Research Journal of Agricultural Science, 57 (3), 2025; ISSN: 2668-926X

http://doi.org/10.59463/RJAS.2025.3.49

STUDIES ON THE CULTIVATION TECHNOLOGY OF *Camelina sativa* L. UNDER THE CONDITIONS OF THE DIDACTIC EXPERIMENTAL STATION TIMIȘOARA

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Abstract. *The present study was carried out at the Didactic and Experimental Station of the University of Life Sciences "King Michael I" from Timișoara during the 2023–2024 agricultural year, with the aim of evaluating the influence of nitrogen and phosphorus fertilization on the productivity of Camelina sativa L. cultivated under the specific conditions of the Banat Plain. The experiment was organized according to a bifactorial design with four replications, where factor A represented nitrogen doses (N0, N40, N80, N120 kg ha⁻¹) and factor B represented phosphorus doses (P0, P40, P80 kg ha⁻¹). The soil of the experimental field was moderately supplied with nitrogen and phosphorus, and well supplied with potassium. Results revealed that both fertilizations had a significant effect on plant growth and seed yield. The highest average yield of 1663 kg ha⁻¹ was recorded in the variant N120P80, representing a 113% increase compared to the unfertilized control (780 kg ha⁻¹). Nitrogen proved to be the dominant factor in determining yield formation, while phosphorus enhanced nitrogen efficiency through a synergistic effect. The results confirm the adaptability of Camelina sativa L. to local pedoclimatic conditions and its responsiveness to rational fertilization, supporting its potential as a sustainable oilseed crop in Western Romania.*

Keywords*: Camelina sativa L., nitrogen fertilization, phosphorus fertilization, seed yield, Banat Plain, sustainable oilseed crops.*

INTRODUCTION

Camelina sativa (L.) Crantz, commonly known as camelina or false flax, is an ancient oilseed species belonging to the Brassicaceae family. Archaeobotanical evidence indicates that it was cultivated in Europe as early as the Bronze Age and was widely used until it was gradually replaced by rapeseed and other oilseed crops during the twentieth century (ZUBR, 2003). In recent years, however, camelina has gained renewed scientific and industrial attention as a climate resilient and sustainable alternative oilseed, suitable for cultivation on marginal lands and under low-input agricultural systems (BERTI ET AL., 2016).

Camelina's agronomic potential derives from its high adaptability to diverse environmental conditions, low fertilizer requirements, and short vegetation period, typically ranging from 85 to 100 days. It can thrive in semi-arid or temperate continental climates, tolerates low temperatures, and has modest sensitivity to pests and diseases (VOLLMANN & EYNCK, 2015). These characteristics make it a valuable component of sustainable farming systems, particularly within the framework of the European Green Deal and the Common Agricultural Policy, which promote crop diversification and resource-efficient agricultural practices (EUROPEAN COMMISSION, 2020).

From a biochemical and industrial perspective, camelina seeds contain 35–40% oil with a distinctive fatty acid profile rich in omega-3 and omega-6 polyunsaturated fatty acids, especially α-linolenic acid (C18:3). This confers camelina oil high oxidative stability and nutritional quality, making it suitable for both edible oil and biofuel production (ABRAMOVIC & ABRAM, 2005; BERTI ET AL., 2016). Moreover, camelina oil exhibits biological and antimicrobial activity, with recent studies demonstrating its inhibitory effects against Campylobacter jejuni and its potential to stimulate beneficial lactic acid bacteria growth (BĂTRÎNA ET AL., 2022b). These properties further expand its application potential in the food, pharmaceutical, and functional feed industries.

Agronomically, *Camelina sativa* is a low-input crop that performs well under conditions where other oilseeds fail to deliver consistent yields. It competes moderately with weeds, requires reduced pesticide inputs, and is well suited for dryland and organic farming systems (OBOUR ET AL., 2015). Because of its adaptability and ecological advantages, camelina is increasingly recognized as a strategic crop for sustainable bioeconomy development. Its inclusion in crop rotations improves soil structure and fertility, while its short growth cycle allows double cropping or relay cropping in temperate regions (AGEGNEHU & SINEBO, 2018).

