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Impact of Suspended Phosphorus Fertilization and Humic Acid Foliar Application on Quantitative and Qualitative Yield Parameters of Cowpea Tuberos Roots (*Vigna unguiculata* L.): Implications for Nutritional Quality and Food Processing

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ABSTRACT

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This study investigated the synergistic effects of foliar-applied suspended phosphorus (SP) and humic acid (HA) on the yield and nutritional quality of cowpea (*Vigna unguiculata* L. cv. Ramshorn). A factorial experiment arranged in a randomized complete block design (RCBD) with three replicates was conducted. Treatments consisted of four SP concentrations (0, 3, 6, and 9 g L⁻¹) and three HA concentrations (0, 2, and 4 mL L⁻¹). Data were analyzed using GenStat software, with means separated by Duncan's multiple range test at $p \leq 0.05$. Results demonstrated that SP fertilization significantly enhanced the number of pods and total pod yield. HA application markedly improved pod nitrogen and protein content, alongside increasing pod length and seeds per pod. A significant interaction was observed between SP and HA. The combined treatment of 9 g L⁻¹ SP and 4 mL L⁻¹ HA proved optimal, producing the highest values for key agronomic and quality parameters: pod number (22.00 plant⁻¹), seeds per pod (10.00), pod length (18.16 cm), total yield (7.087 t ha⁻¹), pod nitrogen (3.33%), and pod protein content (20.86%). These findings highlight the efficacy of combined SP and HA foliar application as a sustainable strategy to concurrently boost the productivity and nutritional value of cowpea grains.

1-Introduction

Cowpea (*Vigna unguiculata* L.), a vital legume crop of the family Fabaceae, is a cornerstone of food security in tropical and subtropical regions globally. Originating in Central Africa, its cultivation has expanded due to a notable resilience to heat and drought stress. Beyond its agronomic robustness, cowpea serves as a critical dietary component, providing a rich source of protein (24–28%), complex carbohydrates (48–56% starch), and essential minerals, thereby addressing nutritional deficits in resource-limited populations [1]. Enhancing both the productivity and nutritional quality of this crop is therefore a key objective for sustainable agricultural systems. Phosphorus (P) is indispensable for realizing optimal crop yields and quality. As a fundamental macronutrient, it is integral to core physiological processes including energy transfer (ATP), photosynthesis, respiration, and nucleic acid synthesis [2]. Phosphorus deficiency severely compromises plant development, leading to reduced carbohydrate metabolism, impaired protein synthesis, and diminished symbiotic nitrogen fixation—a process critical for legumes like cowpea [3].

Consequently, effective P nutrition is paramount not only for biomass accumulation but also for determining the final nutritional profile of the harvestable product. Modern sustainable agriculture increasingly advocates integrating organic amendments to complement mineral fertilization, aiming to mitigate environmental externalities such as groundwater contamination and soil degradation linked to excessive synthetic inputs. Among these, humic substances represent a promising category of natural biostimulants. Derived from the decomposition of organic matter, humic acids are known to improve soil physicochemical properties, enhance nutrient availability and uptake, and

stimulate root development and microbial activity [4].

Their foliar application, in particular, offers a targeted approach to boost plant metabolism and stress tolerance. While the individual roles of phosphorus nutrition and humic acid applications are well-documented for various crops, their interactive effects—especially via foliar delivery—on the agronomic and qualitative traits of cowpea remain insufficiently explored. Foliar feeding with suspended phosphorus fertilizers presents a potential strategy to improve nutrient use efficiency, bypassing soil fixation issues [5,6].

This study therefore investigates the synergistic potential of foliar-applied suspended phosphorus and humic acid on cowpea. We hypothesize that their combined application will significantly enhance both quantitative yield parameters and key qualitative indicators, such as protein content, in cowpea pods. Our objective is to determine an optimal treatment regimen that concurrently maximizes productivity and nutritional value, contributing to climate-resilient and nutrient-sensitive cropping strategies.

2-Materials and Methods

2.1. Experimental Site and Soil Characteristics

A field experiment was conducted during the 2025 growing season at the Horticulture and Forestry Division (Green Belt area), Najaf Al-Ashraf Agriculture Directorate, Iraq. The soil at the experimental site was classified as a silty loam. Key physical and chemical properties of the topsoil (0–30 cm), analyzed prior to planting, are presented in Table 1. The soil was mildly alkaline, with low levels of organic matter and available phosphorus.

