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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Is dual-purpose flax production feasible in the Amik Plain? A preliminary study on cultivar performance and harvesting stage

Amik Ovası'nda çift amaçlı keten üretimi yapılabilir mi? Çeşitler ve hasat zamanları üzerine bir araştırma

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ABSTRACT

The research aimed to investigate the yield and quality parameters of three flax varieties (*Linum usitatissimum* L.) at four different harvesting stages in Amik Plain in the 2021 growing seasons. The experimental design was a randomized complete block in split plot arrangement with three replications. Seed yield and quality parameters were determined after the maturation of seeds at the final harvesting. Harvesting stages (beginning of flowering, capsule formation, green-yellow ripening, and full ripening stages) significantly affected plant height, technical stem length, stem ratio, moisture, and plant fresh weight. Among the cultivars, significant differences were observed in terms of technical stem length, fiber ratio, stem ratio, 1000 seed weight and seed yield. Interaction effects were determined in terms of plant height and moisture ratio. While the cv. Noreum had greater fiber ratio (19.45%), stem ratio (50.97%) and seed yield (241.33 kg da^{-1}), the cv. Karakız had the highest 1000 seed weight (7.99 g). The cv. Beyaz Gelin had the highest technical stem length (67.39 cm). In terms of technical stem length, fiber ratio, and stem ratio parameters, the cv. Beyaz Gelin and the cv. Noreum were in the same statistical group. The fact that harvesting stages do not affect the fiber ratio has led to the conclusion that planting for both purposes may be appropriate in the region.

ÖZET

Araştırma, Amik Ovası koşullarında üç farklı keten çeşidinin (*Linum usitatissimum* L.) dört farklı hasat zamanındaki verim ve kalite unsurlarını incelemeyi amaçlamıştır. Bu doğrultuda, çalışma 2021 üretim sezonunda tesadüf bloklarında bölünmüş parseller deneme desenine göre üç tekerrürlü olarak yürütülmüştür. Tohum verim ve kalitesi üzerine incelemeler son hasat zamanında tohumların olgunlaşması sonrasında yapılmıştır. Hasat zamanları (çiçeklenme başlangıcı, kapsül oluşumu, yeşil-sarı olum ve tam olum aşamaları) bitki boyu, teknik sap uzunluğu, sap oranı, nem oranı, bitki yaş ağırlığı üzerinde istatistiksel olarak anlamlı etkilere neden olmuştur. Çeşitler arasında ise teknik sap uzunluğu, lif oranı, sap oranı, 1000 tohum ağırlığı ve tohum verimi açısından önemli farklılıklar gözlemlenmiştir. Bitki boyu ve nem oranı bakımından interaksiyon etkisi belirlenmiştir. Noreum çeşidi, lif oranı (%19.45), sap oranı (%50.97) ve tohum verimi (241.33 kg da^{-1}) ile öne çıkarken, Karakız çeşidi en yüksek 1000 tohum ağırlığı (7.99 g) ile dikkat çekmiştir. Beyaz Gelin çeşidi ise en yüksek teknik sap uzunluğu (67.39 cm) değerine sahiptir. Teknik sap uzunluğu, lif oranı ve sap oranı parametrelerinde Beyaz Gelin çeşidi ile Noreum çeşidi aynı istatistiksel grupta bulunmaktadır. Hasat zamanlarının lif oranını etkilememesi, bölgede her iki amaca yönelik ekim yapmanın uygun olabileceği sonucuna ulaştırmıştır.

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INTRODUCTION

Flax (*Linum usitatissimum* L) is one of approximately 260 species belonging to the Linaceae family. Historically, flax stands out as one of the oldest fibers and indeed one of the oldest cultivated plants. The first records related to its use date back 9000 years, with its estimated initiation into cultivation approximately 8000 years ago (Cullis, 2007). Although its exact origin remains uncertain, it is known that flax was cultivated for fiber in Ancient Egypt (El-Hariri et al., 1994). Today, flax is a versatile plant cultivated for its seeds, fibers, and dual-purpose production (seed and fiber), with its height ranging between 60-120 cm depending on the variety, planting density, and weather conditions (Muir & Westcott, 2003; Mert, 2020; Aygün & Mert, 2022). Flax, with its extensive history and diverse applications, holds a significant position among cultivated plants. *Linum usitatissimum* L., is a widely cultivated oilseed plant globally. While its durable fibers are mainly used in the textile industry alone or together with cotton fibers in the production of high-quality fabrics, its seeds, rich in healthy oils, find application in various food products. One notable feature of flax is its rich diversity, encompassing cultivars that adapt to different climatic and soil conditions. Additionally, the growth stages and harvesting stages of flax can have a decisive impact on the quantity and quality of the obtained products. Understanding the effects of diversity and harvesting stages on flax cultivation becomes crucial in optimizing agricultural practices and maximizing the industrial utility of this versatile plant.

