RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
56 (6) 2544-2552, 2024
http://doi.org/10.54910/sabrao2024.56.6.36
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

RESPONSE OF RAPESEED (*BRASSICA NAPUS* L.) TO FOLIAR APPLICATION OF ETHEPHON AND TOPPING IN PRODUCTION TRAITS

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SUMMARY

Aimed at determining the effects of topping and various concentrations of ethephon on production traits of rapeseed (*Brassica napus* L.), the latest research proceeded during the winter of 2022–2023 at the University of Basrah, Iraq (30° 57' N latitude, 47° 80' longitude). The experiment layout was in a randomized complete block design, with two factors and three replications according to split plot arrangement. The topping and ethephon occupied the main plots, with symbols as T = topping, E0 = zero ethephon concentration, E1 = 1 ml L^{-1} ethephon, and E2 = 2 ml L^{-1} ethephon. The subplots comprised crop development and growth stages (elongation, flowering, and branching) represented by the symbols S1, S2, and S3. The evaluated traits consisted of plant height (cm), number of branches (branches m^{-2}), leaf area (cm^2), pods per plant (pods $plant^{-1}$), seeds per pod (seeds pod^{-1}), 1000-seed weight (g), seed yield per plant (g $plant^{-1}$), and harvest index (%). The findings indicated ethephon concentrations and topping significantly differed for most traits. The ethephon with concentration of 2 ml L^{-1} showed the highest seed yield (21.38 g $plant^{-1}$); however, it has a nonsignificant difference from the topping treatment (20.75 g $plant^{-1}$). The study showed that spraying at various growth stages had relevant effects on most studied features, and the S1 stage gave remarkable results, with the maximum seed yield (19.26 g $plant^{-1}$). The combination of spraying ethephon (E2, 2 ml L^{-1}) at the S1 stage had the best results, exhibiting the premier grain yield (24.03 g $plant^{-1}$). However, the said treatment was at par with the topping treatment at the same growth stage (23.44 g $plant^{-1}$).

Keywords: Rapeseed (*B. napus* L.)**,** ethephon, topping, growth stages, production, morphological and yield traits

Key findings: The rapeseed (*B. napus* L.) best performed with topping and foliar application of ethephon at 2 mL/L, giving the highest yield of 21.38 and 20.75 g/plant. The topping and spraying had better results for most traits assessed, including plant yield during the elongation stage (S1).

Communicating Editor: Dr. A.N. Farhood

Manuscript received: September 18, 2023; Accepted: May 16, 2024.

Citation: Altoblani HTA, Al-Freeh LMS (2024). Response of rapeseed (*brassica napus* l.) To foliar application of ethephon and topping in production traits. *SABRAO J. Breed. Genet.* 56(6): 2544-2552. http://doi.org/10.54910/sabrao2024.56.6.36.

INTRODUCTION

The rapeseed (*Brassica napus* L.) is a winter crop from the Cruciferae family, grown worldwide. India is where its first cultivation occurred 4,000 years ago. In 2020–2021, its global production estimate was about 68.90 million tons (FAOSTAT, 2022). It is only second to soybeans in terms of producing healthy nutritious oil (40%–50%) with its high content of unsaturated fatty acids (oleic and linoleic), protein (20%), carbohydrates (17%), vitamins (A, D, E, and K), phosphates, and antioxidants, such as, natural phenols and flavonoids (Batool *et al*., 2021). Given its qualities, it is a valuable raw material for the food industry (Begna and Angadi, 2016).

Growing crop service operations, such as, cutting off the growing top, is essential to increase yield due to the crop's rising significance in nurturing crops and industrial sectors in global production (FAOSTAT, 2022). Defining topping is the stimulation of lateral fruiting buds, the redistribution of organic compounds and their transformation into fruiting parts. The enhancement of the leafy area and its composition by an increased efficiency of photosynthesis augmenting its results leads to the apical dominance elimination, which raises yield in quantity and quality (Ban *et al*., 2017).

The number of branches, pods per plant, seeds per pod, and total seed production increased with topping, according to Choudhary *et al*. (2016), following a 30-day period of seed sowing on rapeseed plants. Tadesse *et al*. (2012) observed plants with non-topping rapeseed produced the maximum oil. Ethephon, on the other hand, degrades the metabolite products found in various areas of the plant, increasing its ability to employ these compounds to increase production and components.

