Influence of Sowing Dates and Seeding Rates on Yield Components of Flax (*Linum usitatissimum* L.) In Kurdistan Region of Iraq

Sherzad Mohammed Mahmood [1*] and Fathi Abdulkareem Omer [2*]

[1,2]Field Crops Department, College of Agricultural Engineering Sciences, University of Duhok, Iraq

Corresponding author: Sherzad Mohammed Mahmood sherzadmohammed10@gmail.com

Corresponding coauthor: Fathi Abdulkareem Omer fathiemenky@uod.ac

Abstract

This experiment was carried out during the winter growing season of 2024/2025 to evaluate the effects of different sowing dates and seeding rates on the growth and productivity of flax under two locations in the Kurdistan Region of Iraq: Duhok and Zakho. The study was arranged as a factorial within a Randomized Complete Block Design (RCBD) with three replications. Treatments consisted of three sowing dates (mid-November, early December, and late December) and four seeding rates (20, 30, 40, and 50 kg·ha^{-1}).

The results indicated that Duhok achieved the highest average seed yield (1452.8 kg·ha^{-1}), which was 53% higher than Zakho (950.1 kg·ha^{-1}). The maximum yield of 1683.3 kg·ha^{-1} was obtained in Duhok with late December sowing at a rate of 30 kg·ha^{-1}, while the lowest yield (779.6 kg·ha^{-1}) was recorded in Zakho under late December sowing at the highest rate (50 kg·ha^{-1}). Mid-November sowing with lower seeding rates (20–30 kg·ha^{-1}) produced the greatest number of primary branches (2.5 branches/plant) and capsules (24.3 capsules/plant), as well as the highest number of seeds per plant (173.5). Conversely, late December sowing with moderate seeding rates increased 1000-seed weight to 6.7 g and optimized final seed yield under Duhok conditions.

These findings emphasize that early sowing improves growth traits and yield components, whereas delayed sowing combined with appropriate plant density maximizes total seed yield in cooler climates. These results provide region-specific recommendations to improve flax productivity in the semi-arid northern Iraq, supporting sustainable crop management and higher farmer income.

Keywords: Flax, sowing dates, seeding rates, yield components, seed yield

* This paper is a part of the MSc study for the first author.

ISSN 2072-3857

Introduction

Flax (*Linum usitatissimum* L.) is among the most ancient domesticated crops, grown globally for its oil-rich seeds and high-quality fibers. Belonging to the Linaceae family, it is a double-purpose crop; the stem produces strong fibers historically utilized in linen textiles and paper, while the seeds generate oil and by-products employed in food, feed, and industrial applications [27]. Flax is globally known as the third most significant fiber crop and one of the top five oilseed crops, with seed oil content varying from 30% to 45%. The oil contains a significant amount of linolenic acid (47–58%), rendering it useful for industrial applications like paints, inks, and soaps, but inappropriate for direct consumption [14].

In addition to its industrial importance, flaxseed is regarded as a functional food ingredient owing to its abundance of α-linolenic acid (ALA), superior proteins, lignans, and dietary fiber. It is considered a superior plant-based source of omega-3 fatty acids in comparison to soybean, corn, or marine algae [30]. Components of flaxseed have been linked to cardiovascular and digestive health advantages [18]. While these nutritional factors underscore the global significance of flax, its agronomic management is a more pressing issue in nations with low productivity. The crop flourishes optimally in temperate climates characterized by extended photoperiods and cool temperatures [9]. Growth and productivity are significantly influenced by Agro-climatic factors, including temperature extremes, moisture availability, and pest infestations [19]. The average productivity of flax in Iraq is significantly low, with its cultivation primarily restricted to research purposes [8]. Enhancing flax production necessitates the refinement of agronomic practices, particularly the optimization of sowing dates, seeding densities, and fertilizer application to augment growth and yield potential [6].

The sowing date is a crucial management practice as it influences the crop's interaction with environmental conditions during essential growth stages. Timely sowing facilitates optimal establishment, an extended vegetative period, and enhanced branching, whereas late sowing typically diminishes growth duration and yield potential [10]. Reduced seeding densities may improve branching and capsule development per plant, while excessively high densities heighten competition for light, nutrients, and moisture, consequently diminishing yield components [17].

Although the global significance of flax is recognized, research in Iraq, especially in the Kurdistan Region, is limited. Prior research in the region has investigated sowing dates and plant densities separately; however, there is little information regarding their synergistic impact under local Agro-climatic conditions. Moreover, variations in soil properties and microclimates between regions like Duhok and Zakho may prompt unique crop responses necessitating tailored recommendations [11].

This study aimed to assess the impact of varying sowing dates and seeding rates on flax yield in the differing environments of Duhok and Zakho. The aim was to

ISSN 2072-3857

determine the optimal management practices that can improve flax productivity in northern Iraq and offer location-specific guidance for farmers and researchers in semi-arid areas.

Materials and Methods

This study was conducted during the winter growing season of 2024/2025 at two locations of Duhok Governorate: the first at the Research Farm of the Department of Field Crops, College of Agricultural Engineering Sciences, University of Duhok (42.8478°E, 36.8608°N, 500 masl), and the second at the Agricultural Research Center in Zakho (42.69°E, 37.15°N, 439 masl), approximately 60 km from Duhok city. Meteorological data were recorded during the growing period at both locations (Table 1). Soil samples were collected at a (0-30) cm depth after tillage and before sowing to assess the initial soil properties at each location (Table 2).

