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The Effect of Foliar Spraying of Plant-Derived Smoke in Different Stages of Growth on Quantitative and Qualitative Yield of Safflower (*Carthamus tinctorius* L.)

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This experiment was conducted in a factorial design using a randomized complete block design with three replications at a research farm in Babylon, Iraq, located at coordinates (32º 24′ 07″ N and 44º 43′ 22″ E). The study was carried out over two consecutive years, 2021 and 2022, focusing on safflower. The first factor examined different concentrations of plant-derived smoke (0.5, 1, and 1.5 liters per hectare), with normal water as the control. The second factor involved foliar spraying at various growth stages: 1) emergence, 2) stem elongation, 3) flowering, 4) emergence + stem elongation, 5) emergence + flowering, 6) stem elongation + flowering, and 7) emergence + stem elongation + flowering. The results indicated that foliar spraying with plant-derived smoke at different growth stages significantly affected various traits of safflower plants. Increasing the concentration of smoke water resulted in significant increases in the number of leaves per plant, number of heads per plant, number of seeds per head, biological yield, grain yield, oil yield, and stem diameter in comparison to the control group, except for a decrease in leaf temperature. However, the plant-derived smoke applied at multiple growth stages had a more significant positive effect than single-stage applications. The highest grain yield (3,604 kg/ha; $P<0.05$), oil percentage (23.07%), and oil yield (873.7 kg/ha) were achieved by applying 1.5 L/ha of plant-derived smoke during the seedling, stem elongation, and flowering stages. In conclusion, utilizing plant-derived smoke at various growth stages can enhance both the quantitative and qualitative yield of safflower. The results indicate that foliar spraying with plant-derived smoke, particularly at higher concentrations and during multiple growth stages, can be an effective method for enhancing safflower productivity.
Keywords: Growth stage, foliar spraying, safflower, smoke-water, agricultural productivity, Iraq.

INTRODUCTION

Challenges in oilseed crop production is the worldwide commercial and sustainable development and in middle east is more notable with presence of different kinds of oilseeds for human and animal uses (Gupta, 2015; Narimani-Rad *et al*., 2011). In this regard, Safflower (*Carthamus tinctorius* L.) is an important oilseed crop with big commercial value (Kobuk *et al*., 2019). It is called many names worldwide, such as the American saffron, dyed saffron, wild saffron, and saffron (Kobuk *et al*., 2019). Its seeds have an oil of 30% to 50%, is often preferred over soybean, sunflower, and corn oils (Nazir *et al*., 2021). Its versatility makes it well-suited to marginal areas because of its robust growth capabilities under low agricultural inputs in different climatic conditions. Its deep root system penetration and its brief sensitivity to drought—from flower formation to the middle of the seed-filling stage—improves its drought tolerance and appropriateness for cultivation in marginal soils (Moatshe *et al*., 2020; Manvelian *et al*., 2021). In both developed and developing world, past crop residues are often destroyed because of its agricultural practices (Kulkarni *et al*., 2011). Although it is convenient and cost-effective, it has several risks, such as the destruction of beneficial soil microbes and the potential for air pollution (Mandal *et al*., 2004). So, researchers have used prescribed burning techniques for improving seed germination in fire-prone areas (De Lange and Boucher, 1990). Smoke has many compounds, and a big effort has been made to identify these active substances (Dixon *et al*., 2009). For horticultural uses, smoke is