While flax seed and fiber production have increased globally in the last 20 years, this trend is not observed in Türkiye. Although flax cultivation has been prevalent along the Black Sea coastal region, the production has significantly decreased to almost negligible levels after the Ottoman Empire. The coastal areas of Anatolia are suitable for fiber flax production, and particularly in the Mediterranean Region, the possibilities of dual-purpose production during the winter season have been explored (Aygün & Mert, 2022).

This article aims to comprehensively examine the potential impacts of different flax cultivars and harvesting stages on yield parameters. The results of this study will provide valuable information on new perspectives in flax cultivation and development of sustainable flax cultivation practices.

MATERIALS and METHODS

Field trial was established in the Research and Experimental Fields of Hatay Mustafa Kemal University in December 2020. The soil characteristics of the experimental area are given in Table 1. Soil analysis was carried out at Hatay Mustafa Kemal University, Technology and Research & Development Center.

Table 1. Soil parameters of the experimental area

Çizelge 1. Deneme arazisinin toprak parametreleri

Parameters	Results
pH	7.43
Conductivity (µS cm^{-1})	328
Phosphorus (kg ha^{-1})	24.40
Potassium (kg ha^{-1})	854.0
Calcium (ppm)	8900
Iron (ppm)	14.04
Copper (ppm)	1.59
Manganese (ppm)	20.66
Zinc (ppm)	2.28
Magnesium (ppm)	1679.2
Organic Matter (%)	1.65
Lime (%)	2.4

The experimental design was a randomized complete block in split plot arrangement with three replications. Cultivars were assigned to main plots and harvesting stages were assigned to subplots. Three cultivars of *Linum usitatissimum* L. were used as plant material Karakız, Beyaz Gelin and Noreum. Each experimental plot consisted of 5 rows, 5 meters in length, with a row spacing of 20 cm. Seeding process was carried out in December 2020. A total of 10 kg da^{-1} of nitrogen was applied, half during sowing and half during the flowering stage. Phosphorus and potassium, on the other hand, were applied at 5 kg da^{-1} during sowing. Throughout the cultivation period, irrigation was not applied and the plant water needs were met under natural rainfall conditions. The plants were exposed to a total of 624.3 mm of precipitation from sowing to harvest. According to Kozlowski et al. (2005), flax fibers can grow in regions receiving an annual rainfall of 600-800 mm, with 110-130 mm during the vegetation period. In this regard, the amount of rainfall in the region is deemed sufficient. Climate data were taken from Hatay Meteorology Directorate in order to use the data of the station closest to where the study was conducted.The climatic data for the region are given in Table 2.

Table 2. Climatic data covering the cultivation period and long-term averages (LTA)
Çizelge 2. Deneme alanının yetiştiricilik dönemini ve uzun yıllar ortalamalarını (LTA) kapsayan iklim verileri

Month	Average Monthly Temperature (°C)		Total Monthly Precipitation (mm)	
	2020-21	LTA (1940-2020)	2020-21	LTA (1940-2020)
December	10.7	9.5	79.3	184.1
January	9.5	8.1	334.8	196.9
February	11.1	9.8	37.5	170.0
March	12.5	13.1	98.4	143.3
April	16.8	17.2	73.9	103.5
May	22.2	21.3	0.0	81.0
June	24.4	24.8	0.4	32.0

To observe the development of fibers in plants, the harvesting process was conducted at four different phenological stages, namely beginning of flowering, capsule formation, green-yellow ripening, and full ripening stages (Sequentially 1, 2, 3, 4). At this stage, the technical stems of the harvested plants were separated and retted in a water tank for 15 days. After retting, the dried stems were stripped using a manually operated decorticator (designed by Yusuf Ziya AYGÜN) (Figure 1) to obtain fibers (n=50).