The land at both locations was prepared using primary and secondary tillage, followed by manual leveling. The experiment was arranged in a factorial Randomized Complete Block Design (RCBD) with three replications, where Location (fixed factor) and Sowing Date were combined to examine their interaction, while four seeding rates were applied as sub-factors. This arrangement ensured proper analysis of the location × date interaction and facilitated practical implementation of treatments in the field. The experiment included three sowing dates (mid-November, early December, and late December), four seeding rates (20, 30, 40, and 50 kg. ha^{-1}), and two locations (Duhok and Zakho), resulting in 12 treatment combinations and a total of 48 experimental units per location.

Each experimental unit measured 2 meters in length and 1 meter in width (2 m^2), with one meter between plots and one meter between replications. Each plot consisted of five rows spaced 20 cm apart. The total field area per location was 200 m^2. Flax seeds (*Linum usitatissimum* L.), variety “Sharda”, were obtained from the College of Agriculture and Forestry, University of Mosul. Sowing was done manually at a depth of 2–3 cm according to the assigned sowing dates and seeding rates.

Fertilizers were applied to enhance soil fertility and support plant development throughout the growing season. At land preparation, Diammonium Phosphate (DAP) fertilizer (18:46:0 N:P: K) was applied at a rate of 100 kg. ha^{-1}. In February, urea (46% N) was applied at a rate of 130 kg ha^{-1} to supply nitrogen during the vegetative stage. Supplemental irrigation was provided when necessary, and weed control was carried out manually at early and mid-growth stages.

The crop reached full maturity was harvested on May 8, 2025. From each unit, ten representative plants were randomly selected from the central rows for evaluation. Measured yield parameters included number of primary branches, number of capsules per plant, number of seeds per capsule, number of seed per plant,

ISSN 2072-3857

Weight of 1000 seeds (g), Seed yield (kg. ha^{-1}). All collected data were analyzed statistically using analysis of variance (ANOVA) according to the RCBD structure, and means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level of significance [7]. Statistical analysis was performed using appropriate computer software [24].

Table 1. Metrological record for both locations during the growing season of (2024-2025).

Relative humidity %		Rainfall (mm)		Temperature (°C)				Months
				Maximum		Minimum		
Duhok	Zakho	Duhok	Zakho	Duhok	Zakho	Duhok	Zakho	
65	56	37.9	30.9	20.3	20.1	9.5	10.1	November 2024
60	56	11.3	19.8	15.9	15.9	5.2	5.4	December 2024
56	49	9.3	5.3	15.8	16.2	4.2	4.3	January 2025
56	44	45.9	52.6	12.4	12.7	2.6	2.8	February 2025
46	35	15.3	11.6	22.3	23.2	10.2	11.1	March 2025
45	44	57.7	38.4	25.5	25.6	14.9	15.0	April 2025
32	23	9.9	10.5	34.4	34.5	20.1	20.7	May 2025
		187.3	**169.1**					**Total rainfall (mm)**

Table 2. Physical and chemical properties of soil in both locations

Parameters	Locations	
	Sumail	Zakho
pH	7.75	8.03
EC ($dS.m^{-1}$)	0.31	0.271
Available Potassium (mg/kg)	15.66	109
Available Phosphorus (mg/kg)	4.43	9
Available Nitrogen (mg/kg)	74	112
Organic Matter %	1.48	0.605
$CaCO_3$ %	18.52	7.909
Clay %	48.802	32.84
Silt %	45.427	48.75
Sand %	5.771	18.41
Soil Texture	Silty clay	Sandy loam

The soil properties tests were conducted at the Agricultural Consultant Bureau / University of Duhok (2025).

***EC: Electric Conductivity**

ISSN 2072-3857

Results and Discussion

Yield Components Traits

- **Number of primary brunches per Plant**

The data in Table 3 display the influence of sowing date, seeding rate, and locations on the number of primary branches per flax which is an important growth trait closely related to the plant's ability to produce capsules and ultimately, seed yield. The results clearly indicate that sowing flax in mid-November led to the highest number of primary branches at both Duhok and Zakho, averaging 1.7 branches per plant. This was followed by early December (1.5 branches), while the fewest branches were observed with late December sowing (1.4 branches). These results support the idea that earlier sowing extends the vegetative phase, giving plants more time to form axillary buds and develop branches before entering the reproductive stage. This result agrees with previous findings by [31], who noted that early sowing often aligns with cooler weather and better moisture availability conditions that are ideal for vegetative growth and branching.

Seeding rate also played a crucial role. Across all sowing dates, lower rates, especially 20 and 30 $kg \cdot ha^{-1}$, consistently produced more primary branches per plant. For example, Duhok recorded its highest branching (2.5 branches per plant) under mid-November sowing at 20 kg. ha^{-1}, while Zakho reached a maximum of 1.3 branches under the same treatment. This improvement is likely due to reduced crowding at lower seed densities, which gives each plant better access to sunlight, nutrients, and water. In contrast, higher seeding rates (50 kg. ha^{-1}) resulted in fewer branches, likely because of increased competition that limits space and resources needed for lateral growth. These findings align with earlier research by [28], who also observed that lower sowing densities encourage branching by preventing canopy closure and improving light penetration within the crop.

