the current study. Seed germination is a stage with low water requirements. The amount of moisture required for seed germination is two to three times the weight of the seed (Bewley and Black, 1978). Due to the low water requirement of seeds for germination and seedling growth, this irrigation method can be used to germinate seeds in areas that do not have access to water resources for growing plants. Drought tolerance during *Periploca sepium* seed germination was due to the higher activity of antioxidant enzymes and the accumulation of some salts (An and Liang, 2013). Different wheat cultivars had different responses to different levels of dryness caused by polyethylene glycol (Blum et al., 1980). The drought caused by polyethylene glycol decreased the germination percentage of castor bean (*Ricinus communis* L.) seeds, which is consistent with the results of this study (Babaei et al., 2023).

Dew is an important source of water available in arid or semi-arid regions, and some researchers have sought to measure the amount of dew produced in ecosystems. Dew is reported to form in 53% of the nights in the Mongolia Plateau sandy ecosystem. The dew produced was about 0.15 mm per night and both plant species C3 and C4 used dew (Liu et al., 2020). By using waste rock burials, the air vapor temperature can be lowered to the dew point and water can be produced. These rock wastes can contribute to reforestation in arid areas (Juřička et al., 2020). In the study of the effect of dew on the sand desert ecosystem, it was found that the relative humidity threshold for dew formation and absorption was 30% and dew was involved in the moisture budget and photosynthetic performance of vegetation (Zhuang et al., 2021).

Various methods for dew collection have been studied by researchers such as superhydrophilic / superhydrophobic hybrid surfaces (Hou et al., 2020), hierarchical superhydrophobic surfaces (Rykaczewski et al., 2013), cactus spines (Yi et al., 2019), and tailoring silicone (Liu et al., 2021).

Irrigation of plants at the seed germination stage with thermoelectric module probably has higher water use efficiency than conventional field irrigation methods, because, in this method, only a part of the soil is wet. With this method, water can be provided to seeds and plants continuously. This method of irrigation does not require a piping system and some costs such as irrigation fittings will be reduced. Due to the novelty of this method, its design at the farm scale requires special research.

The reduction of some seed germination characteristics such as caulicle length, caulicle weight, radicle weight, and seed vigor in foxtail millet compared to wheat and radish may be due to the thermophilic nature of this plant.

Water production with a thermoelectric module is suitable for dry and semi-dry areas. In these areas, due to sunny weather, electricity can be generated by solar panels. Due to the high wind speed in these areas, it is possible to generate electricity from wind. Clean energies such as wind and solar energy protect the environment. The thermoelectric module can also be used for afforestation and desert greening.

As a renewable resource, the sun has the ability to provide fuel for life on earth and clean and sustainable energy for all its inhabitants. Solar energy can be converted into electricity through solar photovoltaic modules. The advantages of solar energy are a renewable energy source and its diverse applications, and the disadvantages of solar energy include high cost, dependence on weather, expensive solar energy storage, high volume occupation, and creating pollution caused by the transportation and installation of solar systems with the emission of greenhouse gases (Novasi, 2024). Wind energy is also one of the fastest growing energy sources in the world due to its many advantages. Some of its advantages are the cheapness of wind energy, the inexhaustibility of wind energy, the cleanness of the source, and the stability of wind energy. Disadvantages of wind energy include noise pollution of wind energy, damage to wildlife, pollution caused by the production of wind energy production facilities (Hills, 1996; Pakpasabeghlim, 2024).

Considering the high cost of electricity to extract water from the air, the thermoelectric module can be used in sensitive plant growth stages such as germination and establishment, which require little water. In addition, this module can be used in arid and semi-arid areas for supplementary irrigation in rainy conditions for plants that require little water, such as medicinal plants. According to the above, little energy is consumed in low-input systems such as dry farming of medicinal plants, so energy consumption for water production by thermoelectric method has little effect on the stability of the system. Using renewable and cheap energy such as solar energy to produce electricity increases the stability of the production system.

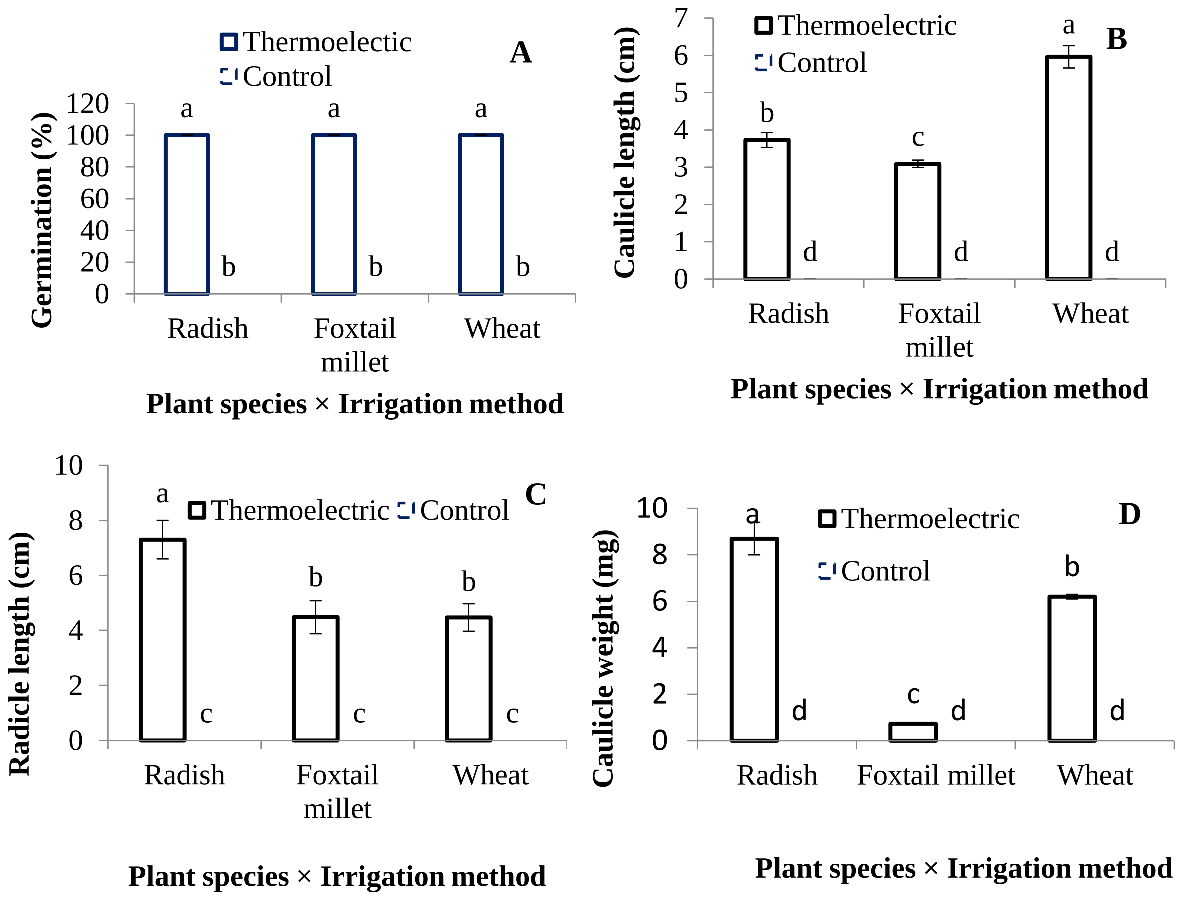


Figure 1. Mean comparisons of the effect of irrigation method and plant species on germination characteristics of wheat, foxtail millet, and radish. A: Seed germination percentage, B: Caulicle length, C: Radicle length, and D: Caulicle weight. Thermoelectric and Control are the method of irrigation with thermoelectric module and without irrigation, respectively. The means with at least one common letter in each trait according to the Duncan test at a 5% probability level are not significantly different. The bar shows mean ± standard error.

Due to the fact that thermoelectric irrigation has the same water quality as distilled water, therefore plant irrigation with thermoelectric method does not cause soil salinity, while micro-irrigation methods such as drip irrigation cause soil salinity and decrease soil quality in the long run due to the presence of salts in the water. Other irrigation methods, such as surface irrigation, which consume a lot of water, can make water and soil salty much faster. If the supply of electricity for water production by thermoelectric method is from fossil sources such as oil, it can cause air pollution. The production of the necessary facilities for thermoelectric irrigation is expensive and is involved in the production of carbon dioxide, but it should be kept in mind that the thermoelectric irrigation system requires a lot of facilities because in this irrigation method, electric wires take the place of water pipes. The pipes in drip irrigation are mostly plastic and have a lot of cost and pollution.

Water production by thermoelectric method increases in conditions. Climatic factors such as air humidity are effective in producing water from the air. The higher the air humidity, the more moisture can be extracted from the air by spending less energy. Harvesting water is more suitable in humid environments or in seasons with high air humidity. In arid and semi-arid regions, air humidity is low, but it is possible to produce water from air. It is suggested to conduct similar research on water production by thermoelectric method in farm conditions in different seasons of the year in terms of air humidity. The reaction of different plants to the thermoelectric irrigation method will definitely be different. Since the production of water by thermoelectric method is energy intensive, it is necessary to conduct more research on dry and medicinal plants that require less water. Considering that the thermoelectric method uses cold to produce moisture from the air, probably cool-season and warm-season plants will have different reactions to this irrigation method, and more research can be done in this field.