In Romania, the first systematic studies on Camelina sativa began in the early 2000s, focusing on its adaptability to different pedoclimatic regions and its potential as a renewable source of oil (IMBREA ET AL., 2011; POPESCU ET AL., 2018). Trials conducted at the University of Life Sciences "King Michael I" from Timișoara and other research centers in western Romania have demonstrated good adaptability and moderate yield potential, typically between 1.0 and 2.0 t ha^{-1} under moderate fertilization. Recent experiments carried out in the western part of the country highlighted that Camelina sativa responds favorably to mineral fertilization, particularly when nitrogen and phosphorus are supplied in balanced proportions (BĂTRÎNA ET AL., 2022).

Fertilization management remains one of the most important factors influencing camelina productivity and oil composition. Nitrogen (N) and phosphorus (P) play essential roles in plant growth and metabolic processes: nitrogen directly affects photosynthetic activity, protein synthesis, and chlorophyll content, while phosphorus contributes to root development, energy transfer, and seed formation (ZANETTI ET AL., 2017; JANKOWSKI ET AL., 2019). A balanced N–P fertilization regime can improve both seed yield and oil accumulation efficiency, whereas excessive nitrogen may reduce oil concentration and delay maturity (VOLLMANN ET AL., 2007).

Although camelina is widely considered a low nutrient demanding crop, its yield potential can be significantly enhanced under appropriate nutrient management. Studies from Central and Eastern Europe have confirmed that rational fertilization particularly combining moderate nitrogen and phosphorus doses leads to higher productivity without compromising oil quality (AGEGNEHU & SINEBO, 2018; BĂTRÎNA ET AL., 2022a). Nonetheless, in Romania, data on the combined effects of N and P fertilization under the specific climatic and soil conditions of the Banat Plain remain scarce. The Banat region of Western Romania is characterized by fertile chernozem soils, moderate continental climate, and a relatively uniform rainfall distribution, providing an excellent environment for evaluating Camelina sativa's agronomic performance. Research carried out at the Didactic and Experimental Station of the University of Life Sciences "King Michael I" from Timișoara offers an opportunity to assess how different nitrogen and phosphorus rates influence yield formation and nutrient use efficiency under these conditions.

The present study was therefore undertaken to evaluate the combined influence of nitrogen and phosphorus fertilization on the growth and productivity of Camelina sativa L. under the specific pedoclimatic conditions of the Banat Plain. The objectives were: (1) to determine the main effects of N and P doses on seed yield; (2) to analyze the N×P interaction in yield formation; and (3) to identify the optimal fertilization regime that maximizes yield and ensures sustainable nutrient management.

By integrating agronomic, environmental, and industrial perspectives, this research aims to contribute to the broader understanding of *Camelina sativa* as a multi purpose, climate resilient oilseed crop for the sustainable intensification of agriculture in Western Romania. The findings are expected to provide practical guidance for optimizing camelina fertilization practices and support its inclusion in environmentally friendly cropping systems aligned with European sustainability goals.

MATERIAL AND METHODS

Experimental site and environmental conditions - yhe research was conducted during the 2023–2024 agricultural year at the Didactic and Experimental Station (DES) of the University of Life Sciences “King Michael I” from Timișoara, located in the western part of Romania (45°45′ N latitude, 21°14′ E longitude, 94 m altitude). The experimental field lies within the Banat Plain, a representative region of the Western Romanian Plain, characterized by a moderate continental climate with oceanic influences.

The average annual temperature of the area is 10.9 °C, while the mean annual rainfall is approximately 620 mm, with rainfall typically concentrated in May–July, coinciding with the main vegetative period of camelina. In the 2023–2024 agricultural year, the recorded total precipitation was 590 mm, with a relatively uniform distribution, but slightly below the multiannual average. The mean monthly temperature ranged from –1.5 °C in January to 22.6 °C in July, with a growing season mean of 16.8 °C. These conditions were favorable for camelina development, although periods of moderate drought were observed in June.