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harnessed by three primary forms: aerial smoke, water smoke extract, and dynamic compounds (KARs). Water smoke, or liquid smoke, is produced industrially by burning plant materials and capturing the resulting smoke in water and evacuated and filtrated (Garrido *et al*., 2023). (Gholami *et al*., 2017) applied smoke water and urea fertilizer to wheat significantly enhanced all components of wheat yield compared to the control groups. This means that smoke water enhances wheat growth indicators and grain yield by better nitrogen efficiency and compensating for yield losses linked to reduced nitrogen uses. Another scholar, the maximum vegetative growth of beans, yield of green pods, and percentage of dry matter accumulation are obtained by foliar spraying with a 1.5% concentration of smoke water (Abou El-Nour, 2021). In addition, plant-derived smoke at a 2000 ppm enhanced seed germination, root and stem length, and the wheat seedling fresh weights (Hayat *et al*., 2021). Wheat seedlings treated with smoke-water solutions has a good health, increased chlorophyll production, photosynthetic pigments, and better photosynthetic activities (Iqbal *et al*., 2016). This raises plant pigments allowing greater sunlight absorption, so it enhances the plant's photosynthetic competence. The heightened response in photosynthetic pigment indicates that the plant smoke is effective like other plant growth hormones in promoting growth through this pathway (Khatoon *et al*., 2020). The development in response to smoke-water solutions is contingent upon specific biochemical activity stimulating vegetative and reproductive growth (Baxter and van Staden, 1994). Smoke treatments raise the synthesis and accumulation chlorophyll a, improving light-use efficiency for plants. In addition, smoke-water solutions enhanced the biosynthesis of ribulose-1,5-bisphosphate carboxylase/oxygenase in chickpeas and corn (Rehman *et al*., 2018); (Aslam *et al*., 2019). Applying smoke water improved gas exchange, photochemical activity and CO_2 fixation, so raising photosynthesis. A rise in maximum quantum efficiency, stomatal conductance, intercellular CO_2 concentration, and net photosynthesis is seen in carrots (Akeel *et al*., 2019). In addition, smoke-water solutions raised the photosynthesis and transpiration rate, and stomatal conductance of Dair wood seedlings which indicates that smoke treatments enhance stomatal opening (Zhou *et al*., 2011). Smoke water regulates growth under both normal conditions and abiotic stresses as a cost-effective and convenient biostimulant for farmers (Khatoon *et al*., 2020). So, this experiment investigated the effects of many concentrations of smoke water at many growth stages on the quantitative and qualitative produce of safflower plants.

MATERIALS AND METHODS

***Test plan*:** An experiment a research farm in Babylon, Iraq was conducted by a randomized complete block design with three replications (32º24′07″N and 44º43′22″E). It concentrated on the cultivation of safflower over two consecutive years, 2021 and 2022. First, different concentrations of plant-derived smoke (0.5, 1, and 1.5 liters per hectare) were examined, with normal water serving as a control. The second foliar spraying at different stages: 1) emergence, 2) stem elongation, 3) flowering, 4) emergence + stem elongation, 5) emergence + flowering, 6) stem elongation + flowering, and 7) emergence + stem elongation + flowering).

***Land preparation*:** To conduct this experiment, land preparation, which included plowing, disking, and leveling, was performed in early autumn. Each experimental plot consisted of six planting rows, each three meters in length. The distance between adjacent plots was set at one meter. Cultivation in the field commenced at the earliest suitable time in November. The spacing between plants within the planting rows was maintained at 10 cm. Irrigation during the growing season was implemented as needed, based on environmental conditions and the growth stage of the plants. Weeding was carried out manually throughout the growing season.

***Application of experimental treatments*:** After preparing various concentrations of plant-derived smoke, the required amount for each plot was calculated based on the concentration per hectare. Foliar spraying was then conducted in the early morning or near evening, using a manual sprayer to enhance absorption, depending on the different growth stages of the plants.

***Measurement of parameters*:** After the physiological treatment and the removal of marginal effects, one square meter of plant sample was collected from each test plot. The biological yield and grain yield were then measured using a precision scale. Following the calculation of grain and biological yields, the harvest index was determined by dividing the economic yield (grain yield) by the biological yield. Additionally, to assess morphological traits—such as stem height and diameter, number of lateral branches, number of leaves, number of pods per plant, number of seeds per pod, and weight of 1,000 seeds—five plants were randomly selected from each test plot, and the relevant parameters were measured.

***Oil percentage and yield*:** The oil content of the seeds collected from each experimental plot was measured using a Soxhlet apparatus. After determining the oil percentage, the oil yield was calculated by multiplying the seed yield by the oil percentage (Soxhlet, 1879).

***Statistical calculations*:** To analyze the variance of the data after assessing their normality, a statistical model based on a compound analysis plan was employed over two years using SAS software. The means were compared using the Least Significant Difference (LSD) test at a five percent probability level. Graphs were created using Excel.

