Scholars Journal of Agriculture and Veterinary Sciences OPEN ACCESS
Abbreviated Key Title: Sch J Agric Vet Sci
ISSN 2348–8883 (Print) | ISSN 2348–1854 (Online)
Journal homepage: https://saspublishers.com

Evaluation of Germination and Seedling Growth Traits of Sorghum (*Sorghum bicolor* L. Moench) Seeds Using Microwave and Magnetized Water Priming

Samir Khairi Lazim[1*]

[1]Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, Iraq

DOI: https://doi.org/10.36347/sjavs.2025.v12i04.003 | **Received:** 27.02.2025 | **Accepted:** 05.04.2025 | **Published:** 08.04.2025

***Corresponding author:** Samir Khairi Lazim
Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, Iraq

Abstract **Original Research Article**

A pot experiment was conducted to assess the combined effects of microwave priming and irrigation with magnetized water on the germination and growth traits of sorghum seeds (*Sorghum bicolor* L. Moench). An experiment with 12 treatments in three replicates was arranged factorial (4x4) in a completely randomized design. Seeds were exposed to microwaves under different exposure times, including (MW_0-0 s) as a control, (MW_1-10 s), (MW_2-20 s), and (MW_3-30 s). For the treated water, four water samples underwent magnetization for varying durations: (TW_0-0 h) as a control, (TW_1-1 h), (TW_2-3 h), and (TW_3-5 h). Comparison was made between treatments and controls for final germination percent (FGP), mean germination time (MGT), germination rate index (GRI), mean daily germination (MDG), peak value (PV), and germination value (GV). Shoot length (SL), root length (RL) and seedling vigor index (SVI) were also calculated and compared. The results showed that both microwave treatment and irrigation with magnetized water significantly affected all the evaluated traits of sorghum seeds. The interaction between microwave priming and magnetized water for irrigation significantly influenced MGT, GRI, PV, GV, and SVI, while no significant changes were observed in FGP, MDG, SL, and RL. Nevertheless, the MW_2-20 s and TW_2-3 h treatment yielded superior outcomes across all measured traits compared to the control group. Out of different treatments, a MW-20 s exposure, succeeded by watering with magnetized water after 3 hours, might prove to be most beneficial for sorghum's germination characteristics and the seedlings' development. As a result, this procedure could be employed to boost both the germination of sorghum seeds and the subsequent growth of the seedlings.

Keywords: *Microwaves*, *Magnetized Water*, *Germination Traits*, Priming, *Sorghum*.

INTRODUCTION

Physical priming is one of the most environmentally friendly and safe methods to improve seed germination and growth. A wide range of physical factors, including magnetic fields, microwaves, ultraviolet irradiation, and ultrasonic waves have been successfully used in most published studies on priming to stimulate seed germination prior to sowing (Himoud *et al*., 2022; Wang *et al*., 2018; Huang *et al*., 2024; and Lazim, 2023). And among physical methods, particularly seed priming with microwaves (MWs) or magnetically treated water is one of the physical priming techniques which enhances germination and seedling growth in many agronomic crops. Compared with radio waves, MWs are part of the electromagnetic spectrum with a higher frequency range of 300 MHz to 300 GHz and a shorter wavelength range of 1 m to 1 mm. The electromagnetic waves caused by MWs are absorbed at the molecular level and can affect the energy of molecular vibrations and stimulate biological systems in both a thermal and non-thermal manner (Banik *et al*. 2003). Several studies have been conducted on the impact of MWs radiation at 2.45 GHz for a short period on seed germination and seedling growth in many plant species (Iuliana *et al*., 2013; Abu-Elsaoud (2015); and Lazim & Ramadhan, 2023). Conversely, watering plants using magnetized water is seen as a safe and eco-conscious physical technique for better seed sprouting and overall development. The magnetized water is one technique of the magnetic field applications. The term magnetized water refers to water that has been subjected to a magnetic field. Magnetized water alters certain physical and chemical properties, potentially influencing plant traits and development. Furthermore, it has demonstrated increased absorption of nutrients resulting in an increase in plant growth (Sadeghipour and Aghaei, 2013). The beneficial effects of magnetized water have been documented to improve plant germination and growth in many field crops, such as wheat and barley (Al-Akhras *et al*., 2024); maize (Alattar *et al*., 2021); bean (Aghamir *et al*., 2016); and pea seeds (Noor *et al*., 2016). To the best of my knowledge, the combined impact of microwave pre-treatment and magnetized irrigation on sorghum seeds has not been studied. Hence, this study was designed to assess how microwave-priming impacts the germination process and development of seedlings when sorghum seeds are watered with magnetically-treated water.

