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The Effect of Water Produced by Peltier Module on Seed Germination of Cucumber, Chickpea, Flax and Camelina

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ABSTRACT

Drought stress in arid and semi-arid regions reduces crop yield. To evaluate the effect of water production with the Peltier module and its effect on seed germination of cucumber, chickpea, flax, and camelina, a study was conducted in the Faculty of Agricultural Science and Engineering, Razi University, Kermanshah, Iran. This study was performed as a factorial experiment in a completely randomized design with three replications. The factors included irrigation methods and plant species. The irrigation method included water production with the Peltier module, control (without irrigation), and irrigation with distilled water. Results showed that irrigation treatment with the Peltier module and irrigation treatment with distilled water in four plants of cucumber, chickpea, flax, and camelina were not different in terms of germination percentage. In the control treatment (without irrigation), seed germination was zero. In all four plants, the irrigation with the Peltier module had a higher caulicle length and root-to-shoot ratio than the control. In three plants of cucumber, chickpea, and flax, the irrigation with the Peltier module had a higher radicle length, seed vigor based on length, seed vigor based on weight, caulicle length, and radicle weight than the control. It is concluded that the Peltier module can germinate the seeds.

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1. Introduction

Drought stress is a serious threat to agricultural production. Climate change has intensified the effects of drought on the human population in arid and semi-arid regions (Huang *et al*., 2016). Drought in the 21st century will be more severe and longer and will cover more parts of the world. According to studies, the health of vegetation has been affected by thermal changes caused by climate change, and in the 21st century, plants are suffering from more severe heat stress (Jiang *et al*., 2022).

Rainfall or irrigation is commonly known as the source of moisture for crops. In arid and semi-arid regions, in addition to rainfall, there are other sources to meet the water needs of plants that are less known, such as fog (Salem *et al*., 2017) and dew (Aguirre-Gutiérrez *et al*., 2019). Dew forms in many parts of the world. Dew formation is influenced by climatic factors. Radiative cooling intensity, wind speed, and water vapor pressure are important environmental factors for dew formation. The relationship between dew characteristics (amount and duration) and environmental factors during the cultivation period in a maize field in a semi-arid region was investigated. In the spring, although the intensity of radiative cooling was strong, dew occurred only in small amounts. In contrast, in summer, dew occurred in greater quantities despite the lower intensity of radiative cooling (Yokoyama *et al*., 2021b). In a study of the effect of dew on the maize field in a semi-arid region, it was observed that maize leaves were soaked by dew for approximately 45% of the total growth period. Dew improved leaf water potential and gas exchange in plants under water deficit stress. The moisture status of the plant due to the leaf wetting is effective on plant physiology (Yokoyama *et al*., 2021a).

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Plastic foils were used to collect dew in laboratory and field experiments under dry conditions of Kenya. The results showed that dew was formed both in laboratory and field conditions. The laboratory and field results were not similar (Tuure *et al*., 2020). The semi-closed fanned greenhouse had high vertical microclimate heterogeneity. Tomatoes were produced in this greenhouse due to the microclimatic conditions. Circulating fans and curtains produced dew. Horizontal airflow did not reduce vertical heterogeneity (Jerszurki *et al*., 2021).

Plant seeds must absorb sufficient moisture for germination, and lack of water affects the germination traits of seeds. Drought reduced the initial seed germination indices such as germination energy, germination rate, and germination index in *Glycyrrhiza glabra* L. and *Glycyrrhiza uralensis* Fisch (Han *et al*., 2022). Drought reduced seed germination, plant establishment, growth, photosynthesis, and water relations in the four chickpea genotypes (Farooq *et al*., 2018). Drought at the level of 12 bar reduced the germination characteristics of flaxseed, including seed germination percentage, root length, shoot length, seedling length, germination rate, seed vigor, and root-to-shoot ratio compared to the control (without drought stress) (Mostafavi, 2011). Wheat and *Camelina sativa* seeds were compared in terms of drought tolerance at the germination stage. Drought created by polyethylene glycol (PEG) caused a more severe decrease in germination index and seedling length of wheat compared to camelina. Camelina seeds contain a jelly-like substance that can absorb water several times its weight (Perera *et al*., 2022). This may be the main reason for drought tolerance of camelina compared to wheat.

There is little research on the water produced by the Peltier module and its use in plant biomass production. Therefore, this study aimed to determine the germination characteristics of cucumber, chickpea, flax, and camelina seeds under the influence of water produced by the Peltier module.