RESULTS

The analysis of variance revealed that the year had a significant effect on the number of safflower branch traits. Additionally, the concentration of plant-derived smoke significantly influenced several traits, including the number of leaves per plant, stem diameter, leaf temperature, number of heads per plant, number of seeds per head, 1000-grain weight, biological yield, grain yield, harvest index, oil percentage and yield, plant height, and number of branches. Furthermore, the effect of water smoke during the plant's growth stages was significant for all traits except the number of branches. The interaction between the year and growth stage also had a significant effect on the number of branches. Moreover, the interaction between the concentration of plant-derived smoke and growth stage significantly affected the traits of the number of per plant, leaf temperature, number of heads per plant, number of seeds per head, biological yield, seed yield, oil yield, and stem diameter as shown in Table 1-4 and Figure 1.

Plant height**:** The results indicate that foliar spraying of safflower plants with plant-derived smoke significantly increased plant height compared to the control group. The tallest plants, measuring 131.3 cm, were achieved with a smoke-water concentration of 1.5 liters per hectare, representing a 12.7% increase over control (Table 2). Additionally, there was no statistically significant difference in the effects on safflower plant height between the concentrations of 0.5 and 1 liters per hectare, as well as between 1 and 1.5 liters per hectare. The timing of foliar spraying during different growth stages also had a notable impact on plant height. The maximum height of 135.5 cm was recorded when spraying occurred during the seedling, stem elongation, and flowering stages, resulting in increases of 12.9%, 11.4%, and 11.15%, respectively, compared to spraying at only one of these stages (Table 3).

Number of branches**:** The number of branches in the safflower plant increased significantly with higher concentrations of plant-derived smoke (Table 2). Foliar spraying with 1.5 L/ha of plant-derived smoke resulted in a 41.7% increase in the number of branches compared to the control group. However, there was no statistically significant difference in the number of safflower branches between foliar spraying at 1 L/ha and 1.5 L/ha of plant-derived smoke (Table 2). The effects of foliar spraying plant-derived smoke at different growth stages varied on the number of branches (Table 3). Spraying during two or three growth stages led to a greater increase in the number of branches compared to spraying at a single stage. The highest number of branches (16.99) was achieved by foliar spraying during the seedling, stem elongation, and flowering stages, resulting in increases of 34.5%, 21.8%, and 28.4%, respectively, compared to foliar spraying at each of these stages individually (Table 3). Foliar spraying of plant-derived smoke at various growth stages over the two years of the experiment produced differing effects on the number of lateral branches. Overall, foliar spraying with plant-derived smoke resulted in a greater increasing effect compared to a more significant increase in all growth stages

Table 1. Variance analysis to investigate the effect of the year, smoke water concentration, and growth stage on the traits of the safflower plant (mean square).

Sources of changes	DF	N. of head per plant	N. of seeds per head	1000- grain weight	Grain yield	Biological yield	harvest index
Year (Y)	1	2.140	0.745	8.035	67372	1458803	3.215
Block (Y)	4	23.150	101.900	17.020	116154	7431587	166.900
Smoke –water concentration (SWC)	3	247.900**	495.700**	389.900**	4187683**	19219957**	103.400**
Y*SWC	3	0.204	0.681	1.974	12726	240619	4.304
Growth stage (Gs)	6	68.440**	132.100**	183.300**	1452484**	4401768**	40.350**
Y*Gs	6	0.074	0.412	1.225	14056	2074*	3.036
SWC*Gs	12	1.648**	5.079**	1.034	62812**	91272**	3.697
Y*SWC*Gs	12	0.073	0.125	0.554	10310	6743	2.336
Error	120	3.378*	9.430	4.375	90486	848718	20.110
CV (%)		12.040	10.570	7.110	11.88	11.2	14.470

**, * Significant at 1 and 5% probability levels.

Table 2. Comparison of the mean effect of smoke-water concentration on the studied traits of safflower.

