

THE EFFECTS OF ORGANIC AND CHEMICAL FERTILIZER FORMS ON FLAXSEED (*Linum usitatissimum* L.) GERMINATION AND SEEDLING DEVELOPMENT

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Abstract. This study aimed to evaluate the effects of different fertilizer types and doses on linseed germination and seedling development. The research focused on comparing the performance of three organic fertilizers (OF1: liquid seaweed, OF2: liquid organic fertilizer with plant-derived amino acids, and OF3: liquid vermicompost) and two chemical fertilizers (CF1: 2% NH₄ and 20% urea; CF2: 5% NO₃, 25% P₂O₅, 2% MgO, 5% Zn) applied in six doses (control, 1000, 2000, 4000, 8000, and 16000 ppm L⁻¹). A completely randomized experimental design with three replications was used. Germination percentage, germination index, seedling length, fresh and dry weights, and seedling vigor were measured to assess the impact of each fertilizer type and dose. The study found that OF3 (liquid vermicompost) yielded the best results for all measured parameters, including germination percentage (88.57%), seedling length (14.29 cm), and vigor index (1264.91). Higher doses of CF1 and CF2 had inhibitory effects, with 16000 ppm L⁻¹ of CF1 completely suppressing germination and 8000 ppm L⁻¹ of CF2 showing no improvement. The findings indicate that organic fertilizers, particularly liquid vermicompost, are effective and eco-friendly alternatives to chemical fertilizers for promoting linseed germination and seedling growth. High doses of chemical fertilizers negatively affect germination and growth, emphasizing the need for sustainable fertilizer practices.

Keywords: doses, flaxseed, germination, organic fertilizer sources, seedling

Introduction

Flax (*Linum usitatissimum* L.) is one of the most common species of the *Linum* genus in the Linaceae family and one of the oldest cultivated plants in the world that includes 13 genera and about 300 species. There are 100 species of *Linum* in the world, both annual and perennial, and 38 species in Türkiye (Yıldırım and Arslan, 2013), 12 of whose species are endemic and the endemism rate is 32.4% (Davis et al., 1988). The *Linum* genus is more common in North and Southwest America, the Mediterranean Basin, and the temperate and subtropical parts of Asia (Öksüz et al., 2015). Anatolia is one of the origin centers of flax. It has been traditionally cultivated for thousands of years.

Flax, an industrial plant, is the only annual and has two forms for use in fiber and oil production. The tall, highly branching forms with strong fibers are grown for fiber production, while the short, partially low branching forms are grown for oil production (Koçak and Bayraktar, 2011). The flax plant is a rich source of fiber, oil, and protein (Öksüz et al., 2015). Linseeds contain 20-25% protein and 35-45% oil (Yılmaz et al., 2021). Linseed oil is one of the drying oils with the highest iodine number of 160-200 among oils. For this reason, it is used as linen oil in the oil paint industry. Linseed oil is used in the production of glass paste and printing ink, textile dyeing, and lubrication. Flax oil is not used as cooking oil because it oxidizes quickly and becomes rancid easily (Tunctürk, 2007). Linseed oil is rich in omega-3 fatty acids. Linseed oil is also used as

an edible oil in human nutrition in breeding varieties with linoleic acid below 3.0% (Yilmaz et al., 2021).

In a previous study, Eyüpoğlu (1999) took a total of 243 453 soil samples from agricultural areas throughout the country in order to reveal the fertility status of Turkey's soils and analyzed the texture, pH, total salt, organic matter, lime, useful potassium, and useful phosphorus in these soils. According to the results of this research; The proportional distribution of loamy, clay loamy, clayey, sandy, and heavy clay soils in terms of texture throughout Turkey was found to be 50.49%, 41.44%, 4.74%, 3.27%, and 0.05%, respectively. In Turkey, slightly alkaline soils have the highest area in terms of pH, followed by neutral, slightly acidic, medium acid, strongly alkaline, and strongly acidic soils, respectively. It has been observed that the amount of organic matter in the soils of Turkey is generally low. In terms of the amount of lime in the soils, calcareous soils have the highest area, followed by less calcareous, calcareous, very calcareous, and highly calcareous areas, respectively. In terms of salt content, unsalted soils had the highest area, followed by slightly salty, moderately salty, and very salty soils, respectively. It has been observed that a large part of our country's soil has high potassium content. In terms of phosphorus amount, it has been determined that a significant part of Turkey's soil is deficient (Parlak et al., 2008).

As known, fertilizers contain the necessary minerals for the development of plants and regulate both physical and chemical properties of the soil and ensure that the plants are easily nourished from the soil. Fertilizers can be found in organic and chemical forms (Tahiluddin et al., 2022). Organic fertilizers are obtained from organic sources and contain N, P, K, and other plant nutrients in different ratios. In addition to providing nutrients to the plants, these plant nutrients help the improvement of the physical, chemical, and biological properties of the soil and the development of plants (Alagöz et al., 2006). The depletion of plant nutrients in the soil causes losses in soil fertility and consequently in the harvest. This deficiency should be supported by mineral and organic fertilizers. Biological fertilizer has many properties. It provides a wide variety of nutrients along with organic matter that improves the physical properties of the soil. However, with long-term use, organic fertilizers show great promise for improving soil properties (Abbas et al., 2012). Organic fertilizers help maintain quality and yield by improving soil composition and increasing the availability of nutrients and are less expensive than synthetic ones. In general, the biological, chemical, and physical properties of the soil are improved after the addition of organic fertilizer. Adding organic waste to the soil reduces evaporation while stabilizing the soil's temperature, reduces stress on the roots of the plant, and provides nutrients, resulting in increased productivity (Kusvuran and Ellialtioglu, 2021). Again, the doses of the fertilizers used are very important for both the plant and the soil. Unconscious and excessively used fertilizers have a negative effect on the plant and the soil (Atakan et al., 2018). Therefore, the determination of the optimum fertilizer form has crucial importance in all development stages of plants.

