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# *Carthamus tinctorius* L. - A SPECIES WITH POTENTIAL FOR EXPANDING CULTIVATED AREAS

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***Abstract***

*Carthamus tinctorius L. – safflower - is a promising oilseed crop for drought-prone regions. Research conducted in the southwestern Banat region on eutric semicarbonatic alluvial soil involved two experiments: one focusing on fertilization and the other on plant density and row spacing. In the fertilization trial, the highest yield of 3335 kg/ha was achieved with an N150P100K60 treatment. This regimen also enhanced grain quality, as evidenced by an increase in the thousand seed weight from 30.4 g in the control to 37.2 g, and an improvement in hectoliter mass from 40.2 kg/hl to 46.2 kg/hl. In a separate experiment evaluating plant density and row spacing, the optimal configuration was found to be 250,000 harvestable plants per hectare with a row spacing of 70 cm, resulting in a yield of 3050 kg/ha. Furthermore, chemical analyses revealed that oil content increased from 30.8% in the control to 40.5% in the $N_{100}P_{100}K_{60}$ treatment, culminating in a maximum oil production of 1398 kg/ha. These results underscore the potential of safflower as a high-yield, high-quality oil crop when appropriate agronomic practices are applied.*

***Key words***: *evolution, milk production, NW Region, Romania, trends.*

## INTRODUCTION

In recent decades, the frequency of years with large climatic deviations, which affect agricultural harvests over large geographical areas and large areas of our country, has determined that a good part of the research activity has moved in this direction (Smuleac et al., 2000). In our country, the pedological and atmospheric drought as well as the particularly high temperatures during the vegetation period have caused large harvest losses for economically important crops in our country. The present research falls in the direction of correcting the structure of crops in drought-affected areas, with more resistant crops (Chițu et al., 2024). Among these important crops we can also mention the safflower.

*Carthamus tinctorius* L., commonly known as safflower, is an ancient oilseed crop belonging to the Asteraceae family. Cultivated for over 4,000 years, safflower has historically been used for its brightly colored petals as a natural dye, its seeds for oil extraction, and its medicinal properties in traditional medicine (Dajue & Mündel, 1996). In modern agriculture, safflower is gaining renewed interest due to its adaptability to arid and semi-arid climates, making it a valuable crop for sustainable farming in water-limited regions (Fernández-Martínez et al., 2015; Imbrea et al., 2017).

Safflower is primarily grown for its high-quality oil, which is rich in unsaturated fatty acids, particularly oleic and linoleic acids (Weiss, 2000). These properties make safflower oil a desirable alternative for culinary, pharmaceutical, and cosmetic applications (Ashrafi & Razmjoo, 2010). Additionally, safflower meal, a byproduct of oil extraction, serves as a protein-rich feed for livestock (Koutroubas et al., 2009). The petals, which contain bioactive compounds such as flavonoids and polyphenols, have been traditionally used in herbal medicine and are now being explored for their potential antioxidant, anti-inflammatory, and cardiovascular benefits (Li et al., 2018). More recently, safflower's industrial applications, including its use in biofuel production and natural dyes, have expanded its economic significance (Singh & Nimbkar, 2016).

Optimal fertilization practices play a crucial role in maximizing safflower yield and oil content. As a deep-rooted crop, safflower efficiently utilizes soil nutrients but responds positively to nitrogen (N), phosphorus (P), and potassium (K) supplementation (Emongor, 2010). Nitrogen is essential for vegetative growth and biomass accumulation, while phosphorus enhances root development and seed production (Sabaghpour et al., 2018). Potassium contributes to stress tolerance and overall plant health (Hussain et al., 2022). However, excessive nitrogen application can delay flowering and increase susceptibility to lodging, necessitating a balanced fertilization strategy (Ghanbari Malidarreh et al., 2020). Recent studies highlight the potential benefits of integrating organic amendments, biofertilizers, and precision nutrient management to improve safflower productivity in diverse agroecological conditions (Yasin Ashraf et al., 2016).

