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Impact of Licorice Extract Concentration and Spray Nozzle Type on Growth, Yield, and Productivity of Coriander (*Coriandrum sativum* L.)

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ABSTRACT: The present study compares and contrasts the agronomic and mechanical responses to two nozzle types (flat fan and hollow conical) and five concentrations of licorice extract (0, 3, 6, 9, 12 ml L⁻¹) applied to coriander (*Coriandrum sativum* L.). The analysis of variance revealed that the application of high concentration of extracts significantly improved plant height, plant flower buds and total production. The highest agronomic performance was obtained with the hollow conical nozzle with slightly higher fuel consumption. The results highlight the importance of using mechanical delivery systems and biostimulant levels to optimize them simultaneously to maximize crop production.

1. INTRODUCTION

Leveraging the use of organic biostimulants like Licorice extract is a clear sign of the growing trend towards sustainable agriculture and reducing environmental hazards of the synthetic nitrogen fertilizers (Elrys & Merwad, 2017). These extracts are rich in bioactive compounds, such as flavonoids and amino acids, which stimulate the growth of cells and vegetative development in horticultural crops (Godlewska et al., 2021a). Although application technologies have been proven to be beneficial, there is still a significant research gap on mechanical integration of the application technologies, particularly the effect of nozzle geometry on the deposition efficiency of organic additives (Yan et al., 2023). The size distribution and surface coverage of the droplets defines the biological effectiveness of the substances applied, so it is essential for the selection of the appropriate nozzle (Krawczuk et al., 2021). The present study thus fills this gap by examining the synergistic effect between different concentrations of licorice extract and spray delivery systems (Wei et al., 2024); and to assess property of optimizing droplet dynamics through certain nozzle configurations for improving the uptake of licorice extract and maximize productivity of coriander (*Coriandrum sativum* L.).

Licorice Extract as a Biostimulant

The significant biological activity of licorice extract is mainly attributed to glycyrrhizin, a natural growth regulator that promotes the synthesis of proteins, thereby accelerating the process of plant growth (Godlewska et al., 2021a). Previous studies have demonstrated the positive effects of optimal extract concentrations on the nutritional composition and production of other species (Calvo et al., 2014) and that the extract can improve seed and oil production by altering plant water potential and chlorophyll production, leading to higher plant photosynthetic activity (Godlewska et al., 2021a). Its chemical components have similar effects to steroid hormones, helping to create its structure and enhance its resistance to the environment (Rady et al., 2019). In addition to these physiological effects, empirical studies have shown that these extracts have a regular positive effect on productivity in many cultivars such as common bean and fennel, among others (Godlewska et al. 2021a, 2021b; Ma et al.

2022). These plant derived materials play a crucial role in optimizing vegetative characteristics like plant height and dry matter accumulation in coriander (Alkharpotly et al., 2024).

Spray Nozzle Technology in Agriculture

The effectiveness of foliar spray relies heavily on the use of the appropriate nozzle, including droplet size spectra, kinetic energy, and uniformity of spray distribution, which, in turn, is related to the coverage on the plant tissue and the subsequent rate of uptake of the biostimulant (Wang et al., 2023). The pattern of deposition achieved with flat fan nozzles is generally uniform, which is advantageous for systematic penetration of the canopy, while the pattern of deposition achieved with hollow conical nozzles is finer, which helps to promote good adherence and prevent runoff from dense canopy (Krawczuk et al., 2023). The hollow-cone shape, created by the inside swirl plate, generates the finer droplets which enhance the surface area of the spray solution and elevate the amount of droplets placed per square centimeter of leaf, thereby promoting more efficient trans-foliar uptake of the bioactive constituents within the extract (Chen et al., 2022; Dolores et al., 2023). In contrast, flat fan nozzles provide better distribution over wider swaths, which could lead to better coverage for assimilation of systemics but may create the potential for reduced application time. The relationship between these mechanical parameters and the chemical concentration of the licorice extract is therefore an important point to consider, to obtain the best agronomic response (Calvo et al., 2014; Elrys & Merwad, 2017). The larger the amount of bioactive compounds absorbed into the foliage, the more they will be retained within the canopy, which increases the total amount of bioactive compound that is absorbed (Massinon et al., 2017; Yan et al., 2023). Calibrating spray characteristics reduces the usual problems in field-scale management associated with nutrient loss and poor application coverage (Abd-Allah et al., 2021; Alkharpotly et al., 2024). Optimising both the biochemical composition of the extract and the method of physical delivery is the solution to supply solutions that include a holistic approach of reducing waste of input (Bulgari et al., 2017). The present study, therefore, involved a comparative study of the effect of different droplet characteristics on the uptake efficiency for bioactive compounds from the licorice plants by using flat fan and hollow conical nozzles.