Studies on fertilizer forms and doses of different sources are generally on field or garden trials or pot trials under greenhouse conditions, and germination and seedling development studies on field crops are less common. In order to obtain a healthy plant, there must be healthy germination. In this respect, studies have shown that supplementation with organic nutrients during germination has an important effect in order to ensure successful germination. In the studies conducted, the organic fertilizers tested by the researchers; It has been shown that it promotes seedling development

(such as length, weight) and germination rate (Kaya and Coşkun, 2020; Kaya and Aysabar, 2024a, b, c, d). Therefore, this study was conducted to determine the encouraging or inhibiting effects of different fertilizer forms and doses on the linseed (*L. usitatissimum* L.) germination and seedling growth).

Materials and methods

This research was carried out in the climate cabinet of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Laboratory of Field Crops Department in March 2020. In the experiment, flaxseed variety (Nareum) seeds obtained from the Black Sea Agricultural Research Institute were used as material, and in the laboratory with climate cabinet, an oven, precision scales, etc., on the 15th day after placing, while seeds are measured for germination, radicle, plumule and seedling development (*Fig. 1*).



Figure 1. Flaxseed variety (Nareum) used in the experiment (date of supply 27.12.2019), and in the laboratory with climate cabinet, an oven, precision scales, etc., on the 15th day after placing, while seeds are measured for germination, radicle, plumule and seedling development

Five fertilizer forms were used as research factors. The chemical compositions of the applied fertilizers:

OF1 “liquid seaweed”: Organic Matter 6% / Water Soluble Potassium Oxide (K_2O) 2% / Alginic Acid 0.3% / Gibberellic Acid ppm 15% / EC (dS/m) 2.1% / pH level 6 – 8.

OF2 “liquid organic fertilizer with plant-derived amino acids”: Organic Matter 25% / Organic Carbon 14% / Organic A 3% / Free Amino Acids 24% / pH degree 4.6.

OF3 “liquid vermicompost”: Total Organic Matter 8% / Total Nitrogen (N) / 0.6% Organic Nitrogen (N) 0.3% / Total Phosphorus Pentaoxide (P_2O_5) 0.01% / Water Soluble Potassium Oxide (K_2O) 0.8% / Total Humic + Fulvic Acid 3% / EC 2.5 dS/m / pH 3-5.

CF1 (2% nitrogen as ammonium (NH_4), 20% nitrogen as urea (CH_4N_2O)).

CF2 (5% nitrogen as nitrate (NO_3), 25% phosphor as di-phosphor penta-oxide (P_2O_5), 2% magnesium as magnesium oxide (MgO), 5% Zn).

All the fertilizer forms were applied in six doses (FD1: control, FD2: 1000 ppm L^{-1} , FD3: 2000 ppm L^{-1} , FD4: 4000 L^{-1} , FD5: 8000 ppm L^{-1} , and FD6: 16000 ppm L^{-1}). Fertilizer forms diluted with tap water were used in the preparation of solutions for fertilizer doses. The research aimed to investigate using a completely randomized experimental design with three replications in order to find the most optimal fertilizer and dose combination.

In the study, 90 petri-plates (130 mm in diameter), each covered with two layers of blotting paper, were used as germination medium. The blotting papers were wetted with 9 mL of solutions. Then, healthy and uniform 25 linseeds were surface sterilized with 5% sodium hypochlorite (NaOCl) solution for 5 min and planted. Petri-plates were covered with parafilm (PM-992) to prevent evaporation of irrigation water. The germination media was a climate-fully controlled cabinet coincided over a cycle of 16/8 h (light/dark) photoperiod ($150 \mu\text{mol PAR m}^{-2} \text{s}^{-1}$, with 60% humidity at a $25 \pm 2^\circ\text{C}$ temperature. The prepared petri-plates were allowed to germinate for 14 days under these conditions. Finally, the seeds were measured for germination and seedling growth. The germinated seeds were counted and divided by the total number of seeds and then multiplied by 100 to get the germination percentage. The radicle and plumule lengths were measured with calipers, and the seedling length was determined by the sum of the radicle length and plumule length. Radicle and plumule were weighed as fresh, and radicle fresh weight and plumule fresh weight were summed, and seedling fresh weight was obtained. The samples were then kept for 24 h at 78°C in the oven, and the dry weight of the radicle and dry weight of the plumula were weighed, and the sum of the seedling dry weights was found. As a result of the multiplication of seedling length and germination rate, the seedling vigor index was found (Uslu et al., 2025).

Statistical analysis of data

All data obtained from the study were processed by SAS 9.0 (v. 9.0, 2002) statistical package. The data were analyzed using analysis of variance (ANOVA) according to the Completely Randomized Experimental Design (CRD). Averages were compared by Least Significant Difference (LSD) multiple comparison test.

Results

The means and LSD groups of observed properties such as germination percentage, germination index, radicle length, plumule length, seedling length, and radicle fresh weight values determined in the linseeds in different fertilizer form applications were given in *Table 1*, and the means and LSD groups of observed properties such as plumule fresh weight, seedling fresh weight, radicle dry weight, plumule dry weight, seedling dry weight, and seedling vigor index values determined in the linseeds in different fertilizer form applications were given in *Table 2*. Radicle plumule and seedling length, radicle plumule and seedling fresh weight, radicle dry weight, and seedling vigor index development were not observed in the CF1/FD6 dose application. In CF2/FD5 dose application, radicle plumule and seedling length, radicle plumule and seedling fresh weight, radicle plumule and seedling dry weight, and seedling vigor index have emerged, but development has not been observed. Additionally, in CF2/FD6 treatment, no post-emergence development was observed in the properties examined, such as germination rate, germination index, radicle, plumule, and seedling length, radicle, plumule, and seedling fresh weight, radicle, plumule, and seedling dry weight, and seedling vigor index. For this reason, while the means of germination percentage and germination index properties obtained from different fertilizer forms and doses applications were performed over 29 values, the means of plumula fresh weight, seedling fresh weight, radicle dry weight, plumula dry weight, seedling dry weight, and seedling vigor index properties obtained from different fertilizer forms and doses' applications were performed over 27 values.

Germination percentage

The mean germination percentage values determined in linseeds in different fertilizer form applications were given in *Table 1*. According to the analysis of variance, the differences between averages of fertilizer forms and the means of fertilizers' dose were found to be statistically significant. Although germination was quite high under control conditions, it was seen that OF3 was more encouraging in terms of germination percentage. Among the fertilizer forms, while the highest germination percentage was obtained from OF3 with 88.57%, the lowest value was obtained from CF2 with 66.29%. When fertilizers' application doses were examined, it was determined that there was no germination in the CF2/FD6 application, and the germination percentage varied between 57.33% and 92.00%. While the lowest value was obtained from the OF1/FD6 application with 57.33%, the highest value was obtained from the OF3/FD5 and CF1/FD5 applications with 92.00% (*Table 1*; *Fig. 2A*).