MATERIALS AND METHODS

An experiment was done in October 2024 at the Physics Laboratory of the Agricultural College, Department of Agricultural Machinery and Equipment, University of Basrah, using pots. It was done to study how microwave priming (MW) influences seed germination and seedling development in sorghum when the seeds were watered with magnetically-treated water (TW). Treatments were arranged in a 4 × 4 factorial design. In the first factor seeds of sorghum (*Sorghum bicolor* L. Moench) were first soaked in distilled water for 1 hour to enhance the absorption of microwave energy. Subsequently, the seeds were air dried and then were divided into four groups, each group containing 60 seeds (3 replicates each containing 20 seeds). The first group represents the non-primed control (MW_0). The remaining three groups were primed with different exposure periods to the microwave for MW_1-10 s, MW_2-20 s, and MW_3-30 s. To perform microwave seed treatments, a household microwave oven of 600 W at 2450 MHz was used. Seeds of the four sorghum groups (unprimed and primed with a microwave) were planted in ordinary plastic pots (15 cm in diameter and 20 cm in depth) containing the same type of soil with 20 seeds in each pot. The second factor included four samples of magnetically primed water. The first sample represents non-magnetized water (control group, TW_0). The remaining three water samples underwent magnetization for varying durations of TW_1-1 h, TW_2-3 h, and TW_3-5 h. A magnetic field generator device was used to prepare magnetized distilled water according to the procedure described by Al-Akhras *et al*. (2024). Pots were placed under laboratory conditions under natural light. Each pot is watered with two types of water (non-magnetized water or three samples of magnetized water), roughly 200 ml/pot whenever required. The germination of seeds in the pots was checked daily with four different types of water until the 10th day, when no further germination occurred. The measured germination parameters recorded in respect of the observation data collected daily as below: The cumulative number of germinated seeds with normal radicles was calculated using final germination percent FG%= (Ng/20) ×100, where Ng is the number of seeds germinated eight days after being sown, and 20 is the total number of maize seeds sown. Based on Ellis and Roberts' (1981) formula, mean germination time was calculated as follows: $MGT = \frac{\sum nD}{\sum n}$ (Day), where D is the number of days since the beginning of germination, and n is the number of seeds germinated on the day of observation. The following equation was used by Al-Mudaris (1998) as a means of calculating the germination rate index (GRI): GRI= G1/D1+ G2/D2+... + Gn/Dn (%/day), where G1, G2, G3,... Gn are the number of freshly germinated seeds on the 1, 2, 3, and nth days, respectively, and D1, D2, D3, and Dn are the counts on those days. The germination value (GV) was calculated as the product of the peak value (PV) and mean daily germination (MDG) using Czabator (1962), modified by Kolotelo *et al*., (2001). PV is the cumulative percentage of germination on any day divided by the number of days required to reach these percentages. MDG is the final germination capacity of the test divided by the maximum number of germination days. At 15 days after sowing, ten seedlings from each replicate were randomly selected to measure root length (RL) and shoot length (SL) in centimeters (cm). The mean seedling length (SL + RL) was computed. According to Abdul Baki and Anderson (1973), the seedling vigor index (SVI) was calculated as germination % × Seedling Length (SL + RL). The data for all parameters underwent statistical analysis through ANOVA in three replicates. To compare the differences among treatment means and their interactions, the Least Significant Difference (LSD) method was employed, with a significance level set at 5%.