With growing global demand for sustainable oil crops, safflower presents promising opportunities for expansion and innovation. Future research should focus on breeding high-yielding and climate-resilient safflower varieties, optimizing fertilization techniques to enhance nutrient use efficiency, and exploring the crop's potential in regenerative agriculture (Fernández-Martínez et al., 2015). Additionally, advancements in biotechnology, such as genetic modification and genome editing, may contribute to improved drought tolerance, pest resistance, and enhanced oil composition (Bătrâna et al., 2021, Ahmadzadeh et al., 2021). As agricultural systems shift toward sustainability, integrating safflower into crop rotation and intercropping systems could further enhance soil health, biodiversity, and farm profitability (Zaman et al., 2019).

## MATERIALS AND METHODS

The research was conducted in the Southwest of Banat, in the Bozovici Depression near the locality of Pătaș. The experiment was a bifactorial design with 3 replications. Factor A involved fertilization with phosphorus and potassium, with the following levels: a1 – $P_0K_{60}$, a2 – $P_{50}K_{60}$, and a3 – $P_{100}K_{60}$; while Factor B consisted of nitrogen fertilization, with the levels: b1 – $N_0$, b2 – $N_{50}$, b3 – $N_{100}$, and b4 – $N_{150}$.

Research on crop density (number of harvestable plants per hectare) and row spacing is an important aspect of cultivation technology - even for species with a high degree of branching, as in the case of safflower, which forms 14 to 60 branches, each ending in a capitulum in which 15 to 20 achenes are produced.

The experiments were carried out in the same area as the previous study during the experimental cycle 2022-2024. This experiment also followed a bifactorial design with 3 replications. Factor A was crop density, with two levels: a1 – 200,000 harvestable plants per hectare and a2 – 250,000 harvestable plants per hectare. Factor B was row spacing, with three levels: b1 – 25 cm, b2 – 50 cm, and b3 – 70 cm. The preceding crop was autumn wheat, and the safflower variety used was CW99OL. Fertilization was applied uniformly using an $N_{150}P_{80}K_{60}$ treatment. The technology implemented in the experimental field was similar to that used in the previous experiment.

For the climatic characterization, data from the Bozovici Meteorological Station were utilized. Analysis of the climatic data indicates that the reference area falls within a moderately temperate continental climate. The limited sub-Mediterranean and oceanic influences impart a distinctive nuance to the depression. The geographical location, topography, and certain local factors give the area its unique climatic dynamics.

The soil in the experimental field is an eutric semicarbonatic alluvial soil. The groundwater table is located at a depth of 3 to 5 meters. The soil texture is that of a coarse clay-loam in the 0-120 cm layer. The soil reaction is slightly alkaline, and the humus content is moderate in the 0-50 cm layer.

The field experiments aimed to optimize fertilization and sowing technology. The safflower variety used was CW99OL, with autumn wheat as the preceding crop. Fertilization with phosphorus and potassium was applied during the autumn plowing, while nitrogen fertilizers were used during the preparation of the seedbed. Soil operations were carried out using conventional methods in the following sequence: disking the soil to destroy the turf and retain moisture; plowing with a moldboard plow to a depth of 23-25 cm; and in spring, preparing the seedbed with a disc cultivator combined with a harrow. Sowing was performed using seed with a purity of 98% and a germination rate of 77%, at a time when the soil temperature at a 5 cm depth reached 5°C. A seeder designed for cereals was used for sowing, and the soil was subsequently harrowed. Weed control was managed with pre-emergence herbicide applications using Trifluralin and Ethafluralin, followed by post-emergence treatment with Sethoxylin and an additional spray during the vegetative stage.