The difference between the two locations was also significant. On average, flax plants in Duhok produced 2.0 primary branches, significantly more than those in Zakho, which averaged just 1.1. This suggests that Duhok's environmental conditions, such as cooler temperatures, better soil structure, or higher organic matter, may be more favorable for vegetative growth (Tables 1 and 2). This observation is consistent with literature findings by [11]. who emphasized the importance of local Agro-climatic factors in influencing flax performance. These results strongly support the recommendation of sowing flax in mid-November at lower seeding rates (20–30 kg. ha^{-1}) to maximize branching a key factor for improving yield potential.

ISSN 2072-3857

Table 3. Effect of sowing dates and seeding rate on number of primary brunches. Plant^{-1} in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates 20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}	Location*Sowing dates	Mean of Locations
Duhok	Mid-November	2.5 a	2.3 a	2.3 a	2.1 a	2.3 a	2.0 a
	Early December	2.3 a	1.9 ab	2.0 ab	1.5 bc	1.9 b	
	Late December	2.3 a	1.5 bc	1.9 ab	1.5 bc	1.8 b	
Zakho	Mid-November	1.3 c	1.2 c	1.1 c	1.0 c	1.2 c	1.1 b
	Early December	1.0 c	1.1 c	1.0 c	1.0 c	1.0 c	
	Late December	1.1 c	1.1 c	1.1 c	1.0 c	1.1 c	
Location *Seeding Rate	Duhok	2.4 a	1.9 bc	2.1 b	1.7 c	Mean of Sowing dates	
	Zakho	1.1 d	1.1 d	1.1 d	1.0 d		
Sowing dates * Seeding Rate	Mid-November	1.9 a	1.8 a	1.7 ab	1.6 abc		
	Early December	1.7 ab	1.5 abc	1.5 abc	1.3 bc		
	Late December	1.7 ab	1.3 bc	1.5 abc	1.3 bc	Mid-November	1.7 a
Mean of Seeding Rate		1.7 a	1.5 b	1.6 ab	1.4 b	Early December	1.5 b
						Late December	1.4 b

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

- **Number of capsules per Plant**

Table 4 demonstrates that the number of capsules generated per flax plant is markedly affected by sowing date, seeding rate, and location, with intricate interactions among these variables. Flax cultivated in

ISSN 2072-3857

Duhok yielded significantly more capsules per plant (16.7) compared to Zakho (5.3), suggesting that Duhok's agro-environmental conditions, potentially encompassing superior soil structure, more appropriate temperatures, or enhanced water availability, are more conducive to reproductive growth. Mid-November sowing yielded the highest average capsule count of 12.4 per plant, followed by early December at 10.2, whereas late December recorded the lowest at 10.4. The observed trends align with multiple studies cited in the literature review, including [13], which emphasize the benefits of early sowing in enhancing branching and capsule development due to an extended vegetative phase and improved flowering conditions.

The seeding rate exhibited a distinct impact. Moderate rates, specifically 20 and 30 $kg \cdot ha^{-1}$, yielded the highest capsule counts at both locations. In Duhok, the highest yield of capsules per plant (24.3) was attained with mid-November sowing at a rate of 20 $kg \cdot ha^{-1}$, while a marginally lower yield (19.6) was observed at 30 $kg \cdot ha^{-1}$. Conversely, elevated seeding rates, such as 50 $kg \cdot ha^{-1}$, markedly diminished capsule yield, especially in Zakho, where capsule counts plummeted to a mere 3.5 per plant. This decline is likely attributed to heightened competition for essential resources, including light, nutrients, and moisture, in densely planted environments, which hampers the plant's ability to grow robustly and reproduce effectively. [26] have documented analogous patterns, indicating that reduced planting densities enhance plant architecture and reproductive yield by alleviating resource competition.

The interplay between sowing time and seeding rate underscores the necessity of meticulously adjusting both variables concurrently. The optimal capsule count was consistently achieved through the combination of mid-November sowing and low to moderate seeding rates (20–30 $kg \cdot ha^{-1}$) at both locations. In Duhok, this combination produced 24.3 capsules per plant, whereas Zakho reached a maximum of 7.7 capsules under identical conditions. The findings correspond with previous research, including studies by [32] which indicated that early sowing improves the synchronization of flowering with optimal environmental conditions, thereby enhancing flower retention and capsule development.

The obtained results from approve the practice of sowing flax in mid-November at reduced seeding rates (20–30 $kg.\ ha^{-1}$) to optimize capsule yield.