Soil characteristics - the soil of the experimental site is classified as a typical chernozem, developed on loess deposits. It has a medium clay-loam texture, good drainage, and moderate to high fertility. Before the experiment was established, composite soil samples were collected from the 0–20 cm layer for agrochemical characterization.

The main properties were as follows: pH (H_2O): 6.8 (neutral reaction); humus content: 3.2%; available nitrogen (N): 64 ppm (medium supply); available phosphorus (P_2O_5): 45 ppm (moderate supply); available potassium (K_2O): 220 ppm (well supplied).

According to these results, the soil was moderately supplied with available nitrogen and phosphorus, which justified the application of mineral fertilization treatments to assess the crop’s response to nutrient inputs.

Biological material - the biological material used in this study consisted of the spring camelina variety *Camelina sativa* L. cv. Calena, a cultivar widely used in Europe due to its high adaptability to continental climatic conditions and stable oil yield. The seed material was certified and obtained from the University of Life Sciences’ collection. The seeds were treated prior to sowing with a fungicidal product based on tebuconazole to prevent early fungal infections.

Experimental design and treatments - the experimental field was organized according to a bifactorial design in randomized blocks, with four replications.

Factor A: Nitrogen (N) fertilization rate

$a_1 = N_0$ – unfertilized control

$a_2 = N_{40}$ – 40 kg N ha^{-1}

$a_3 = N_{80}$ – 80 kg N ha^{-1}

$a_4 = N_{120}$ – 120 kg N ha^{-1}

Factor B: Phosphorus (P) fertilization rate

$b_1 = P_0$ – unfertilized control

$b_2 = P_{40}$ – 40 kg P_2O_5 ha^{-1}

$b_3 = P_{80}$ – 80 kg P_2O_5 ha^{-1}

The total number of treatment combinations was 12 (4 × 3). The fertilizers were applied as follows: phosphorus was incorporated into the soil before sowing, while nitrogen was applied in two equal fractions, half at sowing and half at the rosette stage (BBCH 30–31). Ammonium nitrate (NH_4NO_3, 34% N) was used as the nitrogen source, and triple superphosphate (46% P_2O_5) as the phosphorus source.

Each experimental plot measured 15 m² (3 × 5 m), of which the central 10 m² area was harvested for data collection, excluding border rows to minimize edge effects.

Crop management - camelina was sown in early spring, on March 14, 2024, immediately after soil preparation, when the top 10 cm soil layer reached 6–8 °C. Sowing density was 600 viable seeds m^{-2}, corresponding to a seeding rate of approximately 6 kg ha^{-1}. The sowing depth was 1.5–2.0 cm, with row spacing of 12.5 cm, using a precision small-seed drill.

No irrigation was applied, as the experiment relied entirely on natural rainfall. Weeds were controlled through one mechanical intervention at the rosette stage and manual removal in local patches. No pesticide treatments were necessary during the growing season due to camelina's high resistance to pests and diseases.

Harvesting was carried out on July 10, 2024, when plants reached full maturity (BBCH 89). After cutting, plants were air-dried for three days, followed by threshing with a stationary small plot harvester. Grain yield was corrected to a standard moisture content of 9%.

Data collection and analyzed parameters - the main biometric and yield parameters determined included: plant height (cm), measured on 10 representative plants per plot; number of siliques per plant; number of seeds per silique; thousand-seed weight (TSW, g); seed yield (kg ha^{-1}), expressed at 9% moisture. Oil content (%) was determined from a representative sample using the Soxhlet extraction method with petroleum ether as a solvent. The oil yield (kg ha^{-1}) was calculated based on seed yield and oil content.

Statistical analysis - all data were statistically processed using analysis of variance (ANOVA) for a two-factor randomized block design. The significance of differences between treatments was verified using the Least Significant Difference (LSD) test at confidence levels of 5% ($p < 0.05$) and 1% ($p < 0.01$). The statistical analyses were performed using the software package STATISTICA v.12.0 (StatSoft, Tulsa, USA). Graphical representations were created in Microsoft Excel 2021.