During the full ripening stage, both fiber and seed harvesting were conducted. The last harvest was carried out in June 2021. Yield components were determined.

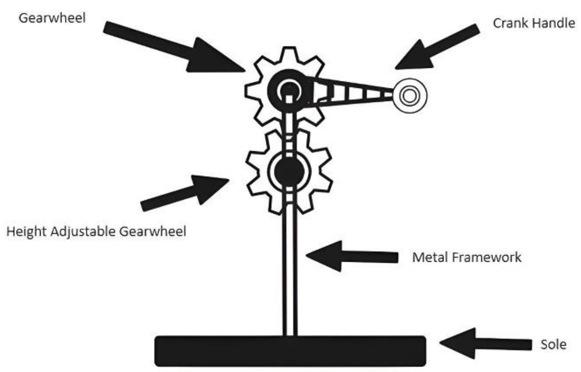

Figure 1. Drawing of the hand-operated decorticator used in the study
Şekil 1. Çalışmada kullanılan elle çalıştırılan dekortikatörün çizimi

The experimental data were subjected to analysis of variance using IBM SPSS Statistics 24 software. Means were grouped using the Tukey multiple comparison test.

RESULTS and DISCUSSIONS

While no significant differences were observed among the cultivars in terms of plant height, the harvesting times and interactions had significant differences. Plant height values varied with respect to harvesting stages, with the highest value recorded in the fourth harvest and the lowest in the first harvest (Table 3). In terms of interaction, the maximum plant height was attained during the final harvesting stage for cultivar Beyaz (Figure 2).

This outcome underscores the importance of considering not only the cultivar itself but also harvest stages for optimizing plant height in agricultural practices. The variation in plant height across different harvesting stages emphasizes the dynamic nature of plant growth, which may be influenced by environmental factors and developmental stages. The observed interaction effect highlights the need for a nuanced approach in managing harvest schedules, particularly for maximizing the growth potential of specific cultivars such as 'Beyaz Gelin'.

Further investigation into the underlying mechanisms contributing to these variations is warranted, as it could provide valuable insights into optimizing cultivation practices and improving overall crop yield. These findings contribute to the broader understanding of the intricate relationships between harvesting stages, plant cultivars, and their interactive effects on plant growth.

Plant heights in oil-type flax range from 25 to 80 cm and fiber-type flax typically fall within the range of 80 to 120 cm (Kymäläinen et al., 2004). The variation in flax plant height is influenced by several factors, including plant type (fiber or oil), nitrogen fertilizer and growth regulator levels, air temperature, day length, irrigation volume, and notably, the plant genotype (Kymäläinen et al., 2004; Koçak & Bayraktar, 2011; Mert, 2020). The extent of these variables underscores the complex interplay of environmental and genetic factors in determining the ultimate height of flax plants.

Table 3. Mean values of some yield components for the three cultivars and four harvesting stages

Çizelge 3. Bazı verim unsurlarının üç farklı çeşit ve dört farklı hasat zamanlarına göre ortalama değerleri

	Plant Height (cm)	**Technical Stem Length (cm)**	**Fiber Ratio of Stem (%)**	**Stem Ratio (Dry/dry w/w)**	**Moisture (%)**	**Fresh Weight (g plant^{-1})**
Cultivars						
Karakız	82.65±1.00	60.82±0.63 **b**	15.62±0.31 **b**	42.63±1.86 **b**	54.08±5.30	6.01±0.65
Beyaz Gelin	86.42±2.36	67.39±1.10 **a**	18.94±0.44 **a**	48.13±2.32 **a**	50.70±7.94	5.05±0.68
Noreum	86.79±1.74	66.69±0.79 **a**	19.45±0.45 **a**	50.97±2.78 **a**	53.23±5.72	4.90±0.62
Harvesting Stages (HS)						
1	77.20±1.16 **c**	62.79±1.17 **b**	17.44±0.86	56.58±2.28 **a**	75.42±0.66 **a**	6.61±0.36 **ab**
2	87.91±1.27 **b**	64.76±1.36 **ab**	18.79±0.68	38.41±0.96 **d**	66.11±0.83 **b**	7.16±0.52 **a**
3	86.21±1.49 **b**	66.95±1.48 **a**	17.77±0.64	42.91±1.43 **c**	48.10±1.03 **c**	5.27±0.41 **b**
4	89.82±1.55 **a**	65.36±1.38 **ab**	18.01±0.78	51.07±1.82 **b**	21.06±3.37 **d**	2.25±0.24 **c**
$F_{Cultivar}$	1.89ns	16.31*	129.37***	28.26**	2.24ns	6.54ns
F_{HT}	164.25***	3.70*	1.43ns	56.62***	588.26***	42.58***
$F_{Cultivar*HT}$	6.44***	0.12ns	0.63ns	0.72ns	12.67***	0.34ns
CV (%)	7.39	6.41	12.19	18.30	41.14	42.07
SEM	1.05	0.69	0.37	1.44	3.61	0.37