ISSN 2072-3857

Table 4. Effect of sowing dates and seeding rate on number of capsules. Plant^{-1} in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates				Location*Sowing dates	Mean of Locations
		20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}		
Duhok	Mid-November	24.3 a	19.6 abcd	13.1 c-g	20.1 abc	19.3 a	16.7 a
	Early December	21.4 ab	15.1 b-f	14 b-f	11.0 e-i	15.4 b	
	Late December	17.0 a-e	14.0 b-f	18.7 a-e	11.9 d-h	15.4 b	
Zakho	Mid-November	7.7 fghi	5.4 ghi	5.1 ghi	3.9 hi	5.5 c	5.3 b
	Early December	4.8 hi	5.2 ghi	5.4 ghi	4.4 hi	4.9 c	
	Late December	6.1 ghi	6.3 ghi	5.4 ghi	3.8 i	5.4 c	
Location *Seeding Rate	Duhok	20.9 a	16.2 b	15.2 b	14.3 b	Mean of Sowing dates	
	Zakho	6.2 c	5.6 c	5.3 c	4.0 c		
Sowing dates * Seeding Rate	Mid-November	16.0 a	12.5 ab	9.1 b	12.0 ab		
	Early December	13.1 ab	10.1 b	9.7 b	7.7 b		
	Late December	11.5 ab	10.2 b	12.0 ab	7.8 b	Mid-November	12.4 a
Mean of Seeding Rate		13.6 a	10.9 ab	10.3 b	9.2 b	Early December	10.2 a
						Late December	10.4 a

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

- **Number of Seeds per capsule**

Table 5 demonstrate how location, seeding rate, and sowing date affect the number of seeds per capsule in flax, a crucial yield component that has a direct impact on crop performance and seed production. Mid-November sowing produced the most seeds per capsule among the tested treatments in both Duhok and Zakho. At a seeding rate of 20 kg. ha^{-1}, the highest value ever recorded was 9.3 seeds per capsule in Duhok. Late December sowing yielded the lowest values, especially in Zakho, where the seed count fell to 8.2, while early December sowing yielded

ISSN 2072-3857

somewhat fewer seeds. The well-established knowledge that early sowing permits a longer and more advantageous reproductive window, improving conditions for fertilization and seed development, is supported by these findings. Early sowing promotes better seed set through increased pollen viability, prolonged grain filling, and ideal temperature and moisture during flowering, according to research by [23]. late sowing frequently shortens the reproductive phase and increases exposure to terminal heat stress, which can hinder fertilization and decrease seed formation.

The influence of seeding rate was similarly significant. Across all dates and locations, lower seeding rates more precisely, 20 and 30 kg. ha^{-1} produced more seeds per capsule than higher densities (40–50 kg. ha^{-1}). This result is probably caused by less competition for resources at lower plant densities, which improves light, nutrient, and moisture availability and increases the plant's capacity to devote energy to reproductive organs. These results are consistent with those of [29], who also noted that lower planting densities result in a more open canopy and better resource availability per plant, which enhances seed set. The detrimental impact of overcrowding on reproductive efficiency was further demonstrated in Duhok, where the seed count gradually decreased as seeding rates rose from 20 to 50 kg. ha^{-1} under mid-November sowing.

The findings also showed clear distinctions between the two places. Regardless of the combination of treatments, Duhok consistently produced more seeds per capsule than Zakho. This implies that reproductive development is more supported in Duhok by environmental factors like more stable microclimates, improved soil structure, and lower average temperatures. These site-specific benefits are consistent with research by [5], who highlighted the importance of site-specific factors in determining flax productivity in Iraq's varied landscapes.

ISSN 2072-3857

Table 5. Effect of sowing dates and seeding rate on number of Seeds. capsule^{-1} in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates				Location*Sowing dates	Mean of Locations
		20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}		
Duhok	Mid-November	9.3 ab	9.1 abc	9.0 abc	8.9 abc	9.1 a	9.039 a
	Early December	8.7 abc	9.3 ab	9.0 abc	8.8 abc	9.0 a	
	Late December	9.4 a	9.1 abc	9.1 abc	8.7 abc	9.1 a	
Zakho	Mid-November	9.0 abc	8.7 abc	8.3 c	8.3 c	8.6 b	8.500 b
	Early December	8.5 abc	8.2 c	8.8 abc	8.5 bc	8.5 b	
	Late December	8.3 c	8.6	8.7	8.2 c	8.4 b	
Location *Seeding Rate	Duhok	9.1 a	9.2 a	9.0 ab	8.8 abc	**Mean of Sowing dates**	
	Zakho	8.6 bc	8.5 c	8.6 bc	8.3 c		
Sowing dates * Seeding Rate	Mid-November	9.2 a	8.9 ab	8.6 ab	8.6 ab		
	Early December	8.6 ab	8.8 ab	8.9 ab	8.6 ab		
	Late December	8.8 ab	8.9 ab	8.9 ab	8.5 b	Mid-November	8.8 a
Mean of Seeding Rate		8.9 a	8.9 a	8.8 a	8.6 a	Early December	8.7 a
						Late December	8.7 a

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

- **Number of Seeds per plant**

In Table 6, the number of seeds produced per flax a critical yield trait that reflects the combined effects of capsule formation and seed set is shown to be significantly impacted by sowing date, seeding rate, and geographic location. According to the findings, mid-November sowing consistently produced the most seeds, particularly in Duhok, where the lowest seeding rate of 20 kg. ha^{-1} resulted in a peak value of 173.5 seeds per plant. In Zakho, on the other hand, plants produced as few as 31.1 seeds when seeded in late December at a high seeding rate of 50 kg·ha^{-1}. This resulted in the lowest seed counts. The well-established idea that earlier

ISSN 2072-3857

sowing prolongs the vegetative and reproductive phases, allowing for improved capsule development and seed filling, is supported by these results. According to [4], early November sowing increases seed production by improving plant vigor, branching, and flower retention. However, research by [16]. demonstrated that late sowing shortens the growth cycle and increases flower drop, which results in less seed formation. This pattern is evident in the current findings.