2. Materials and methods

To investigate the effect of water production with a Peltier module on seed germination of cucumber, chickpea, flax, and camelina, a laboratory experiment was conducted in the Faculty of Agricultural Science and Engineering of Razi University, Kermanshah, Iran in 2016. This experiment was conducted as a factorial in a completely randomized design with three replications. Factors included irrigation method and plant species. Chickpea (*Cicer arietinum* L.) and cucumber (*Cucumis sativus* L.) seeds were local masses of Kermanshah, which were obtained from the seed store. Flax (*Linum usitatissimum* L., Indian variety) was obtained from Razi University seed bank and camelina (*Camelina sativa* L., Sohail variety) was obtained from Dr. Kahrizi in Biston Shafa Medicinal Plant Cultivation and Development Company. The irrigation method included water production with the Peltier module, control (without irrigation), and irrigation with distilled water. For this, the seeds were placed on a filter paper and inside a Petri dish. 6 ml of distilled water was poured on each filter paper during the irrigation treatment with distilled water. In the control treatment, irrigation was not done and in the irrigation treatment with the Peltier module, after connecting the module to the power source, the device was allowed to produce enough water and the produced water was absorbed by the filter paper. The water absorbed by the filter paper was used for seed germination. The technical specifications of the device were dimensions of 40 mm by 40 mm by 5 mm. Capabilities: Internal resistance between 2.5 to 2.8 ohms, operating voltage: 12 volts, cooling power: 60 to 72 watts. The cooling element was a thermoelectric model TEC1-12706.

After one week, the characteristics of seed germination were measured. These characteristics included germination percentage, caulicle length, radicle length, caulicle weight, and radicle weight. A ruler was used to measure radicle length and caulicle length. To measure caulicle weight and radicle weight, these organs were first separated from the seeds. Then the organs were placed in separate bags in an oven at 75 ° C for 24 hours. Finally, the dry weight of caulicle and radicle was obtained with a digital scale. The criterion for seed germination was the growth of caulicle length of 2 mm. Seed vigor based on length was obtained by multiplying the seedling length (radicle length plus caulicle length) by germination percentage. Seed vigor based on weight was obtained by multiplying seedling weight (caulicle weight plus radicle weight) by seed germination percentage.

SAS software (version 9.1.3) was used for data analysis. After analyzing the variance of the data, the

Duncan's test was used to compare the mean of the data at the 5% probability level. Correlation between traits was also obtained using SPSS software.

3. Results and discussion

3.1. Seed germination percentage

Comparison of mean data showed that irrigation treatment with Peltier module and irrigation treatment with distilled water in four plants of cucumber, chickpea, flax, and camelina were not different in terms of germination percentage. In the control treatment (no irrigation), the seeds had zero germination. Therefore, irrigation treatment with the Peltier module led to the germination of cucumber, chickpea, flax, and camelina seeds (Fig. 1a). These results show that the Peltier module can germinate the seeds of crops. In other words, this method can be used for the germination stage of crop seeds. Seed moisture requirement for germination is low. Many seeds need two to three times their weight in water to germinate (Bewley and Black, 1978). The seed germination stage requires little water, but in the field, the whole soil is usually wetted. So the water loss is high. With the help of the Peltier method, only the soil around the seeds can be wetted and moisture loss during germination and seedling emergence can be prevented. In one study, tailoring silicone was used for dew water harvesting panels. It was observed that silicon-based water panels absorbed energy during the day and produced water at night (Liu *et al.*, 2021). Seed germination percentage had a positive and significant correlation with caulicle length, radicle length, root-to-shoot ratio, seed vigor based on length, seed vigor based on weight, caulicle weight, and radicle weight (Table 1). Németh et al. (2004) reported that there was a positive correlation between seed germination characteristics of Turkey oak acorn (*Quercus cerris* L.), which is consistent with the results of our study.