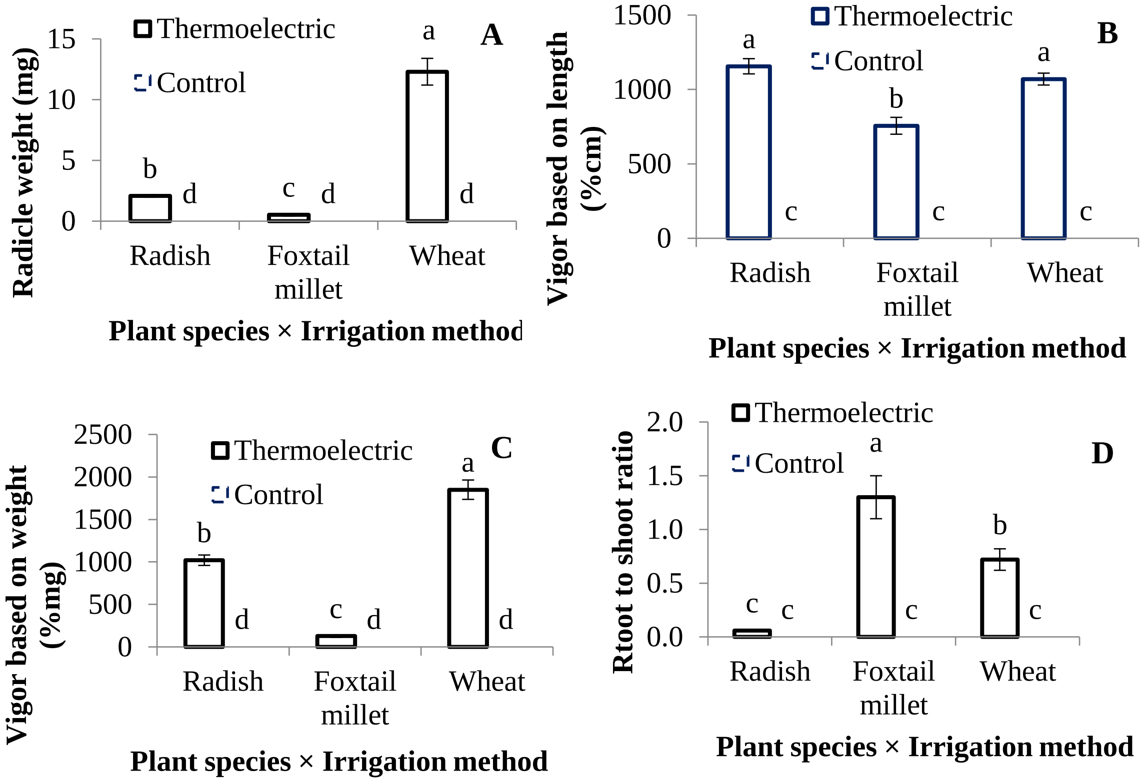


Figure 2. Mean comparisons of the effect of irrigation method and plant species on germination characteristics of wheat, foxtail millet, and radish. A: Radicle weight, B: Seed vigor based on length, C: Seed vigor based on weight, and D: Root to shoot ratio. Thermoelectric and Control are the method of irrigation with thermoelectric module and without irrigation, respectively. The means with at least one common letter in each trait according to the Duncan test at a 5% probability level are not significantly different. The bar shows mean ± standard error.

5. Conclusion

Irrigation by thermoelectric module improved all seed germination traits such as seed germination percentage, caulicle length, radicle length, caulicle weight, radicle weight, and seed vigor in wheat, foxtail millet, and radish and can be considered as a new method of irrigation in arid and semi-arid regions where farmers do not have access to water for growing plants. The following are recommended. 1. Evaluation of water production system by the thermoelectric method in different climates in terms of relative humidity and air temperature. 2. Evaluation of the amount of electricity and surface of the thermoelectric device on the amount of water production and the rate of germination and plant growth. 3. Evaluation of different seeds in terms of seed size, shape, and appendages in irrigation method using the thermoelectric device.

Conflicts of interest

The authors declare no competing interests.

References

Alahacoon, N., & Amarnath, G. (2022). Agricultural drought monitoring in sri lanka using multisource satellite data. *Advances in Space Research, 69*(11), 4078-4097. **doi: 10.1016/j.asr.2022.03.009**

An, Y., & Liang, Z. (2013). Drought tolerance of periploca sepium during seed germination: Antioxidant defense and compatible solutes accumulation. *Acta Physiologiae Plantarum, 35*, 959-967. **doi: 10.1007/s11738-012-1139-z**

Babaei, M., Pirdashti, H., & Bakhshandeh, E. (2023). Ultrasonic waves improve aged seed germination of castor bean (*Ricinus communis* L.) under drought and salt stresses. *Acta Physiologiae Plantarum, 45*, 90. **doi: 10.1007/s11738-023-03563-2**

Bakhshandeh, E., & Gholamhosseini, M. (2019). Modelling the effects of water stress and temperature on seed germination of radish and cantaloupe. *Journal of Plant Growth Regulation, 38*(4). **doi: 10.1007/s00344-019-09942-9**

Bewley, J. D., & M, B. (1978). Imbibition, germination, and growth *In: Physiology and biochemistry of seeds in relation to germination*. Berlin, Heidelberg: Springer. **doi: 10.1007/978-3-642-66668-1_4**

Blum, A., Sinmena, B., & Ziv, O. (1980). An evaluation of seed and seedling drought tolerance screening tests in wheat. *Euphytica, 29*, 727-736. **doi: 10.1007/bf00023219**

Carvalho, M., Matos, M., Castro, I., Monteiro, E., Rosa, E., Lino-Neto, T., & Carnide, V. (2019). Screening of worldwide cowpea collection to drought tolerant at a germination stage. *Scientia Horticulturae, 247*, 107-115. **doi: 10.1016/j.scienta.2018.11.082.**

Groh, J., Slawitsch, V., Herndl, M., Graf, A., Vereecken, H., & Pütz, T. (2018). Determining dew and hoar frost formation for a low mountain range and alpine grassland site by weighable lysimeter. *Journal of Hydrology, 563*, 372-381. **doi: 10.1016/j.jhydrol.2018.06.009.**

Hills, R. L. (1996). *Power from wind: A history of windmill technology*: Cambridge University Press.

Hosseini, S. S., Heidari, H., Ghobadi, M. E., & Nosratti, I. (2020). Effect of dew-irrigation on seed germination in flax, fenugreek, and fennel. *Water Supply, 20*(1), 269-276. **doi: 10.2166/ws.2019.166**

Hou, K., Li, X., Li, Q., & Chen, X. (2020). Tunable wetting patterns on superhydrophilic/superhydrophobic hybrid surfaces for enhanced dew-harvesting efficacy. *Advanced Materials Interfaces*, *7*(2), 1901683. **doi: 10.1002/admi.201901683**

Jia, Z., Wang, Z., & Wang, H. (2019). Characteristics of dew formation in the semi-arid loess plateau of central shaanxi province, china. *Water, 11*, 126. **doi: 10.3390/w11010126**

Jurga, A., Pacak, A., Pandelidis, D., & Kaźmierczak, B. (2023). Condensate as a water source in terrestrial and extra-terrestrial conditions. *Water Resources and Industry, 29*, 100196. **doi: 10.1016/j.wri.2022.100196.**

Juřička, D., Pecina, V., Kusbach, A., Vlček, V., Novotná, J., Pařílková, J., Otgonsuren, B., Brtnický, M., & Kynický, J. (2020). Thermal regime of semi-natural dew collector's perspective for afforestation of semi-arid landscapes. *Environmental Technology & Innovation, 20*, 101125. **doi: 10.1016/j.eti.2020.101125**

Kalthoff, N., Fiebig-Wittmaack, M., Meißner, C., Kohler, M., Uriarte, M., Bischoff-Gauß, I., & Gonzales, E. (2006). The energy balance, evapo-transpiration and nocturnal dew deposition of an arid valley in the andes. *Journal of Arid Environments, 65*, 420-443. **doi: 10.1016/j.jaridenv.2005.08.013.**

Liu, M., Cen, Y., Wang, C., Gu, X., Bowler, P., Wu, D., Zhang, L., Jiang, G., & Beysens, D. (2020). Foliar uptake of dew in the sandy ecosystem of the mongolia plateau: A life-sustaining and carbon accumulation strategy shared differently by c3 and c4 grasses. *Agricultural and Forest Meteorology, 287*, 107941. **doi: 10.1016/j.agrformet.2020.107941.**

Liu, X., Trosseille, J., Mongruel, A., Marty, F., Basset, P., Laurent, J., Royon, L., Cui, T., Beysens, D., & Bourouina, T. (2021). Tailoring silicon for dew water harvesting panels. *iScience, 24*, 102814. **doi: 10.1016/j.isci.2021.102814.**

Moratiel, R., Martínez-Cob, A., Tarquis, A. M., & Snyder, R. L. (2016). Soil water balance correction due to light rainfall, dew and fog in Ebro river basin (Spain). *Agricultural Water Management, 170*, 61-67. **doi: 10.1016/j.agwat.2015.12.013.**

Novasi. (2024). Solar energy; Its advantages and disadvantages. Accessed 30 Aug 2024. From: https://novasi.ir/solar-energy/

Pakpasabeghlim. (2024). What is wind energy? Know the advantages and disadvantages of wind energy. Accessed 30 Aug 2024. From: https://pakpasabeghlim.ir/wind-energy/

Raveesh, G., Goyal, R., & Tyagi, S. K. (2021). Advances in atmospheric water generation technologies. *Energy Conversion and Management, 239*, 114226. **doi: 10.1016/j.enconman.2021.114226.**

Raveesh, G., Goyal, R., & Tyagi, S. K. (2023). Parametric analysis of atmospheric water generation system and its viability in indian cities. *Thermal Science and Engineering Progress, 39*, 101682. **doi: 10.1016/j.tsep.2023.101682.**