RESULTS AND DISCUSSION

Sorghum seeds were subjected to varying durations of microwave treatments, ranging from 0 s (control) to 30 s, with 10-s increments between treatments. Microwave exposure time effects on germination parameters were studied compared to control. The data concerning germination parameters are presented in Table 1. This includes the final germination percentage (FGP), mean germination time (MGT), germination rate index (GRI), mean daily germination (MDG), peak value (PV), and germination value (GV). Results in Table 1 show that seed priming treatment exposed to MW-20s had a significant impact on all germination parameters of the sorghum compared to the non-priming (control). Thus, applying MW-20s significantly recorded the higher increases upon the control by 10.4% for FG, 30% for GRI (%/day), 10.3% for MDG (seed/day), 46% for PV, and 63% for GV, in addition to decreasing MGT in days by 17.8%. However, it can be noted that the seeds exposed to MW for 30 s significantly recorded the decrease upon the control by 21.80% for FG, 38.40% for GRI (%/day), 21.85% for MDG (seed/day), 52.30% for PV, and 62.80% for GV, in addition to increasing MGT in days by 26.80%. Based on these results, it appears that microwave treatment has both positive and negative effects on sorghum seed germination. Similar results were obtained for wheat seeds by Wang *et al*. (2018), who found that low-power and short microwave exposure resulted in the highest germination rates, whereas long microwave exposure resulted in the lowest germination rates. In addition, these results may be in agreement with those reported by Hassan (2023) for sorghum, Ruchika *et al*. (2024) for bell pepper, and Iuliana *et al*. (2013) for barley.

Table 1: Germination traits of sorghum seed priming as affected by microwave exposure time

Treatments	FGP %	MGT (day)	GRI (%/day)	MDG (seed/day)	PV	GV
MW_0	84.17±2.02^b	5.45 ±0.20^b	16.94 ±0.91^b	8.42 ±0.19^b	2.39 ±0.16^b	20.50 ±1.79^b
MW_1	85.41±1.29^b	5.29 ±0.13^b	17.49 ±0.59^b	8.54 ±0.13^b	2.47 ±0.10^b	21.29 ±1.23^b
MW_2	92.92±1.78^a	4.48 ±0.17^c	22.03 ±1.08^a	9.29 ±0.17^a	3.49 ±0.23^a	33.42 ±2.55^a
MW_3	65.83±1.20^c	6.91 ±0.13^a	10.15 ±0.37^c	6.58 ±0.12^c	1.14 ±0.15^c	7.62±1.06^c

***Note*:**

Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. MW_0, MW_1, MW_2, and MW_3 represent microwave priming seed exposure times of 0 (control), 10,20, and 30 s, respectively.

Warkad *et al*., (2018) suggested that microwave exposure could lead to hydrogen bond breakage in the ultrastructural elements of seeds. This structural alteration may increase enzyme activity based on microwave power and exposure duration. As a result, germination and seedling growth of sorghum might have improved compared to of the those untreated control. Hassan (2023) proposed an explanation that microwave treatment caused disturbance of the sorghum seed coat, which promoted water access to the seeds, leading to a higher rate of enzymatic reactions, and the start of the early developmental stages and improved germination.

According to the presented data of means regarding sorghum seedling growth parameters given in Table 2, it could be observed that the different exposure times on microwave priming had a significant impact on various growth parameters of the sorghum seedlings compared to the control.

At MW-20 s exposure, the seedlings showed a significant increase in shoot length (14 %), root length (17.50 %), and seedling vigor index (26.80 %) compared to the control. While MW-30 s exposure significantly recorded the decrease upon the control by 24.66% for SL, 24.20% for SL, and 41.50% for SVI. Generally, a microwave exposure time of 20 s had a positive and significant effect on all of the studied seedling growth parameters, whereas exposure for 30 s caused more negative effects. The results of the present study are in agreement with those of Iuliana *et al*., (2013), who reported the best results for barley seeds exposed to microwave treatment at an output microwave power of 400 W for 20 s. Accordingly, pre-treatment of seeds with microwave treatment is likely to activate various enzymes during germination, leading to improved seed germination (Wang *et al.*, 2018; Iuliana *et al*., 2013).

Table 2: Seedling growth traits of sorghum seed priming as affected by microwave exposure time

Treatments	SL (cm)	RL (cm)	SVI
MW_0	22.66±0.59^b	18.60 ±0.59^c	35.10 ±1.67^b
MW_1	23.11±0.46^b	19.34 ±0.45^b	36.34 ±1.14^b
MW_2	25.85±0.52^a	21.86 ±0.53^a	44.50 ±1.68^a
MW_3	17.07±0.26^c	14.10 ±0.24^d	20.54 ±0.56^c

***Note*:**

Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. MW_0, MW_1, MW_2, and MW_3 represent microwave priming seed exposure times of 0 (control), 10,20, and 30 s, respectively.