Safflower can be affected by a number of diseases, including alternariosis, safflower rust, septoria, fusarium, and gray rot. Among the most common pests are the earth beetle, the safflower midge, the seed bug, and the cotton capsule caterpillar. In the research conducted in the reference area, the incidence of these diseases did not warrant treatment as they remained below the damage threshold. However, an outbreak of earth beetle occurred, for which a treatment with approved insecticides was applied. Harvesting was carried out at full maturity in September, when there was no risk of the achenes shattering.

## RESULTS AND DISCUSSIONS

The synthesis of yield results obtained during the 2022-2024 experimental cycle depending on fertilization is presented in Table 1.

Table 1. Synthesis of yield results obtained during the 2022-2024 experimental cycle depending on fertilization

| NPK Dosage | B factor – nitorogen fertilization | | | | A factor average | | | |
|---|---|---|---|---|---|---|---|---|
| | $N_0$ | $N_{50}$ | $N_{100}$ | $N_{150}$ | yield kg/ha | % | Diff Kg/ha | Sign. |
| $P_0K_{60}$ | 1520 | 1943 | 2405 | 2660 | 2137 | 100 | | |
| $P_{50}K_{60}$ | 1716 | 2278 | 2755 | 2941 | 2422 | 113 | 285 | X |
| $P_{100}K_{60}$ | 1880 | 2080 | 3044 | 3335 | 2584 | 121 | 447 | XX |
| DL 5%= 203 DL 1%= 346 DL 0.1%=672 | | | | | | | | |

| | B factor average | | | |
|---|---|---|---|---|
| | $N_0$ | $N_{50}$ | $N_{100}$ | $N_{150}$ |
| Yield (kg/ha) | 1705 | 2100 | 2734 | 2985 |
| % | 100 | 123 | 160 | 175 |
| Diff. (Kg/ha) | | 395 | 1029 | 1280 |
| Sign. | | XX | XXX | XXX |
| DL 5% = 203 DL 1% = 297 DL 0.1% = 397 | | | | |

Regarding the impact of phosphorus (P) and potassium (K) fertilization on yield, it is observed that Factor A, representing different doses of phosphorus and potassium fertilization (P and K), significantly influences yield levels. In the control variant ($P_0K_0$, without P and K fertilization), the lowest average yield was obtained (2,137 kg/ha). The application of phosphorus and potassium ($P_{60}K_0$) led to an increase in yield to 2,422 kg/ha, indicating a positive influence of these essential nutrients. A combined fertilization with phosphorus and potassium ($P_{60}K_{60}$) had the greatest impact on production, reaching 2,584 kg/ha, confirming the crucial role of these nutrients in yield improvement.

The influence of nitrogen doses on yield highlights that the control variant without nitrogen ($N_0$) results in lower yields (1,520 kg/ha in the $P_0K_0$ variant). Increasing the nitrogen dose ($N_{30}$, $N_{60}$, $N_{90}$) has a direct effect on yield enhancement, with the highest production recorded at the maximum nitrogen dose ($N_{90}$), where the yield reaches an average of 2,985 kg/ha. The differences between nitrogen fertilization levels are statistically significant (XXX for LSD 0.1%), confirming the importance of nitrogen as a limiting factor in achieving high yields.

The analysis of the interaction between fertilization factors indicates that the combined use of nitrogen, phosphorus, and potassium leads to the highest yields. The highest production was obtained in the $P_{60}K_{60}$ - $N_{90}$ variant, indicating a synergistic effect among these nutrients.

In conclusion, P and K fertilization significantly contributes to yield increase, with the maximum effect observed in the combined variant $P_{60}K_{60}$. Nitrogen is a critical factor in yield enhancement, with the maximum dose ($N_{90}$) generating the highest yield increase. The optimal fertilization strategy recommended based on these results is the combination of $P_{60}K_{60}$ doses with the application of a high nitrogen dose ($N_{90}$) to achieve the best yields. The statistically significant differences confirm the validity of the results, supporting the implementation of optimal fertilization strategies in agricultural practice.

The effect of different nitrogen (N) doses on the thousand-kernel weight (TKW) in relation to phosphorus (P) and potassium (K) fertilization is presented in Figure 1.