Smoke-water conc. (L/ha.)	plant height (cm)	N. of lateral branches	1000- grain weight (g)	Harvest index (%)	Oil (%)
0	116.5[c]	11.72[c]	24.97[c]	28.79[b]	18.90[c]
0.5	126.1[b]	14.75[b]	30.08[b]	31.51[a]	21.55[b]
1	129.9[ab]	15.84[a]	31.00[a]	32.49[a]	22.64[ab]
1.5	131.3[a]	16.61[a]	31.68[a]	31.17[a]	23.41[a]

[a,b,c] Significant differences in means are represented by differences in the same column within each classification.

across the highest number of sub-branches obtained in 2022 by plant-derived smoke recorded spraying at the following elongation, and flowering stages (Figure 1).

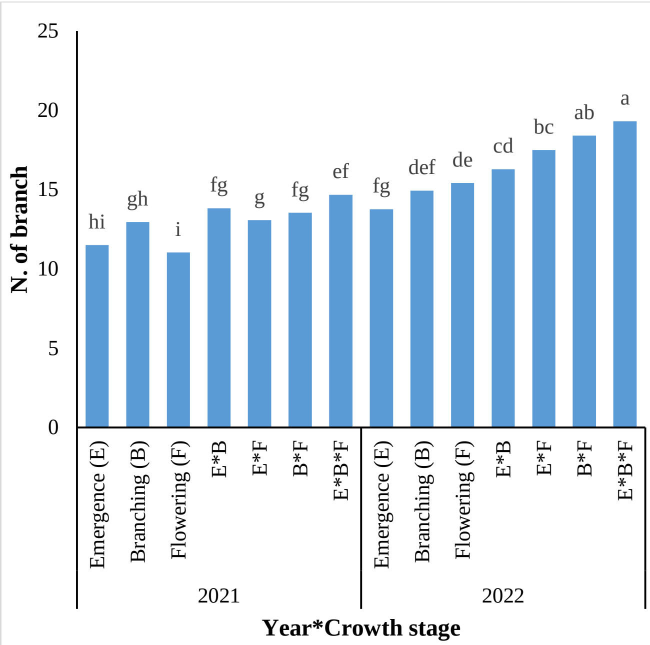

Figure 1. The effect of foliar spraying of smoke water in different stages of growth on the number of branches of safflower plant in two different years.

***1000- grain weight*:** Foliar spraying with plant-derived smoke significantly increased the 1000-grain weight of safflower seeds compared to the control group. The highest 1000-grain weight, recorded at 31.68 grams, was achieved with a concentration of 1.5 L/ha of plant-derived smoke, representing a 27% increase over the control. A statistically significant difference was observed between the treatments of 1 L/ha and 1.5 L/ha of plant-derived smoke regarding their effects on the 1000-grain weight (Table 2). The 1000-grain weight of safflower seeds varied with foliar spraying of plant-derived smoke at different growth stages. Spraying at multiple growth stages resulted in a significant increase in the 1000-grain weight compared to spraying at a single stage. The highest 1000-grain weight was observed when foliar spraying occurred during the seedling, stem elongation, and flowering stages, leading to increases of 22.06%, 19.6%, and 15.6%, respectively, in the 1000-grain weight of safflower seeds compared to spraying at separate growth stages (Table 3).

***Harvest index*:** Foliar spraying of plant-derived smoke positively influenced the harvest index of safflower plants compared to the control group. Although no statistically significant differences were observed among the various concentrations of plant-derived smoke regarding their effects on the safflower harvest index, the concentration of 1.5 L/ha yielded to the highest harvest index at 31.17%, representing a 12% increase over the control (Table 2). The harvest index varied depending on the timing of foliar spraying during different growth stages of the plants. Increasing the frequency of foliar spraying resulted in a significant enhancement of the harvest index across multiple growth stages. Foliar spraying during the seedling + stem elongation, seedling + flowering, and stem elongation + flowering stages produced higher harvest indexes compared to each stage. The highest harvest index, recorded at 32.80%, was achieved through foliar spraying of plant-derived smoke during the combined growth stages of seedling, stem elongation, and flowering. Furthermore, no statistically significant differences were found among the growth stages of seedling, stem elongation, flowering, seedling + stem elongation, and seedling + flowering in terms of their impact on the harvest index (Table 3).