Germination index

In the study, it was seen that OF3 was more encouraging in terms of germination index. When *Table 1* was examined in terms of fertilizer forms, it was observed that the germination index averages ranged from 8.40 to 14.98. While the highest value was obtained from OF3 with 14.98, the lowest value was obtained from OF1 as 8.40. As seen in *Table 1*, when the dose applications of fertilizers were examined, it was found that there was no germination in CF2/FD6 application, and the germination index varied between 3.38 and 15.83. While the lowest germination index value was obtained from OF2/FD6 (3.38) and OF1/FD6 (3.43) applications, the highest value was obtained from OF3/FD3 (15.83) and OF3/FD6 (15.61) applications (*Fig. 2B*).

Radicle length

The radicle length varied between 2.14 and 7.23 cm under the different effects of fertilizer forms, while the highest value was obtained from OF3 with 7.23 cm and the lowest value from CF2 with 2.14 cm (*Table 1*). In the study, it was seen that there was no germination in the CF2/FD5 and CF2/FD6 applications, and the radicle length varied between 0.35 and 8.37 cm. While the highest value was obtained from the OF3/FD6 (8.37 cm) and OF3/FD2 (8.27 cm) applications, the lowest value was obtained from the CF2/FD4 (0.35 cm) and OF2/FD6 (0.40 cm) applications (*Table 1*; *Fig. 2C*). It was seen that the OF3 fertilizer was more encouraging in terms of radicle length.

Plumule length

When *Table 1* was observed in terms of fertilizer forms, it was determined that the plumule length varied between 2.82 and 7.06 cm, while the highest value was obtained from OF3 with 7.06 cm, and the lowest value was obtained from CF2 with 2.82 cm. In the study, there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 treatments; therefore, the plumule length varied between 1.75 and 7.72 cm in terms of fertilizers' dose applications. The highest value was obtained from the OF3/FD6 application with 7.72 cm, while the lowest value was obtained from CF2/FD4 application with 1.75 cm (*Table 1*; *Fig. 2D*).

Table 1. The means of some properties such as germination percentage, germination index, radicle length, plumule length, seedling length and radicle fresh weight obtained in different fertilizer forms and doses in flaxseed, and LSD groups

Fertilizer forms (FF)**	Fertilizer doses (FD)* (ppm L ⁻¹)	GP (%)	GI	RL (cm)	PL (cm)	SL (cm)	RFW (mg)
OF1	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	85.33±2.67 c-e	11.69±0.47 ef	4.35±0.05 g	5.99±0.04 e	10.34±0.10 i	9.27±0.15 j
	FD3	84.00±2.31 de	10.39±0.10 i-k	2.32±0.06 j	5.48±0.10 g	7.80±0.04 k	7.20±0.06 k
	FD4	77.33±0.88 g	6.81±0.12 m	1.96±0.04 k	3.41±0.06 j	5.37±0.10 n	5.77±0.09 n
	FD5	80.00±0.58 fg	4.28±0.10 o	1.36±0.01 m	3.46±0.08 j	4.82±0.09 o	6.27±0.09 m
	FD6	57.33±0.88 j	3.43±0.04 p	0.65±0.00 o	2.68±0.04 l	3.33±0.03 r	7.17±0.09 k
	Mean	78.73±2.54 C	8.40±0.93 D	2.71±0.42 C	4.51±0.33 C	7.22±0.73 C	8.48±0.78 C
OF2	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	88.00±2.52 a-d	12.40±0.39 de	3.77±0.06 g	7.08±0.07 bc	10.85±0.03 h	15.00±0.23 f
	FD3	84.00±2.31 de	10.67±0.13 h-j	3.00±0.03 i	6.61±0.11 d	9.62±0.08 j	12.77±0.15 g
	FD4	82.67±0.88 d-f	9.94±0.12 k	2.28±0.04 j	5.72±0.07 ef	8.00±0.12 k	11.00±0.12 i
	FD5	70.67±1.20 h	5.30±0.09 n	2.01±0.02 k	4.99±0.06 hi	7.00±0.04 l	6.80±0.12 l
	FD6	58.67±1.33 ij	3.38±0.07 p	0.40±0.00 p	3.18±0.05 k	3.58±0.05 q	3.50±0.06 p
	Mean	78.73±2.66 C	9.25±0.91 C	2.84±0.39 B	5.61±0.31 B	8.45±0.65 B	10.72±1.04 B
OF3	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	83.00±1.53 d-f	14.06±0.11 c	8.27±0.10 a	7.18±0.17 b	15.45±0.27 b	20.77±0.15 a
	FD3	89.33±2.03 a-c	15.83±0.19 a	7.28±0.13 b	6.89±0.18 c	14.17±0.23 d	16.37±0.26 e
	FD4	90.67±1.33 ab	15.44±0.22 ab	7.33±0.12 b	7.27±0.06 b	14.59±0.18 c	16.83±0.2 d
	FD5	92.00±2.31 a	15.11±0.17 b	6.52±0.04 d	7.29±0.18 b	13.81±0.15 e	17.60±0.12 c
	FD6	88.00±2.31 b-d	15.61±0.15 a	8.37±0.14 a	7.72±0.06 a	16.09±0.11 a	18.00±0.31 b
	Mean	88.57±0.93 A	14.98±0.20 A	7.23±0.24 A	7.06±0.13 A	14.29±0.35 A	17.47±0.42 A
CF1	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	86.67±2.67 b-d	10.83±0.46 g-i	6.84±0.08 c	5.78±0.09 ef	12.62±0.17 f	11.63±0.15 h
	FD3	70.67±1.20 h	8.36±0.17 l	1.76±0.04 l	3.97±0.01 i	5.73±0.03 m	5.67±0.03 n
	FD4	81.33±1.33 e-g	10.08±0.46 jk	0.94±0.02 n	3.01±0.04 k	3.95±0.06 p	6.77±0.05 l
	FD5	92.00±2.31 a	12.71±0.15 d	0.84±0.01 n	2.44±0.05 m	3.28±0.05 r	2.67±0.03 q
	FD6	80.00±1.15 fg	8.48±0.10 l	-	-	-	-
	Mean	83.18±1.78 B	10.71±0.50 B	2.67±0.62 C	3.54±0.35 D	6.21±0.96 D	6.99±1.25 D
CF2	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	81.33±0.88 e-g	11.17±0.35 f-h	6.03±0.16 e	5.98±0.07 e	12.01±0.09 g	17.37±0.20 c
	FD3	84.00±1.15 de	11.17±0.10 f-h	0.86±0.02 n	3.12±0.04 k	3.98±0.04 p	3.83±0.09 o
	FD4	82.67±1.20 d-f	11.33±0.12 fg	0.35±0.01 p	1.75±0.06 n	2.11±0.05 s	3.83±0.03 o
	FD5	61.33±0.88 i	6.94±0.14 m	-	-	-	-
	FD6	-	-	-	-	-	-
	Mean	66.29±7.49 D	9.07±1.10 C	2.14±0.64 D	2.82±0.46 E	4.96±0.46 E	6.71±1.69 E
LSD $\alpha=0.05$ for FF		1.63	0.26	0.07	0.08	0.12	0.14
LSD $\alpha=0.05$ for FD		1.95	0.29	0.08	0.09	0.13	0.16
CV (%)		3.37	3.77	3.11	2.85	2.20	2.21