Rykaczewski, K., Paxson, A. T., Anand, S., Chen, X. M., Wang, Z. K., & Varanasi, K. K. (2013). Multimode multidrop serial coalescence effects during condensation on hierarchical superhydrophobic surfaces. *Langmuir, 29*, 881-891. **doi: 10.1021/la304264g**

Seo, J., Won, J., Choi, J., Lee, J., & Kim, S. (2022). A copula model to identify the risk of river water temperature stress for meteorological drought. *Journal of Environmental Management, 311*, 114861. **doi: 10.1016/j.jenvman.2022.114861.**

Shafeian, N., Ranjbar, A. A., & Gorji, T. B. (2022). Progress in atmospheric water generation systems: A review. *Renewable and Sustainable Energy Reviews, 161*, 112325. **doi: 10.1016/j.rser.2022.112325.**

Snyder, V. A., Vázquez, M. A., Seldon, J., Beale, A. J., & Ramos, R. (2018). Preliminary evaluation of dew condensers and their use for tree seedling irrigation in puerto rico. *The Journal of Agriculture of the University of Puerto Rico, 102*(1-2), 1-20. **doi: 10.46429/jaupr.v102i1-2.17528**

Tang, D., Wei, F., Qin, S., Khan, A., Kashif, M. H., & Zhou, R. (2019). Polyethylene glycol induced drought stress strongly influences seed germination, root morphology and cytoplasm of different kenaf genotypes. *Industrial Crops and Products, 137*, 180-186. **doi: 10.1016/j.indcrop.2019.01.019.**

Tomaszkiewicz, M., Abou Najm, M., Zurayk, R., & El-Fadel, M. (2017). Dew as an adaptation measure to meet water demand in agriculture and reforestation. *Agricultural and Forest Meteorology, 232*, 411-421. **doi: 10.1016/j.agrformet.2016.09.009.**

Wang, S., Wei, M., Wu, B., Cheng, H., Jiang, K., & Wang, C. (2020). Does N deposition mitigate the adverse impacts of drought stress on plant seed germination and seedling growth?. *Acta Oecologica, 109*, 103650. **doi: 10.1016/j.actao.2020.103650.**

Yi, S. Z., Wang, J., Chen, Z. P., Liu, B., Ren, L., Liang, L., & Jiang, L. L. (2019). Cactus-inspired conical spines with oriented microbarbs for efficient fog harvesting. *Advanced Materials Technologies, 4*, 1900727. **doi: 10.1002/admt.201900727**

Yosefi, M., & Heidari, H. (2022). Evaluation of wheat tolerance during germination and early growth stages to detergent-contaminated water. *Tenside Surfactants Detergents, 59*(1), 95-103. **doi: 10.1515/tsd-2021-2380**

Zhuang, Y., & Zhao, W. (2017). Dew formation and its variation in Haloxylon ammodendron plantations at the edge of a desert oasis, northwestern China. *Agricultural and Forest Meteorology, 247*, 541-550. **doi: 10.1016/j.agrformet.2017.08.032**

Zhuang, Y., Zhao, W., Luo, L., & Wang, L. (2021). Dew formation characteristics in the gravel desert ecosystem and its ecological roles on *Reaumuria soongorica*. *Journal of Hydrology, 603*, 126932. **doi: 10.1016/j.jhydrol.2021.126932.**

Agriculture, Environment & Society (2023) Volume 3, Issue 2, P. 115-125

Agriculture, Environment & Society

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

Increasing the efficiency of *Glomus mosseae* and ACC-deaminase producing bacteria in chickpea by plant residue management

Reza Soleimani [*a]

[a] Soil and Water Research Department, Ilam Agricultural and Natural Resources Research and Education Center, AREEO, Ilam, Iran

ARTICLE INFO

Article history:
Received: 12 March 2023
Accepted: 20 May 2023
Available online: 28 June 2023

Keywords:
Biofertilizer
Residue management
Yield
Nutrient elements

ABSTRACT

Nowadays, managing the production of crops under rainfed conditions for achieving maximum growth potential and yield of plants for food supply is an undeniable necessity. Under rainfed condition, one of important variability in plant physiology is increase of ethylene biosynthesis up to stress ethylene that reduces plant growth. Stress ethylene cause to decline in vegetative period and decrease of yield. Mycorrhiza and ACC-deaminase producing bacteria decline the destructive effects of water deficit stress under rainfed condition. In order to determine the effectiveness of residue conservation and application of *Glomus mosseae* and ACC-deaminase producing bacteria in reducing the effects of water deficit stress in rainfed conditions, this study was conducted as split plots in a randomized complete block design (RCBD) in three replications from 2017 for two cropping years. The main plots include three different residue conservation treatments including residue removal, half residue conservation and total residue conservation and sub-plots at four levels including 1- control (no use of *Glomus mosseae* and ACC-deaminase producing bacteria), 2- application of *Glomus mosseae* 3- inoculation of ACC-deaminase producing bacteria (preparation of Bacillus simplex UT1 inoculation with 107 CFU ml-1 population or colony unit formed in ml and method of seed coating application 4- concomitant use of *Glomus mosseae* and ACC-deaminase-producing bacteria. Quantitative traits of chickpea such as grain and biological yield, 100-seed weight and number of seeds per square meter and quality traits as relative leaf water content (RWC), concentration and total uptake of potassium and zinc as two important elements in water relations were measured in plants. Data were analyzed by SAS v.9.2 software and the means were compared by LSD test. The results showed by keeping half of the residues, 1224 kg/ha of seeds of chickpea was obtained, which showed an increase of 7.81% compared to the control. The yield of chickpea seeds in the treatment of without *Glomus mosseae* and ACC-deaminase producing bacteria was 1097 kg ha^{-1}, while the highest yield of chickpea in the treatment of *Glomus mosseae* and ACC-producing bacteria at the amount of 1294 kg ha^{-1}, which was a statistically significant increase of 17.9% compared to the control. Under residue preservation condition, even the application of ACC-deaminase-producing bacteria alone and the application of *Glomus mosseae* alone showed an increase of 10.3% and 13.1%, respectively, compared to the control. In general, the combined application of *Glomus mosseae* and ACC-deaminase producing bacteria increased yield, yield components and improved nutrient concentration compared to the control treatment. Based on the results of this study, in treatments of residue preservation, the use of *Glomus mosseae* is recommended, especially in combination with inoculation of ACC-deaminase producing bacteria in order to stabilize the production of chickpeas.

Highlights

- The half plant residues improved mycorrhiza and bacteria inoculation efficiency
- Deletion of plant residues reduced microbial inoculation efficiency

[*] Corresponding author.
E-mail address: soleimanir@ut.ac.ir
https://doi.org/10.22034/jelsa.2024.464770.1078

- Plant residue favored nutrient enrichment in plant tissue
- The maintenance of half of plant residues is recommended.

1. Introduction

The researchers reported that the change in plant residue management has a great impact on the soil characteristics and finally the plant yield (Xu et al., 2022). Minimum tillage, at least by preserving the residues, leads to the improvement of the physical characteristics of the soil and the increase of soil moisture (Popolizio et al., 2022). Optimum preservation of plant residues in rainfed condition, through better moisture retention, can have a positive effect on plant yield (Sarangi et al., 2022). Cultivation systems without proper management of residues, creating unfavorable biological and chemical conditions in the soil, reduce the amount of organic carbon and nutrients in the soil (Srinivasarao et al., 2023). The results of various experiments indicate a significant effect of crop rotation on the amount of inorganic and organic nitrogen in the soil and the mineralization process of soil organic nitrogen and residual nitrogen (Singh et al., 2021). In this regard, researchers reported that the use of deep plowing leads to a faster loss of soil moisture and ultimately to a decrease in grain yield, and in contrast to systems without tillage and surface plowing, it leads to a decrease in evaporation (Du and Effah, 2022). Therefore, it can be stated that crop management and tillage methods play an important role in the physical properties and water movement in the soil. By preserving part of the plant residues, conservation agriculture effects on some soil properties such as temperature, storage and distribution of moisture in the soil and soil compaction (Garcia-Tejero c, 2020). In the long term, addition of plant residues compared to burning of the residues increased the yield of the plant by 50%, and this yield increase was the result of improving the dynamics of nutrient elements and biological characteristics of the soil (Korav et al., 2024).

Some non-biological factors, including drought stress, affect the growth and performance of plants, so that minimum bioproductivity is considered a fundamental problem, at least in regions that affected by drouth stress (Anbukkani et al., 2017), so that drought stress in rainfed fields is the most important abiotic factor limiting the growth and production of crops in Iran. Drought is a multi-dimensional stress and is effective at different levels. At the plant level, the response to water deficit stress has a special complexity and is a reflection of the combination of stress effects caused by the lack of water available to the root and the responses at physiological levels of the plant (Tranker et al., 2016). Drought stress induces cell wall destruction and electrolyte leakage from the cell wall (Alzahrani et al., 2018). This stress has an effect on hormonal and physiological changes, and the resulting oxidative damage as one of the important factors limiting plant growth and production (Khan et al., 2020). Oxidative damages and disruption in the production of free oxygen radicals resulted in alteration and destruction of proteins, membrane lipids and other cellular components (Rahman et al., 2021). Reactive oxygen species (ROS), which are an important factor in inducing drought stress, unlike atmospheric oxygen, have unlimited ability to oxidize different cellular components and can lead to oxidative destruction of cells (Puthur, 2016). Therefore, in the process of tolerance to drought stress, these reactive oxygen species should be inhibited, which is possible to some extent with changes in plant physiology (Caverzan et al., 2016).

