NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 43, 2026
www.incda-fundulea.ro; doi.org/10.59665/rar4306 First Online: December, 2025. DII 2067-5720 RAR 2025-7

Sustainable Fertilizer Management with Pelleted Organic Fertilizer and Effective Microorganisms: Improving the Morphological Traits, Yield Components, Bioactive Compounds, and Antioxidant Activity of Chickpeas

Shara Salih Ali

Sulaimani Polytechnic University, Bakrajo Technical Institute, Food Science and Quality Control; Sulaymaniyah, Iraq
*Corresponding author. E-mail: shara.ali@spu.edu.iq

ABSTRACT

Chickpea (*Cicer arietinum* L.) is a crucial legume crops valuable for its economical, nutritional, and agroecological gains. Development of eco-friendly soil amendments represents a strategic innovation, facilitating the bioconversion of organic and microbiological inputs into soil and promoting sustainable resource management. The present research study seeks to investigate the individual and combined impacts of pelleted organic fertilizers (POFs) and effective microorganisms (EMOs) on morphological traits, yield components, bioactive compound, and antioxidant activity of chickpea under semi-arid condition. Factorial experiment was conducted with three replications and six conditions: POFs (0%, 4%, 8% w/w) and EMOs (0, 4, 8 ppm). Both POFs and EMOs significantly enhanced some of morphological trait, yield, bioactive compound (total phenolic content, anthocyanin content, and seeds antioxidant activity. The combined application of 8% POFs and 4 ppm EMOs produced the highest improvements, raising grain yield from [512.9 kg ha^{-1} (control) to 912.5 kg ha^{-1}], 100 seed weight from (29.9 g to 56.4 g), and total phenolic content (TPC) from (125.9 to 212.5 mg FAE 100 g^{-1} D.M.). Antioxidant activity doubled from (1.19 to 2.25 mg TE 100 g^{-1} D.M.). These findings reveal the synergistic potential of combining organic and microbial fertilizer methods to improve chickpea productivity, nutritional quality, and sustainability, presenting a feasible substitute to traditional chemical fertilizers.

Keywords: grain yield, semi-arid agroecosystems, phenolic content, anthocyanin content, DPPH radical.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a globally cultivated crops with production exceeding 15 million tons annually and cultivated in 50+ countries for thousands of years across Asia, Africa, Australia, Europe, and the Americas (Koul et al., 2022). Globally as the third most widely produced legume, chickpea contributes significantly to nutrition and security of the nutritional value, sustainable agriculture, and rural economies (Zhang et al., 2024a). Chickpea is highly valued for its exceptional nutritional profile including 20-25% of protein by weight, making it a crucial dietary component in vegetarian and vegan diets (Boukid, 2021), complex carbohydrates, dietary fiber, while its fat content is low and doesn’t contain any cholesterol. It is also abundant in minerals including folate, iron (Fe), zinc (Zn), magnesium (Mg), and vitamin B6 (Sots et al., 2024). The high fiber content and low glycemic index of chickpea contribute to improved digestive health and better glycemic control (Singh et al., 2021). Chickpea also known for its risk reduction effects of diseases (chronic) and cancer such as cardiovascular disease, obesity, and certain types cancers (Kakaei et al., 2024). Chickpea seeds are not only valued for their macronutrient content but are also valuable resources of biologically active compounds (bioactive) compounds, particularly phenolic acids, flavonoids, and anthocyanins, which collectively contribute for antioxidant activity function and these phytochemicals play an essential role in health of human by neutralizing free radicals (Begum et al., 2023; Noreen et al., 2024). The antioxidant activity of chickpea is mainly due to its high levels of total phenolics and anthocyanins, which exhibit robust free radical scavenging abilities (Nithiyanantham et al., 2012).

Received 4 September 2025; accepted 15 December 2025.

Moreover, the concentration and composition of these bioactive content can change due to genetical, environmental, and agronomical factors, such as regulation of soil in terms of fertility and the use of organic enriched amendment (Pasqualone et al., 2021). Therefore, evaluating the impact of different fertilization strategies on the bioactive compound profile and antioxidant capacity of chickpea seeds is crucial for both nutritional quality and health-promoting properties. As a legume, chickpea forms symbiotic associations with nitrogen (N) fixing (*Rhizobium spp.)* as a bacteria, which promotes the conversion of N fixing bacteria to a form of atmospheric N which is usable by plants (Goyal et al., 2021). The genetic variety of the crop serves as a crucial asset for breeding initiatives focused on enhancing productivity, disease resistance, and resilience to abiotic conditions like drought and heat (Tiwari et al., 2023). The global relevance of chickpeas is highlighted by their exceptional nutritional content, essential role in sustainable and climate resilient agriculture, and economic importance for millions. Conventional fertilization practices, which predominantly rely on synthetic fertilizers, have raised significant concerns regarding their long-term sustainability and environmental impact (Tyagi et al., 2022). In 2022, worldwide chickpea production reached 15.1 million tons, with India contributing nearly 70% of the whole yield. The prolonged usability of chemical fertilizer highlights the urgent need to find a substitute amendment for fertilization strategies and promote more sustainable alternatives. The application of synthetic fertilizers is a notable cause of gas emissions (greenhouse), specially nitrous oxide (N_2O), and their production depends on finite natural resources such as phosphate rock and natural gas, making this approach inherently unsustainable (Aryal et al., 2022). Among these strategies to maintain soil fertility is application of POFs which also known as granular organic fertilizer and have maintained attention due to their role in enhancing the structure of the soil enhanced the availability of nutrient, and support soil in term of health longevity (Babla et al., 2022). POFs are nutrient dense supplements created by compressing composted organic resources such as plant residues, animal manures, and other biodegradable waste, into small, homogenous granular or pellets (Shaji et al., 2021). These fertilizers are designed to facilitate gradual and steady nutrients release (essentials), including N, P, and K, as well as a range of micronutrients, to support the growth and production of plant over an extended period (Asadu et al., 2024). Unlike synthetic fertilizers, POFs not only supply nutrients but also contribute soil organic components, which have crucial potential in enhancing soil health (Bamdad et al., 2022). The application of POFs offers several potential benefits for both soil and plants. POFs demonstrate yield enhancing effects, primarily due to their potential soil fertility enhancement, structure, and availability of the nutrient (Juntahum et al., 2025). Studies indicate that POFs can produce yields equivalent to or surpassing those of conventional fertilizers, particularly when applied for a long period (Šarauskis et al., 2021). EMOs are naturally occurring beneficial microbes found in the soil, including fungi, bacteria, actinomycetes, and yeasts that have adapted to local environmental conditions (Singh and Christina, 2022). These microorganisms have a vital potentials in maintaining the fertility and health of the soil by throughout the decomposition of organic matter nutrient and cycling. Methods for isolating and propagating EMOs have been popularized through practices such as Korean Natural Farming (KNF). This approach typically involves collecting local soil rich in microbial activity (often from undisturbed forest floors), culturing the microbes on a carbohydrate source like cooked rice, and then propagating them through a series of fermentation steps to create a concentrated inoculant that can be applied to agricultural soils (Dahmani et al., 2023). While, the individual benefits of POFs and EMOs on soil health and crop productivity are increasingly recognized, a significant knowledge gap remains regarding their specific and combined effects on chickpea (*Cicer arietinum* L.), particularly concerning growth, yield, and bioactive compounds under semi-arid conditions. This study is among the first study that systematically investigated the synergistic effects of combining POFs and EMOs on chickpea cultivation in in the semi-arid soils of the Kurdistan Region, focusing on both agronomic performance and seed bioactive compounds. It is hypothesized that the combined application of POFs and EMOs will result in greater improvements in chickpea growth, yield components, and bioactive compound content than either amendment alone. Specifically, this study aims to evaluate the effects of POFs and EMOs, individually and in combination, on chickpea morphological traits and yield components, to assess changes in seed bioactive compounds, including total phenolics, anthocyanins, and antioxidant activity and analyzed the relationships among these agronomic and biochemical parameters under semi-arid field conditions. Current research findings will contribute to the development of more sustainable fertilizer management strategies for chickpea, particularly in regions facing soil fertility and water limitations, and may support broader efforts toward environmentally responsible agriculture and food security in semi-arid environments.