Table (1). Analysis of some physical and chemical properties of the soil

Soil property	Value	Unit
Soil separates		
Sand	57.10	%
Silt	25.3	%
Clay	17.6	%
Soil texture	Silty loam	—
pH	7.6	—
Electrical conductivity (EC)	2.55	dS m ⁻¹
Organic matter	1.2	%
Nitrogen (N)	0.261	ppm
Phosphorus (P)	0.245	ppm
Potassium (K)	92.2	

2.2. Experimental Design and Crop Management

The study employed a two-factor factorial arrangement within a Randomized Complete Block Design (RCBD) with three replications. The factors were:

- **Foliar Phosphorus (P):** Four concentrations of suspended phosphorus fertilizer: 0, 3, 6, and 9 mL L⁻¹.
- **Foliar Humic Acid (HA):** Three concentrations of humic acid: 0, 2, and 4 mg L⁻¹.

This resulted in 12 treatment combinations, each replicated three times, totaling 36 experimental plots. Each plot (experimental unit) measured 2 m² and contained 10 cowpea (*Vigna unguiculata* L. cv. 'Ramshorn') plants, established following standard agronomic practices for the region. Foliar applications commenced at the early flowering stage and were repeated twice more at 15-day intervals, ensuring thorough coverage of the vegetative canopy.

2.3. Data Collection

At physiological maturity, five representative plants were randomly sampled from each plot to assess the following parameters:

- **Yield Components:** The number of pods per plant was recorded cumulatively over six harvests (19 May – 15 July 2025). Pod length (cm) and the number of seeds per pod were measured on a random subsample of ten pods per plot.
- **Total Yield:** Fresh pod yield per plot was recorded from all six harvests and converted to tons per hectare (t ha⁻¹).
- **Seed Quality Analysis:** Composite seed samples from each plot were oven-dried at 65°C to a constant weight, ground, and analyzed for:
 - **Total Nitrogen:** Determined using the Micro-Kjeldahl digestion and distillation method [7].
 - **Crude Protein:** Calculated by multiplying the total

nitrogen percentage by the standard factor of 6.25 [7].

○ **Nitrate**

Content: Quantified spectrophotometrically at 410 nm following the salicylic acid method [7].

2.4. Statistical Analysis

All collected data were subjected to analysis of variance (ANOVA) appropriate for a factorial RCBD using GenStat 21st edition statistical software. Treatment means were separated using Duncan's Multiple Range Test (DMRT) at a 5% probability level ($p \leq 0.05$).

3. Results and Discussion

Table (2) shows the significant superiority of the treatment with foliar application of suspended phosphorus fertilizer at a concentration of 9 g L^{-1} , which recorded the highest values for the studied traits, including the number of pods, number of seeds per pod, pod length, and total yield.

The same table also indicates that humic acid at a concentration of 4 mL L^{-1} outperformed the other concentrations for the studied traits (number of pods, number of seeds per pod, pod length, and total yield). Moreover, Table (3) shows a significant superiority of this concentration of humic acid in the qualitative yield indicators, including nitrogen percentage in pods, protein percentage in pods, and nitrate content in pods. The interaction between foliar application of suspended phosphorus fertilizer and humic acid at the concentration of $9 \text{ g L}^{-1} + 4 \text{ mL L}^{-1}$ showed a significant effect on the studied traits of cowpea. This treatment produced the highest values for the measured parameters: number of pods ($22.00 \text{ pods plant}^{-1}$), number of seeds per pod ($10.00 \text{ seeds pod}^{-1}$), pod length (18.16 cm), total yield (7.087 t ha^{-1}), nitrogen percentage in pods (3.33%), protein percentage in pods (20.86%), and nitrate content in pods ($31.33 \text{ mg per } 100 \text{ g dry weight}$). In comparison, the control treatment recorded the lowest values for these traits: number of pods ($14.60 \text{ pods plant}^{-1}$), number of seeds per pod ($5.00 \text{ seeds pod}^{-1}$), pod length (18.16 cm), total yield (4.142 t ha^{-1}), nitrogen percentage in pods (2.10%), protein percentage in pods (13.14%), and nitrate content in pods ($99.47 \text{ mg per } 100 \text{ g dry weight}$).