The overall trend of thousand-kernel weight (TKW) in relation to fertilization shows a consistent increase in TKW as the nitrogen dose increases across all fertilization variants. The highest TKW values are obtained for the maximum nitrogen doses ($N_{150}$), indicating a positive influence of nitrogen on grain weight.

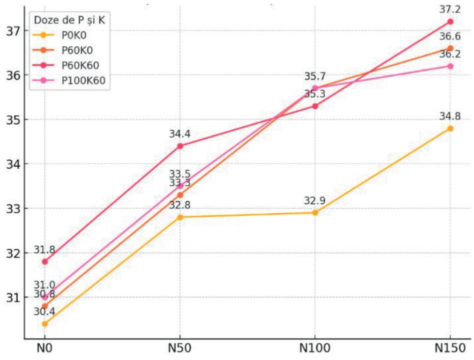


Figure 1. Effect of different nitrogen (N) doses on the thousand-kernel weight (TKW) in relation to phosphorus (P) and potassium (K) fertilization

The impact of phosphorus and potassium on TKW shows that in the absence of P and K fertilization ($P_0K_0$), TKW has the lowest values, regardless of the nitrogen level applied. A significant increase in TKW is observed in the fertilized variants $P_{60}K_0$ and $P_{60}K_{60}$, suggesting that phosphorus and potassium contribute to improving grain weight. The highest TKW value (37.2 g) was recorded in the $P_{60}K_{60}$ + N150 variant, confirming the beneficial interaction between nitrogen, phosphorus, and potassium.

The effect of nitrogen on TKW highlights that in all variants, nitrogen application leads to a progressive increase in TKW. From $N_0$ to $N_{50}$, there is a relatively moderate increase, but after the application of higher doses ($N_{100}$ and $N_{150}$), TKW increases significantly, demonstrating the importance of nitrogen in the formation of larger and heavier grains. The most pronounced increase in TKW is observed in the variants fertilized with phosphorus and potassium ($P_{60}K_{60}$ and $P_{100}K_{60}$), suggesting that the combined application of these nutrients maximizes nitrogen use efficiency.

In conclusion, nitrogen fertilization has a direct and positive effect on grain weight, with the highest values recorded for the $N_{150}$ dose. The combination of nitrogen with phosphorus and potassium optimizes results, with the $P_{60}K_{60}$ and $P_{100}K_{60}$ variants achieving the highest TKW values. To maximize yield and grain quality, a balanced application of nitrogen, phosphorus, and potassium is recommended, while avoiding over-fertilization, which may reduce the economic efficiency of the crop. These results are essential for establishing an optimal fertilization strategy, ensuring both high yields and superior grain quality.

The effect of fertilization on test weight (TW) [kg/hl], an important indicator of production quality, is presented in Figure 2.

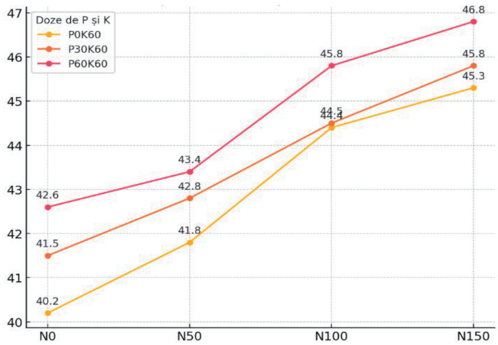


Figure 2. The effect of fertilization on test weight (TW) [kg/hl]

The overall trend of test weight (TW) in relation to fertilization shows a progressive increase in TW with nitrogen application, indicating that fertilization positively influences grain density and quality. The lowest TW values are recorded for $N_0$, while the highest values are obtained for $N_{150}$, confirming the importance of applying an adequate nitrogen dose.

