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Optimizing Canola Cultivation through Adaptive Planting Dates and Nano-Bio Fertilization for Sustainable Yields

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BIO- AND NANO-FERTILIZERS offer significant economic and environmental benefits for sustainable agriculture. This study investigated the synergistic effects of planting dates, nano-fertilizers, and biofertilizers on canola growth, yield, and oil production at Arish University's Faculty of Agricultural and Environmental Sciences during the 2022–2023 and 2023–2024 seasons. The research employed a randomized complete block design with three replicates and eight treatments across two planting dates (20 October and 20 November). Treatments included a baseline control (T1) receiving 50% recommended soil NPK plus conventional NPK foliar spray (19:19:19 at 3 g/L applied at 30 and 45 DAS); an EM1-supplemented control (T5) consisting of T1 protocol with EM1 biofertilizer (5 mL/m²); and experimental treatments combining EM1 (5 mL/m²) with 50% soil NPK plus foliar nano-NPK (19:19:19) at 1, 3, or 5 mL/L. Results established that the combination of early sowing (20 October), EM1 application (5 mL/m²), and nano-NPK at 5 mL/L significantly enhanced vegetative traits (plant height, leaf number, branch number, leaf and branch weights, root length and weight, and leaf area) and yield components (seed yield, 1000-seed weight, seed weight per plant, pod length, pod weight and number, oil percentage, and oil yield). These findings emphasize the potential of integrating bio- and nano-fertilizers as an effective tool for optimizing canola production under changing climatic conditions.

Keywords: Bio fertilization, canola, em1, nano fertilizer, and planting date.

Introduction

Canola (*Brassica napus* L.) is a globally important oilseed crop widely used in food, animal feed, and biofuel industries. Its oil contains 40–45% unsaturated fatty acids—mainly oleic acid—linked to cardiovascular health benefits, with less than 1% erucic acid, making it one of the healthiest edible oils (Hossain et al., 2019; Russo et al., 2021). In addition, canola seeds provide 36–40% protein and are rich in antioxidants, including Vitamin E, carotenoids, and phenolic compounds, thereby enhancing their nutritional value (Bell et al., 2023).

Globally, canola ranks as the second-largest oilseed crop after soybean, cultivated over approximately 107 million hectares with a production of 219 million tons between 2018 and 2020 (FAOSTAT, 2018–2021). In Egypt, canola is considered a strategic crop to help reduce the national vegetable oil deficit of about 1.251 million tons annually (El Gafary et al., 2022). However, expansion remains limited due to abiotic stresses, such as salinity, drought, and high temperatures, especially in newly reclaimed lands (Rezaei et al., 2017; Kanwal et al., 2021).

Climate change has further complicated agricultural practices by altering temperature and rainfall patterns, as well as increasing the frequency of extreme weather events. These changes negatively affect crop growth, yield, and soil fertility, creating an urgent need for adaptive management strategies (Abbass et al., 2022). One such strategy is optimizing sowing time, which plays a critical role in plant development and yield components (Ma et al., 2016). Determining the optimal sowing window based on local climate conditions is especially important in subtropical regions where delayed sowing can lead to shorter flowering durations, exposure to water stress, and reduced productivity (Meier et al., 2020; Monfared et al., 2020; Rosa et al., 2020; Butkevicienė et al., 2021). Emara et al. (2018) identified that early sowing dates significantly

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outperformed late sowing dates in enhancing the productivity of Egyptian cotton (*Gossypium barbadense* L.) cv. Giza 86—particularly when combined with soil-applied nitrogen (45 kg N fed^{-1}) and foliar Lithovit nano-fertilizer (5 g/L). Although previously cited studies affirm the yield advantages of early sowing regimes, Elsobky and Hassan (2021) demonstrated that delayed cowpea planting schedules significantly increased seed yield per hectare, improved harvest index, and enhanced seed purity relative to conventional early-season establishment.

In this context, biofertilizers such as Effective Microorganisms (EM) have emerged as tools to promote sustainable agriculture. Developed in the 1970s, EM formulations comprise lactic acid bacteria, nitrogen-fixing bacteria, and photosynthetic organisms that enhance nutrient availability, accelerate the decomposition of organic matter, and improve plant health (Shi et al., 2020). Their application has been linked to better root development, higher seed germination, and improved crop yields (Batista & Singh, 2021).