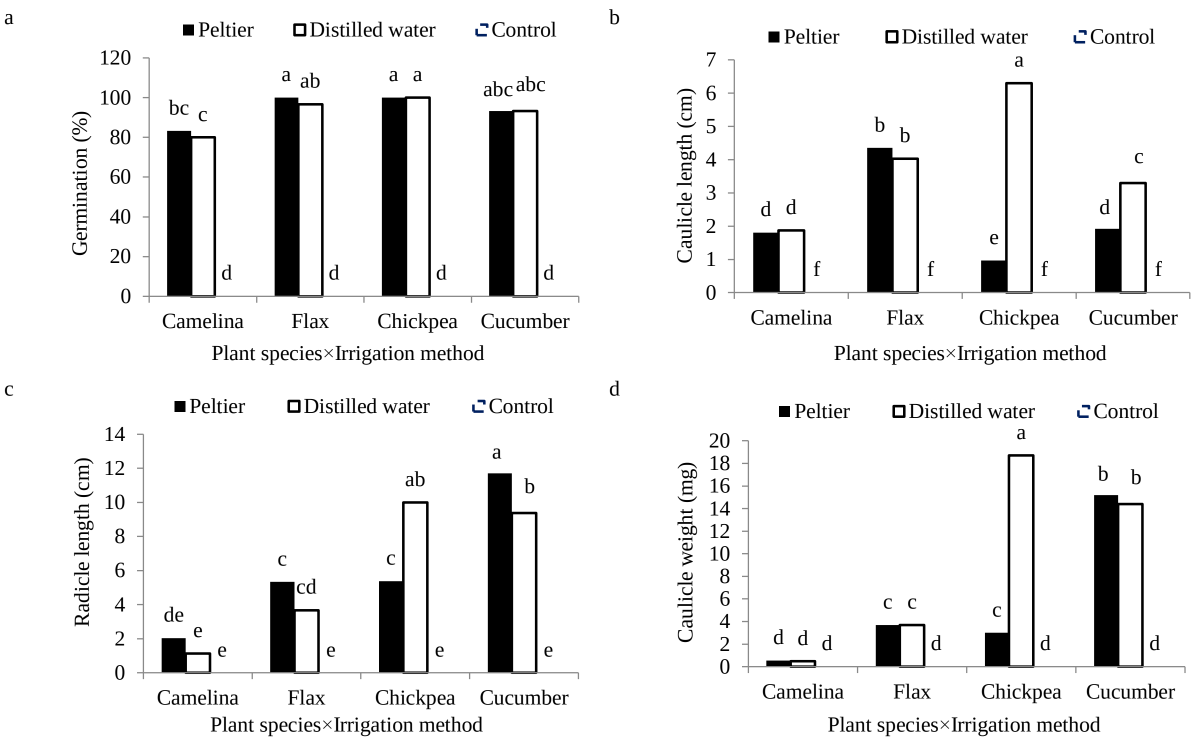

Figure 1. Mean comparisons for the effect of different irrigation methods on seed germination percentage (a), caulicle length (b), radicle length (c), and caulicle weight (d) in cucumber, chickpea, flax, and camelina. Peltier, Distilled water, and Control are irrigation with Peltier module, irrigation with distilled water, and no irrigation, respectively. In each trait, the means with at least one common letter according to Duncan's test at the level of 5% probability are not significantly different.

3.2. Caulicle length

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in flax and camelina were not different in terms of caulicle length. In cucumber and chickpea, it was seen that irrigation with distilled water had a longer caulicle length than irrigation by the Peltier method. However, in all four plants, the irrigation with the Peltier module had a longer caulicle length than the control (Fig. 1b). It was reported that drought of -0.4 MPa did not affect camelina seed germination. The drought of -1.2 MPa reduced its germination by 25%. Stem and root length of camelina decreased under drought but shoot reduction was greater than root (Čanak *et al*., 2020). Caulicle length had a positive and significant correlation with seed germination percentage, radicle length, seed vigor based on length, seed vigor based on weight, caulicle weight, and radicle weight (Table 1). Mangena (2021) reported that there was a positive correlation between shoot length with seed germination percentage and seed vigor in soybean, which is consistent with the results of this study.

3.3. Radicle length

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in flax and camelina were not different in terms of radicle length. In cucumber, it was seen that irrigation with the Peltier module had a longer radicle length than irrigation with distilled water. In chickpea, it was seen that irrigation with distilled water had a longer radicle length than irrigation by the Peltier method. However, in three plants, cucumber, chickpea, and flax, the irrigation with the Peltier module had a longer radicle length than the control (Fig. 1c). PEG-induced drought reduced the radicle length of flax (Mahfouze *et al*., 2017) and wheat (Li *et al*., 2020). Radicle length had a positive and significant correlation with seed germination percentage, caulicle length, root-to-shoot ratio, seed vigor based on length, seed vigor based on weight, caulicle weight, and radicle weight (Table 1). Abiri et al. (2016) reported that radicle length had a positive and significant correlation with germination percentage, germination rate, average germination time, seed vigor index, plumule dry weight, and radicle dry weight in indica rice *(Oryza sativa* L.) varieties.