***Oil percentages*:** The percentage of safflower oil increased significantly with higher concentrations of plant-derived smoke. Foliar spraying with smoke water at concentrations of 0.5, 1, and 1.5 L/ha resulted in increases in oil percentage of 14%, 19.7%, and 23.8%, respectively, compared to the control. However, there was no statistically significant difference in seed oil percentage between the 0.5 L/ha and 1 L/ha concentrations, or between the 1 L/ha and 1.5 L/ha concentrations (Table 2). Foliar spraying of plant-derived smoke at various growth stages also enhanced the seed oil percentage. Spraying at two or three growth stages produced a greater increase in seed oil compared to spraying at a single stage. The highest seed oil percentage (23.07%) was achieved by spraying during the seedling, stem elongation, and flowering stages. This combined approach resulted in

Table 3. Comparison of the average effect of the growth stage on the studied traits of safflower.

Growth stage	plant height (cm)	N. of lateral branches	1000- grain weight (g)	Harvest index (%)	Oil (%)
Emergence (E)	120.0^{e}	12.63^{d}	26.29^{e}	29.44^{c}	20.30^{c}
Branching (B)	121.6^{de}	13.94^{c}	26.83^{de}	30.06^{bc}	20.79^{bc}
Flowering (F)	121.9^{cde}	13.23^{cd}	27.75^{cd}	30.13^{bc}	21.32^{bc}
E*B	127.7^{bc}	15.05^{b}	28.66^{c}	30.40^{abc}	21.62^{abc}
E*F	126.9^{bcd}	15.29^{b}	30.91^{b}	31.73^{abc}	22.04^{ab}
B*F	128.0^{b}	15.97^{ab}	32.09^{b}	32.38^{ab}	22.24^{ab}
E*B*F	135.5^{a}	16.99^{a}	33.49^{a}	32.80^{a}	23.07^{a}

increases of 13.64%, 10.9%, and 8.2% in seed oil percentage compared to spraying at the seedling, stem elongation, and flowering stages individually (Table 3).

***Number of leaves*:** Foliar spraying with plant-derived smoke at various stages of plant growth, compared to regular water, significantly increased the number of leaves on the plants. An increase in the concentration of plant-derived smoke at all growth stages resulted in a marked rise in leaf count compared to the control group (foliar spraying with regular water). The highest average number of leaves per plant (198.2) was recorded with the application of 1.5 liters of plant-derived smoke per hectare during the seedling, stem elongation, and flowering stages. This represented a substantial increase of approximately 27% compared to the lowest leaf count (155.9) observed in the seedling stage with regular water (Table 4).

***Stem diameter*:** The diameter of the safflower stem was influenced by foliar spraying with varying concentrations of plant-derived smoke at different growth stages. As the concentration of plant-derived smoke increased, the stem diameter of safflower also increased across these growth stages. The largest stem diameter, measuring 16.33 cm, was observed with foliar spraying at a concentration of 1.5 L/ha of smoke water during the seedling, stem elongation, and flowering stages (Table 4).

***Leaf temperature*:** Foliar spraying during the growth stages of safflower resulted in a decrease in leaf temperature. As the concentration of plant-derived smoke increased, it was applied during various growth stages, a significant reduction in several temperatures was observed in leaf temperature. The highest leaf temperature (35.40°C) was recorded in the flowering stage and with normal water spraying. The temperature of safflower leaves decreased even after being sprayed with all concentrations of plant-derived smoke. The lowest leaf temperature, recorded at 25.42°C, was observed when 1.5 liters of plant-derived smoke were applied during the three growth stages: seedling, stem elongation, and flowering. This temperature represents a decrease of approximately 28% compared to the highest recorded temperature (Table 4).

***Number of heads per plant*:** The results of comparing the mean data the number of heads per plant increased under with effect application of plant-derived smoke through spraying

Table 4. Comparison of the mean interaction effect of water smoke concentration*growth stage on safflower studied traits.