Concurrently, nanotechnology has opened new avenues in agriculture. Nano-fertilizers enhance nutrient efficiency, reduce leaching, improve photosynthetic capacity, and strengthen stress resistance (Mehta et al., 2015; El-Salhy et al., 2021). Their slow-release properties and increased surface area have shown promising results across crops, including higher plant height, spike number, and grain yield (Gomaa et al., 2018). Specific improvements in fruit yield and quality were reported in citrus (El-Shereif et al., 2023), while in Sudan grass, nano-fertilizers helped reduce input costs and environmental impact (Mohsan, 2021). Furthermore, increasing nano-fertilizer application from 125 to 500 mL fed^{-1} significantly enhanced most measured traits in bread wheat (*Triticum aestivum* L.) across both growing seasons (Morsy et al., 2021).

Despite the proven benefits of biological and nano-fertilizers individually, limited research has addressed their combined application. Recent studies have shown that integrating both can significantly improve crop performance. For instance, Al-Mohammadi and Al-Dolaimi (2024) demonstrated enhanced growth in date palms using nano-fertilizers with EM1 and seaweed extracts. Similarly, Al-Ghazali and Al-Zubaidy (2023) reported improved wheat yield and quality with combined nano and biological fertilization.

Therefore, this study aims to evaluate the interactive effects of planting date, nano-fertilizer, and biofertilizer applications on canola growth, yield, and oil production under arid climatic conditions. The findings are expected to support sustainable practices for enhancing.

Materials and Methods

Study area

The field experiment was conducted at the Experimental Farm of the Faculty of Environmental Agricultural Sciences, Arish University, located in North Sinai, Egypt (31°08'04.3"N, 33°49'37.2"E), during two successive growing seasons (2023/2024 and 2024/2025). A semi-arid climate characterizes the study site. Detailed meteorological data for both seasons are provided in Table 1.

Experimental Layout

The study was conducted on a 240 m² experimental area employing a Randomized Complete Block Design (RCBD) with three replicates, implemented as a split-split plot arrangement. The primary factor consisted of two planting dates (20 October and 20 November), defining the main plots. Within these main plots, sub-plots were assigned to the EM1 bio-fertilizer factor (applied at 5 mL/m² or not applied). Sub-sub-plots were designated for the nano-NPK fertilizer treatments, comprising concentrations of 0, 1, 3, or 5 mL/L.

All treatments received a basal application of 50% of the recommended dose of mineral NPK fertilizer (RDF - Nitrogen, Phosphorus, Potassium). Crucially, only the control treatments (T1 and T5) received an additional foliar spray of conventional NPK (19:19:19) at 3 g/L applied at 30 and 45 days after sowing (DAS). The nano-NPK treatments (T2-T4, T6-T8) were applied as foliar sprays at their respective concentrations (1, 3, or 5 mL/L) at 30 and 45 DAS, replacing the conventional NPK foliar spray.

Two specific control treatments were established:

T1 (Absolute Control): 50% RDF (basal) + Conventional NPK foliar spray (3 g/L) without EM1 and without nano-NPK.

T5 (Bio-fertilizer Control): 50% RDF (basal) + Conventional NPK foliar spray (3 g/L) with EM1 but without nano-NPK.

These controls provided essential reference points for evaluating the effects of replacing the conventional NPK foliar spray with nano-NPK and the addition of EM1.

The complete experiment comprised eight treatments applied to both planting dates:

T1: 50% RDF (basal) + Conventional NPK Foliar (3 g/L) | No EM1

T2: 50% RDF (basal) + Nano-NPK (1 mL/L) Foliar | No EM1

T3: 50% RDF (basal) + Nano-NPK (3 mL/L) Foliar
T4: 50% RDF (basal) + Nano-NPK (5 mL/L) Foliar
T5: 50% RDF (basal) + Conventional NPK Foliar (3 g/L) | With EM1
T6: 50% RDF (basal) + Nano-NPK (1 mL/L) Foliar | With EM1
T7: 50% RDF (basal) + Nano-NPK (3 mL/L) Foliar | With EM1
T8: 50% RDF (basal) + Nano-NPK (5 mL/L) Foliar | With EM1

Field implementation utilized manual drilling for sowing seeds in hills spaced 30 cm apart along rows 50 cm apart, consistent for both planting dates. Farmyard manure was incorporated during land preparation at a rate of 20 m³ per feddan (feddan ≈ 4200 m²). All agronomic practices strictly adhered to the recommendations of the Egyptian Ministry of Agriculture.

Fertilizations

1. Nano Fertilization

The foliar fertilizer used in the nano-NPK treatments was a commercially labeled product (Nano-NPK 19:19:19) supplied by Bio-Nano Technology Company, Egypt. The nano NPK fertilizer formulation comprises the following chemical constituents:19% total nitrogen (N), 19% available phosphate (expressed as P_2O_5), and 19% soluble potash (expressed as K_2O). The interpretation of the observed physiological responses is based on the reported agronomic performance of this product and supported by previous findings on nano-fertilizer efficiency.