One of the most important changes in plant physiology affected by drought stress is the increase in ethylene biosynthesis (stress ethylene). Stress ethylene reduces the vegetative period and ultimately decreases of yield. Ethylene produced by the plant in normal conditions helps to seed germination, development of initial roots, stem elongation and fruit ripening. Ethylene is involved in the stages of seed germination, photosynthesis, transpiration and root development (Danish and Zafar -ul-Hye, 2020). But in their studies, the researchers found the fluctuation in production and contradiction in ethylene function in plants. Low ethylene (at concentrations of 0.05 micrograms per liter of plant extract) is required for seed germination, but further increase in ethylene levels due to environmental stresses reduces plant growth (Glick, 2005). By examining the water stress in plants, it concluded that any type of water stress increased the synthesis of ACC and thus stimulates ethylene biosynthesis. By reducing the ACC concentration on the outer surface of the plant's root tissues, to balance the ACC level inside and outside the plant's root cells, more of the plant's ACC outdoors (in the soil) secreted and created a slope. Concentration from inside the plant tissue reduces the concentration of ACC and thus the ethylene concentration within the plant's root tissues.

With this process, ACC-deaminase-producing bacteria reduce stress ethylene production and its adverse effects on plant growth, so plant plants decrease, especially in early growth (Reed and Glick, 2023). Water stress increased the synthesis of ACC and thus stimulates ethylene biosynthesis. By reducing the ACC concentration on the outer surface of the plant's root tissues, to balance the ACC level, more ACC secreted to the soil. ACC-deaminase-producing bacteria consume ACC and reduce stress ethylene production by above mechanism (Reed and Glick, 2023). Water stress decreases the relative content of water in the leaves by increasing ethylene biosynthesis and reducing the activity of some enzymes (Gowtham et al., 2022). Some fungi and bacteria affect the process of stress ethylene in the plant. Some soil bacteria produce the ACC-deaminase, as they are called ACC-deaminase producing bacteria (Gamalero et al., 2023). This enzyme converts ACC (pre -production of ethylene) to alpha ketobotyrate and ammonium. By adjusting ACC production in plants by ACC-deaminase enzyme producing bacteria, the amount of ethylene production in the plant is prevented. By reducing the ACC concentration at the outer surface of the plant's root tissues, to balance the ACC level inside and outside the plant's root cells, more than the plant's ACC is released out of the root (in the soil), and is also secreted. Creating a concentration slope from the inside of the plant to the outside reduces the ACC concentration and consequently the ethylene concentration within the plant's root tissues. With this process, ACC-deaminase enzyme producing bacteria reduce stress ethylene production and its adverse effects on plant growth so that plant plants decrease (Reed and Glick, 2023). Studies have shown that the percentage of mycorrhiza colonization and dehydrogenase enzyme increased in 0- 30 cm deep as affected by biofertilizer treatment (Wilkes et al., 2021). Mycorrhiza increase the dry weight of the chickpea aerial parts significantly compared to control (Laranjeira et al., 2021). The concentration and absorption of nutrient elements increase in the presence of mycorrhiza. Therefore, improving nutritional conditions along with other beneficial effects of mycorrhiza can moderate the negative effects of drought and increase plant growth and performance. Plants with mycorrhizal inoculation increased their tolerance to water deficit (Ezzati Lotfabadi et al., 2022).

In both greenhouse and field conditions, AM fungi significantly increase the concentration of nutrients such as nitrogen, potassium, phosphorus, calcium, magnesium, manganese, copper, iron, zinc, sodium and chlorine, which it increases plant growth and also has an inhibitory effect on the absorbed sodium to chlorine ratio (Chandrasekaran, 2022). In the study of the effect of inoculation of ACC-deaminase producing bacteria on the growth and yield of wheat, it was found that the bacteria with this enzyme improved grain yield, straw, root weight, root length and absorption of nitrogen, phosphorus and potassium in straw and grain compared to the control. They considered all these effects due to ACC reduction of ethylene level in the plant. As a result of inoculation with bacteria containing ACC-deaminase enzyme, they announced that the activity of the enzyme is variable in different isolates. ACC-deaminase enzyme is directly responsible for different behaviors in plant response to water stress and the use of endophytes with ACC-deaminase activity has the potential to facilitate plant growth (Etesami et al., 2020).

In terms of water resources, Iran is one of the countries with deficit water conditions. On the other hand, agriculture in the country has several challenges. The problem of soil erosion and decreasing its fertility will significantly reduce the yield of crops and will increase production costs. The benefits of conservation agriculture are not limited to increasing the yield of crops. The use of conservation agriculture improves the physical, chemical and biological characteristics of the soil, which can be important in achieving sustainable agriculture. Mycorrhiza and ACC-deaminase producing bacteria increase plants' tolerance to drought stress. Although some researches have been presented regarding the physical and chemical changes of soil under different types of tillage systems, but limited information is available on the changes in the preservation of residues in rainfed conditions and especially its relationship with the inoculation of mycorrhiza and beneficial bacteria. On the other hand, cereals and legumes are the most important plants in the rotations of the rainfed regions. Therefore, the need to implement the current project was strongly recommended. The low performance of crops such as chickpea requires the use of different agricultural management. The use of biological methods, including the use of mycorrhiza and beneficial bacteria, especially in the conditions of water deficit stress prevailing in rainfed farms, are considered as methods of improving the conditions of growth and development of plants in conditions of water deficit stress. By causing changes in the rhizosphere of the plant and in the morphology of the root, as well as the ACC-deaminase producing bacteria, by reducing the stress ethylene in the plant, mycorrhiza increase the tolerance of the plant to the stress conditions in dry conditions.

Due to the low efficiency of inoculation of fungi and beneficial bacteria due to the lack of usable water and low organic matter in the dry conditions, in conservation agriculture due to the preservation of residues, better conditions are expected to increase the efficiency of the inoculation. Therefore, this research was carried out in order to investigate the effect of preserving residues, mycorrhiza and ACC-deaminase producing bacteria under rainfed conditions.

2. Materials and methods

2.1. Experimental location and design

The location of this research was in Ilam province with geographical coordinates of 33 degrees 45 minutes and 36 second as north latitude and 46 degrees 35 minutes and 59 seconds as east longitude. First, in the fall (before any agricultural operation), soil samplings were done to measure physical and chemical properties including electrical conductivity, acidity, organic carbon, nitrogen, phosphorus, potassium, iron, zinc, copper, manganese, lime and texture. The results of the analysis of soil at the experimental site are shown in Table 1. Then the land was plowed when the soil moisture was at the level of field capacity (FC) and immediately prepared with a disk. In order to investigate the effectiveness of the mycorrhiza (*Glomus mosseae*) and ACC-deaminase producing bacteria (*Bacillus simplex* UT1) in different residue management (without residues and with residues) this research was carried out in Cherdavel research station of Ilam province. Experiment was done in the form of split plot in the design of randomized complete blocks. Experimental treatments include management of residues in the main plots (1- no residues, 2- keeping half of the residues, 3- keeping all the residues) and the use of biological fertilizers in the sub-plots (1- *Glomus mosseae* fungus, 2- ACC-deaminase producing bacteria (*Bacillus simplex* UT1) 3- *Glomus mosseae* and ACC-deaminase producing bacteria (*Bacillus simplex* UT1) 4- No use of fungi and bacteria) with three repetitions.

2.2. Preparation of materials and samples

The bacterial inoculants were obtained from the Tehran University with a population of 10^7 CFU ml^{-1} (colony formed per milliliter) and the application method was the seed coating. The steps for preparing the bacteria used were as follows. Using a global positioning system (GPS), location and sampling of rhizosphere soils under wheat cultivation in the conditions of water deficit stress in Ilam province were carried out. In the separation stage, a homogeneous soil suspension was prepared. In this way, 10 grams of soil from the rhizosphere soil obtained by vigorously shaking the roots in a sterile solution of 0.9% sodium chloride to 250 ml Erlenmeyer flasks. These flasks containing 90 ml of sterile distilled water. (Barillot et al., 2013). Then, dilution series (from 10^{-2} to 10^{-9}) were prepared and 0.1 ml of it was spread on petridishes containing culture medium. In order to purify the isolates, the colonies formed from the highest dilutions of each cultured sample were selected and recultured up to three times on the culture medium (Harrigan and McKean, 2004).

The method of Penrose and Glick (2003) was used for the quantitative measurement of alpha-ketobutyrate as an indicator of ACC-deaminase enzyme activity. To evaluate the tolerance of isolates to different levels of dehydration stress, their growth ability in NB culture medium containing different concentrations of polyethylene glycol 6000 was used. Before carrying out this research, by using several stages of testing and comparing the isolates, a bacterium belonging to the *Bacillus simplex* was isolated from the soils of farms with rainfed conditions of Ilam. This bacterium had the characteristics of a superior bacterium for water deficit conditions. The results showed that this bacterium showed a growth trend similar to ammonium consumption due to the decomposition of ACC. The ratio of the colony diameter of *Bacillus simplex* bacteria with ACC decomposition to its diameter with ammonium consumption was equal to one, and also this bacterium was able to produce 380 nanomoles per milligram of protein per hour of alpha-ketobutyrate as a measure of ACC-deaminase enzyme activity and ACC decomposition.

The relative water content (RWC) was measured by selecting the youngest developed leaves from each replicate. In the laboratory, the fresh weight was determined and then the leaves were placed in distilled water for 24 hours at room temperature and in the dark condition, then the turgor weight was determined. In the next step, the leaves were placed in an oven at 70 ºC for 72 hours and dried. The relative amount of water was measured by selecting the youngest developed leaves from each replication. In the laboratory, the fresh weight was determined and then the leaves were placed in distilled water for 24 hours at room temperature and in the dark, and then the turgor weight was determined. In the next step, using dry weight and complete turgor (after 24 hours of leaf floating in distilled water), the relative weight of water was calculated. (Ritchie et al., 1990).

