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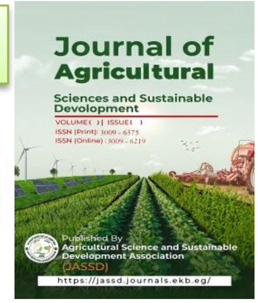

Partial Substitution of Chemical Fertilizers with Compost and Natural Biostimulants Enhances Productivity and Seed Quality in *Pisum sativum*

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Abstract

Partial substitution of chemical NPK fertilizers with compost along with the foliar application of natural biostimulants as humic acid (HA) and licorice root extract (LRE), offers a promising strategy to improve pea (*Pisum sativum* L.) productivity while enhancing soil features as an effective approach to sustainable crop production. Over two consecutive winter seasons (2023/2024 and 2024/2025), field plots received either 100% NPK or a 25% reduction in NPK supplemented with compost alone or combined with HA and/or LRE. The 75% NPK + compost + HA + LRE treatment increased chlorophyll a and b up to 30%, and green pod yield by 9.06% and 6.44% relative to the full NPK control. Seed mineral NPK content and quality parameters, including total carbohydrates, soluble sugars, and crude fiber, were significantly enhanced, while phytic acid levels declined. Post-harvest soil analyses revealed residual gains in available N, P, K, and organic matter up to 10.83%. A comprehensive correlation study demonstrated strong positive associations among soil nutrient availability, leaf pigment concentrations, vegetative growth, yield components, and seed quality traits ($r > 0.85$), whereas phytic acid exhibited consistent negative correlations ($r \approx -0.60$). These findings support a mechanistic cascade whereby improved soil fertility and natural biostimulant-mediated nutrient uptake boost photosynthetic capacity, drive biomass accumulation, and yield gains, simultaneously seed nutritional value.

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INTRODUCTION:

One of the main challenges that face modern agricultural fields is the development of ecologically friendly and sustainable agricultural methods. Increasing crop production without sacrificing environmental integrity is necessary for meeting the rising demand for food and nutrition worldwide **(Kamakaula *et al.*, 2024; Anyibama *et al.*, 2025).** While an extreme use of synthetic chemical fertilizers, especially nitrogen (N), has enhanced yields, it has also had detrimental effects on the environment, including gas emissions, nitrogen leaching, and soil acidification. Furthermore, a persistent and exclusive dependence on inorganic fertilizers degrades physical and chemical parameters of agricultural soil, reduces organic matter, plus inhibits the microbial variety and its activity **(Suhag *et al.*, 2016; Pabby *et al.*, 2001).** Partially replacing chemical fertilizers with organic amendments is suggested as a promising and sustainable way to face the challenges. Organic materials, as compost, manure, biochar, and crop wastes, improve soil features by increasing nutrients availability, stimulating microbial activity, and contributing with lasting soil health **(Gao *et al.*, 2024; Okba *et al.*, 2025)** found that using organic manure in place of 40% of chemical fertilizers greatly enhanced soil quality and decreased pollution. Because soil organic matter promotes nutrient cycling, enhances soil structure, and boosts water-holding capacity, it has a high correlation with crop yield **(Ge *et al.*, 2018).** Compost, in particular, is an important organic amendment because it is rich in key nutrients and has beneficial impacts on root colonization, soil pH, microbial variety and activity, and macro and microelements solubilization **(Rostaei *et al.*, 2024; Abdelhameid *et al.*, 2025; Zhao *et al.*, 2025).**

Compost can be combined with natural biostimulants or organic additives as part of a sustainable nutrient management plan to lessen dependency on synthetic fertilizers. Humic acid (HA) is one of the organic amendments. It is abundant in various organic and inorganic materials that are considered vital to plants' development and, as a result, improve crop production and its quality **(Jung *et al.*, 2021; Pitann *et al.*, 2024**), facilitating cell membrane permeability, besides uptake of various essential nutrients e.g., N, P, K, S, and Zn **(Aydin *et al.*, 2012; Chen *et al.*, 2022**). Besides, increasing pigment content by preserving photosynthesis and enhancing respiration in plants (**Shen *et al.*, 2020 a; Shen *et al.*, 2020 b**). Moreover, humic acids increase the synthesis of different growth-promoting phytohormones such as IAA, cytokinin (**Souza *et al.* 2022**) that activate enzymes, subsequently the antioxidant defense system is activated, resulting in tolerance to ROS **(Olivie-Canellas *et al.*, 2020; Nardi *et al.*, 2021)**. Humic compounds used to reduce the harmful effects of chemical fertilizers thereby reducing environmental pollution **(van Tol de Castro *et al.*, 2021)**. The primary goal of using humic compounds is to mitigate environmental pollution and lessen the adverse effects of chemical fertilizers. HA application is considered a promising strategy for increasing plant production and quality with sustainability **(Yousif *et al.*, 2019**; **El-Kholy & Mohamed, 2025).**

Likewise, using plant natural biostimulants reflects a sustainable strategy for inducing agricultural yield **(Rouphael & Colla, 2020).** Plant biostimulants originated from natural plant sources, and these compounds are different from insecticides and fertilizers. When using appropriate concentrations, they promote the plant growth, yield and its components, and plant tolerance to various environmental stress and climate change **(Ali *et al.*, 2025; Youssef *et al.*, 2025).** Biostimulants have several mechanisms to be a promising strategy, they develop root system design to promote water and nutrients uptake, increase photosynthetic and activate antioxidant defense enzymes that minimize oxidative stress. Subsequently, this reflects on growth, yield and quality of plants, **(Rouphael & Colla, 2020).** Licorice (*Glycyrrhiza glabra* L.) is considered the best natural biostimulant rich in antioxidants, phytohormones, and essential nutrients that supplement physiological functions **(Asan-Ozusaglam & Karakoca, 2014; Rady *et al.*, 2019; Younes *et al.*, 2021)**. Also, LRE contains a range of bioactive compounds, enzymes, and amino acids that provide protein and carbohydrate synthesis, which contributes to stimulation of vegetative growth and yield. Additionally, it contains mevalonic acid, a basic precursor in the biosynthesis of gibberellins (**Adam *et al.*, 2022**). It might be a natural alternative to synthetic auxins as indole-3-butyric acid (IBA) **(Rady et al., 2019).**

After faba bean, green pea (*Pisum sativum* L.) considers the next greatest significant legume crop (**Kumari *et al.* 2013).** In Egypt**,** it is one of the important winter cash crops for both local and export markets. It is a vital vegetable crop renowned for its nutritional richness, containing high levels of protein, total dissolved solids, carbohydrates, vitamins, and essential minerals (e.g., P, Fe, Zn and Ca) (**Hacisalihoglu *et al.*, 2021**). Arab Republic of Egypt has been produced more than 166.000 tons in 2022 and classified one of the top ten countries in all over the world that producing green pea **(Youssef *et al.* 2024).**

No data available on using a combination of compost with humic acid and licorice extract root. This study aims to evaluate the impacts of partially substituting chemical NPK fertilizers with compost in combination with foliar applications of humic acid or licorice root extract on *Pisum sativum* performance and on post-harvest soil health. Specifically, we will assess plant growth, green-pod yield, seed mineral and nutritional quality, and residual soil properties under each treatment. Finally, a correlation analysis will be conducted to elucidate the interrelationships among physiological, yield, seed quality, and available nutrients in soil.