2. Bio-Fertilization

The bio-fertilizer EM1 (Effective Microorganisms) used in this experiment contains various beneficial microorganisms that improve soil fertility and promote plant growth. It includes lactic acid bacteria such as Lactobacillus plantarum, L. casei, and Streptococcus lactis, as well as photosynthetic bacteria like Rhodopseudomonas plustris and Rhodobacter sphacerodes. It was applied in two equal doses, each at a rate of 5 mL/m². The first application occurred after the second thinning of the plants, followed by a second dose at the onset of floral siliqua emergence. Both applications were administered through the drip irrigation system on sandy soils.

Table 1. Meteorological data of El-Arish, North Sinai, region during canola growing seasons of 2022/2023 and 2023/2024.

Months	Average temperature (°C)	Minimum Air Temperature [°C]	Maximum Air Temperature [°C]	Average Relative Humidity (%)	Total precipitation (mm)	Solar Radiation (MJ/m^2/day)
First season 2022-2023						
October-2022	24.16	21.23	28.29	66.80	7.85	16.49
November-2022	20.38	17.36	24.40	66.75	5.35	12.57
December-2022	17.06	13.82	21.36	70.09	6.95	9.90
January-2023	14.54	10.67	19.61	69.40	15.75	12.04
February-2023	12.70	9.62	16.47	71.61	20.10	13.32
March-2023	17.12	12.71	22.72	62.81	11.95	18.77
April-2023	19.28	14.67	25.28	63.95	14.60	23.50
May-2023	22.27	17.72	28.21	63.61	1.35	25.42
Average and Sum	18.44	14.72	23.29	66.88	167.8	16.50
Second Season 2023-2024						
October-2023	24.91	21.99	28.95	68.43	6.05	15.72
November-2023	21.88	18.84	26.15	69.31	5.45	12.49
December-2023	17.19	13.54	21.92	69.69	6.55	9.68
January-2024	14.89	11.23	19.36	67.18	22.25	11.36
February-2024	13.42	10.09	17.50	75.76	19.65	14.32
March-2024	16.13	11.96	21.43	68.82	5.95	19.78
April-2024	20.36	15.90	26.30	68.78	2.30	23.33
May-2024	22.56	18.13	28.29	61.92	1.05	25.33
Average and Sum	18.92	15.21	23.74	68.74	138.5	16.50

Source: Central Laboratory for Agricultural Climate (CLAC, Egypt).

Plant Materials

The plant material used in this study was the "Serw4" canola cultivar. The seeds were obtained from the Oil Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt.

Soil Mechanical and Chemical Analyses

The Soil and Water Department (SWD) conducted mechanical and chemical soil analyses during both growing seasons. The results are summarized in Tables 2 and 3.

Table 2. Mechanical analysis of soil (Average of the two seasons).

Soil Depth (cm)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Soil Texture
0-30	67.1	18.9	2.6	11.4	Sandy loam

Table 3. Chemical analysis of soil (Average of the two seasons).

Soil Depth (cm)	Organic carbon $g.kg^{-1}$.	pH	EC ($dS\ m^{-1}$)	$CaCO_3$ (%)	Organic matter $g.kg^{-1}$.
0-30	1.08	8.515	1.6	3.93	2.05
Soluble Cations (meq L^{-1})				**Soluble Anions (meq L^{-1})**	
K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	HCO_3^-
0.48	2.64	2.19	2.9	1.286	2.405

Recorded Data

The following vegetative traits data were recorded 90 days after sowing:

(plant height (cm)-number of leaves- number of shoots- leaf weight (g)-shoot weight (g)-root weight (g)-root length (cm)-leaf area (cm²))

The following yield components and oil yield data were recorded 150 days after sowing:(seed yield (ton/fed)-1000 seed weight (g) -seed weight/plant (g)-pod length (cm)-pods weight (g) -number of pods-oil percentage (%)-oil yield kg/fed)

Statistical Analysis

Data from both growing seasons were statistically analyzed using the MSTAT-C computer program (Snedecor & Cochran, 1990). The variance analysis was used to examine the data (ANOVA) using a one-way test. Mean values were compared using the multiple-range test (Duncan, 1955) at a significance level of $P \leq 0.05$.