CV: Coefficient of variation, SEM: Standard error of mean, ns: non significant, *: significant at P ≤ 0.05, **: significant at P ≤ 0.01 ***: significant at P ≤ 0.001

It was observed that the technical stem length means differed significantly across cultivars and harvesting stages (Table 3). However, the interaction effect was found to be insignificant. The cv. 'Beyaz Gelin' exhibited the highest technical stem length, while 'Karakız' had the shortest. In terms of harvesting stage, the technical stem length was shortest in the first harvest and increased until the third harvest, with a subsequent decrease observed in the final harvest. This trend can be attributed to the downward expansion of the flowering zone as the flax harvest is delayed. As branching progresses downward, the technical stem shortens. The term 'first branch height' denotes the length of the technical stem from which fibers are extracted in fiber-type plants. This parameter exhibits a strong correlation with various fiber-related characteristics, including fiber length, fiber fineness, fiber ratio, and fiber yield, as indicated by studies such as El-Hariri et al. (2004) and Aydın (2020). Additionally, in oil-type plants, this measurement demonstrates a significant correlation with seed yield, as highlighted in the findings of Çoban et al. (2021). The results of this study are in parallel to the findings of the previous research indicating cultivars in technical stem length among different flax cultivars (Yıldırım, 2005; Tunçtürk, 2007; Örs & Öztürk, 2018; Aslan & Sarıhan, 2020; Aydın, 2020).

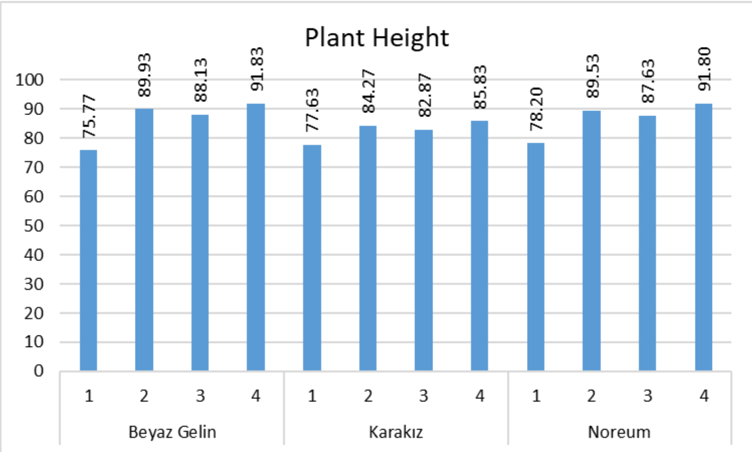

Figure 2. Cultivar x harvesting stage interaction on plant height

Şekil 2. Bitki boyuna ilişkin çeşit x hasat zamanı interaksiyon grafiği

While the impact of cultivars was significant on the bast fiber ratio, the effects of harvesting stages and interaction were found to be insignificant. The 'Noreum' cultivar exhibited the highest bast fiber ratio, whereas 'Karakız' had the lowest (19.45% and 15.62%, respectively). Rashwan et al. (2016) reported significantly different fiber ratios ranging from 10.95% to 18.94% across three different flax cultivars, emphasizing the genotype-dependent nature of fiber content. Similarly, fiber ratios are notably high in fiber-type flax compared to oil-type and dual-type flax, ranging around 60-70% (Abd El-Fatah, 2007; El-Refaey et al., 2010; Bauer et al., 2015).