Table 1. Physical and chemical analysis in depth of 0-30 cm of soil

Year	pH	EC	Ava. P	Ava. K	OC	TN	TNV	Texture
		(dS m^{-1})	(mg kg^{-1})		(%)			
First Year	7.21	0.23	14.1	326	1.35	0.13	21.3	SiCl
Second Year	7.25	0.31	12.7	311	1.12	0.11	23.6	SiCl

Glomus mosseae inoculum includes root remains and fungal organs, sand and soil. The use of mycorrhiza will be done before planting (300 grams per planting line). Then the seeds will be placed on the inoculants. Finally, the seeds and inoculants were covered with soil. The chickpea variety, Adel, with a density of 30 plants per square meter, and all procedures were performed and plant harvesting will be done. In this research, the investigated parameters were seed yield, harvest index, total biomass, 100-grains weight and the number of pods per plant. Analysis of variance and mean comparison were performed with SAS 9.2 program and Duncan's multi-range test, respectively.

3. Results and discussion

Among the superior bacterial isolates with different abilities in terms of ACC-deaminase producing bacteria, a comparison was made. In this experiment, by creating the same conditions (with FC=60%) changes in the dry weight of wheat plants due to inoculation with different isolates were investigated. With this test, it was found that a bacterial isolate, as the superior bacteria with ACC-deaminase producing ability had a more suitable performance than other isolates. After carrying out the genetic identification steps, the results of determining the sequences were checked by Blast software and according to the degree of affinities, it was determined that there is a 99% probability that this bacterial isolate belongs to the *Bacillus simplex* species. The BankIt gene was registered with Accession Number: KT599261. Based on electronic correspondence, this bacterium was included in the mentioned gene bank as *Bacillus simplex* strain UT1.

3.1. Grain yield and biological yield

The main effect of residue management on grain yield and biological yield was significant at the level of 1% and 5% percent, respectively, and had no significant effect on the harvest index. The main effect of biofertilizer application on seed yield, biological yield and harvest index was significant at the level of 5%, 1% and 5%, respectively (Table 2). The yield of chickpea seeds increased from 1137 kg ha^{-1} in the control, with an increase of 8.53%, to 1234 kg ha^{-1} in the condition of preserving half of the residues, and this increase in biological yield was equal to 8.20%. According to these changes in grain and biological yield, the harvest index increased from 44.6% in the condition without residues to 44.8% in the preserving the residues condition (Table 3). In the same case, the results of the researches showed that in an experiment in the conditions of preservation of residues, the use of mycorrhiza increased the chickpea yield while reducing the effects of drought stress (Moradtalab et al., 2019). Other researchers showed that bacteria with the ability to ACC-deaminase producing bacteria were able to significantly increase o root length (Chandra et al., 2018). The use of *Glomus mosseae* in the condition of preservation of residues increases the activity of antioxidant enzymes (superoxide dismutase, catalase and glutathione reductase) (Gong et al., 2005).

Table 2. Variance analysis (Mean square) of chickpea yield, yield components and RWC under residue management and AM and ACC-deaminase producing bacteria

S.O.V	df	Grain yield	Biological yield	100-grains weight	Grains/m^2	RWC %
Year	1	1243 ^{ns}	1053 ^{ns}	2107 ^{ns}	1382 ^{ns}	825 ^{ns}
R(Y)	4	5107304 ^{ns}	38055 ^{ns}	1203 ^{ns}	165 ^{ns}	726 ^{ns}
(M)	2	13067949 **	120654376 *	21053647**	655427 *	6633232 *
Y*M	2	43543 ^{ns}	12074 ^{ns}	1047 ^{ns}	653 ^{ns}	638 ^{ns}
E1	4	21327 ^{ns}	14508 ^{ns}	457 ^{ns}	763 ^{ns}	736 ^{ns}
F	3	20505572*	456301239 **	13065376*	8755436 **	7665534 *
Y*F	3	35734 ^{ns}	1546 ^{ns}	126 ^{ns}	528 ^{ns}	364 ^{ns}
M*F	6	12465 *	11653142 *	45321*	7676632 *	7675534 *
Y*M*F	6	16544 ^{ns}	37644 ^{ns}	543 ^{ns}	866 ^{ns}	486 ^{ns}
E2	36	4114	3215	543	761	628
CV%**%**		16.6	18.3	15.7	15.4	17.8

ns, * and **, non-significant and significant difference at 5% and 1% probability levels, respectively.

Table 3. The effect of residue maintenance on grain yield and yield components

Residue management	Grain yield (Kg/ha)	100-grains weight (gr)	Grains/m^2	RWC (%)
Without residue	839b	21.2c	436b	59.5c
Semi-residue maintenance	934a	a 25.5	473a	68.7a
Total residue maintenance	897b	b 24.3	451b	63.5b

In each column, the similar letter/letters indicated non-significant differences among means

3.2. The effect of application of *Glomus mosseae* and ACC-deaminase producing bacteria on changes in grain yield and relative leaf water content

The main effect of biofertilizer application on grain yield was significant ($p<0.05$) (Table 2). By comparing the mean of the data using the LSD test method, it was determined that the treatment with the use of mycorrhiza and ACC-deaminase producing bacteria with a seed yield of 945 kg ha^{-1} was in the superior statistical group and the yield increase in comparison with the control was equal to 12.4% (Table 3). The researchers stated that mycorrhiza indirectly affects the physiological activities and the growth of the plant and increases the yield (Dorairaj et al., 2020). Under rainfed condition, drought stress naturally causes a significant decrease in chickpea yield and yield components. Since the decrease in water availability for the plant caused a decrease in yield, the use of *Glomus mosseae* and ACC-deaminase producing bacteria could increase seed yield by expanding the root system (Danish and Zafar-ul-Hye, 2019). According to researches, *Glomus mosseae* helps to create drought tolerance in plants by modulating changes in radial hydraulic conductivity (Quiroga et al., 2020). Without residues maintenance, the combined application of *Glomus mosseae* and ACC-deaminase producing bacteria had the greatest effect on increasing yield, followed by the sole application of ACC-deaminase-producing bacteria. In conditions with half of the residues preserved, the combined use of *Glomus mosseae* and ACC-deaminase producing bacteria is about twice more effective than the use of *Glomus mosseae* and ACC-deaminase producing bacteria alone, and in such conditions, this treatment can be recommended. In the conditions with preservation of all the residues, the combined application of *Glomus mosseae* and ACC-deaminase producing bacteria and then the application of *Glomus mosseae* had the best results. The combined application of *Glomus mosseae* and ACC-deaminase producing bacteria showed the greatest effect with an increase of 12.9% in grain yield. In both years, keeping half of the residues caused a significant increase in chickpea yield and yield components. The increase in grain yield as a result of preserving residues has been reported by researchers, and the main reasons for the increase in plant yield in the condition of preserving residues are the increase in the area of the main photosynthesizing organ (leaf), the increase in the number of flowers (the main reproductive organs), the increase in transfer assimilate and photosynthesis and the weight of seeds due to the improvement of humidity conditions (Shu et al., 2022).

3.3. The weight of one hundred seeds and the number of seeds per square meter

Variance analysis of the data showed that the main effect of preserving residues on the weight of one hundred seeds and the number of seeds per square meter was significant at the level of 1% & 5%, respectively (Table 2). The weight of one hundred seeds in the condition of preserving half of the remains (23.2 grams) showed an increase of 9.41 percent compared to the control (22.3 grams) and this increase in the number of seeds per square meter was 8.14 percent (Table 3). Also, the variance analysis of the data showed that the main effect of biofertilizer consumption on the weight of one hundred seeds and the number of seeds per square meter was significant at the level of 5% and 1%, respectively (Table 5). Regarding the weight of 100 seeds, it was found that the combined use of mycorrhiza and ACC-deaminase producing bacteria was the best treatment by increase of 9.23% compared to the control. However, treatments of mycorrhiza alone and inoculation with ACC-deaminase-producing bacteria alone were not statistically higher than the control group (Table 3). The number of seeds per square meter reached 472 with the combined application of mycorrhiza and ACC-deaminase producing bacteria, which was in the superior statistical group compared to the non-application of biofertilizer (with an increase of 12.4%). The treatments of the sole use of *Glomus mosseae* and ACC-deaminase producing bacteria were not statistically higher than the control (Table 4). The variance analysis of the data also showed that the interaction effect of preserving residues in the use of biofertilizers on the weight of 100-grains and the number of grains per square meter was significant at 5% level and had no significant effect, respectively (Table 2). In the conditions with preservation of half of the residues and preservation of the whole residues, the combined application of ACC-deaminase producing bacteria and *Glomus mosseae* was the highest amount (Figure 1).

Table 4. The effect of AM and ACC-deaminase producing bacteria on grain yield and yield components

Residue management	Grain yield (kg ha^{-1})	100-grains weight	Grains m^{-2}	RWC (%)
Control	810b	23.5b	403b	60.2b
AM	933ab	24.6ab	441ab	71.1ab
ACC-deaminase producing bacteria	928ab	24.7ab	450ab	70.7ab
AM and ACC-deaminase producing bacteria	964a	26.4a	470a	76.5a

In each column, the similar letter/letters indicated non-significant differences among means

3.4. Relative water content (RWC)

Analysis of variance of the data showed that the effect of residue preservation on RWC was significant at 1% level (Table 2). So that the amount of RWC showed a significant increase under preserving half of the residue condition (68.7%) compared to the control (59.5) (Table 3). The variance analysis of the data also showed that the interaction effect of residue management in biofertilizer consumption on RWC was significant (Table 2). Without residues, the effect of the combined application of ACC-deaminase producing bacteria and the *Glomus mosseae* on the weight of 100-grains was superior respect to other treatments. In the conditions with preservation of half of the residues and preservation of the whole residues, the combined application of ACC-deaminase producing bacteria and *Glomus mosseae* was the highest amount (Figure 1).