Smoke – water Conc. (L/ha)	Growth stage	N. of leaves Per plant	stem diameter (cm)	Leaf temperature (°C)	N. of head /plant	N. of seeds per head	Biological yield (kg/ha)	Grain yield (kg/ha)	Oil yield (kg/ha)
0	Emergence (E)	155.9^{kl}	11.80^{ghi}	35.15^{ab}	12.11^{lm}	24.68^{kl}	7312^{hi}	2102^{hi}	404.8^{jk}
	Branching (B)	153.9^{l}	11.95^{f-i}	35.08^{ab}	11.79^{m}	24.56^{kl}	7296^{hi}	2094^{hi}	398.6^{k}
	Flowering (F)	154.9^{l}	11.58^{i}	35.40^{a}	12.11^{lm}	24.25^{l}	7315^{hi}	2068^{i}	395.2^{k}
	E*B	154.3^{l}	11.75^{hi}	35.21^{ab}	12.11^{lm}	24.78^{kl}	7294^{hi}	2078^{i}	394.4^{k}
	E*F	155.7^{kl}	11.80^{ghi}	35.14^{ab}	12.03^{lm}	24.63^{kl}	7350^{hi}	2084^{i}	392.3^{k}
	B*F	155.9^{kl}	11.88^{ghi}	35.17^{ab}	12.07^{lm}	24.68^{kl}	7261^{i}	2086^{i}	395.0^{k}
	E*B*F	158.2^{kl}	11.83^{ghi}	35.31^{ab}	12.19^{lm}	24.68^{kl}	7343^{hi}	2082^{i}	390.9^{k}
0.5	Emergence (E)	161.7^{jkl}	12.95^{e-i}	34.58^{ab}	12.68^{klm}	25.48^{jkl}	7547^{ghi}	2222^{gh}	445.6^{ijk}
	Branching (B)	165.7^{g-l}	13.23^{c-i}	34.18^{abc}	13.18^{j-m}	26.08^{i-l}	7715^{ghi}	2354^{f-i}	485.9^{h-k}
	Flowering (F)	169.4^{f-k}	13.60^{b-i}	32.85^{a-e}	14.33^{g-l}	27.72^{g-l}	7897^{f-i}	2415^{f-i}	514.3^{g-j}
	E*B	175.6^{d-j}	13.82^{b-h}	31.75^{a-f}	14.37^{g-l}	28.57^{f-k}	8257^{d-i}	2530^{efg}	546.8^{ghi}
	E*F	178.4^{c-h}	14.15^{a-f}	29.68^{c-h}	15.70^{e-i}	29.93^{d-i}	8330^{d-h}	2614^{d-g}	579.0^{fgh}
	B*F	182.7^{b-f}	14.45^{a-e}	27.63^{fgh}	16.28^{e-h}	30.43^{c-h}	8430^{c-g}	2690^{c-f}	583.1^{e-h}
	E*B*F	187.5^{a-d}	14.83^{a-e}	26.47^{gh}	17.45^{c-f}	31.9^{c-f}	8850^{a-f}	2917^{b-e}	674.3^{c-f}
1	Emergence (E)	162.9^{i-l}	13.12^{d-i}	34.42^{abc}	13.27^{i-m}	26.45^{h-l}	7867^{f-i}	2324^{f-i}	487.3^{h-k}
	Branching (B)	167.6^{g-l}	13.52^{b-i}	33.50^{a-d}	14.32^{g-l}	27.23^{g-l}	7972^{f-i}	2409^{f-i}	518.9^{ghi}
	Flowering (F)	172.5^{e-j}	13.90^{b-h}	32.62^{a-e}	15.30^{f-j}	28.67^{e-k}	8122^{e-i}	2528^{efg}	557.1^{gh}
	E*B	175.9^{d-i}	14.28^{a-e}	30.53^{b-g}	16.15^{e-h}	29.33^{d-j}	8457^{c-g}	2679^{c-f}	603.5^{efg}
	E*F	182.6^{b-f}	14.78^{a-e}	28.27^{e-h}	17.58^{c-f}	31.90^{c-f}	8783^{a-f}	3016^{bc}	689.4^{b-e}
	B*F	187.8^{a-d}	15.08^{a-e}	25.98^{gh}	18.87^{bcd}	32.77^{b-e}	9063^{a-e}	3020^{bc}	717.9^{bcd}
	E*B*F	193.1^{ab}	15.43^{abc}	25.50^{h}	19.80^{abc}	34.50^{bc}	9537^{ab}	3258^{ab}	789.7^{ab}
1.5	Emergence (E)	165.0^{h-l}	13.33^{c-i}	34.02^{abc}	14.12^{h-m}	27.12^{g-l}	8050^{e-i}	2315^{f-i}	479.6^{h-k}
	Branching (B)	169.2^{f-k}	13.98^{b-g}	32.62^{a-e}	14.88^{g-k}	29.47^{d-j}	8288^{d-i}	2404^{f-i}	527.8^{ghi}
	Flowering (F)	174.7^{d-j}	14.70^{a-e}	31.57^{a-f}	16.73^{d-g}	30.87^{c-g}	8508^{b-g}	2499^{fgh}	564.1^{fgh}
	E*B	179.4^{b-g}	14.98^{a-e}	28.87^{d-h}	17.85^{b-e}	32.83^{bcd}	8840^{a-f}	2628^{c-g}	612.8^{d-g}
	E*F	184.4^{a-e}	15.28^{a-d}	27.40^{fgh}	18.95^{bcd}	34.37^{bc}	9237^{a-d}	2933^{bcd}	713.9^{bcd}
	B*F	191.9^{abc}	15.65^{ab}	25.75^{gh}	19.98^{ab}	36.57^{ab}	9405^{abc}	3146^{ab}	783.9^{abc}
	E*B*F	198.2^{a}	16.33^{a}	25.42^{h}	21.23^{a}	38.63^{a}	9832^{a}	3402^{a}	873.7^{a}