MATERIALS AND METHODS:

Field experiment:

Both of two field experiments were located at a private farm (31°22' 73.73'' N latitude and 31°33' 79.57'' E longitude) at Belqas region, Al-Daqahlia Governorate, Egypt in the 2^{nd} and 3^{rd} week of October in 2023/2024 and 2024/2025 respectively to evaluate substitute of chemical fertilizer by addition of compost to soil along with foliar spraying of both HA and LER to exert synergistic effects for enhancing growth, production and seed quality. For that purpose, pea seeds; master B (*Pisum sativum* L.) was obtained from the Agricultural Research Center, Giza, Egypt, and was planted in the two successive seasons. Before cultivation, soil samples were collected from 30 cm in depth and studied for some physical and chemical features by **Jackson (2005).** The physical and chemical analysis of the studied soil during the two seasons are shown in Table no. (1).

Table 1. The physical and chemical properties of the studied soil during 2023-2024 and 2024-2025.

Properties	Value	
	2023/2024	2024/2025
I- Physical properties		
Sand %	34.5	34.30
Clay %	29.38	29.40
Silt %	36.12	36.30
Soil texture	Clay loam	
Saturation percent	58.50	60.00
II – Chemical properties		
pH soil–water suspension ratio (1:2.5)	8.11	8.07
EC (ds m^{-1}) soil: water extract (1:5)	1.33	1.29
$CaCO_3$ (%)	2.36	2.31
Organic matter (%)	1.11	1.20
Available N (mg kg^{-1})	24.13	24.32
Available K (mg kg^{-1})	146	139
Available P (mg kg^{-1})	8.85	8.81
Zn (mg kg^{-1})	0.33	0.37
Fe (mg kg^{-1})	9.58	9.73
Mn (mg kg^{-1})	0.49	0.51
Cu (mg kg^{-1})	2.00	1.92

Experiment layout and Treatments:

The recommended NPK was 96 kg N ha^{-1}, 108 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, were applied as ammonium sulfate (20.6% N) was put as a source of nitrogen, Super-phosphate (15.5% P_2O_5) has been used as a phosphorous source and Potassium sulfate (48% K_2O) has been used as a potassium source. Additiunally, commercial compost was applied at the amount of 12 ton ha^{-1}, it has been broadcast and well mixed with the soil surface layer (0 – 30 cm) through plot preparation according to the treatments, occurring 10 days before the sowing. Natural biostimulants used were humic substances at 2 gL^{-1} and Licorice Root Extract at 5gL^{-1}, applied as foliar spray (three times, the 1st application was after 20 days from planting. Foliar spraying was repeated two times (15 days between them). Chemical analysis of the average of 3 composting trials is presented in Table (2). Humic acid (HA) was obtained from Changsha new-Nutri Agriculture&Technology Co., LTD, China, (humic acid = 80%; fulvic acid = 10%; K_2O = 8%; N= 0.72%; P_2O_5= 0.07%; Mg = 0.30%; Mn = 0.041%; Zn= 0.012 and soluble matter= 95%). The current study consisted of six treatments were organized in a complete randomized block design with three replicates; so, the total experimental units equal 18 units. Each plot area was 10.5 m^2, which had three rows, 5m in length, and 0.7 m in width. Pea seeds were planted 20 cm apart from each other and on one side of the ridges. Treatments are arranged in a complete randomized design, which were: T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ of LRE, T6 = 75% NPK + compost + LRE + HA. (HA: humic acid, LRE: Licorice root extract).

Table 2. The Chemical analysis of the average of 3 composting trials

Analysis	Values
pH (1:10)	7.21
EC (dSm-1)	1.08
Organic matter (%)	29.89
Carbon (%)	15.5
Nitrogen (%)	1.78
Phosphorus (%)	1.09
Potassium (%)	1.14

A preparation and foliar application of Licorice root extract (LRE)

Licorice root (*Glycyrrhiza glabra* L.) was obtained from the Horticulture Research Institute, Agricultural Research Center, Giza, Egypt. Its roots are extracted by weighing 5 g of licorice roots, which were well dried and soaked in 1000ml of water at 50°C for 1 day, then it was filtered and supplemented to liter as a final volume. LRE was used at 5 g l^{-1} and applied as a foliar three times (i.e., 20, 35, and 50 days after pea sowing). Put drops of Tween-20 into the previously prepared extract as a surfactant to give an active and broad penetration of the prepared LRE **(Younes *et al.*, 2021).** Certain chemical components in the LRE are displayed in Table (3).

Table 3. Chemical components of licorice root extract (LRE).

Component	Value
Total phenol (mg GAE/ g Dw)	4.33 mg 100 g^{-1}
Total flavonoid (mg QE/ g Dw)	2.18 mg 100 g^{-1}
Total antioxidant (mg AAE/ g Dw)	71.84 mg 100 g^{-1}
N	20.23 mg g^{-1}
P	21.12 mg g^{-1}
K	43.7 mg g^{-1}
Mg	2.23 mg g^{-1}
Fe	0.08 mg g^{-1}
Zn	0.24 mg g^{-1}

GAE, Gallic acid equivalent; QE, quercetin equivalent; AAE, L-ascorbic acid equivalent; Dw, dry weight; mg, milligram.