3.5. Concentration and absorption of total potassium and zinc

Variance analysis of the data showed that the effect of plant residue management on potassium concentration, total potassium absorption and total zinc absorption was significant at 5%, 1% and 5% levels, respectively, and there was no significant difference on zinc concentration (Table 5). The results showed that the concentration of potassium in the conditions of preservation of half of the residues (1.75%) showed a significant increase compared to the control (Table 6). The total absorbed potassium in the condition of maintaining half of the residues (48.2 kg ha^{-1}) showed an increase of 18.1% compared to the control (40.8 kg ha^{-1}) (Table 6). Variance analysis of data showed that the main effect of biofertilizer application on potassium concentration, total absorbed potassium and total absorbed zinc was significant at 5%, 1% and 1%, respectively, and there was no significant difference on zinc concentration (Table 5). Regarding the concentration of potassium, it was found that the combined application of *Glomus mosseae* and ACC-deaminase producing bacteria was superior to the treatment control. However, the treatments of applying silicon alone and inoculation with ACC-deaminase producing bacteria alone were not in a higher statistical group than the control (Table 7). The concentration of potassium in the aerial parts of chickpea plants with the combined application of *Glomus mosseae* and ACC-deaminase producing bacteria reached 1.78%, which was in the superior statistical group compared to the non-application of biological materials (1.60%) (Table 7). Total potassium absorption showed a 23.1% increase compared to the control with the combined use of *Glomus mosseae* and ACC-deaminase producing bacteria, and this treatment was superior. In the inoculation treatments of ACC-deaminase-producing bacteria alone and the use of *Glomus mosseae* alone compared to the control, the differences were significant and an increase of 15.2% and 14.1% was observed, respectively (Table 7). The absorption of total zinc in the aerial parts of the chickpea plant with the combined application of Glomus mouse fungus and ACC-deaminase producing bacteria reached 7.18 kg/ha, which was in the superior statistical group compared to the non-application of biological materials (26.1%) (Table 7). The treatments using bacteria producing ACC-deaminase enzyme and *Glomus mosseae* showed an increase of 19.5% and 15.9%, respectively, compared to the control. The variance analysis of the data also showed that the interaction effect of residue management in biofertilizer application was significant on total absorption of potassium and zinc at the level of five percent and had no significant effect on the concentration of potassium and zinc (Table 5). In the study of changes in total potassium absorption in the treatment of without plant residues, it was found that the combined application of *Glomus mosseae* and ACC-deaminase-producing bacteria produced the highest amount of total potassium absorption (51.1 kg/ha) (Table 7). The researchers stated that the increase in potassium absorption under water stress conditions improves the water relations in the plant (Akhtyamova et al., 2023). In the treatments for preserving plant residues, *Glomus mosseae* and ACC-deaminase-producing bacteria increase water absorption while stimulating root development. Regarding the total absorbed zinc, in conditions without residues, the combined application of ACC-deaminase producing bacteria *Glomus mosseae* obtained the highest amount of absorbed zinc compared to the control. In the conditions with preservation of residues, the treatment of the combined application of ACC-deaminase producing bacteria and *Glomus mosseae* was superior, and in the conditions of preservation of half of the residues and preservation of all residues, the total zinc absorbed increased by 10.8% and 23.4%, respectively, compared to the control. In the condition of preserving half of the residues, the use of ACC-deaminase-producing bacteria alone and the use of *Glomus mosseae* alone also showed a significant increase in the total absorbed zinc compared to the control (Table 8).

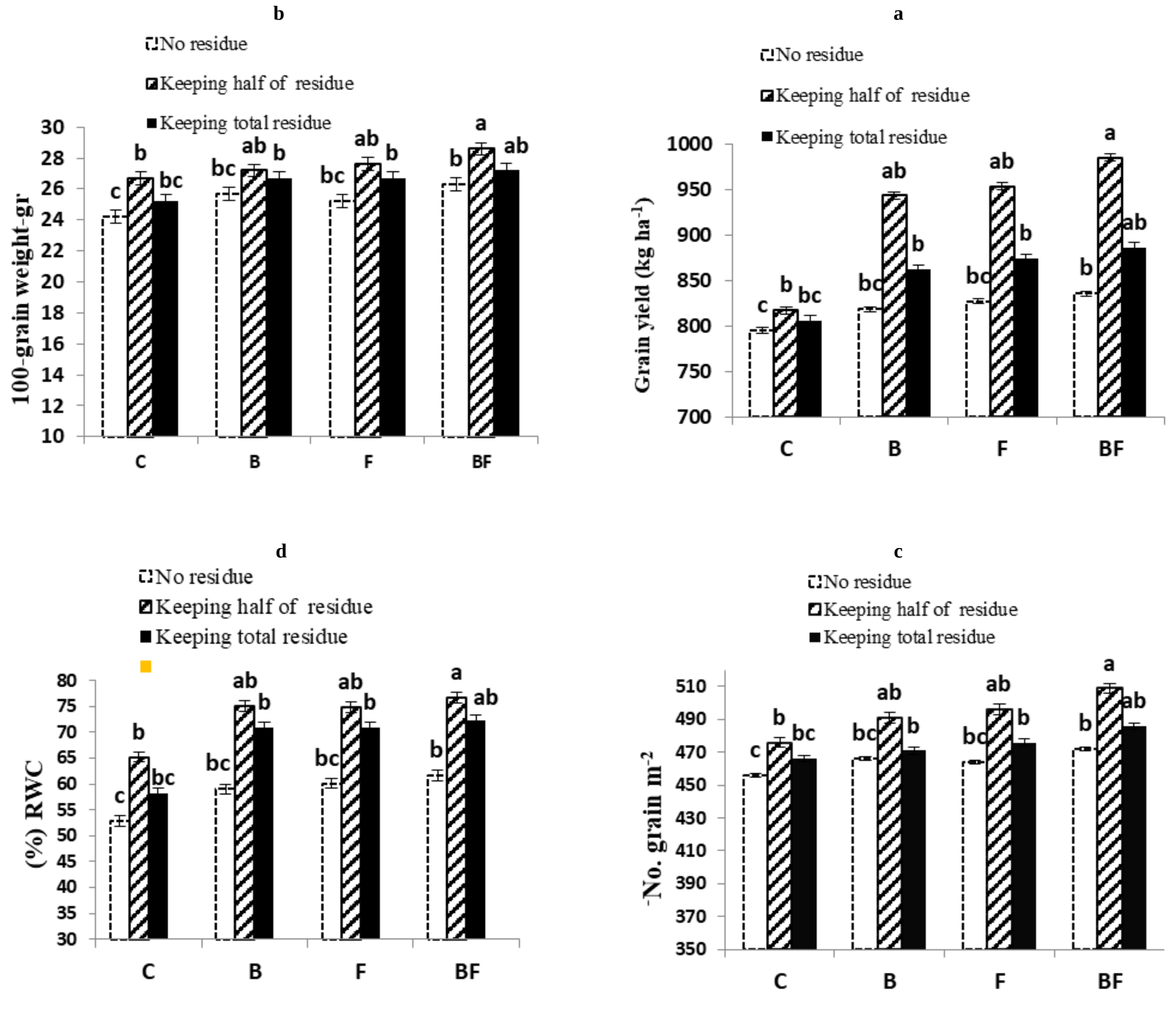


Figure 1. Mean Comparison of the effects of residue management and biofertilizer application on (a) grain yield, (b) 100-grains weight, (c) grains/m^2 and (d) RWC
C: Control; B: ACC-deaminase producing bacteria; F: *Glomus mosseae*; BF: Combined application of ACC-deaminase producing bacteria and *Glomus mosseae*

Since the decrease in water availability for the plant causes a decrease in the absorption of nutrients, the result is a decrease in dry matter yield (Yildirim et al., 2021), but in this stress condition, the use of *Glomus mosseae* and ACC-deaminase-producing bacteria could improve the absorption of nutrients. The results of this research were consistent with the researches of others. In their research, the researchers found that plant growth-promoting bacteria have a positive effect on the plant's antioxidant activity, increasing the absorption of nutrients and plant performance (Kuzmicheva et al., 2017). Researchers showed that *Glomus mosseae* increases the absorption of some elements and increases the plant's tolerance to stress (Greger et al., 2018). In explanation of the effect of *Glomus mosseae* on chickpea yield, it is possible to refer to the results of another research which stated that potassium increases flexibility in stomatal exchanges and reduces transpiration in the conditions of plant residue preservation (Raghavendra et al., 2020). Experiments have shown that bacteria with the ability to produce ACC-deaminase enzyme were able to significantly increase root length (Chandra et al., 2018). The morphological features of the root and the growth of the roots and the ratio of the root to the shoot are necessary in order to maintain the overall balance of the plant physiology and can have a high effect on tolerance to drought stress. Also, Khan et al. (2020) reported that in the condition of preserving residues, with the use of *Glomus mosseae*, the grain yield and biomass of chickpea increased (Tawfiq and Muslim, 2020).

The researches showed that the inoculation of plant growth stimulating bacteria had an effect on the concentration of nutrients in the plant (Billah et al., 2019). In sustainable production, stability of performance in different environmental conditions is considered as the main selection criterion for stress tolerance. Performance stability means a small difference between the potential performance and actual performance (in different environmental conditions).