In the $P_0K_{60}$ variant, TW values are lower across all nitrogen levels, suggesting that an insufficient phosphorus supply affects seed density. A more balanced fertilization with phosphorus and potassium ($P_{30}K_{60}$ and $P_{60}K_{60}$) leads to a significant increase in TW, with the highest effects observed in the $P_{60}K_{60}$ variant. The highest TW value (46.8 kg/hl) was obtained in the $P_{60}K_{60}$ + $N_{150}$ variant, confirming that the interaction between nitrogen, phosphorus, and potassium optimizes production quality.

In all variants, nitrogen application resulted in an increase in test weight. Compared to the control variant ($N_0$ to $N_{50}$), TW increase is moderate, but after the application of higher nitrogen doses ($N_{100}$ and $N_{150}$), a significant improvement in test weight is observed. The most pronounced increase occurs in the $P_{60}K_{60}$ variant, suggesting that the combined application of nitrogen with phosphorus and potassium enhances the metabolic efficiency of plants, leading to higher grain density.

Regarding this parameter as well, it can be affirmed that nitrogen significantly contributes to increasing test weight, being essential for the formation of denser and higher-quality grains. Phosphorus and potassium have a complementary effect, optimizing nitrogen efficiency and leading to higher TW values. The best fertilization strategy for maximizing production quality is the balanced application of $N_{150}$ + $P_{60}K_{60}$. Excessive nitrogen fertilization without an adequate phosphorus and potassium supply may not provide the same benefits, emphasizing the importance of balanced plant nutrition.

The evolution of oil content (%) in relation to fertilization, averaged over the experimental cycle, is presented in Figure 3.

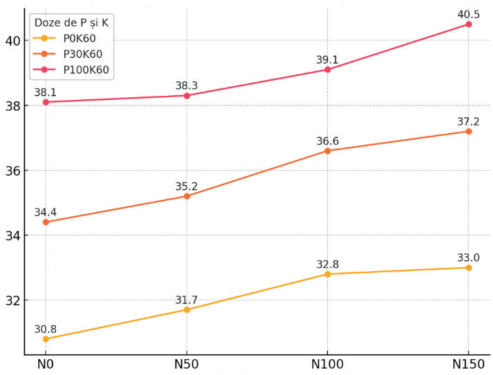


Figure 3. Oil content in relation to fertilization

A gradual increase in oil content is observed with nitrogen application, regardless of the phosphorus and potassium fertilization variant. The lowest oil content values are associated with minimal fertilization ($P_0K_{60}$, $N_0$: 30.8%), while the highest values are obtained under full fertilization ($P_{100}K_{60}$, $N_{150}$: 40.5%).

The impact of phosphorus and potassium on oil content highlights that in the $P_0K_{60}$ variant, oil content increases slowly from 30.8% ($N_0$) to 33.0% ($N_{150}$). At the $P_{30}K_{60}$ level, the values are higher, starting at 34.4% ($N_0$) and reaching 37.2% ($N_{150}$). In the $P_{100}K_{60}$ variant, which benefits from the best phosphorus and potassium fertilization, the highest oil content values are recorded, ranging from 38.1% ($N_0$) to 40.5% ($N_{150}$). These data suggest that phosphorus and potassium application improves nitrogen use efficiency, promoting oil accumulation in seeds.

Nitrogen application results in a progressive increase in oil content; however, this effect is more pronounced in variants with higher levels of P and K. The steepest increase is observed in the $P_{100}K_{60}$ variant, indicating that a balanced application of nitrogen together with P and K optimizes oil biosynthesis in seeds. At high nitrogen doses ($N_{150}$), oil content increases more slowly in variants with reduced fertilization ($P_0K_{60}$), suggesting that nitrogen alone is insufficient to maximize oil content without an adequate phosphorus and potassium supply.

In conclusion, oil content increases with fertilizer application, but the best combination for maximizing this parameter is the use of nitrogen together with high doses of P and K ($P_{100}K_{60}$, $N_{150}$). Phosphorus and potassium play an essential role in oil synthesis, and without them, nitrogen efficiency is reduced. To obtain an oil-rich yield, a balanced fertilization strategy is recommended, incorporating nitrogen, phosphorus, and potassium. Furthermore, nitrogen-only fertilization does not maximize oil content, highlighting the necessity of complete plant nutrition for optimal results.