Results and Discussion

1. **Effect of planting date optimization, bio, and nano fertilizers on canola vegetative traits and their interaction:**

As shown in Table 4, vegetative traits reached their highest values on the first planting date compared to the second across both growing seasons. This phenomenon can be attributed to variations in the meteorological conditions, as detailed in Table 1, which highlights significant differences in the average temperatures and cumulative precipitation between the two planting dates. The increased rainfall, combined with higher temperatures at the onset of the germination phase, contributed to a marked improvement in germination rates, seedling vigor, and overall vegetative development, which continued until optimal temperatures and field capacity were reached. The superiority of early sowing is attributed to optimal thermal conditions during germination (October average: 24.2°C), which accelerate enzymatic activity for photosynthesis and protein synthesis. Concurrently, higher seasonal rainfall (167.8 vs 138.5 mm) improved water availability for meristematic growth (Szczerba *et al.*, 2021).

Table 4. Effect of planting dates, bio, and nano fertilizer on (plant height-leaves number -root number- leaves weight-shoot weight -root weight -root length- leaf area) of canola vegetative growth during two successive growing seasons 2022/23-2023/24.

Characters / Factors	Plant height(cm)	Leaves number	Root number	Leaves weight(g)	Shoot weight (g)	Root weight (g)	Root length cm	Leaf area (cm^2)
***First season* 2022/23**								
20 October	110.44a	43.12a	11.35a	144.28a	156.74a	65.58a	28.68a	181.51a
20 November	103.56b	35.95b	9.84b	135.97b	143.49b	57.13b	26.65b	157.51b
Bio1	104.04b	37.17b	9.70b	139.75b	146.29b	58.48b	25.95b	155.14b
Bio2	109.96a	41.91a	11.48a	140.50a	153.94a	64.23a	29.38a	183.88a
Control	86.78^{d}	25.25^{d}	9.07^{d}	103.38^{d}	104.44^{d}	47.94^{d}	25.16^{d}	142.3d
NPK 1Ml/l	102.04^{c}	33.20^{c}	9.65^{c}	121.86^{c}	122.03^{c}	55.51^{c}	26.92^{c}	160.5c
NPK 3ml/l	114.87^{b}	44.76^{b}	10.52^{b}	144.46^{b}	170.57^{b}	61.92^{b}	28.31^{b}	175.3b
NPK 5ml/l	124.30^{a}	54.94^{a}	13.12^{a}	190.80^{a}	203.41$^{\mathbf{a}}$	80.05$^{\mathbf{a}}$	30.28^{a}	200.0a
2023/24 *Second season*								
20 October	101.60a	38.913a	8.95a	133.41a	145.87a	58.69a	24.82a	154.44a
20 November	94.42b	31.63b	7.77b	124.10b	131.95b	49.42b	23.22b	132.30b
Bio1	94.62b	33.14b	7.44b	126.86b	135.09b	50.92b	22.40b	130.28b
Bio2	101.40a	37.40a	9.28a	130.65a	142.72a	57.19a	25.63a	156.46a
Control	77.28d	21.28d	6.58c	91.45d	93.23d	39.58d	20.99d	116.1d
NPK 1ml/l	92.27c	29.36c	7.45c	113.05c	111.88c	47.67c	23.47c	134.9c
NPK 3ml/l	106.78b	39.82b	8.48b	132.0b	158.92b	55.80b	25.06b	150.0 b
NPK 5ml/l	115.71a	50.61a	10.94a	178.5a	191.60**a**	73.17**a**	26.54a	172.4a

Numbers followed by the same letter in the same columns are not significantly different at 5% DMR (Duncan's Multiple Range).

Regarding bio-fertilization with EM1, it was observed that all vegetative traits increased significantly when plants were fertilized with EM1 at a rate of 5 ml/m² compared to unfertilized plants, as shown in Table 4. This enhancement stems from microbial consortia (Lactobacillus, photosynthetic bacteria) lowering rhizosphere pH and solubilizing bound nutrients (notably phosphorus in alkaline sandy soils). Simultaneous production of phytohormones (auxins/cytokinins) stimulated root meristem activity (Olle & Williams, 2013; Ghabour *et al.*, 2019). The influence of Nano NPK fertilization via foliar spray at a concentration of 5 ml/L significantly enhanced all vegetative parameters, including plant height, number of leaves, number of shoots, number of roots, leaf weight, shoot weight, root weight, root length, and leaf area. The results presented in Table 4 show that plant height, number of leaves, number of roots, leaf weight, shoot weight, root weight, root length, and leaf area exhibited percentage increases over the two growing seasons. Specifically, they achieved increases of (30.2%, 33.2%), (54%, 58%), (30.8%, 39.8%), (45.8%, 48.8%), (48.8%, 51.3%), (40.1%, 45.9%), (16.9%, 20.9%), and (28.9%, 32.7%) during the two growing seasons by respectively, compared to the control treatment. The efficacy of nano-fertilizers stems from their sub-100 nm particle size, which enables stomatal penetration, and a high specific surface area that facilitates rapid nitrogen assimilation. Critically, nano-nitrogen upregulated auxin biosynthesis, driving cell elongation (Al-Asady & Al-Kikkhani, 2019), while bypassing soil nutrient fixation (Liu & Lal, 2014). These findings align with those obtained by Karunakaran et al. (2016), Al-Juthery et al. (2019), Alwakel et al. (2021).

