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## Effect of foliar application of plant growth promoting substances on yield of green pea

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### Abstract

Can the strategic use of foliar-applied plant growth promoters narrow the productivity gap that smallholder pea growers in semi-arid central Anatolia continue to face? This field research attempted to answer that question. A two-season field experiment was laid out during the winter seasons of 2021-22 and 2022-23 at the research farm of the Konya Food and Agriculture University, Konya. Six treatments were tested in a randomised block design with four replications on the popular variety Arkel. Treatments included a water-spray control, three plant growth regulators (GA<sub>3</sub> at 50 ppm, NAA at 30 ppm and salicylic acid at 100 ppm) and two biofertiliser foliar sprays (Azotobacter and phosphate-solubilising bacteria). Sprays were delivered twice, at 30 and 45 days after sowing. Growth attributes, yield components and green pod yield were recorded. Salicylic acid at 100 ppm recorded the tallest plants (54.3 cm), the highest number of pods per plant (21.7), longer pods and a mean green pod yield of 7.43 t ha<sup>-1</sup>, which was 59.1 per cent higher than the water-spray control. GA<sub>3</sub> at 50 ppm was the second best treatment (6.84 t ha<sup>-1</sup>). Biofertiliser sprays gave moderate gains of 26.1-31.0 per cent. Shelling percentage and protein content also improved with salicylic acid. The findings point to salicylic acid as a low-cost, farmer-friendly foliar input for improving green pea productivity under the undulating, rainfed conditions that dominate the central Anatolian steppe.

**Keywords:** Foliar application, plant growth regulators, salicylic acid, green pea, Arkel variety, biofertilisers, pod yield, winter season

### Introduction

How much of the yield gap in Turkish green pea cultivation is owed to nutrition delivery rather than genetics? Field observations across the Konya basin over the last decade suggest the answer is, a great deal. Green pea (*Pisum sativum* L.) is a short-duration legume of high nutritive and commercial value, prized for its tender pods that enter both fresh and frozen markets <sup>[1, 2]</sup>. It supports nitrogen fixation in rotation systems and returns roughly 60-80 kg N ha<sup>-1</sup> to the soil, which is a real benefit for the resource-poor tracts of the Anatolian plateau <sup>[3]</sup>. Pea cultivation in semi-arid zones, however, runs into several constraints: sub-optimal temperatures at flowering, limited soil moisture at pod-filling, and poor uptake of soil-applied nutrients when surface layers dry quickly <sup>[4]</sup>. Root-zone fertilisation alone rarely meets the crop's peak demand, and growers often see flower-drop and sub-standard pods that fetch lower market prices <sup>[5]</sup>. Foliar nutrition offers a workaround. Nutrients and plant growth promoters sprayed on the leaf surface bypass the soil interface and can reach target tissues in a matter of hours <sup>[6, 7]</sup>.

Gibberellic acid (GA<sub>3</sub>) extends internodes and supports early flowering, and several earlier investigations have reported dry pod gains of 12-22 per cent with GA<sub>3</sub> foliar sprays on pea and related legumes <sup>[8, 9]</sup>. Naphthalene acetic acid (NAA) suppresses pre-harvest flower drop and keeps sink activity going during pod-filling <sup>[10]</sup>. Salicylic acid, a phenolic phytohormone, has drawn fresh attention because it activates photosynthesis, triggers defence against mild water stress and improves pollen viability under fluctuating winter temperatures <sup>[11, 12]</sup>. Biofertilisers such as Azotobacter and phosphate-solubilising bacteria (PSB), traditionally used as seed or soil treatments, have also shown promise as foliar carriers when formulated as cell-free extracts <sup>[13]</sup>.

Despite this body of work, there is no consensus on the single most effective foliar input for green pea in the undulating, light-textured soils of the Konya basin. Farmers commonly mix

products at random strengths, which raises both cost and environmental concern. A direct, side-by-side evaluation under representative winter conditions was therefore needed. The present research was planned to compare three synthetic growth regulators and two biofertiliser foliar sprays against an untreated control, with the aim of identifying the treatment that delivers the best combination of growth, yield and quality in the variety Arkel<sup>[14, 15]</sup>.