GP: Germination Percentage, GI: Germination Index, RL: Radicle Length, PL: Plumule Length, SL: Seedling Length, RFW: Radicle Fresh Weight, Fertilizer forms, OF1: Liquid Seaweed, OF2: Liquid Organic Fertilizer with Plant-Derived Amino Acids, OF3: Liquid Vermicompost, CF1: "22% Nitrogen (N), 2% Ammonium Nitrogen (NH₄H₂), 20% Urea Nitrogen (NH₂H) chemical fertilizer containing", CF2: "5% Nitrate Nitrogen (N), 25% P₂O₅, 2% MgO, 5% Zn chemical fertilizer containing". Fertilizer Doses: FD1: Control, FD2: 1000 ppm L⁻¹, FD3: 2000 ppm L⁻¹, FD4: 4000 L⁻¹, FD5: 8000 ppm L⁻¹, FD6: 16000 ppm L⁻¹ ± Standard error. *The means in the same column, expressed with lowercase letters and represented by different letters, are statistically different from each other according to the LSD test within the $p < 0.05$. **The means in the same column capitalized and represented by different letters are statistically different from each other according to the LSD test within the $p < 0.05$ error limits

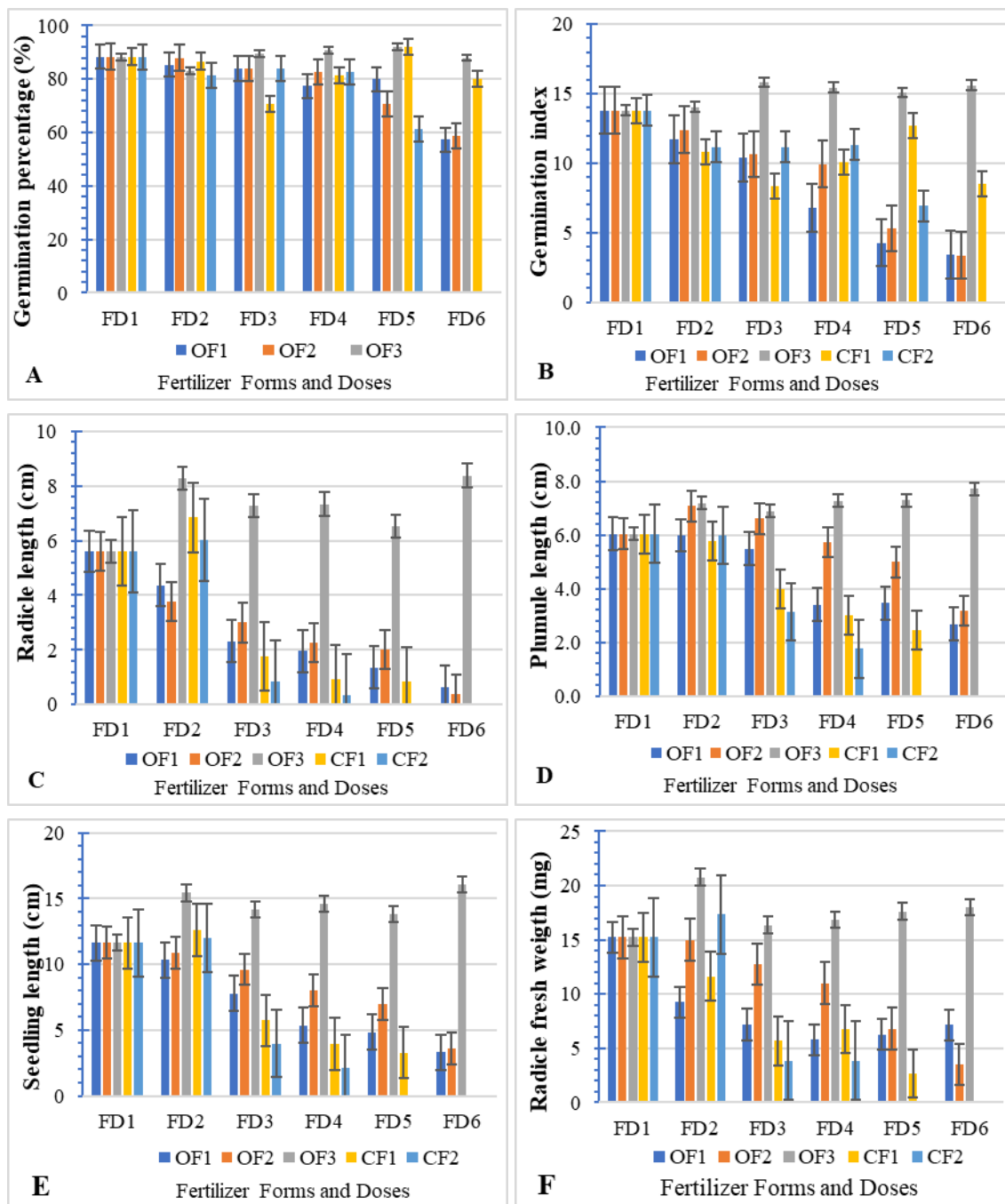


Figure 2. The differences between fertilizer forms and doses on some observed properties such as germination percentage, germination index, radicle length, plumule length, seedling length and radicle fresh weight