Table 5. Interaction of planting dates, bio, and nano fertilizer on (plant height-leaves number -root number- leaves weight-shoot weight -root weight -root length- leaf area) of Canola vegetative growth during two successive growing seasons 2022/23-2023/24.

Characters / Treatments		Plant height(cm)	Leaves number	Root number	Leaves weight(g)	Shoot weight(g)	Root weight(g)	Root length(cm)	Leaf area(cm^2)
***First season* 2022/23**									
20 October	**T1**	88.22h	24.99m	9.11i	102.22k	108.54j	46.34l	24.40h	134.770 j
	T2	100.50f	34.12i	9.65h	133.48g	130.60g	55.89h	26.20f	153.847gh
	T3	115.29d	49.42e	10.53g	145.43e	168.33e	62.30f	27.33e	180.040e
	T4	124.08b	54.17c	13.20c	196.47a	197.97b	83.87b	29.07c	204.040b
	T5	92.06g	28.73k	10.63g	110.30j	113.91i	56.82h	28.24d	157.363g
	T6	112.12de	37.44h	11.30ef	116.40i	122.70h	62.24f	29.37c	189.603d
	T7	121.23bc	50.60d	12.00d	151.17d	185.66d	68.62e	30.40b	199.740bc
	T8	130.03a	65.49a	14.37a	198.75a	226.17a	88.57a	34.46a	232.690a
20 November	**T1**	81.69i	21.09n	7.35l	97.45l	93.19 l	40.27m	22.36i	125.200k
	T2	93.90g	29.26k	7.86k	125.78h	120.67h	50.37j	24.61h	135.090j
	T3	109.77e	39.34g	8.47j	141.25f	161.74f	56.40h	26.30f	140.633i
	T4	118.88c	44.94f	11.43e	175.91c	189.26c	72.43d	27.33e	167.500f
	T5	85.15h	26.21l	9.20i	103.55k	102.12k	48.34k	25.63g	151.910h
	T6	101.64f	31.97j	9.79h	111.78j	114.15i	53.55i	27.50e	163.267f
	T7	113.21d	39.67g	11.10f	139.99f	166.53e	60.37g	29.20c	180.807e
	T8	124.23b	55.14b	13.48b	192.07b	200.25**b**	75.33c	30.27b	195.633c
2023/24 Second season									
20 October	**T1**	78.83i	22.43j	5.95hi	90.62ij	97.63i	37.82j	20.32g	110.703 j
	T2	89.25g	30.59g	7.28fg	120.41e	120.91f	47.11gh	22.91de	128.527 hi
	T3	107.68d	44.80c	8.60de	131.36d	157.16d	56.83e	23.81d	150.350 de
	T4	117.47b	50.67b	10.80b	183.50a	188.49b	77.08b	25.35c	175.317 b
	T5	83.80h	24.06ij	8.59de	98.25gh	102.71h	47.76gh	23.27d	130.700 gh
	T6	102.51e	32.89f	8.92cd	117.09ef	112.96g	56.02e	25.62c	162.083 c
	T7	112.12c	45.66c	9.72c	139.13c	174.82c	64.35d	27.25b	175.063 b
	T8	121.11a	60.16a	11.73ab	186.87a	212.26a	83.00a	29.99a	202.770 a
20 November	**T1**	71.43k	16.86k	5.06i	84.56j	81.34k	33.39k	18.47h	100.707 k
	T2	84.94h	25.79i	5.87hi	113.15f	109.44g	41.49i	21.37fg	112.250 j
	T3	98.55f	33.59ef	6.62gh	128.65d	149.81e	50.09fg	22.96de	120.700 i
	T4	108.82d	40.39d	9.31cd	162.64b	175.94c	63.55d	24.01d	143.657 ef
	T5	75.04j	21.79j	6.70gh	92.36hi	91.24j	39.77ij	21.94ef	122.273 i
	T6	92.39g	28.16h	7.72ef	101.56g	104.21h	46.07h	23.96d	136.847 fg
	T7	108.77cd	35.24e	8.96cd	128.94d	153.88d	51.94f	26.20bc	154.000 d
	T8	115.44b	51.21b	11.92a	180.96a	189.69b	69.05c	26.82b	167.970bc

Numbers followed by the same letter in the same columns are not significantly different at 5% DMR.