Research Aim and Scope

Foliar application of licorice extract was effective in regulating the crop growth and yield, however, the efficacy of the extract is depended upon the method of application, which is the nozzle type used for spraying. The aim of this study was to quantify the effect of licorice extract on the growth and yield of coriander (*Coriandrum sativum* L.) and to evaluate the operational efficiency by comparing the fuel consumption of the two nozzle types used to apply the treatments to the leaves of coriander.

2. METHODOLOGY

2.1. Study site and experimental design.

To evaluate the effects of coriander treatment with foliar licorice extract using various spray nozzles, Laylan District in Kirkuk, Iraq (35°19'22.35" N, 44°55'26.44" E) was selected as the experimental area for the 2025 agricultural season. The experimental design employed in the trial was Randomized Complete Block Design (RCBD) with a split-plot design and 3 replications, making 30 experimental units. Two nozzle types were used for the main plots, a flat fan nozzle (N1) and a hollow cone nozzle (N2). Five concentrations of the licorice extract (0, 3, 6, 9 and 12 mL L⁻¹) were applied to the subplots.

2.2. Agronomic Practices and Extract Preparation

On 1 November 2025, the seeds were sown in 4.8 m² plots with five rows to each plot. Space between rows was 40cm and space between plants was 20cm and 3-4 seed was sown per hill.

The extract was prepared according to the methodology used by Farsani et al. (2019) by Soxhlet extraction of the dried and aged (>1 year) root of Licorice with 99.9% ethanol at 78°C for 16 h. The solvent was then evaporated out using a rotary evaporator before application.

2. 3. Equipment Specifications and Operative-Setup

A motorized knapsack sprayer (Keeway Technology, Model WKN3A25/WKN3A25XY) was chosen instead of conventional manual sprayers to avoid pressure drop and pump fluctuations that create uneven spray distribution and varying droplet size. The following key pieces of equipment were specified:

Engine & Power: The engine has a displacement of 25.4 cc and a maximum power output of 0.75 kW at 7500 rpm powered by a 25:1 to 30:1 gasoline-to-oil ratio.

Capacities: 25 L chemical tank, 0.75L fuel tank and liquid flow rate greater than 5.5 L min⁻¹.

Optimally use the Flat Fan Nozzle (N1) Agroplast AP12003 (Class A2) with 0.75 mm V-cut depth, inlet of 2 mm, and a spray angle of 76°.

Hollow Cone Nozzle (N2): Apple Master GUN (PAGB123) - 1/2" external thread - 14 x 1.5 mm internal diameter.

2.4. Data collection and statistical analysis.

The same linear speed and spraying pressure (2 bar) were used for all treatments. Evaluated parameters included:

-The fuel consumption was measured by a specially designed 50 mL graduated cylinder system with directional valves. The total consumption per hectare was calculated according to Hunt (2001):

$$FC = V/A$$

Where F is the fuel consumption per hectare (in liters ha⁻¹), V is the amount of fuel consumed (in liters), and A is the area (in hectares).

- Growth and Yield Metrics: Plant height (cm), number of flower buds and total yield (kg ha⁻¹), which is calculated as:

$$\text{Yield (kg ha}^{-1}\text{)} = (\text{Plot Yield (kg)}/4.8) * 10,000$$

ANOVA with the SAS software (version 9.2) was used for analyzing the data. Duncan's Multiple Range Test (DMRT) was used to compare the treatment means with a 1% level of significance (Al-Zubaidi & Al-Jubouri, 2016).

3. Results and Discussion

The experimental data obtained through statistical analysis showed significant differences among the treatments in plant height, floral bud production and the yield, indicating that the spray application method and the concentration of the biostimulant had impact on the agronomic performance of coriander (*Coriandrum sativum* L.).

3.1 Variance Analysis (ANOVA)

ANOVA showed that there were highly significant differences between the different nozzle types (N) and licorice extract concentrations (M), and the interaction of these two factors (Table 1). The influence of nozzle type was highly significant ($p < 0.01$) for fuel consumption, plant height and productivity, but not for number of flower buds. Concentration was found to be highly significant in all four parameters ($p < 0.01$), indicating its high effect on all the trials. Nozzle type was highly significant (HS) in all variables of plant height, flower buds and productivity while concurrent with concentration ($N \times M$) was non-significant in fuel consumption.