Seedling length

As seen in *Table 1*, it was observed from the results that the OF3 fertilizer form was more encouraging in terms of seedling length. Seedling lengths varied between 4.96 and 14.29 cm with the effect of fertilizer forms, while the highest value was obtained from OF3 with 14.29 cm, and the lowest value was obtained from CF2 with 4.96 cm. In the study, germination was not observed in the CF1/FD6, CF2/FD5, and CF2/FD6

applications of fertilizers, and seedling length varied between 2.11 and 16.09 cm. The highest value was determined from OF3/FD6 application with 16.09 cm, while the lowest value was obtained from CF2/FD4 application with 2.11 cm (*Table 1; Fig. 2E*).

Radicle fresh weight

According to the fertilizer forms, the radicle fresh weight varied between 6.71 and 17.47 mg, while the highest value was obtained from OF3 with 17.47 mg, and the lowest value was obtained from CF2 with 6.71 mg. When the fertilizers' dose applications were examined, there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 applications. Therefore, it was seen that the radicle fresh weight varied between 2.67 and 20.77 mg. The lowest value was obtained from CF1/FD5 application with 2.67 mg, while the highest value was obtained from the OF3/FD2 application with 20.77 mg (*Table 1; Fig. 2F*).

Plumule fresh weight

When *Table 2* was observed, it was seen that the OF3 and OF2 fertilizer forms were more encouraging in terms of plumule fresh weight. According to the fertilizer forms, it was determined that the plumule fresh weight varied between 25.87 and 55.50 mg. The highest was obtained from OF3 (55.50 mg) and OF2 (55.21 mg), while the lowest value (25.87) was obtained from CF2. As seen in *Table 2*, it was observed that there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 applications, and the plumule fresh weight varied between 14.10 and 63.67 mg. While the lowest value was obtained from CF1/FD4 application with 14.10 mg, the highest value was obtained from OF2/FD3 application with 63.67 mg (*Table 2; Fig. 3A*).

Seedling fresh weight

As seen in *Table 1*, it was observed from the results that the OF3 fertilizer form was more encouraging in terms of seedling fresh weight. In terms of the fertilizer forms, it was seen that the seedling fresh weight varied between 32.59 and 72.97 mg. The highest value was obtained from OF3 with 72.97 mg, while the lowest value was obtained from CF2 with 32.59 mg. In the study, among the fertilizers' dose applications, it was observed that there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 applications, and the seedling fresh weight varied between 20.87 and 77.50 mg. While the lowest value was obtained from CF1/FD4 application with 20.87 mg, the highest value was obtained from OF3/FD2, OF2/FD2, OF3/FD4, OF2/FD3, and OF3/GD6 (77.50, 77.13, 76.73, 76.43, and 76.27 mg, respectively) applications (*Table 2; Fig. 3B*).

Radicle dry weight

According to the fertilizer forms, the radicle dry weight varied between 1.45 and 2.31 mg, while the highest value was obtained from OF3 with 2.31 mg, and the lowest value was obtained from CF2 with 1.45 mg. When the fertilizers' dose applications were examined, there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 treatments. Therefore, it was seen that the radicle dry weight varied between 1.24 and 3.64 mg. The lowest value was obtained from OF2/FD6, OF1/FD3, and OF2/FD5 (1.24, 1.24, and 1.27 mg, respectively), while the highest value was obtained from the OF1/FD6 application with 3.64 mg (*Table 2; Fig. 3C*).

Table 2. The means of some properties such as plumule fresh weight, seedling fresh weight, radicle dry weight, plumule dry weight, seedling dry weight and seedling vigor index obtained in different fertilizer forms and doses in flaxseed, and LSD groups