DATA RECORDED:

Leaf area and pigment:

Leaf samples were separated from the shoot and collected at 70 days after sowing. A mobile application called Petiole, which utilizes image processing techniques **(Singh *et al.*, 2021)** to measure the leaf area (cm^2) of samples, and the leaf area/plant (cm^2) was calculated. Chlorophyll a, chlorophyll b, carotenoid contents, and total chlorophyll (mg g^{-1} f. wt) were assayed in pea fresh leaves (**Saric *et al.* 1976).**

Growth characteristics:

Five pea plant samples were taken in a random way from various plots at 70 days from the planting to study plant height (cm), no. branches $plant^{-1}$, no. leave plant $^{-1}$, Fresh and dry weight $plant^{-1}$ (g), the samples, including stems and leaves, were well dried in the oven at 70 ^{o}C till the weight of the samples was constant **(Black, 1965).**

Yield and yield components:

Five pea plants from each plot were randomly taken after 120 days from planting the pea seeds; mature green pods were harvested at suitable maturity stages. Pods were separated by hand for seed yield and chemical analysis. Assay the number of pods plant^{-1}, Pod length (cm), number of seeds plant^{-1}, Weight seeds plant^{-1}, 100 seed weight (g) and weight green pods ha^{-1} (ton),

Seed analysis

Mineral content

Pea seeds has been dried in the oven at 70° C till constant weight then ground well to a fine powder and the sub samples of 0.5g was wet digested by sulphuric-perchloric acid (1:1) mixture to study and determine the following minerals content: Total nitrogen in pea seeds (%) was estimated by using modified microkjeldahl method (**Jones *et al.* 1991**). Total phosphorus (%) was estimated by using UV spectrophotometry (M. no. UV 2100 S/N: BH 16041603003). P.S.: AC 220 V/ 50 Hz FUSE: 250 V/ 3.15 A FAST- ACTING (**Page *et al.* 1982).** Total potassium (%) by using the Flame-Photometer (JENWAY PFP7 model) (**Page *et al.* 1982).**

Organic component seed

Fiber and total soluble sugar (TSS): Total fiber percentage and TSS of pea seeds were determined by (**A.O.A.C. 2000).**

Total carbohydrate (%) was determined colorimetrically as (grams of glucose /100g dry weight of seeds) **(BeMiller, 2017).**

Phytic acid content (mg 100g^{-1}) was assayed by the modified method of **Haug and Lantzsch (1983).**

Crude protein (%) in pea seeds was calculated via multiplying Nitrogen (%) by 6.25 according to **Tripath *et al.* (1971)**

Total Soluble Sugars (TSSu); in a test tube, mix 0.1 ml of a carbohydrate solution (the prepared samples at a conc. of 1 mg mL^{-1}) with freshly made phenol (1 ml of 5%). The prior mixture is then mixed with 5 millilitres of concentrated H_2SO_4. The test tubes are then left for 10 minutes, vortexed for 30 seconds, then placed in a water bath at room temperature for 20 minutes to change their color. A spectrophotometer was then used to measure the absorbance at 490 nm. Pure glucose was used to calculate the samples' TSSu (g 100g^{-1}) content using a standard curve (**El-Mageed *et al.*, 2022).**

Post-harvest soil analysis:

Following pea plant harvest, soil samples were taken from each plot at a depth of 0 to 15 cm. where the collected samples were thoroughly air dried, crushed, sieved through a 2 mm sieve, and prepared for chemical analyses of the available N, P, and K in soil and organic matter (%) (**Jackson, 2005).**

STATISTICAL ANALYSIS:

Six treatments of the 2023-2024 and 2024-2025 seasons were organized in a completely randomized block design with three replicates. All recorded data were subjected to analysis of variance (ANOVA) using CoStat software. Means of treatment were compared via Tukey's honest significant difference (HSD) test at $\alpha \leq 0.05$ using the minimum significant difference (MSD). In addition to mean comparisons, Pearson's correlation coefficients were calculated between various parameters, including post-harvest soil properties, to elucidate their interrelationships. Correlation matrices were generated based on the average of the two seasons using the same software environment.

RESULTS:

In the face of mounting environmental pressure from synthetic fertilizers and the urgent need to sustain crop productivity, this study provides the first comprehensive evaluation of partially substituting chemical NPK with compost alongside foliar-applied humic acid and licorice root extract in pea cultivation. We systematically measured physiological responses, vegetative growth, yield components, seed mineral and nutritional quality, and residual soil fertility over two seasons. To reveal the underlying coordination among these traits, we also conducted Pearson correlation analyses to support a mechanistic understanding of sustainable nutrient management in *Pisum sativum.*

Leaf area and pigment

Integrating compost as a partial substitute for chemical fertilizers, combined with foliar spraying either with HA or LRE, significantly improved leaf area (cm^2). Fertilized with 75% NPK+ compost +LER+HA recorded the highest leaf area plant^{-1} values (495.00 and 458.00 cm²) during the two growing seasons. About chlorophyll content, the applied 75% NPK+ compost +LRE+HA increased Chl a by (29.63, 12.50%); Chl b by (12.50, 18.52%), and carotenoid by (25.30, 9.57%) in the first and second seasons, respectively, compared to the 100%NPK treatment. In 2023-2024 season, the total chlorophyll content was highest with the 75% NPK+ compost +LRE + HA treatment, while in the 2024-2025 season, there was no significant difference in total chlorophyll content between this treatment and the 75% NPK combined with compost +LRE (Table 4).

Table (4): Partial substitute of chemical fertilizers with compost and natural biostimulants on leaf area plant^{-1} (cm^2) and leaf pigment (mg g^{-1} fwt) of pea (*Pisum sativum* L.).

Treatment	Leaf area plant^{-1} (cm^2)		Chl a (mg g^{-1} fwt)		Chl b (mg g^{-1} fwt)		Carotenoid (mg g^{-1} fwt)		Total chl (mg g^{-1} fwt)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T1	352.2	352.1	0.27	0.32	0.24	0.27	0.083	0.094	0.518	0.603
T2	139.5	167.9	0.18	0.21	0.18	0.23	0.055	0.061	0.376	0.444
T3	300.6	295.6	0.24	0.31	0.24	0.24	0.069	0.083	0.489	0.543
T4	404.1	393.7	0.30	0.34	0.23	0.30	0.098	0.099	0.540	0.644
T5	414.5	386.1	0.33	0.35	0.24	0.32	0.092	0.094	0.580	0.679
T6	495.0	458.0	0.35	0.36	0.27	0.32	0.104	0.103	0.616	0.678
MSD ($\alpha \leq 0.05$)	49.06	52.07	0.027	0.015	0.011	0.023	0.14	0.04	0.027	0.031

T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract. MSD = minimum significant difference

Growth characteristics

Current results from the statistical analysis (Table 5) showed that the effect of compost at 12 ton ha^{-1} with licorice root extract at 5 g L^{-1} and/or humic acid at 2gL^{-1} of pea had a significant result on vegetative growth. The combination of 75% NPk with LRE and humic acid displayed noticeable increments for plant height by (7.92, 11.90%), number of leaves (13.19, 16.89%), fresh weight (20.82, 15.53%), dry weight (21.92, 22.98%) through two seasons respectively, compared to 100% NPK. However, there was no significant difference in the number of branches per plant among the treatments during both seasons.