RESULTS AND DISCUSSIONS

Throughout the 2023–2024 growing season, the meteorological conditions were favorable for camelina development in the Banat Plain. The early sowing period ensured uniform germination, and no significant pest or disease pressure was recorded. Camelina exhibited its characteristic high adaptability to temperature fluctuations and short vegetative period, completing its life cycle in approximately 115 days from sowing to harvest. The recorded rainfall distribution was relatively balanced, with moderate precipitation during the flowering and seed-filling stages, critical phases for yield formation. However, a short dry period in late June slightly affected late-maturing plants, which may have limited final oil accumulation in some treatments.

Influence of fertilization on plant growth parameters - Fertilization had a significant effect on the vegetative growth of *Camelina sativa*. Both nitrogen and phosphorus applications increased plant height compared with the control, indicating a positive physiological response to nutrient availability. The mean plant height in the unfertilized variant (N_0P_0) was 56.3 cm, while in the $N_{120}P_{80}$ variant, it reached 83.5 cm, representing an increase of over 48%. The interaction between nitrogen and phosphorus showed a synergistic effect, as plots receiving combined fertilization displayed significantly taller plants and more uniform canopies. Similar findings were reported by

BĂTRÎNA ET AL. (2022) and IMBREA ET AL. (2011), who observed that moderate to high nitrogen doses (up to 100–120 kg N ha^{-1}) stimulate vegetative growth without excessive lodging. Adequate phosphorus supplementation promotes stronger root systems and accelerates early growth, contributing to better nutrient uptake efficiency.

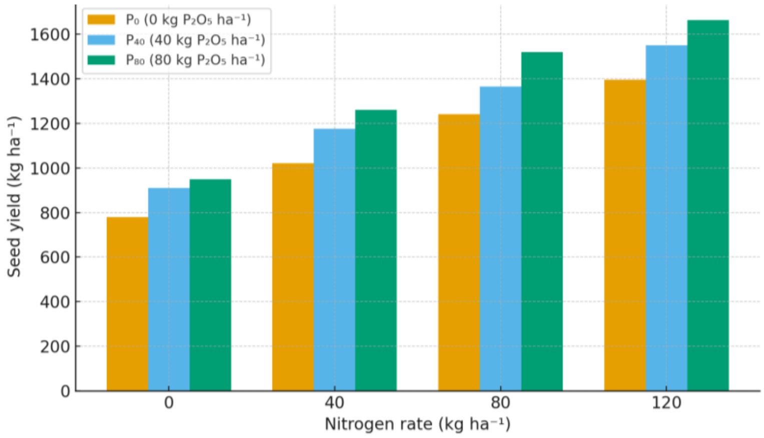

Figure 1. Effect of nitrogen and phosphorus fertilization on *Camelina sativa* seed yield

Seed yield response to nitrogen and phosphorus fertilization - the analysis of variance (ANOVA) indicated that both main factors—nitrogen and phosphorus—had a highly significant ($p < 0.01$) influence on seed yield, as well as their interaction (N×P). Average seed yields across treatments ranged between 780 kg ha^{-1} (N_0P_0) and 1663 kg ha^{-1} ($N_{120}P_{80}$). The increase in yield followed a near-linear trend up to the N_{80}–N_{120} range, beyond which additional nitrogen did not produce proportional yield gains. The yield increase of 113% between the control and the highest fertilized treatment confirms the strong responsiveness of camelina to nutrient availability.

The effect of phosphorus was also statistically significant. For example, at a constant nitrogen level of 80 kg N ha^{-1}, increasing phosphorus from P_0 to P_{80} improved yields from 1240 to 1520 kg ha^{-1}, a gain of approximately 23%. This pattern demonstrates phosphorus's role in improving nutrient balance, seed formation, and siliques filling. These results align with the findings of BĂTRÎNA ET AL. (2022a), who reported similar yield increases (up to 1.6 t ha^{-1}) in Western Romania under comparable fertilization levels. Comparable outcomes were also obtained in Central Europe, where rational N–P management significantly enhanced camelina seed productivity (ZANETTI ET AL., 2017; JANKOWSKI ET AL., 2019).