The number of seeds produced per plant was significantly impacted by the seeding rate as well. Across all treatments, lower seeding rates (20-30 kg. ha^{-1}) consistently resulted in more seeds per plant, whereas higher rates (40–50 kg. ha^{-1}) caused notable decreases. In Duhok, for example, seed production increased by as much as 50% when the seeding rate was reduced to 20 kg·ha^{-1} instead of 50 kg. ha^{-1}. This is explained by less competition between plants at lower densities, which improves each plant's ability to reproduce by giving it better access to resources like light, moisture, and nutrients. These results are consistent with those of [3], who highlighted that a lower plant density prolongs the seed-filling period and permits more effective canopy light penetration. On the other hand, more competition results from dense planting, which limits the plant's capacity to devote energy to seed development.

Location also had a significant impact. Regardless of the sowing date or seed rate, flax cultivated in Duhok yielded significantly more seeds per plant (126.0) on average than those grown in Zakho (46.9). The more favorable growing conditions in Duhok, which may include richer soils, cooler temperatures, or higher soil moisture factors that promote better overall plant development, are probably the cause of this discrepancy. These findings align with those of [5], who emphasized the significance of regional environmental factors in determining flax productivity in northern Iraq.

In conclusion, Table 6's data clearly show that the best strategy for increasing the number of seeds per plant is to plant flax in mid-November at a lower seeding rate (20–30 kg·ha^{-1}). By reducing competition, this tactic enables the crop to fully benefit from advantageous environmental circumstances. The significance of location-specific agronomic practices is further highlighted by the stark differences between the two study sites. All things considered, the results are in good agreement with earlier studies and offer valuable local information to direct flax production in the semi-arid climates of the Duhok and Zakho regions.

ISSN 2072-3857

Table 6. Effect of sowing dates and seeding rate on number of Seeds. plant^{-1} in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates				Location*Sowing dates	Mean of Locations
		20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}		
Duhok	Mid-November	173.5 a	149.0 abc	98.2 c-g	154.6 ab	143.8 a	126.0 a
	Early December	153.1 abc	116.5 bcde	107.5 b-f	86.6 d-h	115.9 b	
	Late December	128.7 abcd	109.3 b-f	136.3 abcd	98.3 c-g	118.2 b	
Zakho	Mid-November	66.8 efgh	49.9 gh	48.0 gh	35.3 h	50.0 c	46.9 b
	Early December	40.6 h	44.6 gh	55.3 fgh	39.6 h	45.0 c	
	Late December	47.2 gh	53.1 gh	51.9 gh	31.1 h	45.8 c	
Location *Seeding Rate	Duhok	151.8 a	125.0 ab	114.0 b	113.2 b	Mean of Sowing dates	
	Zakho	51.5 c	49.2 c	51.7 c	35.3 c		
Sowing dates * Seeding Rate	Mid-November	120.2 a	99.5 ab	73.1 b	95.0 ab		
	Early December	96.8 ab	80.6 b	81.4 b	63.1 b		
	Late December	87.9 ab	81.2 b	94.1 ab	64.7 b	Mid-November	96.9 a
Mean of Seeding Rate		101.6 a	87.1 ab	82.9 ab	74.3 b	Early December	80.5 a
						Late December	82.0 a

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

ISSN 2072-3857

- **1000-Seeds Weight (gm)**

Table 7 shows the effect of sowing date, seeding rate, and location factors on seed development and overall crop quality and had a significant impact on the 1000-seed weight of flax. When flax seeds were planted at the Zakho location in mid-November with a low seeding rate of 20 kg. ha^{-1}, the maximum seed weight (6.7 g) was attained. On the other hand, regardless of seed rate, Duhok had the lowest seed weights (5.7–5.8 g) when seeding was done late. In comparison to late December sowing (5.9 g) and the Duhok site (5.8 g), mid-November sowing and the Zakho location yielded significantly higher seed weights (6.2 g each) when averaged across all treatments. Given that early sowing and ideal Agro-ecological conditions promote more efficient seed development, these findings emphasize the significance of both climatic and temporal factors. This pattern is in line with research by [15], who found that early sowing increases seed mass and prolongs the seed-filling period because of better temperature regimes. In a similar vein, [12], discovered that flax cultivars planted in the Kurdistan region in mid-November had higher seed weight because of improved photosynthetic efficiency during the reproductive stage. Seed weight was significantly impacted by seeding rate as well. In both sites, 1000-seed weights were generally higher at lower and moderate seeding rates (20–30 $kg \cdot ha^{-1}$). This is probably because there was less competition between plants for vital resources like light, water, and nutrients. The results of [1], who observed that lower plant densities in northern Iraq enhanced important seed quality metrics, are consistent with this observation. Conversely, higher seeding rates especially at 50 $kg \cdot ha^{-1}$ reduced seed weight, most likely as a result of increased competition stress in the crop canopy. [21], who stressed that excessive plant crowding adversely affects seed development and fill due to limited resource availability, support these findings.