$^{a-m}$ Significant differences in means are represented by differences in the same column within each classification.

safflower growth, in contrast to the control treatment (foliar spraying with normal water). As the concentration of plant-derived smoke and its foliar spraying increased the number of heads per plant increased significantly. Specifically, a foliar concentration of 1.5 liters per hectare of plant-derived smoke during the seedling and stem elongation stages resulted in an increase in stage seedling+ number of leaves per plant by 26.4% and 19.9%, respectively, seedling and stem elongation stages separately, increased when treated separately. Overall, heads per plant (21.23) were produced in interaction observed of foliar spraying liters per hectare of plant-derived smoke and three growth stages: seedling, elongation, and flowering (Table 4).

***Number of seeds per head*:** The effect of foliar spraying with plant-derived smoke during the growth stages of safflower on the number of seeds per head was significant. Foliar spraying with plant-derived smoke increased the number of seeds per head compared to the control group, which received normal water spraying. Increasing the concentration of plant-derived smoke from 0.5 to 1.5 L/ha resulted in a significantly greater increase in the number of seeds per head. The impact of foliar spraying on seed count varied across different growth stages. When applying various concentrations of plant-derived smoke across two or more growth stages, as opposed to just one, there was a notable increase in the number of seeds per head. The highest number of seeds per head (38.63) was recorded with a foliar spray concentration of 1.5 L/ha of plant-derived smoke during the seedling, stem elongation, and flowering stages (Table 4).

***Biological yield*:** Foliar spraying of plant-derived smoke at various growth stages significantly enhanced the biological yield of safflower compared to conventional water foliar spraying. Increasing the concentration of plant-derived smoke from 0.5 to 1.5 L/ha resulted in a notable increase in biological yield. Furthermore, applying plant-derived smoke at multiple growth stages produced a higher biological yield than applying it at a single growth stage. The highest biological yield of 9,832 kg/ha was achieved with the foliar application of 1.5 L/ha of plant-derived smoke during three stages: seedling, stem elongation, and flowering (Table 4).

***Grain yield*:** The grain yield of safflower significantly increased with the foliar application of plant-derived smoke at various growth stages compared to the application of normal water. Increasing the concentration of plant-derived smoke from 0.5 to 1.5 L/ha resulted in a notable enhancement in grain yield across all growth stages. Furthermore, applying plant-derived smoke through foliar spraying at multiple growth stages yielded a higher grain output than applying it at a single growth stage. The treatment involving foliar spraying of 1.5 L/ha of plant-derived smoke during the seedling, stem elongation, and flowering stages produced the highest grain yield (Table 4).