Yield and yield components

The partial substitution of chemical fertilizers with compost, along with foliar spraying of licorice extract and humic acid, resulted in a statistically significant improvement in crop yield (Table 6). under this treatment, pod number plant^{-1}increased by 13.63% and 26.86% in both seasons, respectively. In the same way, number of seeds per pod, the weight of seeds per plant, 100 seeds weight, and the weight of green pods per hectare increased by (23.71,19.00%; 13.15, 13.17%; 15.17, 15.03% and 9.06, 6.44%) through dual seasons, respectively, compared to 100%NPK. Concerning pod length, there is no significant difference detected among 75%NPK+compost+ humic acid and/or LRE for the 1st season, while in the 2nd season, Partial substitution of chemical fertilizers (75%) with compost either with humic acid or licorice extract led to a significant improvement over the sole application 75% chemical fertilizer, while no significant differences were detected among the other treatments, including the full chemical fertilization (100%). Regarding weight seeds per plant through both seasons, there is no significant effect between 100 NPK and 75%NPK compost combined with either humic or LRE.

Table (5): Partial substituting of chemical fertilizers with compost and natural biostimulants on vegetative growth of pea (*Pisum sativum* L.).

Treatment	Plant height (cm)		Branch number		Leaves number		Fresh weight (g)		Dry weight (g)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T1	50.50	40.60	2.15	2.00	25.33	21.67	59.12	59.10	12.27	11.14
T2	45.17	32.13	1.75	1.40	15.00	15.66	44.76	44.65	8.93	7.83
T3	46.73.	40.46	2.10	2.00	24.33	19.33	57.13	56.83	11.06	9.12
T4	53.17	44.66	2.10	2.00	24.67	23.00	64.5	61.41	13.12	11.15
T5	52.00	43.00	2.25	2.15	26.33	21.00	61.18	59.13	12.66	10.54
T6	54.50	45.43	2.75	2.33	28.67	25.33	71.43	68.28	14.96	13.70
MSD ($\alpha \leq 0.05$)	3.46	3.94	Ns	Ns	2.89	3.10	4.39	3.08	1.84	1.46

T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract. MSD = minimum significant difference

Table (6): Partial substituting of chemical fertilizers with compost and natural biostimulants on the yield of pea (*Pisum sativum* L.).

Treatment	Pods number plant^{-1}		Pod length (cm)		Number of seeds pod^{-1}		Weight seeds plant^{-1} (g)		100 seeds weigh (g)		Weight green pods ha^{-1} (ton)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T1	14.67	13.66	9.12	8.87	7.00	7.00	23.56	23.45	22.28	22.48	6.07	6.05
T2	10.00	9.67	8.00	7.60	5.33	5.67	16.48	16.05	17.71	17.96	5.43	5.65
T3	13.00	12.00	8.90	8.87	6.66	7.66	22.26	22.33	19.60	19.86	5.84	5.82
T4	14.67	14.33	9.40	9.20	8.00	7.66	23.78	23.64	23.19	23.44	6.20	6.13
T5	15.67	14.67	9.30	9.30	7.00	7.66	23.06	22.82	24.63	24.31	6.25	6.21
T6	16.67	17.33	9.50	9.37	8.66	8.33	26.66	26.54	25.66	25.86	6.62	6.44
MSD ($\alpha \leq 0.05$)	2.82	2.42	1.15	0.83	1.94	1.83	2.67	1.52	2.30	1.57	0.24	0.29

T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract. MSD = minimum significant difference.

Seed Quality

Mineral content

During 2023-2024 season, it was shown that it has no significant difference in nitrogen content between the treatment with 100% NPK and that with 75% NPK + compost + LRE + HA. Similarly, in the 2024-2025 season, no significant difference was detected between 100% NPK and 75% NPK + compost + either LRE and/or HA. Likewise, phosphorus content did not differ significantly between 100% NPK and 75% combined with compost and either humic acid or licorice root extract in each season. However, the treatment with 75% NPK + compost + LRE + HA resulted in a significantly higher potassium content with increases of (9.90%) for the first season and (9.0%)

for the second one when compared to 100% NPK (Table 7)

Table (7): Partial substituting of chemical fertilizers with compost and natural biostimulants on mineral components of pea (*Pisum sativum* L.).

Treatment	Nitrogen %		Phosphorous%		Potassium%	
	1st	2nd	1st	2nd	1st	2nd
T1	3.58	3.63	0.509	0.516	1.01	1.00
T2	2.89	2.94	0.364	0.361	0.77	0.82
T3	3.30	3.28	0.441	0.450	0.94	0.91
T4	3.56	3.64	0.495	0.492	1.01	1.00
T5	3.55	3.58	0.486	0.483	0.95	0.95
T6	3.79	3.76	0.508	0.516	1.11	1.09
MSD ($\alpha \leq 0.05$)	0.26	0.19	0.026	0.024	0.16	0.12

T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract. MSD = minimum significant difference.

Organic Component Seed

Applying compost as a partial substitute for chemical fertilizers, combined with foliar spraying of licorice extract and/or humic acid, significantly improved the seed quality of pea seeds (Table 8). The treatment combining 75% NPK + compost + LRE + HA gave a notable increase in the seed fiber content by (2.11%, 2.00%), carbohydrate content by (2.89%, 4.69%), total soluble solids (TSS) by (1.85%, 1.72%), and total soluble sugar, with increases of (4.80%, 3.65%) compared to the 100% NPK treatment during the first season and second one, respectively. However, there was no significant change in protein content between the treatment with 100% NPK and that with 75% NPK + compost + LRE + HA for 1st season. Similarly, during 2024-2025 season, it has been observed that there was no significant difference between 100% NPK; and the treatments that receiving 75% NPK combined by compost with either humic acid or licorice root extract (LRE). In another side, the highest phytic acid content be recorded under the 100% NPK treatment (1.16, 1.17 mg $100g^{-1}$), while the lowest content of phytic acid was observed under the 75% NPK + compost + LRE + HA treatment.