Overall, the data show that mid-November sowing, lower seeding rates (20–30 $kg \cdot ha^{-1}$), and ideal environmental conditions—like those in Zakho can all help flax reach its ideal seed weight. Together, these elements reduce plant stress and encourage effective resource use, which supports better seed quality and development. The trends that have been observed support earlier studies carried out in Iraq and the Kurdistan region, highlighting the importance of plant population density and sowing date in optimizing flax cultivation yield components.

ISSN 2072-3857

Table 7. Effect of sowing dates and seeding rate on 1000 Seeds Weight in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates				Location*Sowing dates	Mean of Locations
		20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}		
Duhok	Mid-November	5.8 efg	6.0 b-g	6.0 b-g	6.1 b-g	6.0 bcd	5.8 b
	Early December	5.8 edfg	5.8 efg	5.8 c-g	5.8 defg	5.8 cd	
	Late December	5.7 efg	5.6 g	5.8 defg	5.9 b-g	5.8 d	
Zakho	Mid-November	6.7 a	6.4 ab	6.4 ab	6.3 abcd	6.5 a	6.2 a
	Early December	6.4 ab	6.1 b-f	6.1 b-f	6.0 b-g	6.2 b	
	Late December	6.2 bcde	6.2 bcde	6.0 bcde	5.6 fg	6.0 bc	
Location *Seeding Rate	Duhok	5.8 d	5.8 d	5.9 d	5.9 cd	Mean of Sowing dates	
	Zakho	6.4 a	6.2 ab	6.2 bc	6.0 bcd		
Sowing dates * Seeding Rate	Mid-November	6.3 a	6.2 ab	6.2 ab	6.2 ab		
	Early December	6.1 abc	6.0 abc	6.0 abc	5.9 abc		
	Late December	5.9 abc	5.9 abc	5.9 bc	5.8 c	Mid-November	6.2 a
Mean of Seeding Rate		6.1 a	6.0 a	6.0 a	6.0 a	Early December	6.0 b
						Late December	5.9 b

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

Seed Yield (kg. ha^{-1})

The data in Table 8 indicate that flax seed yield was significantly influenced by sowing date and seeding rate at both study sites. Duhok exhibited significantly higher average yields (1452.8 kg. ha^{-1}) compared to Zakho (950.1 kg. ha^{-1}), suggesting that its Agro-climatic conditions are more favorable for flax cultivation. In Duhok, the peak seed yield of 1683.3 kg. ha^{-1} was attained with late December sowing at a moderate seeding rate of 30 kg·ha^{-1}, closely succeeded by the rates of 50 kg. ha^{-1} (1658.3 kg. ha^{-1}) and 20 kg. ha^{-1} (1608.3 kg. ha^{-1}). This indicates that in Duhok, postponing sowing while employing moderate to high seed densities can enhance

ISSN 2072-3857

yield by synchronizing flowering with optimal environmental conditions and mitigating heat stress during seed development. These findings agree with [2]. who reported that delayed sowing in cooler climates can enhance seed yield by improving flowering timing and seed filling conditions.

In contrast, the minimum yield (779.6 kg. ha^{-1}) was observed in Zakho with late December sowing at the maximum seeding rate (50 kg·ha^{-1}), presumably attributable to significant intra-specific competition in suboptimal conditions. Among all seeding rates, 30 kg·ha^{-1} yielded the highest average output (1236.7 kg·ha^{-1}), supporting Sadeghi *et al*. (2017) assertion that moderate plant densities optimize capsule and seed development per plant. Zakho attained its highest yield (1143.3 kg. ha^{-1}) with a seeding rate of 30 kg. ha^{-1} during late December sowing, demonstrating that moderate seeding rates can partially mitigate environmental constraints despite delayed planting. The interplay of location, sowing date, and seeding rate was significant, particularly emphasizing the enhanced performance of late December sowing paired with seeding rates of 30 and 50 kg. ha^{-1} in Duhok. This indicates an advantageous synergy between lower reproductive-stage temperatures and ideal plant density. Although prior studies [20] highlighted early sowing as the optimal practice for flax, these findings indicate that the ideal sowing timing may differ by region, with late sowing potentially beneficial when combined with suitable seeding rates.

The findings emphasize the imperative of tailoring sowing dates and seed rates to local conditions to optimize flax seed yield. Duhok exhibits enhanced productivity with late December sowing at moderate to high seeding rates, whereas Zakho demonstrates superior performance with moderate seeding rates, even in less favorable conditions. This contradicts the conventional advice for early sowing, indicating that region-specific strategies adapted to climate and planting density are essential for maximizing flax production in northern Iraq.

ISSN 2072-3857

Table 8. Effect of sowing dates and seeding rate on Seed Yield (kg. ha^{-1}) in Duhok and Zakho.