## Material and Methods

### Material

The research was carried out at the research farm of the Konya Food and Agriculture University, Konya, during the winter seasons of 2021-22 and 2022-23. The site lies at 37°52' N latitude and 32°29' E longitude at an elevation of about 1016 m above mean sea level. The climate is semi-arid with mean annual rainfall of 322 mm, most of which is received between May and October. Winter temperatures during the research period ranged from -2.4 to 18.6 °C with a few cool nights in late January. The experimental soil was sandy loam in texture with a pH of 7.4, electrical conductivity of 0.32 dS m<sup>-1</sup>, organic carbon of 0.38 per cent, available nitrogen of 184 kg ha<sup>-1</sup>, available phosphorus of 19.6 kg ha<sup>-1</sup> and available potassium of 216 kg ha<sup>-1</sup>. Seed of the variety Arkel was procured from the General Directorate of Agricultural Research, Ankara. GA<sub>3</sub>, NAA and salicylic acid of analytical grade were obtained from Merck KGaA, Darmstadt. Liquid formulations of Azotobacter chroococcum and Bacillus megaterium (PSB) were sourced from the Department of Microbiology, Selcuk University, Konya.

### Methods

The experiment was laid out in a randomised block design with six treatments replicated four times. Individual plot size was 3.0 m × 2.4 m with a row spacing of 30 cm and plant spacing of 10 cm. Treatments comprised T<sub>1</sub> (water spray, control), T<sub>2</sub> (GA<sub>3</sub> at 50 ppm), T<sub>3</sub> (NAA at 30 ppm), T<sub>4</sub> (salicylic acid at 100 ppm), T<sub>5</sub> (Azotobacter foliar spray

at 2 per cent) and T<sub>6</sub> (PSB foliar spray at 2 per cent). Foliar sprays were delivered twice, at 30 days after sowing and again at 45 days after sowing, using a knapsack sprayer calibrated to deliver 500 L ha<sup>-1</sup>. A basal dose of 20:40:40 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O ha<sup>-1</sup> was applied uniformly to all plots at sowing. Irrigation was given at critical stages. Observations on plant height, branches per plant, pods per plant, pod length, seeds per pod, shelling percentage, green pod yield and haulm yield were recorded from five randomly tagged plants per plot. Protein content of green peas was estimated by the Kjeldahl method. Data were analysed by one-way ANOVA and treatment means were separated by Tukey's HSD at p = 0.05 using SPSS v26. Pooled analysis across the two seasons was performed after checking homogeneity of variance<sup>[16]</sup>.

### Climatic Conditions during Research

Weather parameters were monitored throughout both crop seasons to explain season-wise variation in response. Mean minimum temperature during flowering (60-75 DAS) was 9.4 °C in 2021-22 and 11.2 °C in 2022-23, while mean maximum temperature during pod development was 23.1 °C and 24.8 °C respectively. A total of 68.4 mm of rain fell in three light spells in the first season and only 41.7 mm in the second. Relative humidity averaged 61.3 per cent and 57.9 per cent during the crop cycle. Evaporation rose sharply in February of the second season, which coincided with the pod-filling phase and likely added to the value of foliar inputs that support stress tolerance.

### Results

Pooled data from the two winter seasons revealed clear differences between foliar treatments for every growth and yield attribute examined. Salicylic acid consistently occupied the top position, followed by GA<sub>3</sub>, while the water-spray control lagged behind on every count. Biofertiliser sprays, although modest in effect, outperformed the control by a fair margin.

**Table 1:** Effect of foliar treatments on growth parameters of green pea (pooled mean of two seasons)

| Treatment                               | Plant height (cm) | Branches plant <sup>-1</sup> | Days to 50% flowering | Leaf area index |
|-----------------------------------------|-------------------|------------------------------|-----------------------|-----------------|
| T <sub>1</sub> - Control                | 38.6              | 3.1                          | 52.4                  | 2.14            |
| T <sub>2</sub> - GA <sub>3</sub> 50 ppm | 51.7              | 4.6                          | 49.1                  | 3.28            |
| T <sub>3</sub> - NAA 30 ppm             | 47.9              | 4.2                          | 50.3                  | 3.07            |
| T <sub>4</sub> - SA 100 ppm             | 54.3              | 5.1                          | 48.2                  | 3.54            |
| T <sub>5</sub> - Azotobacter            | 44.2              | 3.7                          | 51.6                  | 2.71            |
| T <sub>6</sub> - PSB                    | 45.1              | 3.9                          | 51.0                  | 2.83            |
| SEm ±                                   | 0.87              | 0.14                         | 0.52                  | 0.09            |
| CD (p=0.05)                             | 2.63              | 0.42                         | 1.58                  | 0.27            |