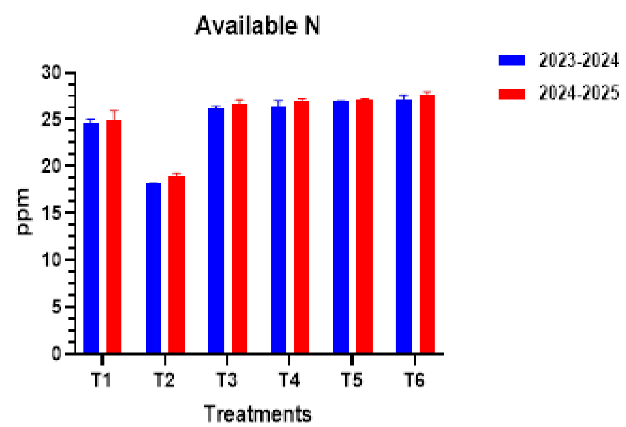
Table (8): Partial substituting of chemical fertilizers with compost and natural biostimulants on seed quality of pea (*Pisum sativum* L.).

Treatment	Fiber %		Carbohydrate %		Phytic acid (mg $100g^{-1}$)		Total soluble solids (g $100g^{-1}$)		Protein %		Total soluble sugar (g 100 g^{-1})	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T1	9.49	9.53	17.33	16.40	1.16	1.17	16.26	16.26	22.35	22.67	9.16	9.29
T2	8.00	8.16	12.98	13.68	1.08	1.07	12.05	13.02	18.06	18.40	8.00	7.94
T3	9.10	9.23	16.41	15.42	1.00	1.02	15.59	15.44	20.63	20.54	8.65	8.45
T4	9.45	9.51	17.40	16.41	0.91	0.90	16.32	16.36	22.25	22.75	9.28	9.33
T5	9.40	9.51	17.43	16.42	0.91	0.89	16.31	16.31	22.21	22.40	9.25	9.28
T6	9.69	9.72	17.83	17.17	0.82	0.80	16.56	16.54	23.71	23.50	9.60	9.63
MSD ($\alpha \leq$ 0.05)	0.17	0.14	0.16	0.72	0.07	0.10	0.26	0.17	1.64	1.20	0.28	0.20

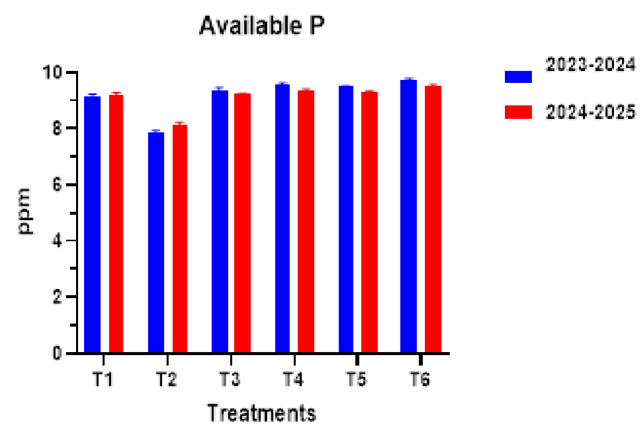
T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract. MSD = minimum significant difference.

Post-harvest soil analysis

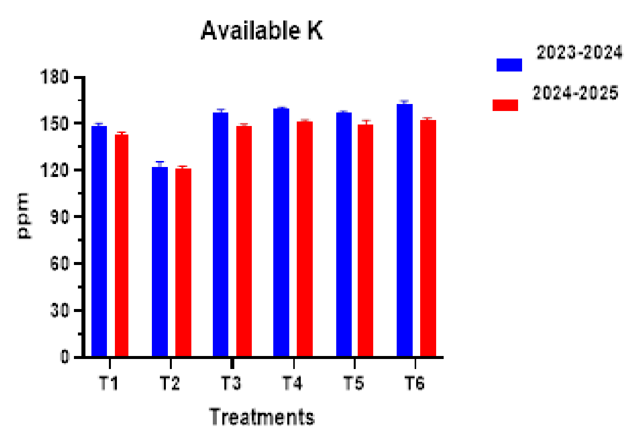
The findings indicate that integrating compost as a partial replacement for chemical fertilizers, in combination with foliar applications of licorice root extract and/or humic acid, substantially improved soil nutrient availability (Table 9). The Fertilized with 75% NPK+compost+LRE+HA recorded the highest available nitrogen (27.18 mg kg^{-1}, 27.63 mg kg^{-1}), increasing by (10.53, 10.83%) compared with 100%NPK through both seasons, respectively. Similarly, this treatment led to notable increases in available phosphorus and potassium (6.57, 9.43 %) for the 1st season and (3.48, 6.76%) for the 2nd, respectively. Regarding organic matter, the incorporation of compost played a pivotal role in improving its content, where75%NPK+compost+ LRE +HA showed the highest increase over 100%NPK cross both seasons at 8.40% and 6.57% respectively.



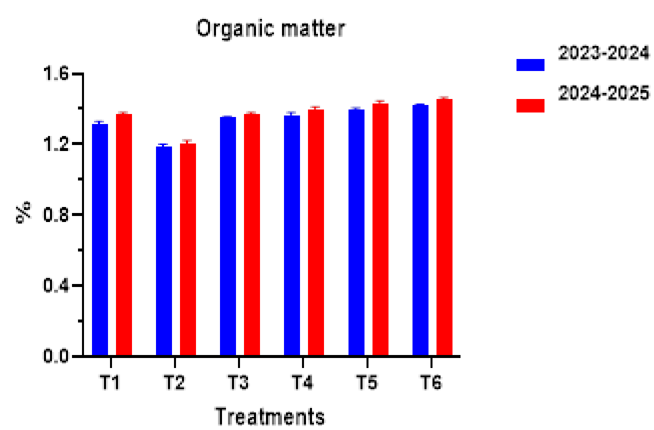
MSD values at α ≤ 0.05 were 1.05, and 1.34 for the 1st and 2nd seasons, respectively.



MSD values at α ≤ 0.05 were 0.16, and 0.19, for the 1st and 2nd seasons, respectively.



MSD values at α ≤ 0.05 were 5.88, and 4.93 for the 1st and 2nd seasons, respectively.



MSD values at α ≤ 0.05 were 0.04, and 0.04 for the 1st and 2nd seasons, respectively.

Fig (1): Effect of compost with humic acid and/ or licorice root extract on available nutrients (mg kg^{-1}), organic matter percentage. For each criterion, columns are significantly different using Tukey's honest significant difference test at α ≤ 0.05 based on minimum significant difference (MSD). Where T1 = 100%NPK, T2=75%NPK, T3=75%NPK+compost, T4=75%NPK+compost+ HA, T5 = 75%NPK+compost+ of LRE, T6 = 75% NPK + compost + LRE + HA, HA: humic acid, LRE: Licorice root extract.