The oil yield, calculated based on grain yield and oil content, is presented in Figure 4.

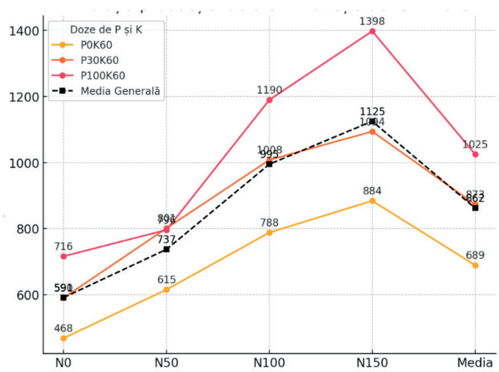


Figure 4. Evolution of oil yield (kg/ha) in relation to fertilization

The data indicate a significant increase in oil yield with the application of higher nitrogen doses, regardless of the phosphorus and potassium fertilization variant. The overall average oil yield increases from 591 kg/ha ($N_0$) to 1125 kg/ha ($N_{150}$), confirming the critical role of nitrogen in production efficiency.

At all nitrogen levels, P and K fertilization leads to a significant increase in oil yield. The $P_0K_{60}$ fertilization level (without additional phosphorus) has the lowest oil yield values, with an average of 689 kg/ha. The $P_{30}K_{60}$ level shows an improvement, reaching an average of 873 kg/ha, demonstrating that phosphorus supplementation enhances nitrogen use efficiency. The $P_{100}K_{60}$ level provides the best results, with an average yield of 1025 kg/ha, and at the maximum nitrogen dose ($N_{150}$), the highest oil yield is achieved: 1398 kg/ha. This trend confirms that balanced phosphorus and potassium fertilization maximizes nitrogen efficiency in oil biosynthesis.

Regarding the influence of nitrogen, it is observed that at $N_0$, the lowest oil yield values are recorded, indicating that insufficient nitrogen supply limits biomass accumulation and, consequently, oil production. At the $N_{50}$ dose, a significant increase in oil yield is observed, but the most substantial effects appear at $N_{100}$ and $N_{150}$. The maximum nitrogen dose ($N_{150}$) results in the highest oil yields across all P and K fertilization variants, confirming that high-dose nitrogen application is crucial for maximizing oil production.

In conclusion, oil yield significantly increases with fertilizer application. However, the best fertilization strategy for maximizing oil production is the combination of nitrogen with high doses of phosphorus and potassium ($P_{100}K_{60}$, $N_{150}$). Nitrogen is essential for maximizing oil yield, but without an adequate phosphorus and potassium supply, its efficiency is reduced. The optimal fertilization strategy is $P_{100}K_{60}$ + $N_{150}$, which generated the highest oil yield (1398 kg/ha).

Research on the influence of plant density and row spacing on the yield of *Carthamus tinctorius* L. is presented in Table 2.

Table 2. The Influence of plant density and row distance on the yield of *Carthamus tinctorius* L.

| A factor - Density | B Factor – Row distance | | | A factor average | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 70 | Yield (Kg/ha) | % | Diff (Kg/ha) | Sign. |
| 200k pl/ha | 2024 | 2516 | 2610 | 2383 | 100 | | |
| 250k pl/ha | 2210 | 2775 | 3050 | 2670 | 112 | 295 | X |
| DL 5%= 196 DL 1%= 356 DL 0,1%=562 | | | | | | | |

| | B factor average | | |
|---|---|---|---|
| | 25 | 50 | 70 |
| Yield (Kg/ha) | 2117 | 2645 | 2830 |
| % | 100 | 125 | 133 |
| Diff. (Kg/ha) | | 528 | 713 |
| Sign. | | XXX | XXX |
| DL 5%= 203 DL 1%= 297 DL 0,1%=397 | | | |