This synergy is explained by EM1 improving soil N-mineralization, while nano-NPK delivers bioavailable nutrients during peak vegetative demand (30–45 DAS). Early sowing extended growth duration under favorable temperatures, amplifying these effects, as shown in Table 5 (Alwakel et al., 2021).

2. Effect of planting date optimization, bio, and nano fertilizers on canola yield component, oil yield, and their interaction

According to the data displayed in Table 6, the yield components and oil yield attained their maximum values on the first planting date compared to the second, throughout both growing seasons. The yield advantage primarily originates from the avoidance of terminal heat stress during flowering (Feb-Mar: 12.7-17.1°C), ensuring complete pollination. An extended grain-filling period under moderate temperatures optimized photoassimilate partitioning to seeds (Butkevicienė *et al*., 2021). Additionally, the results demonstrated that applying EM1 biofertilizer at 5 ml/m² significantly enhanced all yield components compared to the untreated control. These improvements are mediated through the microbial production of growth regulators (e.g., gibberellins), which enhance flower retention and are coupled with enhanced phosphorus solubilization, supporting ATP-dependent lipid biosynthesis (Batista & Singh, 2021). The application of nano NPK fertilizer at a concentration of 5 ml/L resulted in a significant improvement in various plant characteristics, including the number of pods, pod weight (g), pod length (cm), seed weight per plant (g), 1000-seed weight (g), seed yield (ton/fed), oil percentage (%), and oil yield kg/fed. Specifically, the treatment led to increases of 28.92% and 31.18% in the number of pods, 45.85% and 65.17% in pod weight, 23.76% and 28.01% in pod length, 53.37% and 65.14% in the number of seeds per pod, 60.19% and 63.81% in seed weight per plant, 56.66% and 65.33% in 1000-seed weight, 13.36% and 13.52% in oil percentage, and 74.09% and 87.95% in oil yield when compared to the control treatment at first and second season respectively as presented in the data shown in Table 6. The efficacy of nano-NPK fertilization in enhancing canola productivity operates through three well-documented mechanisms. First, nanoparticles exhibit superior phloem-mediated translocation, enabling the targeted delivery of nutrients to developing seeds while minimizing ion leakage (Abd El-Aziz *et al*., 2016). This ensures optimal NPK availability during critical stages of oil accumulation. Second, nano-NPK enhances photosynthetic efficiency by increasing chlorophyll synthesis and photosystem II activity, thereby increasing carbon assimilation, which is essential for lipid biosynthesis (Al-Juthery *et al*., 2019). Third, nano-nitrogen upregulates auxin synthesis (Al-Asady & Al-Kikkhani, 2019), promoting cell division and pod development, which expands sink capacity for oil deposition.

Table 6. Effect of planting dates bio, and Nano fertilizer on (seed yield (ton/fed),1000 seed weight (g), seed weight/plant (g), number of seed/pods, pod length (cm), pods weight (g), number of pods, oli percentage%, oil yield kg/fed) of canola growth traits during 2022/23-2023/24.

Characters / Factors	Number of pods	Pods Weight(g)	Pod length(cm)	Seed weight/ Plant(g)	1000Seed(g)	Seed Yield (ton/fed)	Oil percentage (%)	Oil yield kg/fed
***First season* 2022/23**								
20 October	493.34a	55.03a	7.42a	30.01a	2.94a	1.26a	42.97a	544.70a
20 November	471.15b	50.75b	7.23b	26.41b	2.57b	1.10b	41.57b	464.71b
Bio1	464.56b	50.49b	7.21b	26.22b	2.67b	1.09b	41.08b	454.63b
Bio2	499.92a	55.29a	7.45a	30.19a	2.85a	1.25a	43.45a	554.79a
Control	417.30d	42.97d	6.44d	21.98d	2.11d	0.90d	39.61d	365.35d
NPK 1ml/l	471.07c	50.56c	7.15c	26.79c	2.51c	1.12c	41.26c	464.45c
NPK 3ml/l	502.49b	55.37b	7.76b	30.35b	3.02b	1.27b	43.29b	552.99b
NPK 5ml/l	538.10a	62.67a	7.97a	33.71a	3.38a	1.41a	44.91a	636.03a
***Second season* 2023/24**								
20 October	460.91a	48.26a	6.95a	26.33a	2.82a	1.09a	41.89a	461.99a
20 November	439.30b	44.17b	6.75b	22.69b	2.45b	0.94b	40.99b	386.71b
Bio1	432.83b	43.35b	6.71b	22.53b	2.55b	0.93b	40.27b	378.93b
Bio2	467.38a	49.07a	6.99a	26.50a	2.73a	1.10a	42.62a	472.78a
Control	385.16d	34.74d	5.89c	18.16d	1.99d	0.75d	38.76d	292.30d
NPK 1ml/l	439.40c	43.47c	6.70b	23.08c	2.39c	0.96c	40.49c	388.31c
NPK 3ml/l	470.58b	49.24b	7.28a	26.81b	2.90b	1.11b	42.52b	474.46b
NPK 5ml/l	505.27a	57.38a	7.54a	29.99a	3.26a	1.24a	44.00a	548.33a