The effect of the *Glomus mosseae* and the studied bacteria was to reduce these differences, so that the effect of plant growth stimulating bacteria on increasing the growth of chickpea plants has been reported (Mazumdar et al., 2020). Research results have shown that the plant absorbs more elements such as potassium to increase the concentration of the solution inside the cells (Zahoor et al., 217). Also, aligned with this research, other researchers reported that the amount of potassium in leaves has increased significantly due to the application of drought stress and the use of potassium and mycorrhiza (Samadi et al., 2024). The researchers concluded that in the presence of *Glomus mosseae*, elements such as potassium are transferred from the root to the shoot through the transpiration flow in the xylem (Zhang et al., 2023).

Therefore, the intensity of transpiration in the plant determines the distribution of potassium in the plant organs. Potassium absorbed in the plant causes the formation of a cuticle layer, which can affect transpiration and increase the efficiency of water consumption (Park et al., 2019).

On the other hand, the root architecture has changed with the use of *Glomus mosseae* (Liu et al., 2024) and since the root architecture is an important factor in the colonization efficiency of bacteria and fungi, therefore, the synergistic effects of bacteria and *Glomus mosseae* it leads under rainfed conditions. Also, aligned with this research, in the conditions of not using biological fertilizers, due to the lower absorption of nutrients and water by the plant, it is reflected in the form of a decrease in the number of pods and a decrease in 100-grain weight.

Table 5. Analysis of variance of grain yield, biological yield and harvest index

Variable Sources	df	Potassium concentration	Total absorbed potassium	Zinc concentration	Total absorbed zinc
Year	1	835 ^{ns}	361 ^{ns}	2134 ^{ns}	5732 ^{ns}
T(Y)	4	734 ^{ns}	102 ^{ns}	1732 ^{ns}	6382 ^{ns}
Residue	2	406431*	2530421**	5163 ^{ns}	90754327*
Y×R	2	805 ^{ns}	1578 ^{ns}	1043 ^{ns}	1472 ^{ns}
E1	4	535 ^{ns}	7427۷ ^{ns}	6321 ^{ns}	7038 ^{ns}
Fertilizer	3	164206 *	4576481 **	1852 ^{ns}	6404943 **
Y×F	3	1763 ^{ns}	7592 ^{ns}	1091 ^{ns}	1063 ^{ns}
R×F	6	323 ^{ns}	354821 *	4302 ^{ns}	7504783 *
Y×R×F	6	434^{ns}	1024 ^{ns}	2185 ^{ns}	8049 ^{ns}
E2	36	905	7523	5427	4853
CV%		17.2	15.8	13.8	16.3

ns, * and **, non-significant and significant difference at 5% and 1% probability levels, respectively.

Table 6. The effect of residue management on concentration and total absorption potassium and zinc in areal parts of chickpea

Residue Management	Potassium concentration of areal parts (%)	Total absorbed potassium (kg ha^{-1})	Zinc concentration of areal parts (mg kg^{-1})	Total absorbed zinc (kg ha^{-1})
Residue Deletion	1.61b	40.8c	21.6a	5.51b
Maintenance of semi-residue	1.75a	48.2a	22.7a	6.26a
Maintenance of total residue	1.67ab	44.7b	22.7a	6.07ab

In each column, the similar letter/letters indicated non-significant differences among means

Table 7. The effect of silicon and ACC-deaminase producing bacteria application on potassium and zinc concentration, total absorbed potassium and zinc in areal parts of chickpea

Biological Fertilizer	Potassium concentration of areal parts (%)	Total absorbed potassium (kg ha^{-1})	Zinc concentration of areal parts (mg kg^{-1})	Total absorbed zinc (kg ha^{-1})
Control	1.61b	42.3c	21.4a	5.69c
Mycorrhiza	1.73ab	50.1b	22.3a	6.61b
ACC-deaminase producing bacteria	1.69ab	50.4b	22.4a	6.81b
Mycorrhiza and ACC-deaminase producing bacteria	1.79a	56.3a	22.7a	7.18a

In each column, the similar letter/letters indicated non-significant differences among means

Table 8. Interaction effect of water deficit stress and fertilizer application on total absorbed potassium and zinc in chickpea

Residue management	Control	Mycorrhiza	ACC-deaminase producing bacteria	Mycorrhiza and ACC-deaminase producing bacteria
	Total absorbed potassium (kg ha^{-1})			
Residue removal	41.5c	45.5bc	46.6b	51.1ab
Maintenance of semi-residue	44.8c	49.6b	51.8b	57.1a
Maintenance of total residue	43.5c	47.5b	48.6b	52.2ab
	Total absorbed zinc (kg ha^{-1})			
Residue removal	5.52c	6.41b	6.45b	6.89ab
Maintenance of semi-residue	5.57c	6.63ab	6.74ab	7.34a
Maintenance of total residue	5.71c	6.54bc	6.43b	6.91ab

In each column, the similar letter/letters indicated non-significant differences among means

4. Conclusion

In the condition of drought stress (rainfed condition) with the removal of residues, the grain yield (1137 kg/ha) showed a decrease of 7.86% compared to the condition of maintaining half of the residues (1234 kg/ha) and this decrease in biological yield is equal to 7.58%. Due to these changes in grain and biological yield, the harvest index reached from 44.6% in the condition without preserving residues to 44.8% in the condition of preserving half of the residues. The results of this research showed that in such conditions of residue management, the application of *Glomus mosseae* and ACC-deaminase producing bacteria had positive effects on the yield and yield components of the chickpea. The combined application of *Glomus mosseae* and ACC-deaminase producing bacteria had a 12.4% increase in grain yield per hectare compared to control. In addition to the combined application of *Glomus mosseae* and inoculation of ACC-deaminase producing bacteria, in conditions without residues, inoculation of ACC-deaminase producing bacteria and in the condition of maintaining residues, the use of *Glomus mosseae* had a greatest effect. It had effects on yield, yield components and nutrient concentration. Among the yield components, the number of seeds per square meter received the greatest effect from ACC-deaminase producing bacteria. Since part of the decrease in plant growth under rainfed conditions is related to the increase in the level of ethylene and it's reaching the stress ethylene concentration in the plant tissue. The results also showed that as a result of the use of *Glomus mosseae* and ACC-deaminase producing bacteria, the status of potassium and zinc elements in the aerial parts of chickpea improved significantly. Therefore, there is a requirement to pay more attention to chickpea plant nutrition in soils with low absorption capacity of these elements. In this research, it was found that the differences in performance characteristics and performance components between the use and non-use of *Glomus mosseae* and ACC-deaminase producing bacteria in the condition of non- preserving the plant residues are less and without significant effect. From this point of view, by keeping at least half of the residues, the use of *Glomus mosseae*, especially when the plant is exposed to different stresses, should be considered. Also, according to the obtained results, inoculation of seeds with ACC-deaminase producing bacteria (*Bacillus simplex* UT1) is suggested as a stress-modulating bacteria in rainfed conditions. In general, the combined use of *Glomus mosseae* and ACC-deaminase producing bacteria compared to the control treatment improved the yield, yield components and changed the concentration of nutrients in chickpeas. Although under residue removal condition, the use of *Glomus mosseae* alone had low efficiency, but it is recommended to use it in the conditions of preservation of residues, especially with inoculation of ACC-deaminase producing bacteria.

References

Akhtyamova, Z., Martynenko, E., Arkhipova, T., Seldimirova, O., Galin, I., Belimov, A., Vysotskaya, L., & Kudoyarova, G. (2023). Influence of plant growth-promoting rhizobacteria on the formation of apoplastic barriers and uptake of water and potassium by wheat plants. *Microorganisms*, *11*(5), 1227. **doi: 10.3390/microorganisms11051227**

Alzahrani, Y., Kusvuran, A., Alharby, H. F., Kusvuran, S., & Rady, M. M. (2018). The defensive role of silicon in wheat against stress conditions induced by drought, salinity or cadmium. *Ecotoxicology and Environmental Safety*, *154*(2), 187-196. **doi: 10.1016/j.ecoenv.2019.109378**

Anderson, M. C., Zolin, C. A., Sentelhas, P. C., Hain, C. R., Semens, K., Yilmaz, M. T., Gao, F., Otkin, J. A., & Tetrault, R. (2016). The evaporative stress index as an indicator of agricultural drought in Brazil: An assessment based on crop yield impacts. *Remote Sensing Environment*, *174*(2), 82-99. **doi: 10.1016/j.rse.2015.11.034**

Arafa, A. A., Hussin, S. F. M., & Mohamed, H. S. (2013). Effect of potassium fertilizer, biostimulants and effective microorganisms on growth, carbohydrates concentration and ion percentage in the shoots of potato plants. *Journal of Plant Production*, *4*(1), 15-32. **doi: 10.21608/jpp.2013.68605**

Barillot, C. D., Sarde, C. O., Bert, V., Tarnaud, E., & Cochet, N. (2013). A standardized method for the sampling of rhizosphere and rhizoplan soil bacteria associated to an herbaceous root system. *Annals of*

Microbiology, *63*(1), 471-476. **doi: 10.1007/s13213-012-0491-y**

Barra, P.J., Inostroza, N. G., Acuna, J. J., Mora, M. L., Crowley, D. E., & Jorquera, M. A. (2016). Formulation of bacterial consortia from avocado (*Persea americana* Mill) and their effect on growth, biomass and superoxide dismutase activity of wheat seedlings under salt stress. *Applied Soil Ecology*, *102*(3), 80-91. **doi: 10.1016/j.apsoil.2016.02.014**

Billah, M., Khan, M., Bano, A., Hassan, T. U., Munir, A., & Gurmani, A. R. (2019). Phosphorus and phosphate solubilizing bacteria: Keys for sustainable agriculture. *Geomicrobiology Journal*, *36*(1), 904-916. **doi: 10.1080/01490451.2019.1654043**

Caverzan, A., Casassola, & A., Brammer, S. P. (2016). Antioxidant responses of wheat plants under stress. *Gen Molecular Biology*, *391*(3), 1-6. **doi: 10.1590/1678-4685-gmb-2015-0109**