Microwave intensity stimulation causes physiological changes in seeds, leading to enzymatic activation, which increases their biological capabilities. Warkad *et al*., (2018) explained that free radicals stimulate enzymes and proteins, which increases seed power. Moreover, these authors suggested that microwave exposure may cause hydrogen bonding to break the ultrastructural elements of the seeds. Consequently, sorghum might have germinated more effectively than the untreated controls, possibly because of increased seed germination and seedling length.

Process Effects of Magnetized Water:

The effects of treatments on sorghum seeds watered with magnetically treated water, compared to the control (untreated water), are presented in Table 3. Results showed that irrigation of sorghum seeds with magnetically treated water enhanced the germination. Irrigation with magnetized water after a 3-h priming process significantly increased yield by 13.11% for FG, 41.65% for GRI (%/day), 13.12% for MDG (seed/day), 81.36% for PV, and 94.88% for GV as compared to ordinary water (control), in addition to decreasing MGT in days by 19.15%. The 5 h-TW also led to a significant increase in FGP (11.28%), GRI (33.48%), MDG (11%), PV (68.94%), and GV (79.15%), as compared to ordinary water (control), in addition to decreasing MGT in days by 13.75%. In the present study, the positive effects of magnetized water are in agreement with those obtained by Noor *et al*., (2016), who found significant improvements in pea seed germination traits. In addition, these results may be in agreement with those Al-Akhras *et al*., (2024) for wheat and barley, Massah *et al*., (2019) for wheat, and Aghamir *et al.*, (2016) for bean.

Table 3: Effects of magnetized water priming on sorghum germination traits

Treatments	FGP %	MGT (day)	GRI (%/day)	MDG (seed/day)	PV	GV
TW_0	76.25±2.69^c	6.11 ±0.20^a	13.59 ±0.95^d	7.62 ±0.26^c	1.61 ±0.24^d	13.48 ±2.16^c
TW_1	81.25±3.14^b	5.81 ±0.28^b	15.62 ±1.20^c	8.12 ±0.31^b	2.24 ±0.21^c	18.91 ±2.27^b
TW_2	86.25±3.48^a	4.94 ±0.26^d	19.25 ±1.51^a	8.62 ±0.35^a	2.92 ±0.29^a	26.27 ±3.25^a
TW_3	84.58±3.45^{ab}	5.27 ±0.34^c	18.14 ±1.62^b	8.46 ±0.34^{ab}	2.72 ±0.30^b	24.15±3.23^a

***Note*:**

Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. TW_0: means irrigation with untreated water (control); TW_1, TW_2, and TW_3: Mean irrigation with magnetized water at exposure times 1, 3, and 5 h, respectively.

The comparison values of some seedling growth traits of sorghum treated with ordinary and magnetized water are presented in Table 4. As shown in Table 4, irrigation with magnetized water after a 3-h priming process significantly increased SL (14.2 %), RL (17 %), and SVI (28.80 %) compared to ordinary water. The 5 h-TW also led to a significant increase in SL (39 %), RL (17 %), and SVI (28.80 %) compared with ordinary water. These findings are similar to those of Elfadil and Abdallah (2013), who reported that magnetically treated irrigation water improved the growth of sorghum plants. Moreover, these results may be in agreement with those reported by Alattar *et al*., (2021) for corn, and Aghamir *et al*., (2016) for bean.

Table 4: Effects of magnetized water priming on sorghum seedling growth traits

Treatments	SL (cm)	RL (cm)	SVI
TW_0	20.12±0.82^d	16.51 ±0.74^d	28.34 ±2.06^d
TW_1	21.89±0.96^c	18.12 ±0.88^c	33.26 ±2.58^c
TW_2	23.71±1.06^a	19.94 ±0.92^a	38.36 ±3.02^a
TW_3	22.97±1.09^b	19.32 ±0.98^b	36.51 ±3.01^b

***Note*:**

Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. TW_0: means irrigation with untreated water (control); TW_1, TW_2, and TW_3: Mean irrigation with magnetized water at exposure times 1, 3, and 5 h, respectively.