Numbers followed by the same letter in the same columns are not significantly different at 5% DMR.

Table 7. Effect of interaction between planting dates, bio, and Nano fertilizer on (seed yield (ton/fed),1000 seed weight (g), seed weight/plant (g), number of seed/pods, pod length (cm), pods weight (g), number of pods, oli percentage%, oil yield kg/fed) of canola growth traits during 2022/23-2023/24.

Characters / Treatments		Number of pods	Pods weight	Pod length	Seed weight/plant	1000seed	Seed Yield	Oil percentage (%)	Oil yield kg/fed
***First season* 2022/23**									
20 October	**T1**	416.39i	41.41h	6.40h	21.20k	2.10j	0.89e	39.30k	349.6k
	T2	475.75g	50.44e	7.18e	26.17i	2.53g	1.10d	41.38g	454.4h
	T3	498.05ef	55.57d	7.87bc	30.32f	3.10d	1.27c	42.37f	537.4f
	T4	516.03d	62.03b	8.03ab	33.48c	3.53b	1.40b	44.34d	621.4d
	T5	428.94h	46.61f	6.71g	26.58h	2.35h	1.11d	40.37hi	446.6i
	T6	494.74f	54.71d	7.22de	31.42d	2.92e	1.32c	42.40f	557.4e
	T7	533.94c	60.89b	7.91abc	34.45b	3.24c	1.45b	46.33b	668.8b
	T8	582.91a	68.55a	8.07a	36.43a	3.73a	1.53a	47.23a	722.0a
20 November	**T1**	401.68j	39.34i	6.09i	19.45m	1.95k	0.81f	38.64l	314.0l
	T2	432.97h	45.65fg	7.01f	22.27j	2.23i	0.93e	39.81j	371.9j
	T3	474.90g	50.70e	7.37d	26.20i	2.75f	1.10d	40.54h	445.7i
	T4	500.73ef	58.76c	7.76c	30.67e	3.13d	1.28c	42.27f	542.7f
	T5	422.19i	44.50g	6.57g	20.67l	2.05j	0.80f	40.13i	351.2k
	T6	480.84g	51.42e	7.20e	27.31g	2.35h	1.14d	41.44g	474.1g
	T7	503.09e	54.30d	7.88bc	30.45ef	2.98e	1.28c	43.91e	560.1e
	T8	552.75b	61.31b	8.01ab	34.23b	3.14d	1.44b	45.81c	658.0c
Second season 2023/24									
20 October	**T1**	381.79k	31.68h	5.65g	17.43i	1.98j	0.72ef	8.23g	276.5j
	T2	444.76gh	42.03f	6.76de	22.60g	2.41g	0.94d	40.30e	377.5h
	T3	468.25e	48.77d	7.43abc	26.66e	2.98d	1.11c	41.25d	456.5f
	T4	483.78d	55.94b	7.59ab	29.89c	3.41b	1.24b	43.29c	535.4c
	T5	397.44i	38.99g	6.22f	22.75g	2.23h	0.94d	39.24f	370.2h
	T6	463.46f	48.82d	6.80de	27.60d	2.80e	1.15c	41.22d	472.6de
	T7	499.61c	55.43bc	7.46abc	30.94b	3.12c	1.28b	45.25b	579.2b
	T8	548.15a	64.37a	7.68a	32.77a	3.61a	1.36a	46.29a	628.1a
20 November	**T1**	371.07l	31.41h	5.60g	15.48j	1.83k	0.64g	38.26g	244.9k
	T2	400.90i	38.50g	6.52e	18.45h	2.11i	0.76e	39.26f	299.7i
	T3	443.34h	45.14e	6.88d	22.77g	2.63f	0.94d	40.28e	380.0h
	T4	468.71e	53.34c	7.27c	26.92e	3.01d	1.12c	41.27d	460.9ef
	T5	390.35j	36.88g	6.08f	16.97i	1.93j	0.71f	39.28f	277.6j
	T6	448.49g	44.54e	6.71de	23.66f	2.23h	0.98d	41.17d	403.5g
	T7	471.13e	47.63d	7.36bc	26.88e	2.86e	1.11c	43.30c	482.1d
	T8	520.43b	55.88b	7.62ab	30.41bc	3.02d	1.26b	45.15b	568.9b

Numbers followed by the same letter in the same columns are not significantly different at 5% DMR.