MATERIAL AND METHODS

Plant Material and Experimental Design

Current study was implemented at the Bakrajo Technical Institute's experimental farm in Sulaimani, Kurdistan Region of Iraq (35°32'52.8"N, 45°21'16.6"E), to evaluate the growth and yield performance of a local spring chickpea genotype (*Cicer arietinum* L.). Seeds were sown on February 21th, coinciding with immediate rainfall and 80% humidity. Plants were harvested four months and half after seeds sowing, to analyse morphological traits and yield components traits of the chickpea variety (local). The experiment employed 81 pots (5-liter capacity, 260 mm diameter, 340 mm height) filled with Bakrajo soil. Treatments consisted of amending the soil with POFs at rates of 0%, 4%, and 8% (w/w), and foliar application of EMOs, also referred to as EMOs at doses of (0, 4, and 8 ppm). The (EMOs) was produced following methods of Korean Natural Farming (KNF) (Dahmani et al., 2023). Foliar applications of EMOs applied in early morning within three stages, during early growth stages, after transplanting and before flowering to support fruit set. Proper dilution was assured to prevent leaf burn. control group with untreated soil was included. Harvesting was done when the grains had reached full maturity, measurements were taken for the morphological traits included plant height, branch number, days to 50% anthesis (days), days to physiological maturity (days). After drying the chickpeas to 12% moisture content, components of the yield [pods number plant^{-1}, seed number plant^{-1}, seeds weight plant^{-1} (g), 100 seed weight (g) and grain yield (kg ha^{-1})] were also assessed. Adequate rainfall (averaging 5 mm per 24 hours) during the growing season ensured sufficient water availability for the crop.

Bioactive contents and antioxidant activity determination

The bioactive content [The total phenolic content (TPC), total anthocyanin content] and antioxidant activity determination was done by milling the dried chickpea seeds first into flour using a miller equipped with a sieve of (1 mm) size. Each sample was analyzed three times to ensure reproducibility. The determination methods was done by following methods done by Pasqualone et al. (2014).

Statistical Analyses

Statistical analyses was done by using (XLSTAT 2019.2.2.59614, Addinsoft, France). All data were analysed by using ANOVA (two-way) at level of significance of $\alpha = 0.05$. For the multiple comparisons of the post hoc of (Tukey’s Honestly Significant Differences) was then applied to determine the effects of each variable and treatment, as well as their first-order interaction.

RESULTS AND DISCUSSION

Table 1, illustrated the effect of varied application rate of POFs on the morphological traits of chickpea including the height of the plant, branches number, days to 50% anthesis and days to physiological maturity. Plant height was significantly affected by POFs (Pr > F = 0.0002), with the highest plant recorded under PO8 (39.22 ± 6.90 cm), followed by PO4 (34.44 ± 4.59 cm), and the lowest in the unfertilized control (32.13 ± 6.79 cm). The branch numbers plant^{-1} was also significantly influenced by POFs (Pr > F = 0.0463), with PO8 showing the highest number (13.26 ± 1.84), while PO4 and the control had similar, lower values (10.65 ± 1.36 and 10.54 ± 2.18, respectively). In contrast, days to 50% anthesis were not significantly affected by fertilization (Pr > F = 0.3043), with values ranging from 85.27 ± 7.99 days in the control to 91.46 ± 3.48 days in PO8. Days to physiological maturity, however, were significantly increased by POFs (Pr > F = 0.0013), with the highest value in PO8 (147.32 ± 12.56 days), followed by PO4 (135.83 ± 4.59 days), and the lowest in the control (131.55 ± 15.93 days).

Table 1. Main effect of different concentration of POFs on morphological traits of chickpea (mean ± standard deviation)

Main Treatment	Plant Height (cm)	Branches No. Plant^{-1}	Days to 50% Anthesis	Days to Physiological Maturity
Only Soil (Control)	32.13 ± 6.79 a	10.54 ± 2.18 b	85.27 ± 7.99 a	131.55 ± 15.93 a
PO4	34.44 ± 4.59 b	10.65 ± 1.36 b	86.70 ± 1.35 a	135.83 ± 4.59 b
PO8	39.22 ± 6.90 a	13.26 ± 1.84 a	91.46 ± 3.48 a	147.32 ± 12.56 a
Pr > F	0.0002*	0.0463*	0.3043^{ns}	0.0013*

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

Main effect of varied application rate of EMOs on the morphological traits of chickpea is presented in Table 2. A significant effect of EMOs was observed for plant height (Pr > F < 0.0001), branch numbers plant^{-1} (Pr > F = 0.0024), and days to physiological maturity (Pr > F < 0.0001), while the effect on days to 50% anthesis was not significant (Pr > F = 0.0194). Plant height was significantly influenced by the EMOs treatments, with the highest value recorded in EMO4 (38.46 ± 7.18 cm), followed by the control (35.35 ± 8.03 cm), and the lowest in EMO8 (31.98 ± 1.99 cm). The branch numbers plant^{-1} increased significantly with higher doses of EMOs, with EMO8 showing the highest number (12.21 ± 0.74), followed by EMO4 (11.95 ± 2.74), and the lowest in the control (10.30 ± 2.14). Days to 50% anthesis were not significantly influenced by the EMOs treatments, with values ranging from 83.02 ± 5.56 days in the control to 91.14 ± 2.69 days in EMO8. However, days to physiological maturity were significantly extended by EMOs, with the highest value observed in EMO8 (145.93 ± 3.92 days), followed by EMO4 (142.96 ± 14.92 days), and the lowest in the control (125.82 ± 9.59 days).