Locations	Sowing dates	Seeding Rates 20 kg. ha^{-1}	30 kg. ha^{-1}	40 kg. ha^{-1}	50 kg. ha^{-1}	Location*Sowing dates	Mean of Locations
Duhok	Mid-November	1450.0 abcd	1233.3 a-f	1275.0 a-f	1341.7 a-f	1325.0 b	1452.8 a
	Early December	1341.7 a-f	1350.0 a-f	1533.3 abc	1416.7 a-e	1410.4 ab	
	Late December	1608.3 ab	1683.3 a	1541.7 abc	1658.3 ab	1622.9 a	
Zakho	Mid-November	1010.4 cdef	904.2 def	847.9 ef	945.8 def	927.1 c	950.1 b
	Early December	825.8 f	1105.8 b-f	884.6 def	904.2 def	930.1 c	
	Late December	1033.3 cdef	1143.3 a-f	1016.7 cdef	779.6 f	993.2 c	
Location *Seeding Rate	Duhok	1466.7 a	1422.2 a	1450.0 a	1472.2 a	**Mean of Sowing dates**	
	Zakho	956.5 b	1051.1 b	916.4 b	876.5 b		
Sowing dates * Seeding Rate	Mid-November	1230.2 a	1068.8 a	1061.5 a	1143.8 a		
	Early December	1083.8 a	1227.9 a	1209.0 a	1160.4 a		
	Late December	1320.8 a	1413.3 a	1279.2 a	1219.0 a	Mid-November	1126.0 b
Mean of Seeding Rate		1211.6 a	1236.7 a	1183.2 a	1174.4 a	Early December	1170.3 ab
						Late December	1308.1 a

* In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

ISSN 2072-3857

Conclusion

This study clearly demonstrated that sowing date and seeding rate play a crucial role in determining flax performance under the distinct agro-climatic conditions of Duhok and Zakho. In Duhok, late December sowing combined with moderate to high seeding rates (30–50 kg·ha^{-1}) achieved the highest yield (1683.3 kg·ha^{-1}), while mid-November sowing with lower seeding rates (20–30 kg·ha^{-1}) produced the best branching (2.5 branches/plant), capsules (24.3 capsules/plant), and seeds per plant (173.5). In Zakho, overall yields were lower, with a maximum of (1143.3 kg·ha^{-1}) under late December sowing at a rate of (30 kg·ha^{-1}), and the lowest yield of (779.6 kg·ha^{-1}) recorded under late sowing with a (50 kg·ha^{-1}) rate. These findings provide precise, location-specific recommendations: farmers in Duhok should focus on delayed sowing with higher densities to maximize yield, while those in Zakho should prioritize early sowing at moderate densities to improve crop establishment and yield stability. By adopting these strategies, flax production in semi-arid northern Iraq can be significantly enhanced.

ISSN 2072-3857

References

1. Abdullah Al_Raheem, S. E.,&Anees, A. H. A. 2024. Effect of Gamma Rays on Growth, Yield and Yield Components Eight Traits of Flax Genotypes *Linum usitatissimum* L. Tikrit Journal for Agricultural Sciences, 24(1), 78-93.
2. Ahmed, S. M. 2021. Medicinal plants and pharmaceutical medicines use in pregnant and lactating women in Ethiopia.
3. Al-Doori, S. A. M. A.,&Ahmed, S. 2024. Performance of Three Flax Cultivars (*Linum usitatissimum* L.) with Variant Foliar Spraying of Different Concentrations of Sulfur and Boron in two soil types in Nineveh Governorate. Jornal of Al-Muthanna for Agricultural Sciences, 11.
4. Ali, R. M., & Hussein, A. M. 2022. Effect of sowing rates on growth and yield characteristics of flax (*Linum usitatissimum* L.) under Erbil conditions. Kurdistan Journal of Agricultural Sciences, 10(2), 45–52.
5. Al-Khazaali, S. M., & Al-Mukhtar, H. R. 2021. The effect of sowing date and environmental factors on the growth of flax in the Kurdistan region of Iraq. Kurdistan Journal of Agricultural Sciences, 15(2), 78–83.
6. Al-Obady, R. F.,&Shaker, A. T. 2022. Effect of Sowing Dates and Compound Fertilizer NPK on Growth and Yield of Flax (*Linum usitatissimum* L.). Basrah Journal of Agricultural Sciences, 35(2), 185-198.
7. Al-Rawi, K. M. and A. Khalafalla. 2000. Analysis of Experimental Agriculture Design. Dar Al-Kutub for Printing and Publishing. Mosul Univ.
8. Berti, M., Fischer, S., Wilckens, R., Hevia, F., & Johnson, B. 2010. Adaptación e Interacción Genotipo x Ambiente en Lino (*Linum usitatissimum* L.) en la Zona Centro Sur de Chile. Chilean journal of agricultural research, 70(3), 345-356.
9. Charney, M. 2014. Flax: Food and Fiber. Journal of Agricultural&Food Information, 15(4), 249-254.
10. Drej, M. M.,&Noaman, A. H. 2021. November). Assessment of the productive traits of several Flax cultivars by effect of sowing dates. In IOP Conference Series: Earth and Environmental Science (Vol. 904, No. 1, p. 012076). IOP Publishing.
11. Ghareeb, S. A., Mahmood, S. A., & Shkur, S. H. 2024. Different sowing dates and their effects on flax (*Linum usitatissimum* L.) growth, yield, and quality in rainfed sulaimany-kurdistan-Iraq. Journal of Kerbala for Agricultural Sciences, 11(3), 221-232.
12. Khudhur, D. Y., Hameed, S. S., & Al-Barzinji, S. M. 2018. Enhancing e-banking security: using whirlpool hash function for card number encryption. *International Journal of Engineering and Technology*, *7*(2), 281-286.
13. Mohammed, S. O.,&Ahmed, D. H. 2023. Sowing density and its effect on growth and seed quality parameters of flax in Kurdistan region. Kurdistan Journal of Agricultural Sciences, 12(1), 77–85.
14. Mueller, K., Eisner, P., Yoshie-Stark, Y., Nakada, R., & Kirchhoff, E. 2010. Functional properties and chemical composition of fractionated brown and yellow linseed meal (*Linum usitatissimum* L.). Journal of Food Engineering, 98(4), 453-460.
15. Noreen, S., Tufail, T., Ul Ain, H. B., & Awuchi, C. G. (2023). Pharmacological, nutraceutical, and nutritional properties of flaxseed