Table 7 clearly shows that the interaction effects of various factors, including planting date, EM1 bio-fertilizer, and nano-NPK fertilization, on vegetative traits, yield components, and oil yield are studied. The optimal combination for maximizing all previous traits was achieved when canola was sown on the initial planting date in October, combined with the application of EM1 bio-fertilizer at a rate of 5 ml/m^2 and a foliar spray of 5 ml/L Nano NPK fertilizer, administered 30 and 45 days after sowing. This breakthrough results from EM1 enhancing soil N availability, nano-NPK ensuring a sustained nutrient supply during seed filling, and early sowing extending photosynthetic activity. The synergy elevated sucrose flux for lipid synthesis, increasing harvest index by 18.3-22.7% (Alwakel *et al.*, 2021; WA Al-Juthery & Al-Maamouri, 2020).

Conclusion

This study highlights the significant interaction effects of planting date, bio-fertilization with EM1, and nano-NPK fertilization on canola vegetative traits, yield components, and oil yield. The optimal outcomes were achieved when canola was sown on the initial planting date in October, combined with the application of EM1 bio-fertilizer and a foliar spray of 5 mL/L Nano NPK fertilizer at 30 and 45 days after sowing. This combination enhanced plant growth and maximized seed yield and oil content, significantly boosting oil yield. These findings offer a sustainable and practical approach to enhancing the quantity and quality of canola production by improving the oil percentage in the seeds and overall oil production. To enable large-scale application, further multi-location field trials and cost–benefit analyses are recommended to assess the economic feasibility and consistency of these practices across diverse growing environments. Such efforts would support broader adoption by farmers and contribute to more resilient and sustainable oilseed production systems.

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تحسين زراعة الكانولا من خلال تعديل مواعيد الزراعة والتسميد النانوي والحيوي لتحقيق إنتاجية مستدامة

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توفر الأسمدة الحيوية والنانوية فوائد اقتصادية وبيئية كبيرة للزراعة المستدامة حيث استهدفت هذه الدراسة - المنفذة بكلية العلوم الزراعية والبيئية بجامعة العريش خلال موسمي 2023-2022 و2024-2023 - تحليل التأثير التكاملي لمواعيد الزراعة والأسمدة النانوية والمخصبات الحيوية على نمو وإنتاجية وجودة زيت الكانولا واعتمد البحث تصميم القطاعات الكاملة العشوائية بثلاثة مكررات وثماني معاملات شملت موعدين للزراعة (20 أكتوبر و20 نوفمبر) حيث تضمنت المعاملات مجموعة ضابطة أساسية (T1) تلقت 50% من الجرعة الأرضية الموصى بها من NPK مع رش ورقي بالأسمدة التقليدية NPK (19:19:19 بتركيز 3 جم/لتر عند 30 و45 يوماً من الزراعة) ومجموعة ضابطة مدمجة مع (T5) EM1 طبقت نفس بروتوكول T1 مع إضافة المخصب الحيوي EM1 (5 مل/م²) إلى جانب معاملات تجريبية جمعت بين EM1 (5 مل/م²) و50% جرعة NPK أرضية ورش ورقي بالأسمدة النانوية NPK (19:19:19) بتركيزات 1 أو 3 أو 5 مل/لتر وقد أثبتت النتائج تفوقاً معنوياً للزراعة المبكرة (20 أكتوبر) مع تطبيق EM1(5 مل/م²) والسماد النانوي NPK (5 مل/لتر) في تعزيز الصفات الخضرية المتمثلة في ارتفاع النبات وعدد الأوراق والفروع وأوزانها وطول الجذور ووزنها والمساحة الورقية وكذلك مكونات المحصول بما يشمل محصول البذور ووزن الألف بذرة ووزن البذور/نبات وطول القرون ووزنها وعددها ونسبة الزيت وإنتاجيته مما يؤكد إمكانية دمج الأسمدة الحيوية والنانوية كأداة فعالة لتحسين إنتاجية الكانولا النوعية والكمية تحت ظروف التغير المناخي.

الكلمات المفتاحية : التسميد الحيوي، الكانولا، EM1، الأسمدة النانوية، موعد الزراعة.