Correlation study

To understand their connections, the two seasons' data underwent interrelationship analysis. Table (9) presents a comprehensive correlation matrix that reveals a highly integrated network connecting soil health, plant physiological traits, yield components, and seed quality parameters. Chlorophyll a, chlorophyll b, and total chlorophyll display extremely strong positive correlations (r > 0.95) with leaf area, plant height, fresh and dry biomass, pod number, seed number per pod, and pod yield per hectare. This indicates that enhancements in photosynthetic pigment content translate directly into improved vegetative growth and reproductive output. Carotenoid content likewise shows robust positive correlations (r ≈ 0.85–0.90) with these agronomic traits, underscoring its supportive role in light harvesting and photoprotection.

Soil available nitrogen, phosphorus, potassium, and organic matter also correlate strongly (r > 0.83) with plant growth and seed quality metrics. These results confirm that the combined treatment not only boosts in-season performance but also leaves a legacy of elevated residual soil fertility. Seed concentrations of N, P, and K further reflect this enhanced nutrient availability, correlating positively with pigment levels and yield components and demonstrating that efficient nutrient uptake is a key driver of the observed agronomic gains.

Seed quality parameters, total soluble sugars, crude fiber, total carbohydrates, and total soluble solids exhibit high positive correlations (r ≈ 0.88–0.98) with both physiological and yield traits, highlighting the systemic improvement of both yield quantity and end-use quality. In contrast, phytic acid shows consistent negative correlations (r ≈ –0.58 to –0.74) with nearly all performance indicators, revealing its antagonistic relationship with yield and nutritional value.

Discussion

Numerous studies confirm that the use of synthetic chemical fertilizers is highly effective in promoting plant growth, development besides improving productivity. However, their long-term and continuous application adversely affects soil health and reduces the activity of beneficial soil microorganisms, ultimately leading to a negative effect on soil fertility due to their unbalanced nutrient composition **(Prakash, 2023).** A promising strategy for sustainable agriculture can be achieved by the partial substitution of chemical fertilizers with organic addition. Organic inputs as FYM, compost, and vermicompost, have multiple positive effects on soil health **(Leogrande *et al.*, 2024).** These improvements contribute to enhanced nutrient availability, crop quality, and overall productivity **(El-Saied and Rashwan, 2021).** Compost, in particular, contains organic matter and essential mineral nutrients that can stimulate the root system and water and nutrient uptake, finally improving plant growth and crop yield **(Mohammed *et al.*, 2025).** Compost application has a vital role in adjusting soil pH, increasing porosity, moisture content, aggregate stability, organic matter, and the availability of P and K, but decreasing the bulk density **(Rivier *et al.*, 2022; Mohammed *et al.*, 2025).**

Table 9. Investigating correlations using data averaged across the two seasons.