Oil content and oil yield - nitrogen and phosphorus fertilization affected not only seed yield but also the oil content of the harvested seeds. Although nitrogen promotes vegetative biomass and seed yield, excessive nitrogen can reduce oil accumulation due to increased protein synthesis at the expense of lipid formation (BERTI ET AL., 2016). In this study, oil content ranged between 32.8% ($N_{120}P_{80}$) and 37.6% (N_0P_0). The highest oil percentages were recorded in treatments with moderate fertilization ($N_{40}P_{40}$ and $N_{80}P_{40}$), indicating that balanced nutrient supply supports both yield and oil concentration. Consequently, oil yield—which combines seed yield and oil content—showed the highest value in the $N_{120}P_{80}$ treatment, reaching 624 kg ha^{-1}, followed by $N_{80}P_{80}$ (598 kg ha^{-1}). The observed trend supports previous research demonstrating that the optimal fertilization strategy for camelina maximizes oil yield at intermediate nitrogen levels combined with sufficient phosphorus availability (VOLLMANN ET AL., 2007; BĂTRÎNA ET AL., 2022a).

http://doi.org/10.59463/RJAS.2025.3.49

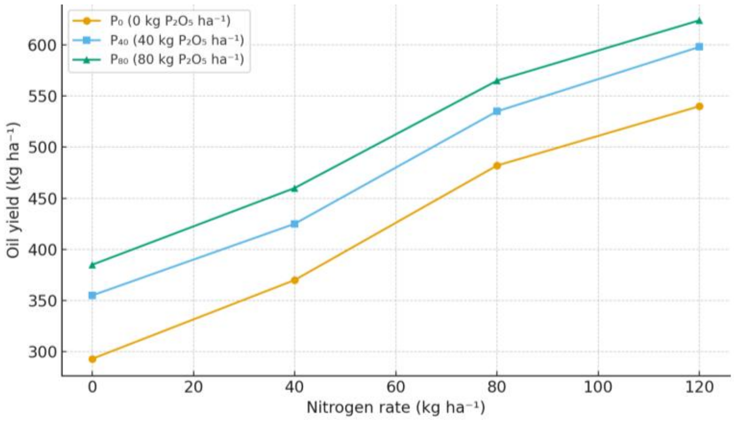

Figure 2. Interaction between nitrogen and phosphorus fertilization on oil yield of *Camelina sativa*

Relationship between yield components and fertilization - yield components such as the number of siliques per plant, number of seeds per silique, and thousand-seed weight (TSW) were also positively influenced by fertilization. The number of siliques per plant increased from 68 (control) to 121 ($N_{120}P_{80}$). The number of seeds per silique ranged between 12 and 18, with the highest values under $N_{80}P_{80}$ and $N_{120}P_{40}$. The thousand-seed weight (TSW) varied from 0.93 to 1.12 g, showing a modest but consistent increase with fertilization intensity. Correlation analysis indicated a strong positive relationship between seed yield and both plant height (r = 0.87) and siliques number (r = 0.91), confirming that improved vegetative growth directly contributes to higher yield potential.

Comparative interpretation and agronomic implications - the obtained results demonstrate that camelina is responsive to rational mineral fertilization even on moderately fertile soils. The yield response pattern suggests that nitrogen is the dominant factor in yield formation, while phosphorus acts synergistically to improve nutrient efficiency and reproductive performance. Compared to other oilseed crops, camelina exhibited moderate yield potential but superior ecological adaptability. The ability to produce over 1.6 t ha^{-1} under non-irrigated conditions confirms its suitability for semi-arid and temperate continental regions. Moreover, the stability of yield components and absence of lodging or disease symptoms emphasize the crop’s resilience and low input advantage. Its reduced sensitivity to climatic variability and balanced response to fertilization make it a valuable crop for inclusion in rotation systems aimed at reducing production risks and improving soil fertility.