Table 2. Main effect of different rate of EMOs on morphological traits of chickpea (mean ± standard deviation)

Main Treatment	Plant Height (cm)	Branches No. Plant^{-1}	Days to 50% Anthesis	Days to Physiological Maturity
Only Soil (Control)	35.35 ± 8.03 a	10.30 ± 2.14 b	83.02 ± 5.56 a	125.82 ± 9.59 b
EMO4	38.46 ± 7.18 a	11.95 ± 2.74 b	89.27 ± 4.95 a	142.96 ± 14.92 b
EMO8	31.98 ± 1.99 b	12.21 ± 0.74 a	91.14 ± 2.69 a	145.93 ± 3.92 a
Pr > F	<.0001**	0.0024*	0.0194^{ns}	<.0001**

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

Table 3, summarizes the combined effects of POFs and EMOs on the morphological traits of chickpea. The analysis revealed that treatment combinations had a highly significant effect on plant height ($Pr > F < 0.0001$), branch numbers plant^{-1} ($Pr > F = 0.0021$), and days to physiological maturity ($Pr > F = 0.0005$), whereas the effect on days to 50% anthesis was not statistically significant ($Pr > F = 0.1338$). Plant height was significantly increased by several fertilization regimes. The greatest plant height was recorded in the (Soil + POF8 + EMO4) treatment (45.93 ± 2.53 cm), followed by Soil + POF8 + EMO0 (42.00 ± 1.32 cm), Soil + EMO4 + POF0 (40.67 ± 1.15 cm), and (Soil + POF4 + EMO0) (40.00 ± 0.00 cm). In contrast, the unfertilized control exhibited the lowest plant height (24.06 ± 2.48 cm). These results indicate that both mineral and organic fertilization, particularly at higher doses and in combination, substantially promote vegetative growth. The branch numbers plant^{-1} was also significantly enhanced by organic fertilizer combination. The highest number was observed in the (Soil + POF8 + EMO4) treatment (15.67 ± 2.08), with other high values in (Soil + EMO8 + POF0) (12.96 ± 1.66), (Soil + POF8 + EMO0) (12.90 ± 1.01), and (Soil + POF4 + EMO8) (12.46 ± 1.16). The control group had the lowest branch number (7.67 ± 2.00), underscoring the positive impact of organic combination of fertilization on branching. No significant differences were detected among treatments for days to 50% flowering, with values ranging from 75.30 ± 9.91 days in the control to 96.27 ± 1.10 days in (Soil + POF8 + EMO4), suggesting that fertilization did not markedly influence the onset of flowering (Figure 1). In contrast, days to physiological maturity were significantly prolonged by several organic combination fertilization treatments. The longest maturity period was observed in (Soil + POF8 + EMO4) (164.00 ± 4.00 days), followed by (Soil + EMO8 + POF0) (151.33 ± 2.31 days), (Soil + POF8 + EMO8) (144.28 ± 1.46 days), and (Soil + POF4 + EMO8) (142.17 ± 7.00 days). The control reached maturity earliest (112.32 ± 1.00 days).

Table 3. Combined effect different concentration of POs and EMOs on morphological traits of chickpea (mean ± standard deviation)

Treatments Combinations	Plant Height (cm)	Branches No. Plant^{-1}	Days to 50% Anthesis	Days to Physiological Maturity
Only Soil (Control)	24.06 ± 2.48 c	7.67 ± 2.000 b	75.30 ± 9.91 a	112.32 ± 1.00 c
Soil + POF4 + EMO0	40.00 ± 0.00 a	10.33 ± 2.08 b	85.61 ± 5.38 a	131.45 ± 5.14 b
Soil + POF8 + EMO0	42.00 ± 1.32 a	12.90 ± 1.01 a	88.15 ± 13.41 a	133.68 ± 13.62 b
Soil + EMO4 + POF0	40.67 ± 1.15 a	11.00 ± 1.00 b	85.65 ± 13.60 a	131.01 ± 13.05 b
Soil + EMO8 + POF0	31.67 ± 0.58 b	12.96 ± 1.66 a	94.86 ± 6.81 a	151.33 ± 2.31 a
Soil + POF4 + EMO4	28.77 ± 0.81 b	9.17 ± 1.440 b	85.88 ± 0.94 a	133.88 ± 2.72 b
Soil + POF4 + EMO8	34.56 ± 7.15 b	12.46 ± 1.16 a	88.60 ± 1.22 a	142.17 ± 7.00 b
Soil + POF8 + EMO4	45.93 ± 2.53 a	15.67 ± 2.08 a	96.27 ± 1.10 a	164.00 ± 4.00 a
Soil + POF8 + EMO8	29.72 ± 0.82 b	11.21 ± 0.58 b	89.95 ± 0.94 a	144.28 ± 1.46 a
Pr > F	<.0001**	0.0021*	0.1338^{ns}	0.0005*

Mean values followed by different letters with each columns denote statistically significant differences by (Tukey's at $\alpha = 0.05$).

The main effects of varied application rate of POFs the on yields component traits of chickpea including [pod number plant^{-1}, seed no. pod^{-1}, seed weight plant^{-1} (g), 100 seed weight (g), grain yield (kg ha^{-1})] illustrated in Table 4. Statistical analysis indicated that grain yield was significantly affected by the treatments ($Pr > F = 0.0108$), whereas the number of pods plant^{-1}, seeds per pod, seed weight plant^{-1}, and 100 seed weight were not significantly influenced (all $Pr > F > 0.01$). The number of pods plant^{-1} ranged from 30.47 ± 6.19 in the control to 36.93 ± 7.02 in the PO8 treatment, with no significant differences among treatments ($Pr > F = 0.0410$). Similarly, the number of seeds per pod did not differ significantly, with values between 1.05 ± 0.03 (PO4) and 1.35 ± 0.22 (PO8) (*Pr* > *F*= 0.1013). Seed weight plant^{-1} showed a numerical increase with fertilization, from 30.54 ± 3.99 g in the control to 38.44 ± 4.65 g in PO8, but this difference was not statistically significant (*Pr* > *F* = 0.0271). 100 seed weight was highest in the PO8 treatment (47.25 ± 6.68 g), compared to 39.07 ± 7.98 g in the control and 40.32 ± 4.16 g in PO4, yet the effect was not significant (*Pr* > *F* = 0.0132). In contrast, grain yield was significantly increased by fertilization, with the highest value observed in the PO8 treatment (779.49 ± 99.53 kg ha^{-1}), compared to 681.27 ± 142.05 kg ha^{-1} in the control and 663.13 ± 33.46 kg ha^{-1} in PO4.

Table 4. Main Effect of different concentration of POFs on yield component traits of chickpea (mean ± standard deviation)

Main Treatment	Pod No. Plant^{-1}	Seed No. Pod^{-1}	Seed Weight Plant^{-1} (g)	100 Seed Weight (g)	Grain Yield (kg ha^{-1})
Only Soil (Control)	30.47 ± 6.19 b	1.20 ± 0.18 a	30.54 ± 3.99 b	39.07 ± 7.98 b	681.27 ± 142.05 b
PO4	31.73 ± 5.05 b	1.05 ± 0.03 a	33.92 ± 1.31 a	40.32 ± 4.16 b	663.13 ± 33.46 b
PO8	36.93 ± 7.02 b	1.35 ± 0.22 a	38.44 ± 4.65 a	47.25 ± 6.68 a	779.49 ± 99.53 a
Pr > *F*	0.0410^{ns}	0.1013^{ns}	0.0271^{ns}	0.0132^{ns}	0.0108*

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

Figure 1. Morphological traits of chickpea (*Cicer arietinum L.*) under different fertilization treatments. (a) combined treatment (Soil + POF8 + EMO4), (b) Only Soil (Control), (c) (Soil + EMO4 + POF0), (d) (Soil + POF8 + EMO0).