The results show that at a plant density of 200,000 plants/ha, the yield ranges between 2,024 kg/ha and 2,610 kg/ha, depending on row spacing. At a density of 250,000 plants/ha, the yield is higher, varying between 2,210 kg/ha and 3,050 kg/ha. The mean value for Factor A indicates an increase in yield at the higher plant density (2,670 kg/ha compared to 2,383 kg/ha), with a significant difference of 295 kg/ha. These results suggest that a higher plant density favors increased safflower (*Carthamus tinctorius* L.) production.

The influence of row spacing on yield shows a significant production increase as row spacing widens: at 25 cm: 2,117 kg/ha, at 50 cm: 2,645 kg/ha, and at 70 cm: 2,830 kg/ha. Regarding significant differences, yield increased by 528 kg/ha at 50 cm compared to 25 cm and by 713 kg/ha at 70 cm compared to 25 cm. These results suggest that increasing row spacing contributes positively to yield improvement, possibly due to reduced competition between plants for resources.

The interaction between factors highlights a favorable combined effect of plant density and row spacing. At high density (250,000 plants/ha) and 70 cm row spacing, the highest yield was obtained (3,050 kg/ha). At the lower density (200,000 plants/ha) and 70 cm row spacing, the yield was lower (2,610 kg/ha) but remained superior to the values recorded at narrower row spacings.

## CONCLUSIONS

Following the analyses conducted on various aspects of safflower (*Carthamus tinctorius* L.) cultivation, including total yield, thousand-kernel weight (TKW), test weight (TW), oil content, and oil yield, the following conclusions can be drawn regarding the effects of nitrogen (N), phosphorus (P), and potassium (K) fertilization:

- Nitrogen fertilization significantly contributes to improving crop yield. Nitrogen application leads to a progressive increase in total yield, both in terms of grain production (kg/ha) and oil content. The highest TKW and TW values were obtained at the maximum nitrogen dose (N150), confirming the crucial role of nitrogen in optimal plant development and seed quality. In all experimental variants, increasing the nitrogen dose resulted in a substantial rise in oil yield (kg/ha), with the highest values recorded at $N_{150}$.

- Phosphorus and potassium application optimizes nitrogen use efficiency. P and K fertilization led to significant production increases, demonstrating that while nitrogen is essential, it requires the support of other nutrients to maximize yield. The lowest values for all measured indicators were recorded in the $P_0K_0$ variant (without P and K fertilization), emphasizing the importance of complete plant nutrition. The best fertilization strategy was the combination of a high nitrogen dose ($N_{150}$) with $P_{60}K_{60}$ or $P_{100}K_{60}$, where the highest values for total production and seed quality were achieved.
- The interaction between N, P, and K maximizes oil yield. Oil content (%) progressively increased with fertilization, reaching maximum values in the $P_{100}K_{60}$ + $N_{150}$ variant. The highest total oil yield (kg/ha) was obtained in the $P_{100}K_{60}$ + $N_{150}$ variant (1,398 kg/ha), confirming that balanced fertilization is essential for high yield and superior crop quality. The application of nitrogen without P and K led to limited increases in oil content, demonstrating that nitrogen-only fertilization is insufficient for achieving maximum oil production.
- The impact of plant density and row spacing on seed production was also significant. The highest yield was obtained at a density of 250,000 plants/ha with a row spacing of 70 cm.

The obtained results confirm that balanced fertilization with nitrogen, phosphorus, and potassium has a direct and significant impact on the yield and quality of safflower cultivation. The $N_{150}$ + $P_{100}K_{60}$ fertilization strategy is optimal for maximizing both total production and oil content, making it a recommended practice for farmers seeking high-yield and high-quality safflower crops.

These conclusions are relevant for optimizing fertilization technologies and improving the economic efficiency of oilseed crops, with important implications for the development of sustainable agriculture.

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