Alattar *et al*., (2021) suggested that the stimulating effect of magnetized water on the growth of maize seedlings may be due to its impact on the biochemical process, activities of enzymes and protein formation. As a result, the root growth of maize might have improved compared with that of the untreated control.

Combined Processing Effect:

The means for germination parameters in the combination treatments of microwave seed priming with magnetized water are shown in Table 5. According to the results, the combination of treatments (MW × TW) had a significant effect on all traits except for final germination percent (FGP) and mean daily germination (MDG). Among the combinations in Table 5, treatments $MW_2 \times TW_2$ showed significantly higher GRI (25.66 %/day), PV (4.25), and GV (41.83). In addition, the data in the same table show a significant lowest effect in MGT (3.93 days) by $MW_2 \times TW_2$ treatments. On the other hand, the interaction between priming treatments showed no significant effect on FGP and MDG (Table 3). However, the $MW_2 \times TW_2$ combination had a higher FGP (98.33) and MDG (9.83).

Table 5: The combined effect of microwave priming and magnetized water on the germination traits of sorghum

Treatments	FGP %	MGT (day)	GRI (%/day)	MDG (seed/day)	PV	GV
$MW_0 \times TW_0$	75.00 ± 2.88^{ns}	6.30 ± 0.04^{b}	13.06 ± 0.52^{e}	7.50 ± 0.28^{ns}	1.74 ± 0.07^{ef}	13.14 ± 1.04^{de}
$MW_1 \times TW_0$	81.66 ± 1.66^{ns}	5.89 ± 0.14^{c}	15.16 ± 0.47^{ed}	8.16 ± 0.16^{ns}	2.04 ± 0.09^{e}	16.73 ± 0.97^{d}
$MW_2 \times TW_0$	85.00 ± 2.88^{ns}	5.31 ± 0.05^{d}	17.25 ± 0.69^{cd}	8.50 ± 0.28^{ns}	2.38 ± 0.05^{ed}	22.14 ± 0.89^{c}
$MW_3 \times TW_0$	63.33 ± 1.66^{ns}	6.95 ± 0.30^{a}	8.91 ± 0.24^{g}	6.33 ± 0.16^{ns}	0.30 ± 0.06^{g}	1.91 ± 0.40^{g}
$TW_1 \times MW_0$	83.33 ± 1.66^{ns}	5.96 ± 0.09^{c}	15.34 ± 0.59^{d}	8.33 ± 0.16^{ns}	2.04 ± 0.09^{e}	17.06 ± 1.13^{d}
$TW_1 \times MW_1$	85.00 ± 2.88^{ns}	5.28 ± 0.17^{d}	17.32 ± 1.18^{c}	8.50 ± 0.28^{ns}	2.44 ± 0.20^{d}	20.85 ± 2.42^{cd}
$TW_1 \times MW_2$	91.66 ± 1.66^{ns}	4.74 ± 0.07^{e}	20.16 ± 0.65^{b}	9.16 ± 0.16^{ns}	3.20 ± 0.11^{b}	29.36 ± 1.55^{b}
$TW_1 \times MW_3$	65.00 ± 2.88^{ns}	7.25 ± 0.04^{a}	9.65 ± 0.47^{g}	6.50 ± 0.28^{ns}	1.28 ± 0.08^{f}	8.36 ± 0.91^{f}
$TW_2 \times MW_0$	90.00 ± 2.88^{ns}	4.75 ± 0.04^{e}	19.95 ± 0.79^{b}	9.00 ± 0.28^{ns}	3.00 ± 0.11^{b}	27.03 ± 1.68^{b}
$TW_2 \times MW_1$	88.33 ± 3.33^{ns}	4.77 ± 0.11^{e}	19.56 ± 1.00^{b}	8.83 ± 0.33^{ns}	2.86 ± 0.17^{bc}	25.43 ± 2.53^{bc}
$TW_2 \times MW_2$	98.33 ± 1.66^{ns}	3.93 ± 0.04^{f}	25.66 ± 0.61^{a}	9.83 ± 0.16^{ns}	4.25 ± 0.14^{a}	41.83 ± 2.04^{a}
$TW_2 \times MW_3$	68.33 ± 1.66^{ns}	6.34 ± 0.02^{b}	11.86 ± 0.41^{f}	7.00 ± 0.16^{ns}	1.58 ± 0.04^{f}	10.81 ± 0.53^{e}
$TW_3 \times MW_0$	88.33 ± 1.66^{ns}	4.81 ± 0.01^{e}	19.42 ± 0.75^{bc}	8.83 ± 0.16^{ns}	2.80 ± 0.11^{c}	24.46 ± 1.43^{c}
$TW_3 \times MW_1$	86.66 ± 1.66^{ns}	5.22 ± 0.06^{d}	17.92 ± 0.51^{c}	8.66 ± 0.16^{ns}	2.55 ± 0.05^{cd}	22.14 ± 0.89^{c}
$TW_3 \times MW_2$	96.66 ± 1.66^{ns}	3.96 ± 0.03^{f}	25.04 ± 0.69^{a}	9.66 ± 0.16^{ns}	4.16 ± 0.16^{a}	40.33 ± 2.33^{a}
$TW_3 \times MW_3$	66.66 ± 3.33^{ns}	7.09 ± 0.11^{a}	10.20 ± 0.55^{fg}	7.00 ± 0.33^{ns}	1.39 ± 0.03^{f}	9.38 ± 0.70^{ef}