Fertilizer forms (FF)**	Fertilizer doses (FD)* (ppm L ⁻¹)	GP (%)	GI	RL (cm)	PL (cm)	SL (cm)	RFW (mg)
OF1	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	85.33±2.67 c-e	11.69±0.47 ef	4.35±0.05 g	5.99±0.04 e	10.34±0.10 i	9.27±0.15 j
	FD3	84.00±2.31 de	10.39±0.10 i-k	2.32±0.06 j	5.48±0.10 g	7.80±0.04 k	7.20±0.06 k
	FD4	77.33±0.88 g	6.81±0.12 m	1.96±0.04 k	3.41±0.06 j	5.37±0.10 n	5.77±0.09 n
	FD5	80.00±0.58 fg	4.28±0.10 o	1.36±0.01 m	3.46±0.08 j	4.82±0.09 o	6.27±0.09 m
	FD6	57.33±0.88 j	3.43±0.04 p	0.65±0.00 o	2.68±0.04 l	3.33±0.03 r	7.17±0.09 k
	Mean	78.73±2.54 C	8.40±0.93 D	2.71±0.42 C	4.51±0.33 C	7.22±0.73 C	8.48±0.78 C
OF2	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	88.00±2.52 a-d	12.40±0.39 de	3.77±0.06 g	7.08±0.07 bc	10.85±0.03 h	15.00±0.23 f
	FD3	84.00±2.31 de	10.67±0.13 h-j	3.00±0.03 i	6.61±0.11 d	9.62±0.08 j	12.77±0.15 g
	FD4	82.67±0.88 d-f	9.94±0.12 k	2.28±0.04 j	5.72±0.07 ef	8.00±0.12 k	11.00±0.12 i
	FD5	70.67±1.20 h	5.30±0.09 n	2.01±0.02 k	4.99±0.06 hi	7.00±0.04 l	6.80±0.12 l
	FD6	58.67±1.33 ij	3.38±0.07 p	0.40±0.00 p	3.18±0.05 k	3.58±0.05 q	3.50±0.06 p
	Mean	78.73±2.66 C	9.25±0.91 C	2.84±0.39 B	5.61±0.31 B	8.45±0.65 B	10.72±1.04 B
OF3	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	83.00±1.53 d-f	14.06±0.11 c	8.27±0.10 a	7.18±0.17 b	15.45±0.27 b	20.77±0.15 a
	FD3	89.33±2.03 a-c	15.83±0.19 a	7.28±0.13 b	6.89±0.18 c	14.17±0.23 d	16.37±0.26 e
	FD4	90.67±1.33 ab	15.44±0.22 ab	7.33±0.12 b	7.27±0.06 b	14.59±0.18 c	16.83±0.2 d
	FD5	92.00±2.31 a	15.11±0.17 b	6.52±0.04 d	7.29±0.18 b	13.81±0.15 e	17.60±0.12 c
	FD6	88.00±2.31 b-d	15.61±0.15 a	8.37±0.14 a	7.72±0.06 a	16.09±0.11 a	18.00±0.31 b
	Mean	88.57±0.93 A	14.98±0.20 A	7.23±0.24 A	7.06±0.13 A	14.29±0.35 A	17.47±0.42 A
CF1	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	86.67±2.67 b-d	10.83±0.46 g-i	6.84±0.08 c	5.78±0.09 ef	12.62±0.17 f	11.63±0.15 h
	FD3	70.67±1.20 h	8.36±0.17 l	1.76±0.04 l	3.97±0.01 i	5.73±0.03 m	5.67±0.03 n
	FD4	81.33±1.33 e-g	10.08±0.46 jk	0.94±0.02 n	3.01±0.04 k	3.95±0.06 p	6.77±0.05 l
	FD5	92.00±2.31 a	12.71±0.15 d	0.84±0.01 n	2.44±0.05 m	3.28±0.05 r	2.67±0.03 q
	FD6	80.00±1.15 fg	8.48±0.10 l	-	-	-	-
	Mean	83.18±1.78 B	10.71±0.50 B	2.67±0.62 C	3.54±0.35 D	6.21±0.96 D	6.99±1.25 D
CF2	FD1	88.40±0.99 a-d	13.81±0.26 c	5.60±0.04 f	6.04±0.09 e	11.64±0.09 g	15.23±0.06 f
	FD2	81.33±0.88 e-g	11.17±0.35 f-h	6.03±0.16 e	5.98±0.07 e	12.01±0.09 g	17.37±0.20 c
	FD3	84.00±1.15 de	11.17±0.10 f-h	0.86±0.02 n	3.12±0.04 k	3.98±0.04 p	3.83±0.09 o
	FD4	82.67±1.20 d-f	11.33±0.12 fg	0.35±0.01 p	1.75±0.06 n	2.11±0.05 s	3.83±0.03 o
	FD5	61.33±0.88 i	6.94±0.14 m	-	-	-	-
	FD6	-	-	-	-	-	-
	Mean	66.29±7.49 D	9.07±1.10 C	2.14±0.64 D	2.82±0.46 E	4.96±0.46 E	6.71±1.69 E
LSD α=0.05 for FF		1.63	0.26	0.07	0.08	0.12	0.14
LSD α=0.05 for FD		1.95	0.29	0.08	0.09	0.13	0.16
CV (%)		3.37	3.77	3.11	2.85	2.20	2.21

PFW: Plumule Fresh Weight, SFW: Seedling Fresh Weight, RDW: Radicle Dry Weight, PDW: Plumule Dry Weight, SDW: Seedling Dry Weight, SVI: Seedling Vigor Index; Fertilizer forms: OF1: Liquid Seaweed, OF2: Liquid Organic Fertilizer with Plant-Derived Amino Acids, OF3: Liquid Vermicompost, CF1: “22% Nitrogen (N), 2% Ammonium Nitrogen (NH₄H₂), 20% Urea Nitrogen (NH₂H) chemical fertilizer containing”, CF2: “5% Nitrate Nitrogen (N), 25% P₂O₅, 2% MgO, 5% Zn chemical fertilizer containing”. Fertilizer Doses: FD1: Control, FD2: 1000 ppm L⁻¹, FD3: 2000 ppm L⁻¹, FD4: 4000 L⁻¹, FD5: 8000 ppm L⁻¹, FD6: 16000 ppm L⁻¹ ± Standard error. *The means in the same column, expressed with lowercase letters and represented by different letters, are statistically different from each other according to the LSD test within the *p* < 0.05 error limits. **The means in the same column, capitalized and represented by different letters, are statistically different from each other according to the LSD test within the *p* < 0.05