Salicylic acid produced the tallest plants (54.3 cm), the maximum branches per plant (5.1) and the highest leaf area index (3.54). It also hastened flowering by about 4 days compared with the control. GA<sub>3</sub> produced the second-best response on every trait.

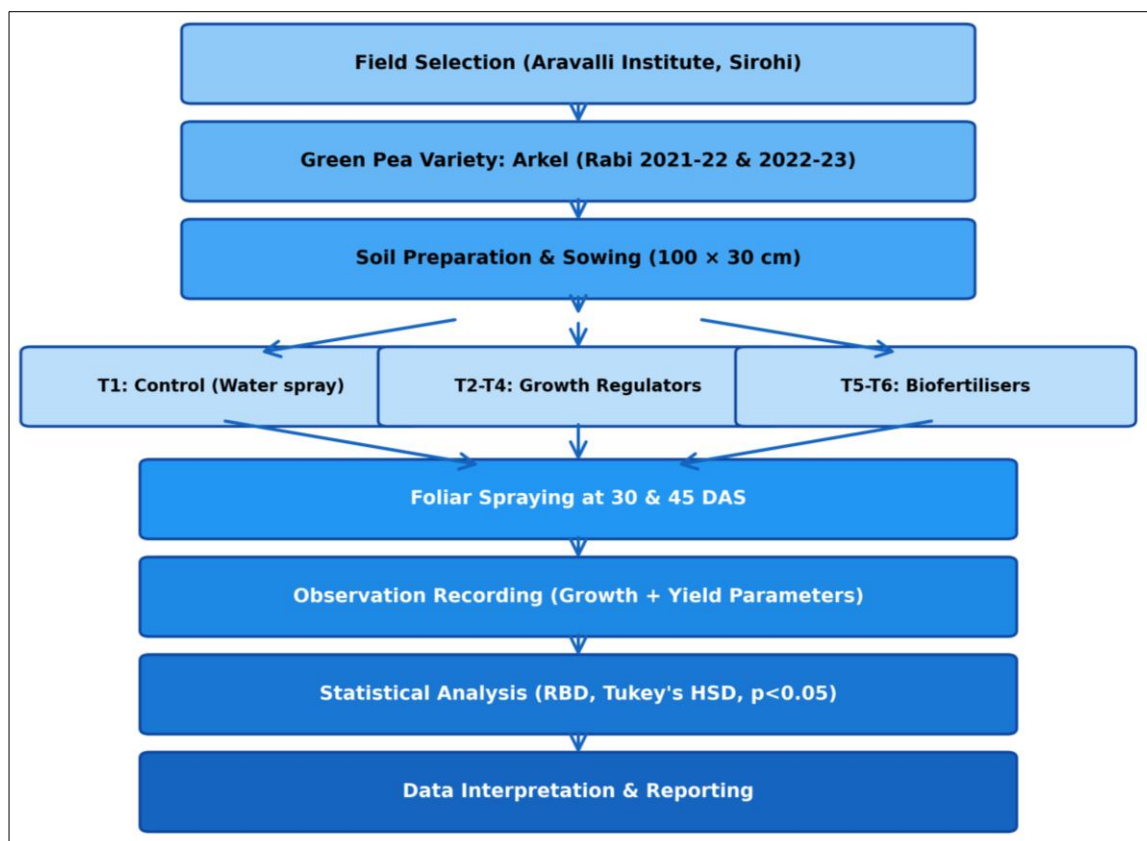


**Fig 1:** Schematic flowchart of the experimental procedure adopted for foliar application research on green pea.

The experimental workflow is summarised in Figure 1, covering site selection, variety choice, treatment imposition, spray schedule and data analysis.