Table 5, presents the main effects of EMOs on yield component traits of chickpea. The analysis revealed that organic fertilization had a highly significant effect on pod number plant^{-1} (Pr > F < 0.0001), 100 seed weight (Pr > F = 0.0001), and grain yield (Pr > F = 0.0014), while no significant effects were observed for seed number per pod (*Pr* > *F* = 0.2288) or seed weight plant^{-1} (Pr > F = 0.0062). Pod number plant^{-1} was significantly increased by organic fertilization, with the highest value recorded in the EMO8 treatment (36.80 ± 2.95), followed by EMO4 (34.48 ± 8.73), and the lowest in the control (27.85 ± 2.90). 100 seed weight was also significantly enhanced in EMO8 (46.72 ± 1.94 g), compared to EMO4 (43.66 ± 9.02 g) and the control (36.26 ± 4.62

g). Grain yield was maximized in the EMO8 treatment (771.23 ± 66.56 kg ha^{-1}), with lower values in EMO4 (734.11 ± 127.85 kg ha^{-1}) and the control (618.55 ± 74.73 kg ha^{-1}). In contrast, seed number per pod and seed weight plant^{-1} showed no significant difference among treatments, with values ranging from 1.10 ± 0.08 to 1.27 ± 0.29 for seed number per pod, and from 31.17 ± 2.12 g to 37.82 ± 4.53 g for seed weight plant^{-1}.

Table 5. Main Effect of different rate of EMOs on yield component traits of chickpea (mean ± standard deviation)

Main Treatment	Pod No. Plant^{-1}	Seed No. Pod^{-1}	Seed Weight Plant^{-1} (g)	100 Seed Weight (g)	Grain Yield (kg ha^{-1})
Only Soil (Control)	27.85 ± 2.90 b	1.10 ± 0.08 a	33.91 ± 4.84 a	36.26 ± 4.62 b	618.55 ± 74.73 b
EMO4	34.48 ± 8.73 b	1.27 ± 0.29 a	37.82 ± 4.53 a	43.66 ± 9.02 b	734.11 ± 127.85 b
EMO8	36.80 ± 2.95 a	1.23 ± 0.15 a	31.17 ± 2.12 a	46.72 ± 1.94 a	771.23 ± 66.56 a
Pr > F	<.0001**	0.2288^{ns}	0.0062^{ns}	0.0001**	0.0014**

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

The combined effects of POFs and EMOs on the on yield component traits of chickpea was determined in Table 6. The analysis revealed that treatment combinations had a significant effect on pod number plant^{-1} (*Pr > F* = 0.0002), 100 seed weight (Pr > F = 0.0015), and grain yield (*Pr > F* = 0.0015), while no significant effects were observed for seed number per pod (*Pr > F* = 0.1308) or seed weight plant^{-1} (*Pr > F* = 0.0894). Pod number plant^{-1} was significantly increased by several fertilization combinations, with the highest value observed in the (Soil + POF8 + EMO4) treatment (46.83 ± 1.90), followed by (Soil + EMO8 + POF0) (38.90 ± 1.82), (Soil + POF4 + EMO8) (38.87 ± 5.22), and Soil + POF8 + EMO8 (32.62 ± 1.08). The control exhibited the lowest pod number (24.22 ± 4.22). 100 seed weight was also significantly enhanced by combined fertilization, with the highest value in Soil + POF8 + EMO4 (56.40 ± 1.21 g), followed by (Soil + EMO8 + POF0) (49.33 ± 0.58 g), Soil + POF4 + EMO8 (46.13 ± 3.31 g), and Soil + POF8 + EMO8 (44.69 ± 1.46 g). The control had the lowest 100 seed weight (29.87 ± 2.25 g). Grain yield was maximized in the (Soil + POF8 + EMO4) treatment (912.47 ± 16.17 kg ha^{-1}), with other high values in (Soil + EMO8 + POF0) (860.33 ± 10.50 kg ha^{-1}), (Soil + POF8 + EMO8) (752.96 ± 9.62 kg ha^{-1}), and (Soil + POF4 + EMO8) (700.40 ± 99.70 kg ha^{-1}). The control yielded the lowest (512.88 ± 28.24 kg ha^{-1}). In contrast, seed number per pod and seed weight plant^{-1} did not differ significantly among treatments (Figure 2).

Table 6. Combined effect of different concentration of POs and EMOs on yield component traits of (mean ± standard deviation)

Treatments Combinations	Pod No. Plant^{-1}	Seed No.Pod^{-1}	Seed Weight Plant^{-1} (g)	100 Seed Weight (g)	Grain Yield (kg ha^{-1})
Only Soil (Control)	24.22 ± 4.22 b	1.01 ± 0.02 a	27.29 ± 3.34 b	29.87 ± 2.25 b	512.88 ± 28.24 b
Soil + POF4 + EMO0	28.00 ± 2.65 b	1.08 ± 0.13 a	35.75 ± 2.57 a	38.25 ± 3.66 b	669.73 ± 53.85 b
Soil + POF8 + EMO0	31.33 ± 5.51 b	1.20 ± 0.15 a	38.70 ± 8.58 a	40.66 ± 8.59 b	673.05 ± 145.28 b
Soil + EMO4 + POF0	28.29 ± 5.46 b	1.14 ± 0.12 a	36.16 ± 8.37 a	38.00 ± 8.44 b	670.60 ± 145.48 b
Soil + EMO8 + POF0	38.90 ± 1.82 a	1.44 ± 0.51 a	28.17 ± 3.55 b	49.33 ± 0.58 a	860.33 ± 10.50 a
Soil + POF4 + EMO4	28.32 ± 0.58 b	1.01 ± 0.01 a	33.29 ± 1.14 a	36.59 ± 1.21 b	619.25 ± 5.61 b
Soil + POF4 + EMO8	38.87 ± 5.22 a	1.07 ± 0.12 a	32.73 ± 5.65 a	46.13 ± 3.31 a	700.40 ± 99.70 a
Soil + POF8 + EMO4	46.83 ± 1.90 a	1.67 ± 0.58 a	44.00 ± 1.47 a	56.40 ± 1.21 a	912.47 ± 16.17 a
Soil + POF8 + EMO8	32.62 ± 1.08 b	1.19 ± 0.04 a	32.62 ± 1.47 a	44.69 ± 1.46 a	752.96 ± 9.62 a
Pr > F	0.0002*	0.1308^{ns}	0.0894^{ns}	0.0015**	0.0015**

Mean values followed by different letters with each columns denote statistically significant differences by (Tukey's at α = 0.05).