3.4. Caulicle weight

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in cucumber, flax, and camelina were not different in terms of caulicle weight. In chickpea, it was seen that irrigation with distilled water had a higher caulicle weight than irrigation by the Peltier module. However, in three plants, cucumber, chickpea, and flax, the irrigation with the Peltier module had a higher caulicle weight than the control (Fig. 1d). Drought reduced seedling weight of Iranian knapweed (*Centaurea depressa* M. Bieb.) (Ebadi *et al*., 2014) which is consistent with the results of this study. Caulicle weight had a positive and significant correlation with seed germination percentage, caulicle length, radicle length, root-to-shoot ratio, seed vigor based on length, seed vigor based on weight, and radicle weight (Table 1). It was reported that there was a positive correlation between seedling weight and seed vigor in maize (Heidari, 2012), which is consistent with the results of this study.

3.5. Radicle weight

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in flax and camelina were not different in terms of radicle weight. In chickpea and cucumber, it was seen that irrigation with distilled water had a higher radicle weight than irrigation by the Peltier module. However, in two plants, cucumber and chickpea, the irrigation with the Peltier module had a higher radicle weight than the control (Fig. 2a). Water deficit stress decreased caulicle length, caulicle fresh weight, and caulicle dry weight in common bean (*Phaseolus vulgaris* L.) genotypes (Soltani *et al*., 2017). Radicle weight had a positive and significant correlation with seed germination percentage, caulicle length, radicle length, root-to-shoot ratio, seed vigor based on length, seed vigor based on weight, and caulicle weight (Table 1). It has been reported that there was a positive correlation between seedling weight and seedling emergence in the leek (Ermiş *et al*., 2015), which is consistent with the results of this study.

3.6. Seed vigor based on length

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in cucumber, flax, and camelina were not different in terms of seed vigor based on length. In chickpea, it was seen that irrigation with distilled water had a higher seed vigor based on length than irrigation by the Peltier method. However, in three plants, cucumber, chickpea, and flax, the irrigation with the Peltier module had a higher seed vigor based on length than the control (Fig. 2b). Chickpea seed vigor decreased under drought caused by PEG and this parameter was a good indicator for evaluating drought tolerance of chickpea (Koskosidis *et al*., 2020). Seed vigor based on length had a positive and significant correlation with seed germination percentage, caulicle length, radicle length, root-to-shoot ratio, seed vigor based on weight, caulicle weight, and radicle weight (Table 1). The positive correlation between seed vigor based on length and seed germination percentage, caulicle length, and radicle length is because these parameters are the components of the seed vigor based on length. Air-water vapor is one of the potential sources of water for irrigating plants. The percentage of air humidity depends on its temperature. In hot weather, the percentage of humidity increases, for example, at 30°C, the percentage of humidity is 4.24% (McElroy, 2002). Water production from air-water vapor is expensive and should be considered for energy supply, but the water produced is pure, and irrigating plants and seeds with this water is preferable to irrigating with conventional irrigation sources that have some impurities. Due to irrigation of fields with impure water sources, overtime after evaporation of water from the soil surface, salts remain and due to the accumulation of salts, the soil becomes saline. Efficient irrigation methods such as drip irrigation play a lesser role in soil salinity, but the same irrigation methods also cause soil salinity in the long run.

3.7. Seed vigor based on weight

Mean comparisons showed that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water in cucumber, flax, and camelina were not different in terms of seed vigor based on weight. In chickpea, it was seen that irrigation with distilled water had a higher seed vigor based on weight than irrigation by the Peltier module. However, in three plants, cucumber, chickpea, and flax, the irrigation with the Peltier module had a higher seed vigor based on weight than the control (Fig. 2c). Water deficit stress decreased radicle weight, caulicle weight, and seedling vigor index in red kidney bean (Mohammadzadeh *et al*., 2015). Seed vigor based on weight had a positive and significant correlation with seed germination percentage, caulicle length, radicle length, root-to-shoot ratio, seed vigor based on length, caulicle weight, and radicle weight (Table 1). The positive correlation between seed vigor based on weight and seed germination percentage, caulicle weight and radicle weight is because these parameters are the components of seed vigor based on weight.