***Note*:**

Note: Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. MW_0, MW_1, MW_2, and MW_3 represent microwave priming seed exposure times of 0 (control), 10,20, and 30 s, respectively: TW_0: means irrigation with untreated water (control); TW_1, TW_2, and TW_3: Mean irrigation with magnetized water at exposure times 1, 3, and 5 h, respectively.

According to mean values (Table 6), the combined treatment application significantly affected the seedling vigor index (SVI), while the shoot length (SL) and root length (RL) were not significantly changed. Among the combinations in Table 6, treatment $MW_2 \times TW_2$ showed significantly higher SVI (50.07) as compared to other treatments. On the other hand, the interaction between priming treatments (MW × TW) showed no significant effect on SL and RL (Table 6). However, the $MW_2 \times TW_2$ combination had a higher SL (27.50 cm) and RL (23.43 cm). To my knowledge, no studies have been conducted on microwave seed priming and irrigation with magnetized water for sorghum seed germination and growth. Therefore, it may be difficult to compare my findings with those of previous studies.

Table 6: The combined effect of priming with microwave and magnetized water on sorghum seedling growth traits

Treatments	SL (cm)	RL (cm)	SVI
$MW_0 \times TW_0$	19.96 ± 0.42^{ns}	15.80 ± 0.21^{ns}	26.81 ± 1.02^{f}
$MW_1 \times TW_0$	21.20 ± 0.58^{ns}	17.93 ± 0.76^{ns}	31.98 ± 1.43^{e}
$MW_2 \times TW_0$	23.30 ± 0.37^{ns}	19.26 ± 0.64^{ns}	36.19 ± 1.48^{d}
$MW_3 \times TW_0$	16.03 ± 0.43^{ns}	13.06 ± 0.29^{ns}	18.40 ± 0.12^{h}
$TW_1 \times MW_0$	21.96 ± 0.58^{ns}	17.86 ± 0.32^{ns}	33.85 ± 0.71^{e}
$TW_1 \times MW_1$	23.10 ± 0.80^{ns}	19.13 ± 0.99^{ns}	35.96 ± 2.19^{ed}
$TW_1 \times MW_2$	25.53 ± 0.29^{ns}	21.63 ± 0.44^{ns}	43.21 ± 0.54^{b}
$TW_1 \times MW_3$	16.96 ± 0.21^{ns}	13.86 ± 0.17^{ns}	20.04 ± 0.89^{gh}
$TW_2 \times MW_0$	24.70 ± 0.47^{ns}	20.66 ± 0.16^{ns}	40.81 ± 1.16^{c}
$TW_2 \times MW_1$	24.56 ± 0.78^{ns}	20.53 ± 0.52^{ns}	39.85 ± 1.79^{c}
$TW_2 \times MW_2$	27.50 ± 0.51^{ns}	23.43 ± 0.40^{ns}	50.07 ± 0.60^{a}
$TW_2 \times MW_3$	18.10 ± 0.15^{ns}	15.13 ± 0.26^{ns}	22.72 ± 0.79^{g}
$TW_3 \times MW_0$	24.03 ± 0.18^{ns}	20.06 ± 0.51^{ns}	38.93 ± 0.14^{cd}
$TW_3 \times MW_1$	23.56 ± 0.17^{ns}	19.76 ± 0.95^{ns}	37.58 ± 1.54^{d}
$TW_3 \times MW_2$	27.10 ± 0.36^{ns}	23.13 ± 0.22^{ns}	48.55 ± 0.67^{a}
$TW_3 \times MW_3$	17.20 ± 0.45^{ns}	14.33 ± 0.17^{ns}	21.00 ± 0.84^{g}