The effects of cultivars and harvesting stages on the stem ratio were significant, while the interaction effect was found to be insignificant. The cv. 'Noreum' exhibited the highest stem ratio, followed by 'Beyaz Gelin' and 'Karakız' having the lowest ratio. In terms of harvesting stages, the highest stem ratio was observed during the first harvest, followed by a sharp decline in the subsequent harvests and a subsequent increase. This can be attributed to the relatively low branching of the plant during the initial harvest period, which coincides with the onset of flowering. Subsequent harvests witnessed an increase in stem ratio due to a significant weight gain in the fruiting zone as capsule formation progressed.

In later harvest periods, the plants lost a considerable amount of moisture in the fruiting zone, primarily because drying in the stem and shedding of leaves begins during capsule formation in flax. Subsequently, as the capsules get yellow, there is a decrease in mass in the fruiting zone, accompanied by thickening of the stem.

The influence of cultivars on plant moisture content was found to be insignificant, while the effects of harvesting stage and interaction were significant. From the first harvest to the final harvest, there were dramatic reductions in the moisture content. While all cultivars exhibited similar moisture levels up to the third harvest, the sharp decrease in moisture observed in the final harvest, particularly in the 'Beyaz Gelin' cultivar, can be attributed to the interaction effect (Figure 3). This phenomenon is linked to a genetic trait related to the rapid transition of the cultivar into its full maturity phase.

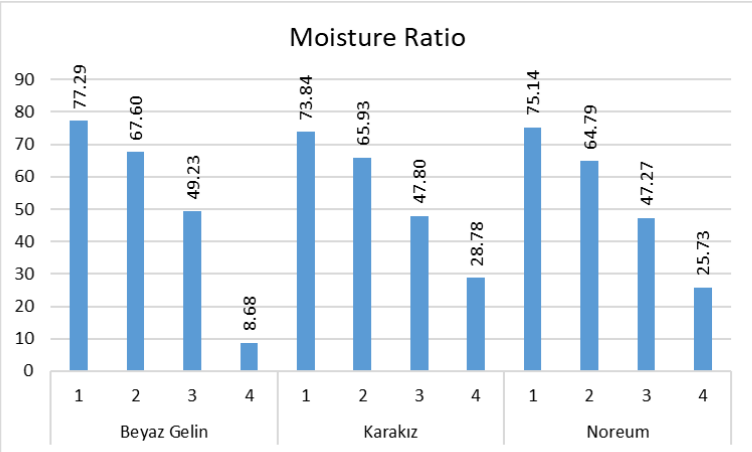

Figure 3. Cultivar x harvesting stage interaction on moisture content.

Şekil 3. Nem oranına ilişkin çeşit x hasat zamanı interaksiyon grafiği

The effect of harvest stage on plant fresh weight was significant, while the effects of cultivars and interaction were found to be insignificant. The plant fresh weight increased until the second harvest and then started to decline. Despite the accumulation of dry matter in the plant as harvesting stage was delayed, the observed decrease in plant fresh weight after the second harvest is quite normal due to dramatic moisture reductions. Consequently, the highest fresh weight was recorded at the second harvest while the lowest was observed in the final harvest (7.16–2.25 g, respectively).

The impact of cultivars on seed number per capsule was found to be insignificant with values ranging between 7.90 and 8.32 seeds capsule^{-1}. The highest value was observed in the cv. 'Beyaz Gelin' while the lowest was in the cv. 'Karakız' (Table 4). Similar studies have also suggested that the number of seeds in the capsule is not influenced by cultivars (Yıldırım, 2005; Kurt et al., 2006). However, it is important to note that this outcome may vary based on ecological conditions and cultivation practices. Seed number per capsule is considered a crucial parameter for achieving high seed yield (Aygün & Mert, 2022).