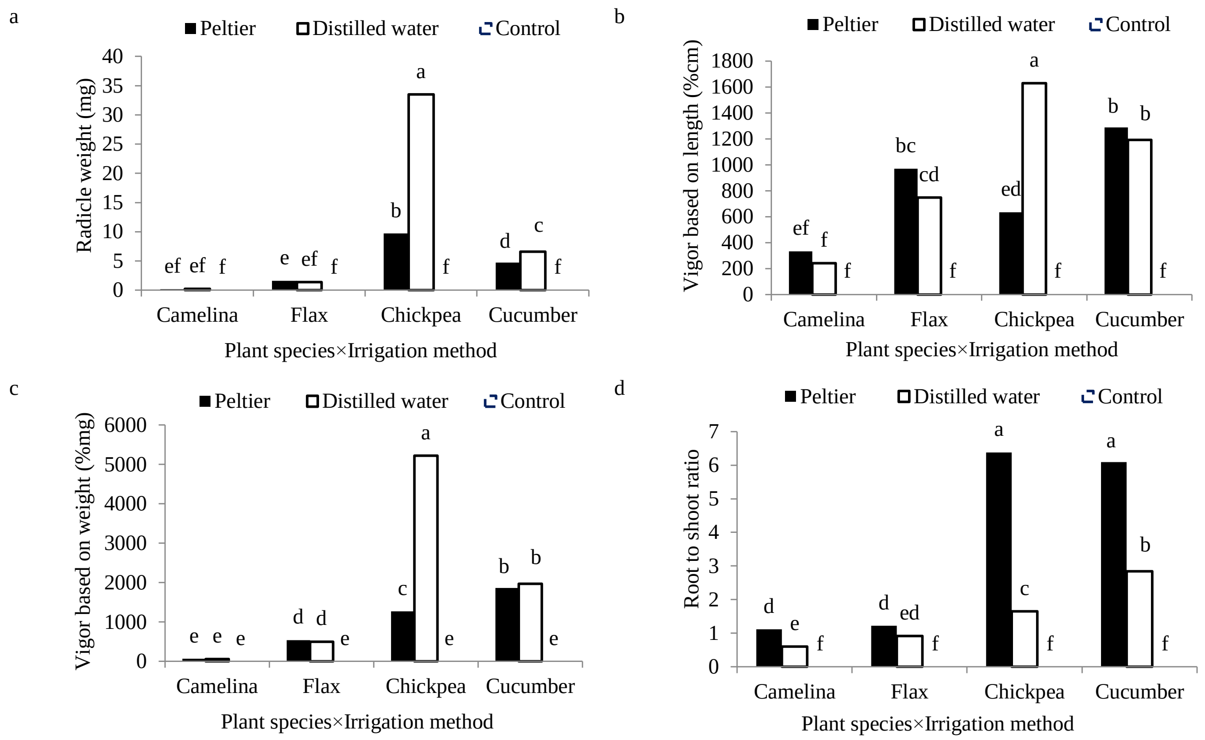

Figure 2. Mean comparisons for the effect of different irrigation methods on radicle weight (a), seed vigor based on length (b), seed vigor based on weight (c), and root to shoot ratio (d) in cucumber, chickpea, flax, and camelina. Peltier, Distilled water, and Control are irrigation with Peltier module, irrigation with distilled water, and no irrigation, respectively. In each trait, the means with at least one common letter according to Duncan's test at the level of 5% probability are not significantly different.

Table 1. Pearson correlation coefficient between germination characteristics of cucumber, chickpea, flax, and camelina seeds under the influence of different irrigation methods

	Germination	Caulicle length	Radicle length	Root/Shoot	Vigor based on length	Vigor based on weight	Caulicle weight	Radicle weight
Germination	1							
Caulicle length	0.759**	1						
Radicle length	0.701**	0.641**	1					
Root/Shoot	0.599**	0.181	0.780**	1				
Vigor based on length	0.774**	0.821**	0.959**	0.633**	1			
Vigor based on weight	0.515**	0.668**	0.791**	0.470**	0.825**	1		
Caulicle weight	0.554**	0.638**	0.926**	0.591**	0.897**	0.891**	1	
Radicle weight	0.420*	0.597**	0.594**	0.333*	0.660**	0.949**	0.706**	1

**: Correlation is significant at the 0.01 level. *: Correlation is significant at the 0.05 level.

3.8. Root to shoot ratio

Mean comparisons showed that the irrigation treatment with the Peltier module had a higher root-to-shoot ratio than the irrigation treatment with distilled water in cucumber, chickpea, and camelina. In flax, it was seen that the irrigation treatment with the Peltier module and the irrigation treatment with distilled water were not different in terms of root-to-shoot ratio. However, in all four plants, the irrigation with the Peltier module had a higher root-to-shoot ratio than the control (Fig. 2d). A deeper and stronger root system leads to increased plant resistance to drought (Xu *et al*., 2015) and drought increases root-to-shoot ratio (Polania *et al*., 2017). Root-to-shoot ratio had a positive and significant correlation with seed germination percentage, radicle length, seed vigor based on length, seed vigor based on weight, caulicle weight, and radicle weight (Table 1).