Statistical validation - the results of the ANOVA test confirmed the high statistical significance ($p < 0.01$) of both main factors (N and P) and their interaction (N×P) on seed yield. The $LSD_{0.05}$ for yield differences between nitrogen levels was 65 kg ha^{-1}, and for phosphorus levels 58 kg ha^{-1}. Differences exceeding these thresholds were considered statistically significant. Graphical representations of yield trends (Figure 1 and Figure 2) clearly illustrate the positive linear response to increasing nitrogen and phosphorus levels up to the optimum dose combination ($N_{120}P_{80}$).

CONCLUSIONS

The results of this research clearly demonstrate that *Camelina sativa* (L.) Crantz has strong agronomic potential under the pedoclimatic conditions of the Banat Plain, confirming its adaptability and resilience in moderate continental climates. The crop completed its vegetation cycle within a relatively short period, exhibiting good uniformity, reduced pest and disease pressure, and stable performance despite minor rainfall fluctuations during the 2023–2024 growing season.

Nitrogen and phosphorus fertilization exerted a decisive influence on the growth dynamics, yield formation, and oil productivity of camelina. The bifactorial experimental design revealed highly significant main and interaction effects ($p < 0.01$) between the two nutrients, emphasizing their synergistic contribution to yield formation. Nitrogen primarily determined vegetative growth and seed formation, whereas phosphorus enhanced root development, nutrient uptake, and the efficiency of nitrogen utilization.

Seed yield increased progressively with rising nitrogen and phosphorus doses, reaching a maximum of 1663 kg ha^{-1} under the $N_{120}P_{80}$ treatment. Compared with the unfertilized control (N_0P_0), this represented an improvement of more than 110%**,** confirming the crop's responsiveness to mineral nutrition. However, yield increases were less pronounced beyond 80 kg N ha^{-1}, suggesting that excessive nitrogen applications do not necessarily translate into proportional gains and may reduce nutrient use efficiency. Therefore, the optimum fertilization level for seed yield under the tested conditions was estimated around $N_{80}P_{80}$**.**

Oil content exhibited an inverse trend relative to nitrogen supply, decreasing from 37.6% in the control to 32.8% under the highest fertilization level. Nevertheless, the oil yield per hectare followed the seed yield pattern, with the best results under $N_{120}P_{80}$ (624 kg ha^{-1}). These findings confirm that moderate nitrogen fertilization, in combination with adequate phosphorus, ensures a favorable balance between quantitative (seed yield) and qualitative (oil concentration) traits.

The analysis of yield components further supports this conclusion. The number of siliques per plant, number of seeds per silique, and thousand-seed weight (TSW) all increased under fertilized conditions. Correlation analysis showed a strong positive relationship between seed yield and both plant height ($r = 0.87$) and siliques number ($r = 0.91$), indicating that improvements in vegetative growth directly enhance reproductive output.

From a practical perspective, these results demonstrate that *Camelina sativa* can achieve stable and economically viable yields with moderate fertilization rates**,** thus minimizing input costs and environmental impact. This confirms camelina's suitability as a low input oilseed crop for sustainable and integrated farming systems in Western Romania. Its adaptability to local climatic conditions and relatively modest nutrient requirements make it particularly valuable for inclusion in crop rotations aimed at improving soil structure, biodiversity, and nitrogen balance. From an environmental standpoint, the rational application of fertilizers—particularly when phosphorus is optimized relative to nitrogen—can improve nutrient use efficiency and reduce losses to the environment. The integration of camelina into crop rotations could also enhance agroecosystem sustainability by reducing pest cycles and providing an early-sown, early-harvested species that allows better temporal distribution of field operations.

Overall, the study confirms that *Camelina sativa* is a promising oilseed crop capable of delivering both agronomic performance and ecological benefits under Western Romanian conditions. Future research should focus on multi-year and multi-location trials to validate these results, the optimization of fertilization under variable rainfall regimes, and the investigation of genotype × fertilization interactions. In addition, studying the effects of mineral nutrition on fatty acid composition and oxidative stability of camelina oil would provide further insights into its industrial potential.

In conclusion, *Camelina sativa* represents a viable and sustainable alternative to conventional oilseed crops such as rapeseed or sunflower, offering opportunities to diversify agricultural production and strengthen the environmental performance of farming systems in Romania and similar temperate regions of Europe.

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