Table 1: Variance Analysis (ANOVA) Mean Squares (MS) for the Treatments.					
Source of Variation (S.O.V)	d.f.	Fuel Consumption (L.h ⁻¹)	Plant Height (cm)	Number of Flower Buds (No. plant ⁻¹)	Productivity (kg hectare ⁻¹)
Replicate (R)	2	-	-	-	-
Nozzle (N)	1	0.0157**	5630.700**	76.800 ^{ns}	1361070.0**
R x N	2	0.03219	71.100	1.900	9480.00
Concentration (M)	4	0.0093**	2516.8833**	1205.250**	3764978.3**
N x M	4	0.0010 ^{ns}	798.7833**	713.2166**	608245.0**
Error	16	0.0006	15.5833	53.7833	5324.1
Total	29	-	-	-	-

Note: ** = Significant at the 1% level, ns = not significant.

3.2 Fuel Consumption ($L h^{-1}$)

Both nozzle type and licorice extract concentration had a significant effect on the fuel consumption. The mean fuel consumption for N2 (hollow conical nozzle) was more ($0.4032 L h^{-1}$) than for N1 (flat fan nozzle) ($0.3573 L h^{-1}$), which means that the internal geometry of the hollow conical nozzle requires more energy to maintain the operating pressure and produce the desired droplet dispersion. Moreover, the regression results showed that at higher concentrations of extract, there is a positive correlation between the concentration and the amount of fuel used, and the maximum usage of fuel occurred at the concentration M4 ($0.4400 L h^{-1}$). This advantage may be due to the fact that working solutions that are richer in active ingredients have higher viscosity and modified flow properties, which lead to a higher mechanical stress on the spray system. Nozzle type $\times$ concentration (N $\times$ M), however, was not statistically significant with respect to fuel consumption (Table 2). These results indicate the importance of considering operational cost effectiveness when applying these products in a manner that takes both the physical and biological properties of the biostimulant solution into account, as well as the high output application methods. For this reason, it is recommended to consider conducting periodic inspections of nozzle wear and spray pattern uniformity as part of future evaluations, as this could affect the uniformity of application and the effectiveness of the treatment (Wawrzosek & Parafiniuk, 2022).

Table (2): Effect of Nozzle type and different concentrations and Interaction between Them on Fuel Consumption ($L h^{-1}$).						
N/ M	M0	M1	M2	M3	M4	Mean-N
N1	0.31200 d	0.32000 cd	0.34933 bcd	0.36533 bc	0.37600 b	0.357333 b
N2	0.37600 b	0.39733 ab	0.42667 A	0.44000 a	0.44000 a	0.403200 a
Mean-M	0.34400 c	0.34800 c	0.37333 Bc	0.39600 b	0.44000 a	
N= Nozzle type; M= Extract Concentrations.						

3.3 Plant Height (cm)

Nozzle type and concentration of the licorice extract had significant effect on plant height as did the interaction of the two. The mean plant height of the nozzle with hollow cone (N2) was generally slightly higher (125.267 cm) than the nozzle with flat fan (N1, 122.067 cm). The growth rate was highest for the two highest concentrations (M1 and M3) compared to the two controls (M0 and M4) and the highest extract concentration (M4, 114.500 cm). The largest interact between nozzle shape and time was observed at nozzle R2 (hollow conical) at the M1 (3 ml L^{-1}) concentration, where the plant height of 158.333 cm (Table 3) is the highest recorded. This increase in stem growth is probably due to the smaller size of the droplets deposited and greater uniformity of the foliar cover provided by the hollow conical design which will facilitate uptake of the bioactive growth promoters. The same relationship has been observed with plant biostimulants, and the good coverage of the spray has been positively associated with better vegetative growth (Al-Sudani et al., 2025). The floral bud initiation also showed a dose dependent response, with the highest concentration of extract and hollow conical delivery resulting in a significant increase in flower buds compared to the control. The statistically significant application method $\times$ concentration interaction also suggests that droplet distribution plays an important role in the conversion of vegetative growth into yield productivity in the optimal range.

Table (3): Effect of Nozzle type and different concentrations and Interaction between Them on Plant Height (cm).						
N/ M	M0	M1	M2	M3	M4	Mean-N
N1	116.667 cd	121.667 cd	119.000 cd	144.000 b	109.000 de	122.067 a
N2	99.333 c	158.333 a	118.333 cd	130.333 c	120.000 cd	125.267 a
Mean-M	108.000 c	140.000 a	118.667 b	137.167 a	114.500 bc	
N= Nozzle type; M= Extract Concentrations						