Table 4. Some seed yield component of the three flax cultivars

Çizelge 4. Üç keten çeşidine ait bazı tohum verimi bileşenleri

	Seed number per capsule	1000 Seed Weight (g)	Number of Branches	Number of Capsules	Seed Yield (kg da^{-1})
Cultivars					
Karakız	7.90±0.35	7.99±0.02 **a**	6.17±0.30	15.83±0.87	174.33±11.98 **b**
Beyaz Gelin	8.32±0.35	6.35±0.05 **b**	6.33±0.44	18.20±1.32	234.00±22.91 **a**
Noreum	8.17±0.49	5.96±0.13 **c**	5.73±0.18	16.53±1.56	241.33±6.94 **a**
$F_{Cultivar}$	0.19ns	173.82**	5.45ns	0.87ns	10.19*
CV (%)	7.73	13.91	9.12	13.02	18.18
SEM	0.21	0.31	0.18	0.73	13.12

CV: Coefficient of variation, SEM: Standard error of mean, ns: non significant, *: significant at P ≤ 0.05, **: significant at P ≤ 0.01

The effect of cultivars on the thousand seed weight was found to be significant. The highest thousand seed weight was observed in the cv. 'Karakız' while the lowest was in the cv. 'Noreum' (7.99-5.96 unit plant^{-1}, respectively). Studies have reported significant differences among cultivars in terms of thousand seed weight (Yıldırım, 2005; Tunçtürk, 2007; Örs & Öztürk, 2018; Aslan & Sarıhan, 2020; Aydın, 2020) a parameter highly correlated with seed yield (Çopur et al., 2005; Aydın, 2020).

The effect of cultivars on the number of branches was found to be insignificant. The number of branches varied between 5.73 and 6.33 unit plant^{-1} across cultivars. While plant density can influence the number of branches in flax, branching remains a genetic trait. Studies indicate variations in the number of branches among flax cultivars, possibly influenced by plant types (oil, fiber, and dual type), cultural practices, plant density, and ecological differences (Yıldırım, 2005; Tunçtürk, 2007; Aslan & Sarıhan, 2020; Aydın, 2020).

The impact of cultivars on capsule number per plant was not significant, with counts ranging between 15.83 and 18.20 unit plant^{-1}. According to Yıldırım (2005) and Aydın (2020), there is a linear relationship between capsule count and seed yield. However, the simultaneous formation and/or ripening of all capsules on branches terminating with capsules may not occur uniformly, as the cultivation period may not be sufficient for all branches to end with capsules (Aygün & Mert, 2022). The results align with the previous studies indicating that capsule count is not significantly influenced by cultivars (Yıldırım, 2005; Kurt et al., 2006; Aydın, 2020). However, similar to the number of branches, capsule count varies significantly based on plant type in studies using different cultivars (Örs & Öztürk, 2018; Aslan & Sarıhan, 2020; Aygün & Mert, 2022).

The impact of cultivars on seed yield was found to be significant, with the highest seed yield recorded in the cv. 'Noreum' at 241.33 kg da^{-1} and the lowest in the cv. 'Karakız' at 174.33 kg da^{-1}. While seed yield is a crucial parameter for oil-type and dual-type flax, it is not as sought after for fiber-type flax. This is because in flax plants harvested for fiber, seed maturation is not anticipated and they are harvested earlier. Seed yield is influenced by plant types and, naturally, genotype. Studies indicate significant differences in seed yield among flax cultivars (Yıldırım, 2005; Tunçtürk, 2007; Örs & Öztürk, 2018; Aslan & Sarıhan, 2020; Aydın, 2020).

In conclusion, this study comprehensively investigated the impact of different harvesting stages of flax cultivars on various agricultural parameters and provided important information.

Significant technical stem length variation was identified among different cultivars, suggesting that genetic diversity plays a role in morphological traits. Harvest stages were found to be significant effect on the technical stem length, highlighting the importance of strategic planning for optimum harvesting time. Considerable disparities were observed among cultivars concerning fiber content and seed yield. The cv. 'Noreum' demonstrated superiority, excelling in both fiber content and seed yield.

Meticulous planning of agricultural practices and cultivar selection is essential to meet specific goals. Tailoring cultivar choices based on whether the emphasis is on fiber or seed production is crucial. Determining optimal harvesting stage is critical for maximizing both fiber and seed yields. This decision should factor in diverse agricultural strategies and prevailing climate conditions.

In conclusion, the outcomes of this study highlight the pivotal roles of cultivar selection and harvesting stages in shaping the agricultural performance of flax. Future research endeavors, comparing results across diverse ecosystems and under varied climatic conditions, will contribute to a more comprehensive understanding of the genetic diversity and adaptability of the flax plant.

STATEMENT OF CONFLICT OF INTEREST

The author(s) declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

STATEMENT OF ETHICS CONSENT

Ethical approval is not applicable, because this article does not contain any studies with human or animal subjects.

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