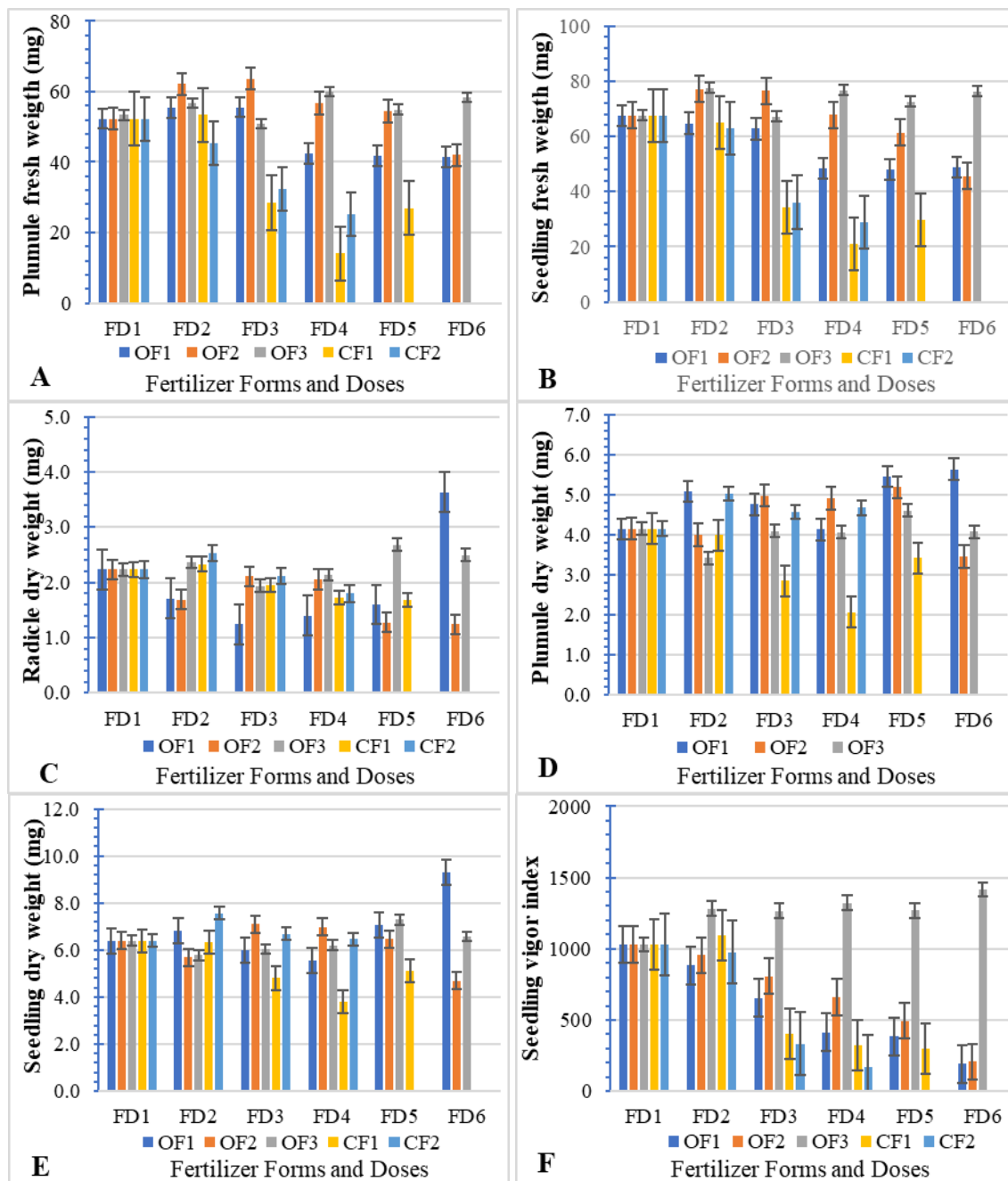


Figure 3. The differences between fertilizer forms and doses on some observed properties such as plumule fresh weight, seedling fresh weight, radicle dry weight, plumule dry weight, seedling dry weight and seedling vigor index

Plumule dry weight

When Table 2 was observed, it was seen that the OF1 fertilizer forms were more encouraging in terms of plumule dry weight. According to the fertilizer forms, it was observed that the plumule dry weight varied between 2.75 and 4.87 mg. The highest was obtained from OF1 (4.87 mg) and OF2 (2.75 mg), while the lowest value was obtained from CF2 with 25.87. As monitored in Table 2, it was observed that there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 applications, and the plumule dry

weight varied between 2.06 and 5.64 mg. While the lowest value was obtained from CF1/FD4 application with 2.06 mg, the highest value was obtained from OF1/FD6 application with 5.64 mg (*Table 2; Fig. 3D*).

Seedling dry weight

As observed in *Table 1*, it was determined from the results that the OF1 fertilizer form was more encouraging in terms of seedling dry weight. In terms of the fertilizer forms, it was observed that the seedling dry weight varied between 4.40 and 6.85 mg. The highest value was obtained from OF1 with 6.85 mg, while the lowest value was obtained from CF1 with 4.40 mg. In the study, among the fertilizers' dose applications, it was observed that there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 applications, and the seedling dry weight varied between 3.78 and 9.28 mg. While the lowest value was obtained from CF1/FD4 application with 3.78 mg, the highest value was obtained from OF1/FD6 treatment with 9.28 mg (*Table 2; Fig. 3E*).

Seedling vigor index

In the study, it was seen that OF3 was more encouraging in terms of seedling vigor index. When the fertilizer forms were examined in *Table 2*, it was seen that the seedling vigor index averages ranged from 419.32 to 1264.91. While the highest value was obtained from OF3 with 1264.91, the lowest value (419.32) was obtained from CF2. As seen in *Table 2*, when the dose applications of fertilizers were examined, it was found that there was no germination in CF1/FD6, CF2/FD5, and CF2/FD6 treatments, and the seedling vigor index values varied between 174.24 and 1416.31. While the highest seedling vigor index value was obtained from OF3/FD6 (1416.31) application, the lowest values were obtained from CF2/FD4, OF1/FD6, and OF2/FD6 (174.24, 190.98, and 209.84, respectively) applications (*Table 2; Fig. 3F*).

Correlation among the observed properties

In the study, a correlation analysis was performed to reveal the relationships between all investigated properties of linseeds subjected to fertilizer forms and doses of different sources. The correlations among all investigated properties were thought to be significant ($p < 0.01$) due to common and complex dose interactions occurring in plant organs of different fertilizer forms (*Table 3*). As presented in *Table 3*, one of the most important properties is the germination percentage. It was found to have significant positive correlations with germination index (GI), radicle length (RL), plumula length (PL), seedling length (SL), radicle fresh weight (RFW), plumula fresh weight (PFW), seedling fresh weight (SFW), radicle dry weight (RDW), plumula dry weight (PDW), seedling dry weight (SDW), and seedling vigor index (SVI) ($r = 0.802$, $r = 0.510$, $r = 0.609$, $r = 0.574$, $r = 0.546$, $r = 0.560$, $r = 0.580$, $r = 0.487$, $r = 0.504$, $r = 0.529$, and $r = 0.592$, respectively).

Discussion

The aim of this study was to determine the encouraging or inhibiting effects of different fertilizer forms and doses on germination and seedling growth in linseed (*L. usitatissimum* L.). Vermicompost fertilizers used in place of chemical fertilizers can build organic matter and increase soil pH. Additional benefits of vermicompost include

resistance to diseases sometimes seen in organic farming and prevention of early season deficiencies (Bellitürk, 2018). It is well known that chemical fertilizers play a vital role in high agricultural production. However, in the current scenario, the overuse of fertilizers poses environmental problems that are often difficult to overcome in developing countries (Sun et al., 2012). Worm compost is now often offered as an attractive alternative to chemical fertilizers (Bidabadi et al., 2016). At the wider scale of regional food systems, composting with vermicompost means recycling nutrients in food waste (Mengistu et al., 2017), agricultural and industrial waste; otherwise, these wastes will be taken to landfills. Compost can thus reduce the use of chemical fertilizers (Bellitürk et al., 2017).

Table 3. Correlation table for observed properties of *L. usitatissimum* L.