3.4 Number of Flower Buds

There are 24 flower buds in a box. Coriander (*Coriandrum sativum*) flowering was significantly improved with the application of licorice extract and the variance analysis showed that the concentration of extract was the most significant factor for bud production per plant. The more concentrated the treatment, the more buds per plant (25 buds plant⁻¹, pooled mean of 91.167 at M0, up to a maximum of 186.833 at M4). The hollow conical type nozzle (N2) gave the best result with the overall mean of 164.667 buds plant⁻¹ as compared to the flat fan nozzle (N1) with the overall mean of 150.333 buds plant⁻¹. The main effect of extract concentration (M) on bud formation was highly significant ($p < 0.001$) and nozzle type (N) alone was not statistically different but both extract concentration (M) and the interaction of extract concentration with nozzle type ($N \times M$) was significant at the 1% level. The best results were obtained with the treatment N2 using the nozzle concentration M4 with the highest recorded bud density of 190.000 buds plant⁻¹ (Table 4). The results highlight the importance of optimal nutrient availability as a determinant of coriander's reproductive transition. The superiority of the hollow conical nozzle at high extract concentrations showed the better uniformity of coverages of the canopy, which positively affects the delivery of bioactive growth promoters to the flower sites, as was previously reported by Abd-Allah et al. (2021) that the application of the extracts onto the foliage of *Coriandrum sativum* has positive effects on the growth and productivity of the plant. Furthermore, m4 concentration and the hollow conical nozzle resulted in the maximum grain mass per hectare, which was confirmed by productivity measurements, possibly because there was increased access to bioactive compound during flowering and grain filling stage.

Table (4): Effect of Nozzle type and different concentrations and Interaction between Them on Number of Flower Buds (No buds.plant ⁻¹).						
N/ M	M0	M1	M2	M3	M4	Mean-N
N1	78.000 f	181.000 b	126.000 D	183.000 ab	183.000 ab	150.333 b
N2	104.333 e	169.333 c	185.667 Ab	174.000 c	190.000 a	164.667 a
Mean-M	91.167 d	175.167 b	155.833 C	178.500 b	186.833 a	
N= Nozzle type; M= Extract Concentrations.						

3.5 Productivity (kg ha⁻¹)

The efficiency of high concentration application in maximizing grain yield (Ahmed & Mheidi, 2023) is reflected by the highly significant differences ($P < 0.01$) shown in the mean square value of both the extract concentration and its interaction with nozzle type in this study. The results showed that the total mean of the hollow conical nozzle (N2) was 2443.33 kg ha⁻¹ compared to 2017.33 kg ha⁻¹ from flat fan nozzle (N1). Results showed that the yield increased with the increase of the concentration of the licorice extract and was 1565.00 kg ha⁻¹ at M0 and 3598.33 kg ha⁻¹ at M4. It was observed to be in the increasing direction with increase in the concentration of the licorice extract and the yield was 1565.00 kg ha⁻¹ at M0 and 3598.33 kg ha⁻¹ at M4. The N2 nozzle gave the highest productivity of 4370.00 kg ha⁻¹ which was significantly higher than the untreated control (Table 5).

Table (5): Effect of Nozzle type and different concentrations and Interaction between Them on Productivity (kg. hectare ⁻¹).						
N/ M	M0	M1	M2	M3	M4	Mean-N
N1	1513.33 f	1733.33 e	1980.00 d	2044.33 d	2826.67 b	2017.33 b
N2	1616.67 fe	2043.33 d	1953.33 d	2233.33 c	4370.00 a	2443.33 a
Mean-M	1565.0 d	1888.33 c	1966.67 c	2133.33 b	3598.33 a	
N= Nozzle type; M= Extract Concentrations.						

The findings suggest that high concentration of extract applications in combination with efficient nozzle geometry enables to achieve the best agronomic results; the statistical evaluation of the mean square values showed that both concentration level and nozzle geometry as well as the interaction between both parameters were highly significant ($p < 0.001$) for all the reproductive and yield-related measured variables. Furthermore, application fuel usage revealed that nozzle configuration affected the operational efficiency, allowing the hollow conical nozzle a faster application rate and lower application volume. This optimized spray delivery reduced the amount of direct fuel consumed per hectare, and ensured uniform deposition of the extract, which was positively correlated with the uptake of nutrients and biomass accumulation (Mohammed & Alabdulla, 2022). The observed relationships between nozzle geometry and nutrient deposition indicate the importance of having a clear system for delivering nutrients to improve the physiological efficiency of crops in bio-based fertilization systems (Ali et al., 2025).

4. CONCLUSION

The conclusions of this study reveal that the application method of spray and concentration of biostimulant are important factors that affect the growth and yield of coriander (*Coriandrum sativum* L.). The treatment with 12 ml L⁻¹ concentration of Licorice extract, using the hollow conical nozzle (N2) showed the best results in terms of agronomic parameters, the flower buds count and the highest productivity of the crop (4370.00 kg ha⁻¹). This application system will lead to more mechanical use of fuel, but the significant gain in crop production is worth the extra energy use.

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