Table 7, presents the main effects of different concentrations of pelleted organic fertilizer (POF) on bioactive compound content and antioxidant activity in chickpea. The analysis revealed that organic fertilization had a highly significant effect on TPC (Pr > F < 0.0001), anthocyanin content (Pr > F < 0.0001), and antioxidant activity (Pr > F < 0.0001). TPC was significantly increased by higher concentrations of pelleted organic fertilizer, with the highest value observed in the POF8 treatment (196.91 ± 14.41 mg FAE 100 g^{-1} D.M.), followed by POF4 (172.65 ± 12.38 mg FAE 100 g^{-1} D.M.), and the lowest in the control (157.88 ± 27.18 mg FAE 100 g^{-1} D.M.). Similarly, anthocyanin content was maximized in POF8 (1.56 ± 0.17 mg C3GE g^{-1} D.M.), with lower values in POF4 (1.28 ± 0.20 mg C3GE 100 g^{-1} D.M.) and the control (1.13 ± 0.25 mg C3GE 100 g^{-1} D.M.). Antioxidant activity also showed a significant increase with higher fertilizer concentration, reaching its peak in POF8 (2.06 ± 0.22 mg TE 100 g^{-1} D.M.), compared to POF4 (1.85 ± 0.25 mg TE 100 g^{-1} D.M.) and the control (1.61 ± 0.33 mg TE 100 g^{-1} D.M.).

Table 7. Main Effect of different concentration of POFs on bioactive compound and antioxidant activity of chickpea (mean ± standard deviation)

Main Treatment	Total Phenolic Content (mg FAE 100 g^{-1} D.M.)	Anthocyanin Content (mg C3GE 100 g^{-1} D.M.)	Antioxidant Activity (mg TE 100 g^{-1} D.M.)
Only Soil (Control)	157.88 ± 27.18 b	1.13 ± 0.25 b	1.61 ± 0.33 b
POF4	172.65 ± 12.38 b	1.28 ± 0.20 b	1.85 ± 0.25 b
POF8	196.91 ± 14.41 a	1.56 ± 0.17 a	2.06 ± 0.22 a
Pr > F	<0001**	<0001**	<0001**

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

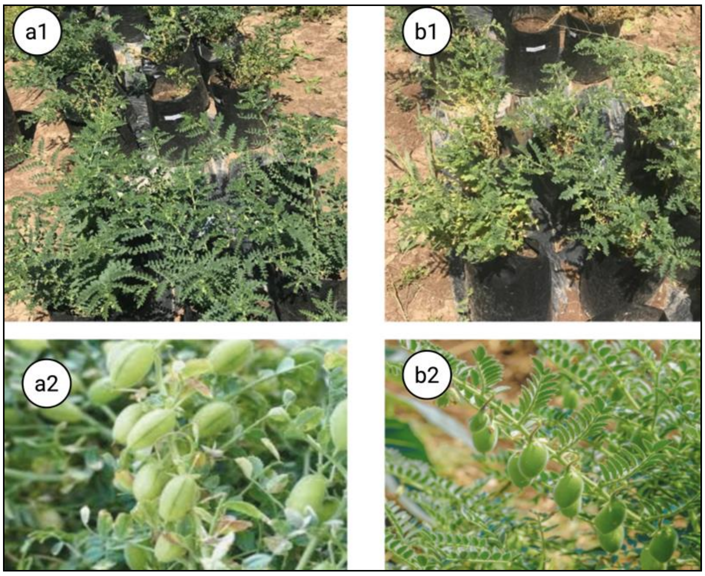

Figure 2. Yiled component taits of chickpea (*Cicer arietinum* L.) under different fertilization treatments. (a1,2) combined treatment (Soil + POF8 + EMO4), (b1,2) Only Soil (Control).

Table 8, presents the main effects of different concentrations of effective microorganisms (EMOs) on bioactive compound content and antioxidant activity in chickpea. The analysis showed that EMO application had a highly significant effect on TPC (*Pr > F* < 0.0001), anthocyanin content (*Pr > F* < 0.0001), and antioxidant activity (Pr > F < 0.0001). TPC was significantly increased by EMO treatments, with the highest value recorded in EMO8 (191.57 ± 10.13 mg FAE 100 g^{-1}), followed by EMO4 (181.15 ± 22.41 mg FAE 100 g^{-1}), and the lowest in the control (154.73 ± 22.97 mg FAE 100 g^{-1}). Anthocyanin content was also significantly enhanced in EMO8 (1.53 ± 0.12 mg C3GE 100 g^{-1} D.M.) and EMO4 (1.40 ± 0.25 mg C3GE 100 g^{-1} D.M.), compared to the control (1.07 ± 0.23 mg C3GE 100 g^{-1} D.M.). Similarly, antioxidant activity was maximized in EMO8 (2.10 ± 0.13 mg TE 100 g^{-1}), with lower values in EMO4 (1.93 ± 0.25 mg TE 100 g^{-1}) and the control (1.51 ± 0.25 mg TE 100 g^{-1}).

Table 8. Main Effect of different different rate of EMOs on bioactive compound and antioxidant activity of chickpea (mean ± standard deviation)

Main Treatment	Total Phenolic Content (mg FAE 100 g^{-1} D.M.)	Anthocyanin Content (mg C3GE 100 g^{-1} D.M.)	Antioxidant Activity (mg TE 100 g^{-1} D.M.)
Only Soil (Control)	154.73 ± 22.97 b	1.07 ± 0.23 b	1.51 ± 0.25 b
EMO4	181.15 ± 22.41 a	1.40 ± 0.25 a	1.93 ± 0.25 a
EMO8	191.57 ± 10.13 a	1.53 ± 0.12 a	2.10 ± 0.13 a
Pr > F	<0001**	<0001**	<0001**

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

Effects of different combinations of pelleted organic fertilizer (POF) and effective microorganisms (EMO) on bioactive compound content and antioxidant activity in chickpea illustrated in Table 9. The analysis revealed that treatment combinations had a highly significant effect on TPC (Pr > F < 0.0001), anthocyanin content (Pr > F < 0.0001), and antioxidant activity (Pr > F < 0.0001). TPC was maximized in the Soil + POF8 + EMO4 treatment (212.48 ± 2.65 mg FAE 100 g^{-1} D.M.), followed by Soil + POF8 + EMO8 (200.40 ± 4.14 mg FAE 100 g^{-1} D.M.) and Soil + POF4 + EMO8 (186.81 ± 2.81 mg FAE 100 g^{-1} D.M.). The lowest value was observed in the control (125.96 ± 3.02 mg FAE 100 g^{-1} D.M.). Anthocyanin content was also highest in Soil + POF8 + EMO4 (1.72 ± 0.07 mg C3GE 100 g^{-1} D.M.), with Soil + POF8 + EMO8 (1.62 ± 0.04 mg C3GE 100 g^{-1} D.M.) and Soil + POF4 + EMO8 (1.53 ± 0.01 mg C3GE 100 g^{-1} D.M.) showing similarly elevated values, while the control had the lowest anthocyanin content (0.81 ± 0.03 mg C3GE 100 g^{-1} D.M.). Antioxidant activity followed the same trend, with the highest value in Soil + POF8 + EMO4 (2.25 ± 0.06 mg TE 100 g^{-1} D.M.), and high values also recorded in Soil + POF8 + EMO8 (2.18 ± 0.05 mg TE 100 g^{-1} D.M.) and Soil + POF4 + EMO8 (2.15 ± 0.02 mg TE 100 g^{-1} D.M.). The control again had the lowest antioxidant activity (1.19 ± 0.03 mg TE 100 g^{-1} D.M.).