	GI	RL	PL	SL	RFW	PFW	SFW	RDW	PDW	SDW	SVI
GP	0.802 **	0.510 **	0.609 **	0.574 **	0.546 **	0.560 **	0.580 **	0.487 **	0.504 **	0.529 **	0.592 **
GI		0.762 **	0.706 **	0.763 **	0.742 **	0.514 **	0.595 **	0.473 **	0.277 **	0.365 **	0.798 **
RL			0.865 **	0.972 **	0.933 **	0.697 **	0.787 **	0.557 **	0.341 **	0.441 **	0.974 **
PL				0.959 **	0.924 **	0.922 **	0.961 **	0.652 **	0.624 **	0.673 **	0.943 **
SL					0.962 **	0.827 **	0.897 **	0.621 **	0.486 **	0.565 **	0.994 **
RFW						0.788 **	0.876 **	0.681 **	0.480 **	0.583 **	0.955 **
PFW							0.987 **	0.670 **	0.800 **	0.802 **	0.798 **
SFW								0.701 **	0.751 **	0.779 **	0.873 **
RDW									0.748 **	0.886 **	0.596 **
PDW										0.970 **	0.449 **
SDW											0.530 **

**Correlation is significant at the 0.01 level. Pearson Correlation

According to the results, fertilizer forms have significantly affected all attributes of germination and seedling. In the analysis of variance, the differences between the averages of the fertilizer forms and the means of the fertilizer dose were found to be statistically significant at the $P < 0.01$ level for all observed characteristics. The results were consistent with the highest findings of radicle length in liquid vermicompost reported by Kaya and Erdönmez (2020). Kaya and Erdönmez (2020), in their study to determine the effect of similar fertilizer forms of different origins (liquid seaweed, liquid organic fertilizer with plant-derived amino acids, and liquid vermicompost) and doses on seed germination and seedling development of soybeans (*Glycine max* (L.) Merrill), they reported that the liquid vermicompost form increased the germination rate, germination index, radicle length, radicle and plumula fresh weight, and seedling vigor index of soybeans rather than other applications. Kaya and Coşkun (2020), in their study to determine the effect of the fertilizer forms of organic origin (liquid seaweed, liquid organic fertilizer with plant-derived amino acids, and liquid vermicompost) and doses on seed germination and seedling development of rapeseed (*Brassica napus* L.); they reported that the liquid vermicompost form increased the radicle, plumule and seedling length, fresh root weight, radicle dry weight of rapeseed rather than other applications. The results were consistent with the highest finding of seedling length in liquid vermicompost treatment reported in this previous study. Additionally, in another previous, Arancon et al. (2012) reported that increasing concentrations of liquid vermicompost applied to tomato seeds increased the fresh root weight of tomato seedlings. Zimny et al. (2001), in their studies investigating the effect of farm manure

and vermicompost on sugar beet, reported that vermicompost used at the level of 10 t ha⁻¹ can be used instead of animal manure at the level of 30 t ha⁻¹ and that it creates biomass through more root and leaf development. Additionally, Özkan et al. (2016) reported that as the amount of vermicompost increased, the yield and plant height in spinach increased. In a previous study conducted by Suthar (2009) with vermicompost and farm manure applied together with a chemical fertilizer combination in garlic; they stated that the properties of root length, leaf length, shoot length, fruit weight, number of cloves in garlic fruit, and leaf number per plant of 15 t ha⁻¹ vermicompost + %50 recommended NPK application gave the maximum value compared to other applications. In fact, these findings make it necessary to carry out other studies in which not only organic or chemical fertilizers were tested separately but also mixed in different proportions and applied in organomineral form. Consequently, organomineral fertilizer studies will be carried out after this research that we have conducted to determine the effects of different fertilizer forms and doses on linseed development and seed germination. Also, in a previous study, Köksal et al. (2017) declared that increasing doses of vermicompost caused an increase in the fresh weight of *Beta vulgaris* L. var. Cicola. Abafita et al. (2014) reported that the addition of vermicompost increased the fresh weight and yield of tomato (*Solanum lycopersicum*) varieties in general compared to the control. Additionally, Arancon et al. (2012) reported that increasing concentrations of liquid vermicompost applied to tomato seeds increased radicle dry weight in tomato seedlings.

It is also worth mentioning that, it was found to have significant positive correlations with germination index (GI), radicle length (RL), plumula length (PL), seedling length (SL), radicle fresh weight (RFW), plumula fresh weight (PFW), seedling fresh weight (SFW), radicle dry weight (RDW), plumula dry weight (PDW), seedling dry weight (SDW), and seedling vigor index (SVI) ($r = 0.802$, $r = 0.510$, $r = 0.609$, $r = 0.574$, $r = 0.546$, $r = 0.560$, $r = 0.580$, $r = 0.487$, $r = 0.504$, $r = 0.529$, and $r = 0.592$, respectively). The similar results were reported for Brassica napus by Kaya and Coşkun (2020). Additionally, these properties, which are physiologically related to each other, have been reported to be positively related to each other for soybean under lead stress (Kaya and Eryiğit, 2021).

As a result, it was seen that the liquid vermicompost fertilizer form was more encouraging in terms of observed parameters.

Conclusions

In this study, it was determined that fertilizer forms consisting of different fertilizer sources have statistically significant effects on the germination and seedling development of linseed. It was observed that liquid vermicompost among the fertilizer forms examined had the highest positive effect on germination and seedling development, while liquid organic fertilizer containing amino acids of plant origin had the lowest effect. In the study, it was determined that flax seeds did not germinate in the third chemical fertilizer mixture [9% Boron + 14% Zinc (Zn-Sulfate)] applications. At the 16000 ppm L⁻¹ chemical fertilizer dose of the first chemical fertilizer form [22% Nitrogen (N), 2% NH₄H₂, 20% NH₂H], it was determined that there was no improvement in other properties except germination percentage and germination index. In the fifth dose (8000 ppm L⁻¹) application of the second chemical fertilizer form [5% Nitrate (NO₃) + 25% P₂O₅ + 2% MgO + 5% Zn], no other properties were determined

except germination percentage and germination index, and at the sixth fertilizer dose of the same fertilizer form (16000 ppm L⁻¹), it was determined that no observation could be performed from any feature due to the absence of germination. As a result of this study, it was determined that liquid vermicompost fertilizer applications have a significant stimulating effect on germination and seedling development.

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