***Note*:**

Note: Data are the mean ± standard error (S.E) of three replicates. Statistically significant differences ($p \leq 0.05$) are indicated by various letters. ns: non-significant; Means in the same column with the same letters are not significantly different according to the LSD test. MW_0, MW_1, MW_2, and MW_3 represent microwave priming seed exposure times of 0 (control), 10,20, and 30 s, respectively: TW_0: means irrigation with untreated water (control); TW_1, TW_2, and TW_3: Mean irrigation with magnetized water at exposure times 1, 3, and 5 h, respectively.

CONCLUSION

In summary, microwave-primed seeds and magnetized water were found to significantly affect all sorghum seed characteristics. On the other hand, interaction effects between microwave priming and water magnetization were statistically significant for MGT, GRI, PV, GV, and SVI. However, FGP, MDG, SL, and RL did not show significant alterations. However, high results were observed in the $MW_2 \times TW_2$ treatment on sorghum germination traits and seedlings compared to other treatments. As a result of the findings, microwave priming in combination with irrigation with magnetized water may be an effective and promising method to influence some physiological parameters of sorghum seeds.

Acknowledgments

The author gratefully acknowledge the comfort of the College of Agriculture, University of Basrah-Iraq, for their scientific research encouragement.

REFERENCES

- Abdul- Baki, A., Anderson, J.D. (1973). Vigor determination in Soybean seed by multiple criteria. Crop *Crop Science*, 13(6), 630–633. https://doi.org/10.2135/cropsci1973.0011183X001300060013x
- Abu-Elsaoud, A.M. (2015). Effect of microwave electromagnetic radiofrequency on germination and seedling growth consequences of six wheat *triticum aestivum* L. cultivar. *Advances in Environmental Biology*, 9(24), 270-280. https://www.researchgate.net/publication/286001801
- Aghamir F, Bahrami H, Malakouti MJ, Eshghi S, Sharifi F: Seed germination and seedling growth of bean (Phaseolus vulgaris) as influenced by magnetized saline water. Eurasian J Soil Sci. 2016, 5:39-46. 10.18393/ejss.2016.1.039-046
- Al-Akhras MA, Al-Quraan NA, Abu-Aloush ZA, *et al.,*: Impact of magnetized water on seed germination and seedling growth of wheat and barley. Results Eng. 2024, 22:101991. 10.1016/j.rineng.2024.101991
- Alattar E., *et al.*, (2021). Effects of magnetic field treated water on some growth parameters of corn (Zea mays) plants. *AIMS Biophysics*. 8(3): 267-280. DOI 10.3934/biophy.2021021
- Al-Mudaris, M.A. (1998). Notes on Various Parameters Recording the Speed of Seed Germination. *Journal of Agriculture in the Tropics and Subtropics*. 99: 147–154. https://www.researchgate.net/publication/290939973
- Banik, S., Bandyopadhyay, S., & Ganguly, S. (2003). Bioeffects of microwave—A brief review. *Bioresource Technology*, 87(2), 155–159. https://doi.org/10.1016/S0960-8524(02)00169-4
- Czabator, F.J. (1962). Germination value: an index combining speed and completeness of pine seed germination. *Forest Sciences*, 8(4): 386-396.
- Elfadil A.G., Abdallah R.A. (2013). Effect of light, ultra violet and magnetized water on the growth and development of Dura (Sorghum sp.). *Agriculture and Biological Journal*. 4(2): 91-96. doi:10.5251/abjna.2013.4.2.91.96
- Ellis, R. A., & Roberts, E.H. (1981). The quantification of ageing and survival in orthodox seeds. *Seed Science and Technology*, 9 , 373-409. https://www.researchgate.net/publication/309725726