Table 9. Combined effect of different concentration of POs and EMOs on bioactive compound and antioxidant activity of chickpea (mean ± standard deviation)

Main Treatment	Total Phenolic Content (mg FAE 100 g^{-1} D.M.)	Anthocyanin Content (mg C3GE 100 g^{-1} D.M.)	Antioxidant Activity (mg TE 100 g^{-1} D.M.)
Only Soil (Control)	125.96 ± 3.02 f	0.81 ± 0.03 h	1.19 ± 0.03 h
Soil + POF4 + EMO0	160.38 ± 2.85 de	1.05 ± 0.04 fg	1.56 ± 0.04 fg
Soil + POF8 + EMO0	177.86 ± 3.67 cd	1.35 ± 0.07 cd	1.77 ± 0.09 de
Soil + EMO4 + POF0	162.21 ± 1.71 de	1.20 ± 0.05 ef	1.69 ± 0.08 ef
Soil + EMO8 + POF0	185.48 ± 0.93 bc	1.39 ± 0.06 cd	1.96 ± 0.06 bc
Soil + POF4 + EMO4	168.76 ± 2.74 de	1.27 ± 0.03 de	1.84 ± 0.03 cd
Soil + POF4 + EMO8	186.81 ± 2.81 bc	1.53 ± 0.01 bc	2.15 ± 0.02 ab
Soil + POF8 + EMO4	212.48 ± 2.65 a	1.72 ± 0.07 a	2.25 ± 0.06 a
Soil + POF8 + EMO8	200.40 ± 4.14 b	1.62 ± 0.04 ab	2.18 ± 0.05 ab
Pr > F	<.0001**	<.0001**	<.0001**

Mean values followed by different letters with each column represents statistically significant differences according to Tukey's test at α = 0.05.

Increasing the rate from PO0 to PO8 raised plant height by approximately 22%, branch number by 39%, and grain yield by 31% (Tables 3 and 6), confirming that organic amendments can supply nutrients steadily while stimulating rhizosphere activity (Shu et al., 2022; Zhang et al., 2024b). A modest delay in phenology was also evident: days to physiological maturity lengthened from 132 days in the control to 164 days in PO8, a trend frequently associated with gradual nutrient release from organic matrices (Pooja and Ameena, 2021). These results parallel to those of Pasqualone et al. (2021), who recorded plant heights of 48.2 cm and 14.2 branches per plant under composted fertilization versus 32.7 cm and 8.1 branches in the unfertilized control, and of (Costantini et al., 2021), who reported comparable gains under organic management. The lack of significant effect on days to 50% anthesis suggests that EMOs primarily influence later developmental stages rather than the onset of flowering, which aligns with numerous investigations which indicated that the influence of EMOs on plant flowering is not consistently substantial (Youssef et al., 2021a) and sometimes there is no significant effect or even adverse outcomes from EM treatment (Olle and Williams, 2013). The growth advantage became more pronounced when POF was integrated with effective microorganisms (EMO). The Soil + POF8 + EMO4 treatment produced the tallest plants (51 cm), the highest branch count (16 per plant), and the greatest grain yield (0.98 t ha^{-1}) (Tables 5 and 8). Comparable synergistic boosts have been documented by Nahusenay et al. (2024), who combined Mesorhizobium strain CP-M41 with blended NPSB fertilizer and obtained 45 cm plant height and 16 branches per plant. The enhanced performance is generally attributed to EMO-mediated solubilization of macro- and micronutrients coupled with phytohormone production, which together intensify vegetative growth and nutrient remobilization during reproductive stages (Das et al., 2022; Banik et al., 2023). Pod number, hundred seed weight, and grain yield all increased significantly with EMO rate, yet seeds per pod remained unchanged, mirroring earlier reports that EMO affects sink size more than sink number (Youssef et al., 2021b). The lack of significant effects on pod number, seeds per pod, seed weight $plant^{-1}$, and hundred seed weight suggests that yield improvement is likely due to cumulative, rather than individual, component responses, as also noted by Getahun (2021). Only grain yield reacted sharply to sole POF, whereas pod number and individual seed mass were statistically static. This corroborates Kumar et al. (2023), who attributed yield gains in organic pulse systems to cumulative rather than component-specific effects. When POF and EMO were combined, however, pod number rose by 27% and 100 seed weight by 18%, indicating that microbial inoculation can unlock latent yield components that organic nutrition alone cannot exploit. Regarding yield components, EMO application significantly raised pod number $plant^{-1}$, hundred seed weight, and grain yield, with the maximum values consistently observed in the EMO8 treatment. These results are in lines with earlier research study determined that the EMOs can enhance yield and seed quality in legumes by promoting beneficial microbial populations and improving soil health condition (Jena et al., 2022). Yield component analysis further revealed that pod number $plant^{-1}$, hundred seed weight, and grain yield were significantly increased by the combined application of POFs and EMOs. The highest values for these traits were consistently observed in the (Soil + POF8 + EMO4) treatment, indicating a strong synergistic effect. These results corroborate the observations of Dave et al. (2024), who reported that the integration of organic and microbial fertilizers can lead to substantial yield increases in legumes. The in significant effects on seed number per pod and seed weight $plant^{-1}$ might be due to the improvements in the yield are primarily due to increased pod production and seed size, rather than changes in seed set or individual seed mass. These results underscore the efficacy of combining organic and microbial fertilization methods to enhance chickpea growth and output, advocating for their implementation in sustainable agriculture practices. Antioxidant activity reached its peak in EMO8 and it is in strong agreement with (Pasqualone et al., 2021), who reported that organic fertilization significantly increased phenolic and anthocyanin content as well as antioxidant activity in chickpea, and with Ibrahim et al. (2013), who found similar enhancements in organically fertilized legumes. The significant increase in the branch number of and elongation of physiological maturity with increased rate of EMO doses may be attributed to the root improvement and uptakes of the nutrient, as reported by Huang et al. (2021). Specifically, the combination of POF8 with EMO4, rather than EMO8, produced the most pronounced improvements across agronomic and quality traits. This suggests a threshold or saturation effect, where excessive microbial inoculation (EMO8) in the presence of abundant organic substrate (POF8) may not further enhance, and could even slightly inhibit, plant performance. Such outcomes may be attributed to competitive interactions among microbial populations at higher inoculum densities, or to shifts in soil nutrient dynamics that favor microbial over plant uptake at excessive EMO rates (Costantini et al., 2021). Similar findings have been reported in legume systems, where moderate levels of microbial inoculants, when paired with optimal organic fertilization, maximize both yield and bioactive compound accumulation, while higher doses can lead to diminishing or plateauing returns (Kumar et al., 2023). Therefore, the observed synergy between POF8 and EMO4 highlights the importance of optimizing both organic and microbial inputs to achieve the best agronomic and nutritional outcomes in chickpea cultivation, rather than simply maximizing each component independently.