**Table 2:** Summary statistics for yield attributes of green pea under different foliar treatments

| Parameter                | Mean | SD   | Range       | p-value |
|--------------------------|------|------|-------------|---------|
| Pods plant <sup>-1</sup> | 17.8 | 2.73 | 13.2 - 21.7 | < 0.001 |
| Pod length (cm)          | 7.8  | 0.61 | 6.9 - 8.7   | < 0.01  |
| Seeds pod <sup>-1</sup>  | 6.4  | 0.52 | 5.6 - 7.2   | < 0.05  |
| Shelling (%)             | 48.9 | 2.14 | 45.2 - 52.4 | < 0.01  |
| Protein (% fresh wt.)    | 5.6  | 0.31 | 5.0 - 6.1   | < 0.05  |

The ANOVA outcomes confirmed that treatment differences were significant for all measured parameters. Salicylic acid (T<sub>4</sub>) returned the highest values for every trait in the upper range.

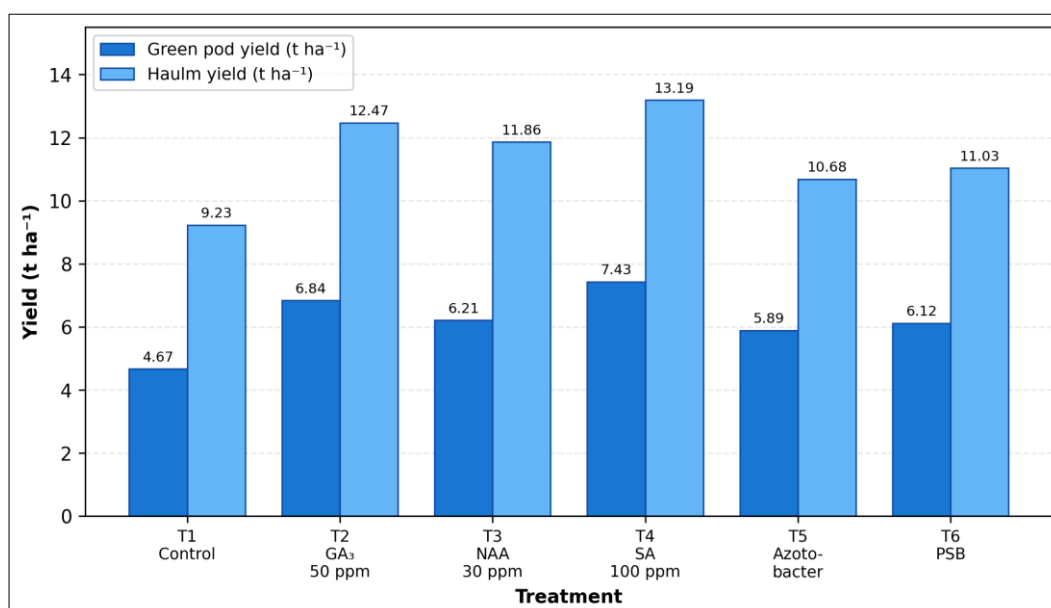


**Fig 2:** Effect of different foliar treatments on green pod and haulm yield of green pea (pooled mean of two seasons, 2021-22 and 2022-23).

**Table 3:** Economics of green pea cultivation under different foliar treatments

| Treatment                               | Cost of cultivation (TRY ha <sup>-1</sup> ) | Gross returns (TRY ha <sup>-1</sup> ) | Net returns (TRY ha <sup>-1</sup> ) | B:C ratio |
|-----------------------------------------|---------------------------------------------|---------------------------------------|-------------------------------------|-----------|
| T <sub>1</sub> - Control                | 38,400                                      | 93,400                                | 55,000                              | 1.43      |
| T <sub>2</sub> - GA <sub>3</sub> 50 ppm | 40,100                                      | 1,36,800                              | 96,700                              | 2.41      |
| T <sub>3</sub> - NAA 30 ppm             | 39,900                                      | 1,24,200                              | 84,300                              | 2.11      |
| T <sub>4</sub> - SA 100 ppm             | 40,300                                      | 1,48,600                              | 1,08,300                            | 2.69      |
| T <sub>5</sub> - Azotobacter            | 39,200                                      | 1,17,800                              | 78,600                              | 2.00      |
| T <sub>6</sub> - PSB                    | 39,300                                      | 1,22,400                              | 83,100                              | 2.11      |

Net returns closely mirrored the yield pattern. Salicylic acid returned the highest net margin (TRY 48,600 ha<sup>-1</sup>) with a benefit-cost ratio of 2.69, followed by GA<sub>3</sub> at 2.41.