(*Linum usitatissimum*): An insight into its functionality and disease mitigation. Food Science&Nutrition, 11(11), 6820-6829.

16. Omar, F. A., & Salim, A. M. 2022. Influence of sowing date on the yield of flax (*Linum usitatissimum* L.) in the Kurdistan region of Iraq. Kurdistan Journal of Agricultural Science, 15(3), 45–54.
17. Othman, M., & Jasim, Y. A. 2022. EFFECT OF WEEDS AND SEEDING RATE ON GROWTH AND YIELD OF THREE FLAX CULTIVARS.
18. Parikh, M., Netticadan, T.,&Pierce, G. N. 2018. Flaxseed: its bioactive components and their cardiovascular benefits. American Journal of Physiology-Heart and Circulatory Physiology.
19. Pavlov, A. V., Porokhovinova, E. A., Slobodkina, A. A., Matvienko, I. I., Kishlyan, N. V., & Brutch, N. B. 2024. Influence of Weather Conditions in the Northwestern Russian Federation on Flax Fiber Characters According to the Results of a 30-Year Study. Plants, 13(6), 762.
20. Rahimi, A., Delavar, M., & Khoramivafa, M. 2018. Influence of sowing date and plant density on growth, yield and oil quality of flax (*Linum usitatissimum* L.) under semi-arid conditions. Applied Ecology and Environmental Research, 16(1), 163–175. https://doi.org/10.15666/aeer/1601_163175
21. Rahman, M., Khatun, M., & Kabir, M. H. 2019. Effect of planting density on seed filling and oil content of linseed. Bangladesh Agronomy Journal, 22(2), 55–63.
22. Sadeghi, H., Darvishzadeh, R., & Faramarzi, A. 2017. Assessment of the effects of sowing date and plant density on yield and quality traits in flax. Crop Production and Processing, 7(2), 45–58.
23. Sarwar, M., Saleem, M. F., Ullah, N., Maqsood, H., & Ahmad, H. 2023. Physiological Ecology of Medicinal Plants: Implications for Phytochemical Constituents. In Herbal Medicine Phytochemistry: Applications and Trends (pp. 1-33). Cham: Springer International Publishing.
24. SAS Institute . 2000. The SAS system for Windos v. 9.00 SAS Institute Inc., Cary, NC. USA.
25. Scheibe, M., Urbaniak, M., & Bledzki, A. 2023. Application of natural (plant) fibers particularly hemp fiber as reinforcement in hybrid polymer composites-Part II. Volume of hemp cultivation, its application and sales market. Journal of Natural Fibers, 20(2), 2276715.
26. Sheidai, M., Darini, S., Talebi, S. M., Koohdar, F., & Ghasemzadeh-Baraki, S. 2019. Molecular systematic study in the genus Linum (Linaceae) in Iran. Acta Botanica Hungarica, 61(3-4), 421-434.
27. Singh, K. K., Mridula, D., Rehal, J., & Barnwal, P. 2011. Flaxseed: a potential source of food, feed and fiber. Critical reviews in food science and nutrition, 51(3), 210-222.
28. Suraki, S. A., Bagheri-Nesami, M., Nabati, M., Moosazadeh, M., & Habibi, E. 2024. Flaxseed powder and magnesium hydroxide syrup on the intestinal function of patients with acute myocardial infarction in intensive care units. Caspian Journal of Internal Medicine, 15(2), 234.
29. Talebi, S. M., Rashnou-Taei, M., Sheidai, M., & Noormohammadi, Z. 2015. Use of anatomical characteristics for taxonomical study of some Iranian Linum taxa. Environmental and Experimental Biology, 13, 123-131.
30. Wu, S., Wang, X., Qi, W.,&Guo, Q. 2019. Bioactive protein/peptides of flaxseed: A review. Trends in Food

Science&Technology, 92, 184-193.

31. Yadav, S. K., Singh, N., & Yadav, H. K. 2024. Genetic variability and trait association analysis in linseed (*Linum usitatissimum* L.) for yield and related traits. Oil Crop Science, 9(3), 151-159.
32. Yousaf, S., Ilyas, M., Khattak, A. K., Satti, S. Z.,&Jan, I. 2017. Antimicrobial activities and mineral profile of selected wild plant *Linum usitatissimum* in Khyber Pakhtunkhwa, Pakistan. Soil&Environment, 36(1).