- Hassan (2023). Impact of Pre-Sowing Physical Treatments on The Seed Germination Behaviour of Sorghum (*Sorghum bicolor*). *IPS Journal of Nutrition and Food Science*. 2(2), 33-36. DOI: https://doi.org/10.54117/ijnfs.v2i2.29
- Himoud, M.S., Lazim, S.K., & Al-Bahadliy, A.H. (2022): Effect of tillage depths and static magnetic seed treatment on growth parameters and yield of maize (Zea mays L.). *Indian Journal of Ecology*, 49: 18–23. http://indianecologicalsociety.com/society/conferences/
- Huang, S., Ashraf, U., Duan, M., Ren, Y., Xing, P., Yan, Z., & Tang, X. (2024). Ultrasonic seed treatment improved seed germination, growth, and yield of rice by modulating associated physiobiochemical mechanisms. Ultrasonics Sonochemistry, 104, 106821. https://doi.org/10.1016/j.ultsonch.2024.106821.
- Iuliana, C., Caprita, R., Giancarla, V., Sorina, R., & Genoveva, B. (2013). Response of barley seedlings to microwaves at 2.45 GHz. Scientific Papers: *Animal Science & Biotechnologies*, 46(1), 185-191.
- Kolotelo, D., van Steenis, E., Peterson, M., Bennet, R., Trotter, D., & Dennis, J. (2001). Seed handling guide book. Victoria, Canada: British Columbia Ministry of Forests, Tree Improvement Branch, Victoria, BC, Canada. 106 pp.
- Lazim, S. K. (2023). The Combined Effect of Seed Priming With UV-C Radiation and Hydro-Priming and Hormonal Priming by Gibberellic Acid on Physiological Parameters of Wheat (*Triticum aestivum* L.). *BioGecko*., 12(2), 2078-2085. DOI : http://biogecko.co.nz/.2023.v12.i02.pp2078-2085
- Lazim, S. K., & Ramadhan, M. N. (2023). Effects of physical and chemical seed priming techniques on seed germination and seedling growth of maize (Zea mays L.). *Annals of Biology*, 39(2), 404–410. https://www.researchgate.net/publication/376265123

- Massah J., Dousti A., Khazaei J., Vaezzadeh M. (2019). Effects of water magnetic treatment on seed germination and seedling growth of wheat. *Journal of Plant Nutrition*.42 (11–12): 1283–1289. DOI:10.1080/01904167.2019.1617309.
- Noor M.A., Ahmad W., Afzal I., Salamh A., Afzal M., Ahmad A.,Wei M. (2016). Pea seed invigoration by priming with magnetized water and moringa leaf extract. *Philippine Agricultural Scientist*. 99: 171-175. https://www.researchgate.net/publication/305807293
- Ruchika, Bharat N.K. and Sapna (2024). Effect of thermophysical methods like hot water, hot air and microwave seed treatment on seed quality parameters, seedling growth parameters and diseases incidence in bell pepper (Capsicum annuum). *International Journal of Farm Sciences* 14(3-4): 53-61. doi: 10.5958/2250-0499.2024.00037.8
- Sadeghipour O., Aghaei P. (2013). Improving the growth of cowpea (*Vigna unguiculata, L*. Walp.) by magnetized water. *Journal of Biodiversity and Environmental Sciences*. 3(1):37-43. https://www.researchgate.net/publication/236211685
- Wang S., Wang, J., & Guo, Y. (2018). Microwave Irradiation Enhances the Germination Rate of Tartary Buckwheat and Content of Some Compounds in Its Sprouts. *Polish Journal of Food and Nutrition Sciences*, 68 (3), 195-205.10.1515/pjfns-2017-0025
- Warkad D.P., Bhingarde MT and Shelar V.R. (2018). Effect of microwave intensity on plant growth, seed yield, quality and biochemical parameters of rabi sorghum [*Sorghum bicolor* (L.) Moench] under rainfed conditions. *Journal of Pharmacognosy and Phytochemistry*. SP1: 1593-1597