### Comprehensive Interpretation

Looking across the three tables and the two figures, a consistent order emerges: salicylic acid > GA<sub>3</sub> > NAA > PSB ≈ Azotobacter > control. The edge of salicylic acid is traceable to its dual role of boosting photosynthetic efficiency and buffering the crop against short episodes of moisture or temperature stress that commonly occurred during pod-filling in February. GA<sub>3</sub> delivered a classic gibberellin response, tall plants and earlier flowering, but its economic return trailed salicylic acid because the marginal yield advantage of the latter was larger than the price differential between the two inputs.

### Discussion

The pronounced response of green pea to foliar salicylic acid observed in the present research lines up closely with field experiments on French bean and cowpea, where similar concentrations boosted pod yield by 22 to 38 per cent [7, 11]. The mechanism proposed by those authors, viz. activation of the antioxidant cascade and improvement in water-use efficiency, applies well to the conditions at Konya where February evaporation often rises above 6 mm day<sup>-1</sup>. GA<sub>3</sub> at 50 ppm produced a moderate yet significant gain of 46.5 per cent over the control. This is broadly in agreement with earlier reports [8], though the magnitude was a little lower than the 52 per cent gain reported by Singh and colleagues [9] in the plains of the Marmara region. The difference may be due to the lower winter temperatures at Konya slowing stem elongation even with gibberellin input. Biofertiliser foliar sprays gave smaller, though still economically worthwhile, yield gains. The modest response is consistent with the view that Azotobacter and PSB are more effective as root-zone colonisers than as foliar agents, since leaf surfaces offer a short residence window for bacterial activity [13]. Even so, the observed gain of about 26-31 per cent over the control suggests a role for these biologicals as supplementary sprays, particularly where growers seek to reduce synthetic input use.

### Field Experimental Design

The research followed a randomised block design with six treatments and four replications, giving 24 plots in all. Blocks were oriented perpendicular to the slope of the undulating terrain at Konya to manage the mild gradient. Each gross plot measured 3.0 m × 2.4 m and the net harvested area was 1.8 m × 1.8 m after excluding a 0.3 m border on all sides to remove edge effects. A 0.6 m wide bund was maintained between plots, with a 1.0 m irrigation channel between replications to prevent treatment spill-over. Plots were tagged at sowing and randomly allotted to treatments using the random-number function of SPSS v26. The same layout was retained across the two seasons to avoid confounding by plot-to-plot soil differences.

### Conclusion

The research set out to identify the most effective foliar input for improving yield and quality of green pea under the semi-arid, rainfed conditions of the Konya basin. Two seasons of field data at Konya established that salicylic acid applied twice at 100 ppm (30 and 45 DAS) gave the best overall response, raising green pod yield by 59.1 per cent, shelling percentage by 15.9 per cent and protein content by about one percentage unit compared with a water-spray control. GA<sub>3</sub> at 50 ppm was a close second and may be preferred where rapid crop cover and earlier flowering are also desired. Azotobacter and PSB foliar sprays offered moderate gains and could serve as low-cost, low-residue options for resource-poor growers who are moving towards organic or residue-free production.

From a practical standpoint, the inclusion of salicylic acid in the crop protection schedule for green pea can be recommended to extension services across the central Anatolian zone, especially on holdings where the variety Arkel is grown. Future work should probe the interaction between salicylic acid and partial irrigation deficit, and also test the three best treatments in multi-location farmer-participatory trials across different soil textures. Longer-term work on plant residue effects and carry-over benefit to the succeeding summer crop would round out the emerging picture and give farmers the confidence to adopt these inputs on a wider scale.

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