The difference between plants in terms of tolerance to salinity and drought may cause plants to react to irrigation with water produced by the Peltier method and distilled water. Although there was no difference between irrigation with the Peltier method and irrigation with the distilled water in terms of most of the germination characteristics of the plants, the reaction of chickpea was slightly different from the rest of the plants. The quality of water may be different in the two methods of Peltier and distilled water. For example, the water produced by the Peltier method may have an electric charge (Rastegar and Sadeghi, 2015). Magnetic water is more easily absorbed by the cell membrane and accelerates seed germination (Zhang *et al*., 2022). Magnetic water causes the increase of water molecules per unit volume, the solubility of water increases and affects the absorption of cations and anions, and the plant has more access to solutes. Magnetic water causes better absorption of nutrients (Alemán *et al*., 2022).

By creating a cold surface, the Peltier module condenses the air vapor into water. The cold surface is provided by electric current (Macia *et al*., 2004). Two semiconductors are used in the thermoelectric cooling structure or Peltier device. The passage of electric current through this semiconductor causes a temperature difference. The decrease in temperature on one side of this plate is used to cool the air and produce water. Some of the benefits of the Peltier device include easier maintenance, no pollution such as chlorofluorocarbons, and long life. One of the disadvantages of the Peltier device is its limited thermal range (Zhao and Tan, 2014).

Water production by methods such as the Peltier module is proposed for arid and semi-arid areas. In these areas, the weather is usually clear and cloudless most of the time, so it is possible to generate electricity with the help of solar panels. Also, in these areas, due to the wind, it is possible to generate electricity with the help of wind. These two types of energy are considered clean energy and help to preserve the environment. The use of water production methods such as Peltier modules to regenerate forests and prevent desertification is also important because there is no access to water resources in these areas and transporting water to these areas is costly and in some areas may be impossible. In terms of reforestation, the dew produced is sufficient to meet the water needs of seedlings and irrigate them. Dew can reduce tree mortality in drought conditions or arid and semi-arid regions. Dew is used as a tool to measure adaptation to climate change and reforestation. Dew affects the daily soil moisture by up to 3 % (Tomaszkiewicz *et al*., 2017).

Water use efficiency in the Peltier irrigation method is probably higher than methods such as surface irrigation because, in this method, only the point around the seed or root of the plant can be wetted, but in the surface irrigation method, the whole soil is wetted and the contact surface of moisture with air increases. In addition, in this method, moisture can be maintained permanently in the seed or root area of the plant. Using this method does not require a tool such as a water pipe inside the farm and saves on water transfer costs. The only cost at the farm level is wiring for on-farm electricity, which can be saved by using cheap connections and thin wires. This means that the uniform distribution of water on the farm and the delivery of water to all plants is one of the main problems of irrigation systems and requires a high cost. Field-scale system design and cost reduction in the Peltier module irrigation method need further researches. Due to the novelty of this method, the design and implementation of this method are very different from conventional methods of water distribution in the field such as sprinkler irrigation.

4. Conclusion

Irrigation treatment with the Peltier module was able to germinate cucumber, chickpea, flax, and camelina seeds and no difference was observed between this method and irrigation with distilled water in terms of germination percentage. In three plants of cucumber, chickpea, and flax, the irrigation with the Peltier module had a higher radicle length, seed vigor based on length, seed vigor based on weight, caulicle length, and radicle weight than the control. It is suggested to evaluate the water production system with the Peltier module at the seedling stage and the whole plant at the field scale. It is recommended to evaluate the Peltier irrigation system with conventional irrigation methods such as drip irrigation at the field scale in future researches.

Conflict of interests

The authors declare no conflict of interest in to report.

Ethics approval and consent to participate

The authors declare not to use human or animals in this research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

The authors embedded all data in the manuscript.

Authors' contributions

All authors had an equal role in experiment design, implementation, statistical analysis and manuscript writing.

Informed consent

The authors declare not to use any patients in this research.

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