		Plant pigments				Plant measurement					Pod analysis			Yield			Seed quality analysis									Soil analysis			
	Leaf area	Chla	Chlb	Carotenoid	Total chl	Height	Branches	Leave	Fresh wt.	Dry wt.	Number/plant	Length	Seed number	Seed wt./plant	100-seed wt.	Pod wt./ha	N%	P%	K%	Protein %	Soluble sugar	Fiber	Carbohydrate	Phytic acid	Total solids	N	P	K	Organic matter
Leaf area	**1.00**																												
Chla	**0.98**	**1.00**																											
Chlb	**0.97**	**0.98**	**1.00**																										
Carotenoid	**0.88**	**0.86**	**0.86**	**1.00**																									
Total chl	**0.98**	**1.00**	**0.99**	**0.87**	**1.00**																								
Plant height	**0.97**	**0.95**	**0.93**	**0.87**	**0.95**	**1.00**																							
Branch number	**0.65**	**0.66**	**0.64**	**0.54**	**0.66**	**0.63**	**1.00**																						
Leave number	**0.97**	**0.92**	**0.89**	**0.85**	**0.92**	**0.93**	**0.59**	**1.00**																					
Fresh wt.	**0.96**	**0.92**	**0.91**	**0.88**	**0.92**	**0.94**	**0.62**	**0.98**	**1.00**																				
Dry wt.	**0.94**	**0.88**	**0.91**	**0.79**	**0.90**	**0.91**	**0.60**	**0.92**	**0.94**	**1.00**																			
Pod number/plant	**0.97**	**0.95**	**0.95**	**0.85**	**0.96**	**0.92**	**0.58**	**0.93**	**0.93**	**0.93**	**1.00**																		
Pod length	**0.88**	**0.89**	**0.85**	**0.74**	**0.88**	**0.87**	**0.66**	**0.88**	**0.86**	**0.80**	**0.80**	**1.00**																	
Seed number/pod	**0.82**	**0.77**	**0.76**	**0.70**	**0.77**	**0.82**	**0.64**	**0.84**	**0.87**	**0.80**	**0.80**	**0.79**	**1.00**																
Seed wt./plant	**0.97**	**0.95**	**0.95**	**0.85**	**0.96**	**0.92**	**0.58**	**0.93**	**0.93**	**0.93**	**1.00**	**0.80**	**0.80**	**1.00**															
100-seed wt.	**0.95**	**0.94**	**0.98**	**0.84**	**0.96**	**0.93**	**0.61**	**0.87**	**0.90**	**0.91**	**0.93**	**0.79**	**0.75**	**0.93**	**1.00**														
Pod wt./ha	**0.96**	**0.97**	**0.98**	**0.85**	**0.98**	**0.94**	**0.62**	**0.89**	**0.92**	**0.93**	**0.96**	**0.81**	**0.77**	**0.96**	**0.96**	**1.00**													
Seed N%	**0.95**	**0.94**	**0.93**	**0.91**	**0.94**	**0.93**	**0.53**	**0.93**	**0.96**	**0.90**	**0.95**	**0.79**	**0.77**	**0.95**	**0.92**	**0.95**	**1.00**												
Seed P%	**0.91**	**0.90**	**0.88**	**0.86**	**0.90**	**0.89**	**0.47**	**0.92**	**0.94**	**0.86**	**0.88**	**0.80**	**0.73**	**0.88**	**0.86**	**0.89**	**0.96**	**1.00**											
Seed K%	**0.88**	**0.82**	**0.85**	**0.77**	**0.84**	**0.85**	**0.58**	**0.88**	**0.92**	**0.89**	**0.82**	**0.80**	**0.80**	**0.82**	**0.85**	**0.87**	**0.87**	**0.88**	**1.00**										
Seed protein %	**0.95**	**0.94**	**0.93**	**0.91**	**0.94**	**0.93**	**0.53**	**0.93**	**0.96**	**0.90**	**0.95**	**0.79**	**0.77**	**0.95**	**0.92**	**0.95**	**1.00**	**0.96**	**0.87**	**1.00**									
Total sugar	**0.97**	**0.95**	**0.95**	**0.91**	**0.96**	**0.94**	**0.55**	**0.94**	**0.95**	**0.94**	**0.95**	**0.83**	**0.75**	**0.95**	**0.94**	**0.95**	**0.98**	**0.95**	**0.86**	**0.98**	**1.00**								
Fiber	**0.94**	**0.94**	**0.90**	**0.86**	**0.93**	**0.91**	**0.56**	**0.94**	**0.96**	**0.86**	**0.90**	**0.88**	**0.81**	**0.90**	**0.86**	**0.91**	**0.96**	**0.97**	**0.88**	**0.96**	**0.94**	**1.00**							
Carbohydrate	**0.96**	**0.95**	**0.92**	**0.88**	**0.95**	**0.93**	**0.56**	**0.95**	**0.96**	**0.87**	**0.93**	**0.86**	**0.80**	**0.93**	**0.89**	**0.92**	**0.97**	**0.97**	**0.85**	**0.97**	**0.96**	**0.99**	**1.00**						
Phytic acid	**-0.69**	**-0.68**	**-0.70**	**-0.59**	**-0.69**	**-0.68**	**-0.74**	**-0.58**	**-0.58**	**-0.62**	**-0.66**	**-0.60**	**-0.68**	**-0.66**	**-0.69**	**-0.68**	**-0.53**	**-0.37**	**-0.52**	**-0.53**	**-0.56**	**-0.47**	**-0.51**	**1.00**					
Total solids	**0.93**	**0.94**	**0.88**	**0.84**	**0.92**	**0.91**	**0.55**	**0.94**	**0.94**	**0.83**	**0.88**	**0.90**	**0.78**	**0.88**	**0.84**	**0.88**	**0.94**	**0.96**	**0.83**	**0.94**	**0.92**	**0.99**	**0.99**	**-0.46**	**1.00**				
Soil available N	**0.89**	**0.91**	**0.84**	**0.80**	**0.89**	**0.88**	**0.67**	**0.89**	**0.90**	**0.76**	**0.83**	**0.92**	**0.83**	**0.83**	**0.78**	**0.82**	**0.85**	**0.85**	**0.76**	**0.85**	**0.83**	**0.93**	**0.93**	**-0.60**	**0.95**	**1.00**			
Soil available P	**0.93**	**0.93**	**0.87**	**0.83**	**0.91**	**0.91**	**0.63**	**0.94**	**0.93**	**0.82**	**0.88**	**0.90**	**0.84**	**0.88**	**0.81**	**0.87**	**0.91**	**0.89**	**0.80**	**0.91**	**0.88**	**0.96**	**0.96**	**-0.59**	**0.97**	**0.98**	**1.00**		
Soil available K	**0.90**	**0.90**	**0.83**	**0.77**	**0.88**	**0.89**	**0.63**	**0.91**	**0.90**	**0.79**	**0.83**	**0.91**	**0.86**	**0.83**	**0.77**	**0.82**	**0.84**	**0.83**	**0.76**	**0.84**	**0.83**	**0.92**	**0.92**	**-0.61**	**0.94**	**0.98**	**0.98**	**1.00**	
Soil organic matter	**0.94**	**0.95**	**0.91**	**0.83**	**0.94**	**0.92**	**0.67**	**0.91**	**0.92**	**0.84**	**0.90**	**0.90**	**0.84**	**0.90**	**0.86**	**0.90**	**0.89**	**0.85**	**0.78**	**0.89**	**0.88**	**0.93**	**0.94**	**-0.68**	**0.94**	**0.97**	**0.97**	**0.97**	**1.00**

Even when used at a low rate, compost has to be used to improve soil chemical and physical characteristics **(Yassin *et al.*, 2023),** support the growth and activity of beneficial microorganisms, which continuously decompose organic compounds to maintain soil nutrient balance. So, compost application can reduce soil leaching of nutrients, thus minimizing the need for chemical fertilizers and enhancing crop productivity. Subsequently, compost combined with humic acid foliar application has been stated to improve growth, yield, and crop quality **(Maucieri *et al.*, 2019; Kamran *et al.*, 2025).**

Humic acid (HA) promotes vegetative growth by enhancing nutrient uptake, exhibiting a high chelating capacity, and developing plant cell metabolism **(Weissy *et al.*, 2018). Hafeez *et al.* (2024)** highlighted the important role of HA in improving various morphological traits in black cumin plants. While **Roudgarnejad *et al.* (2021)** observed similar benefits in beans.

HA has stimulated vegetative growth by different mechanisms, through metabolism of macro- and micro minerals, activating growth-regulating hormones and enzymes, improving membrane permeability, and enhancing protein synthesis (**Ulukan, 2008; Weissy *et al.*, 2018).** Consequently, that reflects on plant biomass and crop yield **(Roudgarnejad *et al.*, 2021; Rashwan & El-Saied, 2022)**. additionally, HA has been stated to expand photosynthetic rate, leaf area, which together contribute to increased yield and yield components **(Canellas *et al.*, 2015).** Besides dry matter accumulation, HA can enrich seed protein content by improving essential nutrient uptake **(Eneji *et al.*, 2013).** Correspondingly, HA supports absorption of micronutrients in a better way and improves crop quality by improving synthesis of total soluble sugars (TSSu), proteins, plus essential vitamins that reflect positively on nutritional quality in several crops **(Hakan *et al.*, 2011).** Thus, HA application is reflected as an effective strategy to reduce the use of chemical fertilizer with alleviate environmental pollution when applied at an appropriate rate. Therefore, foliar spraying of HA is recommended for farmers as a cost-effective practice for use in agriculture **(Roudgarnejad *et al.*, 2021).** Our results match with the results of **Firouzabadi *et al.* (2025) and Sobhani & Shokoufar (2024),** who recommended the positive impact of humic acid as a foliar application on cowpea plants