CONCLUSIONS

The present study provides compelling evidence that the integrated utilization of POFs and EMOs can significantly enhance chickpea (*Cicer arietinum* L.) morphological traits, yield components, bioactive compound content, and antioxidant activity under semi-arid conditions. Both amendments, when applied individually and in combination, contributed to increases in plant height, branch number, pod number, 100 seed weight, grain yield, total phenolic content, anthocyanin content, and antioxidant activity. Notably, the combined application of 8% POFs and 4 ppm EMOs produced the most pronounced improvements across all measured parameters, indicating a synergistic effect that maximizes both agronomic performance and seed nutritional quality. These findings indicate the potential of integrating organic and microbial fertilization as a sustainable substitute for inorganic fertilizers, particularly in semi-arid agroecosystems where soil fertility and water availability are limited. Adoption of such strategies can enhance soil quality, mitigate ecological effects, and enhance both the biomass productivity and nutritive content of chickpea crops. Further long term and multi locations further studies are recommended to confirm these results across different environments and chickpea genotypes, and to assess the broader agroecological and economic impacts of these fertilizer combinations.

REFERENCES

Aryal, B., Gurung, R., Camargo, A.F., Fongaro, G., Treichel, H., Mainali, B., Puadel, S.R., 2022. *Nitrous oxide emission in altered nitrogen cycle and implications for climate change*. Environmental Pollution, 314, 120272. doi:https://doi.org/10.1016/j.envpol.2022.120272

Asadu, C.O., Ezema, C.A., Ekwueme, B.N., Onu, C.E., Onoh, I.M., Adejoh, T., Okoye, J.O., 2024. *Enhanced efficiency fertilizers: Overview of production methods, materials used, nutrients release mechanisms, benefits and considerations*. Environmental Pollution and Management, doi:https://doi.org/10.1016/j.epm.2024.07.002.

Babla, M., Katwal, U., Yong, M.-T., Jahandari, S., Rahme, M., Chen, Z.-H., Tao, Z., 2022. *Value-added products as soil conditioners for sustainable agriculture*. Resources, Conservation and Recycling, 178, 106079. doi:https://doi.org/10.1016/j.eti.2023.103505

Bamdad, H., Papari, S., Lazarovits, G., Berruti, F., 2022. *Soil amendments for sustainable agriculture: Microbial organic fertilizers*. Soil Use and Management, 38(1): 94-120. doi:https://doi.org/10.1111/sum.12762

Banik, C., Bakshi, S., Laird, D.A., Smith, R.G., Brown, R.C., 2023. *Impact of biochar-based slow-release N-fertilizers on maize growth and nitrogen recovery efficiency*. Journal of Environmental Quality, 52(3): 630-640.

Begum, N., Khan, Q.U., Liu, L.G., Li, W., Liu, D., Haq, I.U., 2023. *Nutritional composition, health benefits and bio-active compounds of chickpea (Cicer arietinum L.)*. Frontiers in Nutrition, 10, 1218468. doi:https://doi.org/10.3389/fnut.2023.1218468

Boukid, F., 2021. *Chickpea (Cicer arietinum L.) protein as a prospective plant-based ingredient: A review*. International Journal of Food Science and Technology, 56(11): 5435-5444. doi:https://doi.org/10.1111/ijfs.15046

Costantini, M., Summo, C., Centrone, M., Rybicka, I., D'Agostino, M., Annicchiarico, P., Pasqualone, A., 2021. *Macro-and micro-nutrient composition and antioxidant activity of chickpea and pea accessions*. Polish Journal of Food and Nutrition Sciences, 71(2): 177-185. doi:https://doi.org/10.31883/pjfns/135813

Dahmani, R., Borsali, A.H., Merzouk, A., Zouidi, M., Aouadj, S.A., Khatir, H., 2023. *The Effect of Beneficial Autochthonous Microorganisms (Bams) on the Chemical Quality of Agricultural Soils and Olive Production in the Wilaya of Tlemcen (Western of Algeria)*. Advanced Research In Life Sciences, 7(1): 1-9. doi:https://doi.org/10.2478/arls-2023-0001

Das, P.P., Singh, K.R., Nagpure, G., Mansoori, A., Singh, R.P., Ghazi, I.A., Singh, J., 2022. *Plant-soil-microbes: A tripartite interaction for nutrient acquisition and better plant growth for sustainable agricultural practices*. Environmental Research, 214, 113821. doi:https://doi.org/10.3390/agronomy14030609

Dave, K., Kumar, A., Dave, N., Jain, M., Dhanda, P.S., Yadav, A., Kaushik, P., 2024. *Climate change impacts on legume physiology and ecosystem dynamics: a multifaceted perspective*. Sustainability, 16(14), 6026. doi:https://doi.org/10.3390/su16146026

Getahun, A., 2021. *Estimating genetic variability, gene effect, heritability, and genetic advance of yield component agronomic traits: towards the improvement of peanut agronomic traits*. agriRxiv(2021), 20210234086. doi:https://doi.org/10.31220/agriRxiv.2021.00058

Goyal, R.K., Mattoo, A.K., Schmidt, M.A., 2021. *Rhizobial-host interactions and symbiotic nitrogen fixation in legume crops toward agriculture sustainability*. Frontiers in Microbiology, 12, 669404. doi:https://doi.org/10.3389/fmicb.2021.669404

Huang, X., Muneer, M.A., Li, J., Hou, W., Ma, C., Jiao, J., Zheng, C., 2021. *Integrated nutrient management significantly improves pomelo (Citrus grandis) root growth and nutrients uptake under acidic soil of southern China*. Agronomy, 11(6), 1231. doi:https://doi.org/10.3390/agronomy11061231

Ibrahim, M.H., Jaafar, H.Z.E., Karimi, E., Ghasemzadeh, A., 2013. *Impact of Organic and Inorganic Fertilizers Application on the Phytochemical and Antioxidant Activity of Kacip Fatimah (Labisia pumila Benth)*. Molecules, 18(9): 10973-10988. doi:https://doi.org/10.3390/molecules180910973

Jena, J., Maitra, S., Hossain, A., Pramanick, B., Gitari, H.I., Praharaj, S., Mandal, T.K., 2022. *Role of legumes in cropping system for soil ecosystem improvement*. Ecosystem Services: Types, Management and Benefits, Nova Science Publishers, Inc, 415: 1-21.