Chandra, D., Srivastava, R., & Sharma, A. K. (2018). Influence of IAA and ACC Deaminase Producing Fluorescent Pseudomonads in Alleviating Drought Stress in Wheat (*Triticum aestivum*). *Agricultural Research*, *7*(1), 290-299. **doi: 10.1007/s40003-018-0305-y**

Danish, S., & Zafar-ul-Hye, M. (2019). Co-application of ACC-deaminase producing PGPR and timber-waste biochar improves pigments formation, growth and yield of wheat under drought stress. *Scientific Reports*, *9*(1), 1-13. **doi: 10.1038/s41598-019-42374-9**

Dorairaj, D., Ismail, M. R., Sinniah, U. R., & Tan, K. B. (2020). Silicon mediated improvement in agronomic traits, physiological parameters and fiber content in *Oryza sativa*. Acta *Physiologiae Plantarum*, *42*(1), 1-11. **doi: 10.1007/s11738-020-3024-5**

Du, C., & Effah, Z. (2022). Effects of straw mulching and reduced tillage on crop production and environment: A review. *Water*, *14*(16), 2471. **doi: 10.3390/w14162471**

Gowtham, H. G., Singh, S. B., Shilpa, N., Aiyaz, M., Nataraj, K., Udayashankar, A. C., Amruthesh, K. N., Murali, M., Poczai, P., Gafur, A., & Almalki, W. H. (2022). Insight into recent progress and perspectives in improvement of antioxidant machinery upon PGPR augmentation in plants under drought stress: a review. *Antioxidants*, *11*(9), 1763. **doi: 10.3390/antiox11091763**

Greger, M., Landberg, T., & Vaculik, M. (2018). Silicon influences soil availability and accumulation of mineral nutrients in various plant species. *Plants 7*(1), 41-50. **doi: 10.3390/plants7020041**

Kang, H., Zhang, M., Zhou, S., Guo, Q., Chen, F., Wu, J., & Wang, W. (2016). Overexpression of wheat ubiquitin gene, Ta-Ub2, improves abiotic stress tolerance of Brachypodium distachyon. *Plant Science*, *248*(2), 102-115. **doi: 10.1016/j.plantsci.2016.04.015**

Khan, Z. S., Rizwan, M., Hafeez, M., Ali, S., Adrees, M., Qayyum, M. F., Khalid, S., Rehman, M. Z., & Sarwar, M. A. (2020). Effects of silicon nanoparticles on growth and physiology of wheat in cadmium contaminated soil under different soil moisture levels. *Environmental Science and Pollution Research*, *27*(4), 4958-4968. **doi: 10.1007/s11356-019-06673-y**

Kuzmicheva, Y. V., Shaposhnikov, A. I., Petrova, S. N., Makarova, N. M., Tychinskaya, I. L., Puhalsky, J. V., Parahin, N. V., Tikhonovich, I. A., & Belimov, A. A. (2017). Variety specific relationships between effects of rhizobacteria on root exudation, growth and nutrient uptake of soybean. *Plant and Soil, 419*(1), 83-96. **doi: 10.1007/s11104-017-3320-z**

Liu, C. Y., Hao, Y., Wu, X. L., Dai, F. J., Abd-Allah, E. F., Wu, Q. S., & Liu, S. R. (2024). Arbuscular mycorrhizal fungi improve drought tolerance of tea plants via modulating root architecture and hormones. *Plant Growth Regulation*, *102*(1), 13-22. **doi: 10.1007/s10725-023-00972-8**

Martin, T. N., Nunes U. R., Stecca, J. D. L., & Pahins, D. B. (2017). Foliar application of silicon on yield components of wheat crop. *Revista Caatinga*, *30*(3), 578-585. **doi: 10.1590/1983-21252017v30n305rc**

Mohite, B. (2013). Isolation and characterization of indole acetic acid IAA producing bacteria from rhizospheric soil and its effect on plant growth. *Journal of Soil Science and Plant Nutrition*, *13*(3), 638-649. **doi: 10.4067/s0718-95162013005000051**

Moradtalab, N., Hajiboland, R., Aliasgharzad, N., Hartmann, T. E., & Neumann, G. (2019). Silicon and the association with an arbuscular-mycorrhizal fungus (*Rhizophagus clarus*) mitigate the adverse effects of drought stress on strawberry. *Agronomy*, *9*(1), 41-52. **doi: 10.3390/agronomy9010041**

Pande, A. M., Kulkarni. N. S., & Bodhankar, M. G. (2016). Effect of PGPR with ACC-deaminase activity on growth performance of wheat cultivated under stress conditions International. *Journal of Applied Research*, *2*(4), 723-726. **doi: 10.1038/s41598-019-42374-9**

Park, Y. G., Park, S. M., Na, C. I., & Kim, Y. (2019). Identification of Optimal Concentration of Silicon Application and Its Roles in Uptake of Essential Nutrients in Soybean (*Glycine max* L). *Journal of Crop Science and Biotechnology*, *22*(1), 1-10. **doi: 10.1007/s12892-018-0266-0**

Parray, J. A., Jan, S., Kamili, A. N., Qadri, R. A., Egamberdieva, D., & Ahmad, P. (2016). Current perspectives on plant growth-moting rhizobacteria. *Journal of Plant Growth Regulation*, *32*(1), 1-26. **doi: 10.1007/s00344-016-9583-4**

Penrose, D. M., & Glick, B. R. (2003). Methods for isolating and characterizing ACC deaminase-containing plant growth-moting rhizobacteria. *Physiology of Plants, 118*(1), 10-15. **doi: 10.1034/j.1399-3054.2003.00086.x**

Puthur, J. T. (2016). Antioxidants and cellular antioxidation mechanism in plants. *South Indian Journal of Biological Science*, *21*(1), 9-13. **doi: 10.22205/sijbs/2016/v2/i1/100335**

Quiroga, G., Erice, G., Aroca, R., Zamarreno, A. M., Garcia-Mina, J. M., & Ruiz-Lozano, J. M. (2020). Radial water transport in arbuscular mycorrhizal maize plants under drought stress conditions is affected by indole-acetic acid (IAA) application. *Journal of Plant Physiology*, *246*(1), 153-165. **doi: 10.1016/j.jplph.2020.153115**

Raghavendra, M., Singh, Y. V., Das, T. K., & Meena, M. C. (2020). Residual effect of crop residue and potassium management on greengram productivity, soil and canopy temperature depression in maize and wheat under zero tillage maize-wheat-greengram cropping system. *International Journal of Current Microbiology and Applied Sciences*, *9*(9), 3639-48. **doi: 10.20546/ijcmas.2020.909.449**

Ritchie, S. W., & Nguyen, H. T. (1990). Leaf water content and gas exchange parameters of two wheat genotypes differing in drought resistance. *Crop Science*, *30*(2), 105-111. **doi: 10.2135/cropsci1990.0011183x003000010025x**

Samadi, A., Derafshi, M., Hassani, A., Gholamhoseini, M., Asgari Lajayer, B., Astatkie, T., & Price, G. W. (2024). Effects of Biofertilizers and Potassium Sulfate on Nutrients Uptake and Physiological Characteristics of Maize (*Zea mays* L.) Under Drought Stress. *Journal of Crop Health*, *76*(1), 209-218. **doi: 10.1007/s10343-023-00954-w**

Sapre, S. S., & Vakharia, D. N. (2019). Effect of silicon under water deficit on antioxidant enzymes activities at different phenological stages in Wheat (*Triticum aestivum* L). *Indian Journal of Agricultural Biochemistry*, *32*(1), 30-36. **doi: 10.5958/0974-4479.2019.00004.2**

Shu, X., Zou, Y., Shaw, L. J., Todman, L., Tibbett, M., & Sizmur, T. (2022). Applying cover crop residues as diverse mixtures increases initial microbial assimilation of crop residue derived carbon. *European Journal of Soil Science*, *73*(2), 13232. **doi: 10.1111/ejss.13232**

Talaat, N. B., & Shawky, B. T. (2016). Dual application of 24-epibrassinolide and spermine confers drought stress tolerance in maize (*Zea mays* L) by modulating polyamine and tein metabolism. *Journal of Plant Growth Regulation*, *352*(4), 518-533. **doi: 10.1007/s00344-015-9557-y**

Trankner, M., Jakli, B., Tavakol, E., Geilfus, C., Cakmak, I., & Dittert, K. (2016). Magnesium deficiency decreases biomass water-use efficiency and increases leaf water-use efficiency and oxidative stress in barley plants. *Plant Soil*, *406*(3), 409-423. **doi: 10.1007/s11104-016-2886-1**

Yildirim, E., Ekinci, M., & Turan, M. (2021). Impact of biochar in mitigating the negative effect of drought stress on cabbage seedlings. *Journal of Soil Science and Plant Nutrition*, *21*(3), 2297-2309. **doi: 10.1007/s42729-021-00522-z**

Zahoor, R., Zhao, W., Abid, M., Dong, H., & Zhou, Z. (2017). Potassium application regulates nitrogen metabolism and osmotic adjustment in cotton (*Gossypium hirsutum* L) functional leaf under drought stress. *Journal of Plant Physiology*, *215*(1), 30-38. **doi: 10.1016/j.jplph.2017.05.001**

Zhang, H., Han, X., Liu, K., Zhang, W., Zhou, Y., & Tang, M. (2024). Synergistic effect of extra potassium application and AM fungi on drought tolerance of *Lycium barbarum*. *New Forests*, *55*(1), 101-117. **doi: 10.1007/s11056-023-09969-7**

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://aes.uoz.ac.ir
Email: aes@uoz.ac.ir