***Oil yield*:** Applying plant-derived smoke as a foliar spray at various growth stages significantly enhanced safflower oil yield per hectare. The oil yield increased notably with higher concentrations of plant-derived smoke, ranging from 0.5 to 1.5 L/ha. The timing of foliar spraying during different growth stages also influenced oil yield; multiple applications during the seedling, stem elongation, and flowering stages resulted in a greater increase compared to single-stage applications. The highest oil yield of 873.7 kg/ha was achieved with 1.5 L/ha of plant-derived smoke applied during the seedling, stem elongation, and flowering stages. This method increased oil yield by 115.8%, 119.1%, and 121% compared to foliar spraying with regular water during the seedling, stem elongation, and flowering stages, respectively (Table 4).

DISCUSSION

The plant-derived smoke used in agronomy and horticulture is crucial. According to research, smoke as a phytohormone, positively influences the growth characteristics and biological performance of plants. These bioactive compounds of smoke are novel growth regulators enhancing many growth parameters (Khatoon *et al*., 2020). In addition, foliar spraying with plant-derived smoke raises the grain yield and improves the ecological features of plants. So, the use of smoke water is an effective method to enhance the growth, yield, and the general features of plants in agriculture (Iqbal *et al*., 2016). Spraying plant-derived smoke to safflowers at different growth stages increases plant height, branches, the weight of 1,000 grains, harvest index, oil percentage, leaves, stem diameter, number of heads per plant, seeds per head, biological yield, grain yield, and oil yield. According to the results foliar spraying with plant-derived smoke at two or three growth stages, in contrast to just one growth stage, had a more pronounced positive effect on all studied traits, except for leaf temperature confirming those from the by (Kulkarni *et al*., 2007) on the effects of smoke water and butenolide on the growth of okra and tomato seedlings. The results revealed that treating okra seedlings with smoke water (1:500) significantly increased many growth parameters in relation to the control treatment. These parameters are stem and root length, fresh and dry seedling weight, number of leaves, leaf area, and stem thickness. In addition, the foliar application of smoke water and butenolide affected the growth of tomato seedlings. The results suggest using smoke water or butenolide through foliar spraying as a cost-effective method for more growth of vegetable crop seedlings. In Watsonia borbonica, smoke water treatment (1:500 by volume) flowered more from 20% to 90% (Light *et al*., 2009). So, smoke provides a viable solution for better flowering in certain plants. In addition, smoke water has significantly enhanced the growth parameters of papaya seedlings. (Light *et al*., 2009) showed that smoke water treatment improved many growth-related parameters in papaya seedlings compared to the control groups increasing a 50.45% increase in the growth of aerial parts, a substantial rise 96.59% in fresh weight and 88.88% in dry weight of aerial parts, respectively, and a 14.94% rise in the number of leaves. So, foliar spraying of plant-derived smoke water (PDSW) and karrikinolide (KAR1) enhanced carbonic anhydrase (CA) enzyme activity by 34.05% and 27.42%, in respect, in relation to the control (Singh *et al*., 2023). Also, the interaction between smoke or carricinolide and phytohormones in plants is crucial in mediating responses related to growth and development (Akeel *et al*., 2019). These enhance many aspects of plant biology, such as morphological, physiological, and performance-related parameters, finally improving plant (Singh *et al*., 2023). This synergy between smoke or carricinolide and phytohormones shows the complex mechanisms where external factors affect plant growth and development, with insights into potential strategies to optimize plant performance and health.

***Conclusion*:** The study found that foliar spraying of safflower plants with smoke water at various growth stages had significant effects on multiple traits. Increasing the concentration of smoke water, compared to the control, significantly enhanced plant height, the number of branches, 1000-grain weight, harvest index, oil percentage, the number of leaves per plant, stem diameter, the number of heads per plant, the number of grains per head, biological yield, seed yield, and oil yield. Foliar spraying with smoke water during two or three growth stages produced a more pronounced increase in the examined traits compared to spraying at only one stage. For all traits, except leaf temperature, the highest values were achieved with foliar spraying of 1.5 L/ha of smoke water during the seedling, stem elongation, and flowering stages. Accordingly, the study suggests that foliar application of smoke water, particularly at higher concentrations (1.5 L/ha) and across multiple growth stages (seedling, stem elongation, flowering), can significantly enhance both the quantity and quality of safflower yield.

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