Juntahum, S., Klinsukon, C., Senawong, K., Katekaew, S., Sokudlor, N., Laloon, K., 2025. *Assessing the Potential for Producing Compost Pellets with Binders from Cassava Industry By-products and Supplemented with Trichoderma*. Case Studies in Chemical and Environmental Engineering, 101221. doi:https://doi.org/10.1016/j.cscee.2025.101221

Kakaei, M., Rehman, F.U., Fazeli, F., 2024. *The effect of chickpeas metabolites on human diseases and the application of their valuable nutritional compounds suitable for human consumption*. Cellular, Molecular and Biomedical Reports, 4(1): 30-42. doi:https://doi.org/10.55705/cmbr.2023.395591.1153

Koul, B., Sharma, K., Sehgal, V., Yadav, D., Mishra, M., Bharadwaj, C., 2022. *Chickpea (Cicer arietinum L.) biology and biotechnology: From domestication to biofortification and biopharming*. Plants, 11(21), 2926. doi:https://doi.org/10.3390/plants11212926

Kumar, S., Gopinath, K., Sheoran, S., Meena, R.S., Srinivasarao, C., Bedwal, S., Praharaj, C., 2023. *Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems*. Frontiers in Microbiology, 13, 1041124. doi: https://doi.org/10.3389/fmicb.2022.1041124

Nahusenay, G., Wolde, G., Tena, W., Tamiru, T., 2024. *Chickpea (Cicer arietinum L.) growth, nodulation, and yield as affected by varieties, Mesorhizobium strains, and NPSB fertilizer in Southern Ethiopia*. Frontiers in Plant Science, 15, 1372082. doi:https://doi.org/10.3389/fpls.2024.1372082

Nithiyanantham, S., Selvakumar, S., Siddhuraju, P., 2012. *Total phenolic content and antioxidant activity of two different solvent extracts from raw and processed legumes, Cicer arietinum L. and Pisum sativum L*. Journal of food Composition and Analysis, 27(1): 52-60. doi:https://doi.org/10.1016/j.jfca.2012.04.003

Noreen, A., Hameed, A., Shah, T.M., 2024. *Field screening and identification of biochemical indices of pod borer (Helicoverpa armigera) resistance in chickpea mutants*. Frontiers in Plant Science, 15, 1335158. doi:https://doi.org/10.3389/fpls.2024.1335158

Olle, M., and Williams, I., 2013. *Effective microorganisms and their influence on vegetable production - a review*. The Journal of Horticultural Science and Biotechnology, 88(4): 380-386. doi:https://doi.org/10.1080/14620316.2013.11512979

Pasqualone, A., Delvecchio, L.N., Mangini, G., Taranto, F., Blanco, A., 2014. *Variability of total soluble phenolic compounds and antioxidant activity in a collection of tetraploid wheat*. Agricultural and Food Science, 23(4): 307-316. doi:10.23986/afsci.47985

Pasqualone, A., Summo, C., De Angelis, D., Cucci, G., Caranfa, D., Lacolla, G., 2021. *Effect of mineral and organic fertilization on Desi and Kabuli Chickpea (Cicer arietinum L.): Plant growth and production, hydration properties, bioactive compounds, and antioxidant activity*. Plants, 10(7), 1441. doi:https://doi.org/10.3390/plants10071441

Pooja, A., and Ameena, M., 2021. *Nutrient and PGR based foliar feeding for yield maximization in pulses: A review*. Agricultural Reviews, 42(1): 32-41. https://arccjournals.com/journal/agricultural-reviews/R-2056

Šarauskis, E., Naujokienė, V., Lekavičienė, K., Kriaučiūnienė, Z., Jotautienė, E., Jasinskas, A., Zinkevičienė, R., 2021. *Application of granular and non-granular organic fertilizers in terms of energy, environmental and economic efficiency*. Sustainability, 13(17), 9740. doi:https://doi.org/10.3390/su13179740

Shaji, H., Chandran, V., Mathew, L., 2021. *Organic fertilizers as a route to controlled release of nutrients*. Controlled Release Fertilizers for Sustainable Agriculture, Elsevier: 231-245.

Shu, X., He, J., Zhou, Z., Xia, L., Hu, Y., Zhang, Y., Liu, W., 2022. *Organic amendments enhance soil microbial diversity, microbial functionality and crop yields: A meta-analysis*. Science of the Total Environment, 829, 154627. doi:https://doi.org/10.1016/j.scitotenv.2022.154627

Singh, B., and Christina, E., 2022. *Indigenous microorganisms as an effective tool for in situ bioremediation*. Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, Elsevier, 2: 273-295.

Singh, M., Manickavasagan, A., Shobana, S., Mohan, V., 2021. *Glycemic index of pulses and pulse-based products: a review*. Critical Reviews in Food Science and Nutrition, 61(9): 1567-1588. doi:https://doi.org/10.1080/10408398.2020.1762162

Sots, S., Kustov, I., Butsenko, I., 2024. *Chemical composition of Chicpea*. Grain Products & Mixed Fodder's, 24(4): 17-24. doi:https://10.15673/gpmf.v24i4.2994

Tiwari, P.N., Tiwari, S., Sapre, S., Tripathi, N., Payasi, D.K., Singh, M., Tripathi, M.K., 2023. *Prioritization of physio-biochemical selection indices and yield-attributing traits toward the acquisition of drought tolerance in chickpea (Cicer arietinum L.)*. Plants, 12(18), 3175. doi:https://doi.org/10.3390/plants12183175

Tyagi, J., Ahmad, S., Malik, M., 2022. *Nitrogenous fertilizers: Impact on environment sustainability, mitigation strategies, and challenges*. International Journal of Environmental Science and Technology, 19(11): 11649-11672. doi:https://doi.org/10.1007/s13762-022-04027-9

Youssef, M.A., Yousef, A.F., Ali, M.M., Ahmed, A.I., Lamlom, S.F., Strobel, W.R., Kalaji, H.M., 2021a. *Exogenously applied nitrogenous fertilizers and effective microorganisms improve plant growth of stevia (Stevia rebaudiana Bertoni) and soil fertility*. AMB Express, 11: 1-10. doi:https://doi.org/10.1186/s13568-021-01292-8

Youssef, M.A., Yousef, A.F., Ali, M.M., Ahmed, A.I., Lamlom, S.F., Strobel, W.R., Kalaji, H.M., 2021b. *Exogenously applied nitrogenous fertilizers and effective microorganisms improve plant growth of stevia (Stevia rebaudiana Bertoni) and soil fertility*. AMB Express, 11(1), 133. doi:https://doi.org/10.1186/s13568-021-01292-8

Zhang, J., Wang, J., Zhu, C., Singh, R.P., Chen, W., 2024a. *Chickpea: its origin, distribution, nutrition, benefits, breeding, and symbiotic relationship with Mesorhizobium species*. Plants, 13(3), 429. doi:https://doi.org/10.3390/plants13030429

Zhang, X., Li, P., Zhao, M., Wang, S., Sun, B., Zhang, Y., Jiang, N., 2024b. *Organic fertilizer with high nutrient levels affected peanut-growing soil bacteria more than fungi at low doses*. Agronomy, 14(4), 765. doi:https://doi.org/10.3390/agronomy14040765