Licorice root extract is an natural biostimulant rich in various bioactive compounds, with antioxidants, osmoprotectants, sugars, various vitamins, essential minerals, some amino acids, and phytohormones such as gibberellins (GAs) **(Abd El Mageed *et al.*, 2025; Elrys and Merwad, 2017)** One of its key components is mevalonic acid, which serves as a basic precursor in the biosynthesis of gibberellins that stimulate the cell division and lead to increase in leaf area that result enhancing a photosynthetic activity **(Nikee *et al.*, 2014; Adam *et al.*, 2022**). Also, LRE might be used as a natural alternative to synthetic auxins such as indole-3-butyric acid (IBA) **(Rady *et al.*, 2019).** So**,** its compounds provide physiological, biochemical, and molecular mechanisms that help growth, yield, and plant adaptability to numerous climate changes. The presence of K^+ in the extract contributes to osmotic regulation and stomata control (**Marschner, 1995; Dubey, 2005).** Presence of Iron (Fe) and various essential nutrients (Table 3) activates various enzymes involved in the biosynthesis of chlorophyll, which develops chlorophyll content and leaf greenness **(Zayed *et al.*, 2011).** LRE plays a vital role in enhancing soluble carbohydrates and total soluble sugars, which play a significant part in energy supply for plant metabolism **(Rady *et al.*, 2019).** LRE considers a promising eco-friendly alternative to synthetic chemical fertilizers and some growth regulators because its natural origin and various physiological effects. It improves growth and production without harming human health or the environment **(Singh *et al.*, 2024; Hosseini *et al.*, 2022; Abd El Mageed *et al.*, 2025).** On the other hand, phytic acid, a natural phenolic compound that represents the primary phosphorus storage form in different legumes, including pea seeds. While it is essential for seed development but its high concentration in seeds reduces iron and zinc bioavailability, hence influencing the nutritional quality of the legume seeds **(Lindsay *et al.*, 2022).** The results are in line with **(Ali *et al.*, 2025),** who found that spraying the wheat with LER at 10% improves growth and yield.

The current results indicate that partially substituting mineral fertilizers with compost, in combination with spraying of licorice extract and humic acid, gave significant enhancements in vegetative parameters, yield components, and quality traits of pea. Furthermore, there is an enhancement in soil residual nutrients. This reflects its significant role as a sustainable and promising strategy for improving crop development and maintaining soil fertility. These results agree with **Hosseinifarahi *et al.* (2024),** who described that combining LRE with HA has a significant effect on the vegetative growth, yield components, and mineral content of pepper. Parallel results were stated by **Al-Zebari and Sarhan (2019**) on spinach.

The correlation patterns study validates the mechanistic cascade initiated by partially substituting chemical fertilizers with compost, humic acid, and licorice root extract. Enhanced soil organic matter and nutrient availability create a fertile foundation that enables more efficient uptake of N, P, and K. This improved nutrient status drives chlorophyll and carotenoid synthesis, expanding leaf area, and maximizing photosynthetic capacity. The resulting increase in photosynthetic output fuels greater biomass accumulation, pod formation, and seed filling, as evidenced by the very high correlations among pigments, vegetative growth, and yield components **(Canellas *et al.*, 2015, Zayed *et al.*, 2011)**

Natural biostimulants amplify this nutrient–photosynthesis–yield axis through complementary modes of action. Humic acid chelates micronutrients and alters root membrane permeability, accelerating nutrient influx. Licorice extract contributes to phytohormone precursors, antioxidants, and osmoprotectants that stimulate cell division, bolster stress resilience, and enhance carbohydrate metabolism. The positive associations between seed quality attributes (sugars, fiber, carbohydrates) and both soil fertility and photosynthetic pigments reflect these multifaceted physiological enhancements **(Roudgarnejad *et al.*, 2021)**. Meanwhile, the inverse relationship between phytic acid and performance metrics underscores the dual benefit of the integrated approach: not only is yield and quality elevated, but anti-nutritional compounds are simultaneously reduced, improving the nutritional profile of pea seeds. This results agreed with (**Lindsay *et al.*, 2022).**

Collectively, these findings demonstrate that organic amendments and natural biostimulants under reduced synthetic fertilizer rates can sustainably intensify pea production. By reinforcing soil health, optimizing physiological processes, and enhancing seed quality, the approach delivers holistic improvements in agricultural performance. Future research should test the robustness of these correlation patterns across diverse environments, cropping cycles, and legume species to refine application rates, optimize timing, and support broader adoption of integrated nutrient management strategies.

CONCLUSION:

The excessive and long-term usage of chemical fertilizers caused several agronomic and environmental concerns, including nutrient imbalances, degradation of soil structure, and suppression of beneficial soil microorganisms. Consequently, the partial substitution of chemical fertilizers with organic fertilizers, as compost, is recognized as a sustainable approach to restore soil fertility, enhance nutrient supply, and support environmentally friendly crop production. Furthermore, the foliar application of natural biostimulants, including humic acid and licorice root extract, may complement the effect of compost and have shown promising results in enhancing both the productivity and seed quality of pea, along with improving soil nutrient availability. The two-season field trial confirms that replacing 25% of chemical NPK with compost and foliar-applied HA and LRE not only sustains but enhances pea productivity, seed quality, and soil fertility. The correlation analysis elucidates the underlying interactions: enriched soil nutrient pools facilitate higher tissue N, P, and K, which in turn elevate chlorophyll and carotenoid levels, expand leaf area, and maximize photosynthesis. Enhanced photosynthetic output drives greater vegetative growth and reproductive performance, as reflected by the very high correlations ($r > 0.95$) among pigments, biomass, pod yield, and seed filling. Simultaneously, improved carbohydrate and fiber accumulation in seeds correlates positively with soil and physiological parameters, while phytic acid content declines in tandem with yield and quality improvements. This integrated organic–inorganic nutrient management strategy therefore offers a dual benefit, boosting agronomic performance and nutritional value while building long-term soil health. Future studies should validate these correlation patterns across diverse pedoclimatic conditions and cropping systems to fine-tune amendment rates and application timings, thereby facilitating wider adoption of sustainable pea production practices.

DECLARATIONS:

Ethics approval and consent to participate

Consent for publication: This study was conducted following established ethical values in scientific research. No human or animal was involved that would need approval from an ethics agency.

Availability of data and materials: The data and materials that were generated or analyzed during this study are available from the corresponding author.

COMPETING INTERESTS: There is no conflict of interest in this publication.

Funding: Not appropriate.

AUTHORS' CONTRIBUTIONS: Authors contributed equally in writing, editing, and finalizing the manuscript. They read and agreed for submission of manuscript to this journal.

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