Table 2. Effect of foliar application of suspended phosphorus and humic acid and their interaction on quantitative yield traits of cowpea pods

Humic Acid (mL L^{-1})	Suspended Phosphorus (g L^{-1})	Number of Pods (pods plant^{-1})	Number of Seeds per Pod (seeds pod^{-1})	Pod Length (cm)	Total Pod Yield (t ha^{-1})
0 (Control)	0	14.60 l	5.00 g	12.20 g	4.142 j
2	0	15.76 j	6.00 f	13.20 f	4.657 i
4	0	17.60 h	6.00 f	13.73 e	4.813 h
0	3	18.76 f	5.00 g	14.50 d	4.938 gh
2	3	20.60 d	6.66 ef	14.43 d	5.053 g
4	3	21.76 b	7.33 de	15.86 c	5.212 f
0	6	14.83 k	6.66 ef	15.73 c	5.317 f
2	6	15.96 i	7.66 cd	16.20 c	5.668 e

4	6	17.86 g	8.33 bc	14.69 d	5.957 d
0	9	19.00 e	7.33 de	17.30 c	6.323 c
2	9	20.86 c	9.00 b	18.46 b	6.550 b
4	9	22.00 a	10.00 a	20.04 a	7.087 a

Notes: Values followed by different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$

Table 3. Effect of foliar application of suspended phosphorus and humic acid, and their interaction, on quality traits of cowpea pods.

Humic Acid (ml/L)	Suspended Phosphorus (g/L)	Nitrate content (mg/100 g DW)	Protein content (%)	Nitrogen content (%)
0	Control	99.47 a	13.14 f	2.10 f
2	0	76.10 b	13.32 ef	2.13 ef
4	0	68.70 c	14.20 e	2.27 e
0	3	81.77 b	14.12 ef	2.26 ef
2	3	62.67 cd	15.17 d	2.42 d
4	3	55.87 d	15.99 cd	2.55 cd
0	6	57.33 d	15.57 d	2.49 d
2	6	46.70 e	16.83 c	2.69 c
4	6	48.47 e	18.68 b	2.99 b
0	9	44.17 e	17.82 b	2.85 b
2	9	42.17 e	18.75 b	2.99 b
4	9	31.33 f	20.86 a	3.33 a

Notes: Values followed by different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$

Phosphorus is considered an essential nutrient for plants, playing a critical role in photosynthesis, energy transfer, and enzyme regulation. Its availability positively affects plant growth, increases dry matter accumulation, and enhances pod number, which in turn leads to higher yields and elevated protein concentration in seeds [8]. Phosphorus is vital because it is a key component in ATP formation, which transfers energy within the plant. This energy supports cell enlargement and proliferation by stimulating overall vegetative biomass, consequently increasing the plant's dry weight [9]. Organic acids, such as humic and fulvic acids, also play an important role in plant growth. They are carbon-based compounds

that contribute to the development of plant tissues [10,11]. Organic matter is absorbed by plant roots, releasing ions that are readily available and quickly transported, allowing the plant to utilize them in physiological processes. This facilitates nutrient uptake and provides the energy necessary for absorption, especially during critical growth stages [12].

4-Conclusions

This study demonstrates that foliar application of suspended phosphorus (SP) and humic acid (HA) is an effective strategy for simultaneously enhancing both the productivity and nutritional quality of cowpea (*Vigna unguiculata* L.). The results conclusively show that the highest

concentration of SP (9 g L⁻¹) and HA (4 mL L⁻¹), when applied in combination, elicited a significant synergistic response. This optimal treatment (9 g L⁻¹ SP + 4 mL L⁻¹ HA) produced the highest values across all measured agronomic and quality parameters: pod number (22.00 plant⁻¹), seeds per pod (10.00), pod length (20.04 cm), total yield (7.087 t ha⁻¹), seed nitrogen (3.33%), and crude protein content (20.86%). Concurrently, it significantly reduced pod nitrate concentration (31.33 mg per 100 g DW) compared to the control (99.47 mg per 100 g DW). The individual effects of SP were most pronounced on yield components, while HA primarily enhanced qualitative traits such as nitrogen and protein content. The physiological basis for these improvements can be attributed to the complementary roles of both inputs. SP likely fueled the energy-intensive processes of flowering, pod set, and seed filling through its central role in ATP synthesis and photosynthesis. HA, acting as a bio stimulant, presumably improved nutrient uptake efficiency, membrane permeability, and overall plant metabolism, thereby amplifying the utilization of the applied phosphorus. The marked reduction in nitrate content further suggests that HA promoted better nitrogen assimilation into proteins. In conclusion, the integrated foliar application of suspended phosphorus and humic acid offers a promising, sustainable agronomic practice. It effectively bridges the gap between quantitative yield enhancement and nutritional fortification in cowpea. This approach is particularly valuable for resource-constrained soils, such as the alkaline, low-phosphorus soil used in this trial, providing a practical pathway to improve both food output and nutritional security in legume-based cropping systems.

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AUTHORS' CONTRIBUTIONS

All activities were performed by author.

COMPETING INTEREST

The author affirm that he has no financial conflicts of interest or competing interests in this study.

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