As a result, limited development is effective, managing the link between sources and sank. Ethephon is also important for terminating apical dominance and shortening internodes because it inhibits gibberellins and produces ethylene, which decreases plant height (Devi *et al*., 2011). Chris and Richard (2002) also found that ethephon could be highly useful when utilized correctly, but it is also dependent on the stage and chosen concentration. Darginavičien *et al*. (2011) discovered spraying with 10 mM ethephon increased the quantity and weight of pods and seeds in rapeseed plants.

According to Mahmoud (2016), rapeseed plants sprayed with 0, 100, 200, and 300 mg L^{-1} of ethephon at various concentrations produced more branches at 100 mg L^{-1}. As a result, each plant produced more pods and seeds, increasing the total number of seeds, 1000-seed weight, and the seeds' oil content. Consequently, it was helpful to determine which technique best supports the growth. The presented study sought to determine the effects of the topping and various concentrations of ethephon on the production traits of rapeseed (*Brassica napus* L.).

MATERIALS AND METHODS

A field experiment on rapeseed (*Brassica napus* L.) commenced during the crop season of 2022–2023 at the Agricultural Research Station, University of Basrah, Iraq. The evaluation of topping treatments and ethephon spraying effects had different concentrations. These treatments comprised T = topping and ethephon concentrations at E0 = no ethephon, E1 = ethephon at 1 ml L^{-1}, and E2 = ethephon 2 ml L^{-1}, used during different stages of the plant's life and filled the main plots. Representing these stages are the letters S1, S2, and S3, which correspond to the stages of elongation, flowering, and branching, respectively, filling the secondary plots.

The experiment proceeded in three replications using a randomized complete block design and split-plot arrangement. Each replication included 12 experimental units (2 m² × 2 m²). Rapeseed (Pactol var.) sowing ensued on October 20, 2022. The silty clay loam soil used for agriculture had the following composition: N = 32.00 m mol L^{-1}, P = 10.98 mg kg^{-1}, and K = 90.51 mg kg^{-1}. Applying fertilizer rate of 100 kg P_2O_5 ha^{-1} (P_2O_5 46%) of superphosphate fertilizer happened before planting. Application of 240 kg N ha^{-1} of urea followed when 3–4 leaves emerged after thinning the first batch, with the second batch applied when flowering buds appeared (Alhilfi and Al-freeh, 2023). There are five lines on the experimental unit, spaced 30 cm apart (Al-Rikabi, 2021).

In contrast to the control treatment, sprayed only with distilled water, the ethephon spraying on plant shoots based on the concentrations and the spraying dates studied used a portable 16-liter sprinkler. Adding a surfactant (bright cleaning solution) had a rate of 1.5 cm^3 per 10 l of solution. Minimizing excessive heat, the spraying occurred early in the morning (because of the low temperature, a high relative humidity, and a stable wind speed to reduce the spray evaporation at the time of spraying or after. Thereby, this allows the stomata on the leaves to absorb the droplets). The harvest of plants took place on April 24, 2023, and continued until April 30, 2023, when they were fully mature. Random selections of 10 plants from each experimental unit proceeded. Measurement of recorded data included plant height, leaf area, the number of branches per plant, number of pods per plant, number of seeds per pod, weight of 1000 seeds, plant seed yield, and harvest index.

Statistical analysis

Using the Genstat statistical software helped study the data statistically, with the means of the parameters compared using the least significant difference test (LSD 0.05).

RESULTS AND DISCUSSION

Plant height

In rapeseed, a major effect with increasing concentration of ethephon lowered plant height, with an average plant height of 177.89 cm. E2 plants were 16.39% shorter than the comparison treatment, which had the highest average of the trait at 212.78 cm (Table 1). The role of ethephon at this concentration may refer to the decrease in plant height. It has the opposite effect on plants that gibberellin does by preventing or hindering the conversion of the compound Geranyl pyrophosphate to Coponyl pyrophosphate. This is the first step in the gibberellin biosynthesis chain in the subapical meristematic region and represents the primary meristem for elongation before reducing plant height (Moore, 1980; Attia and Jadooa, 1999).

Significant correlation was evident between the ethephon spraying stage and plant height, with the elongation stage-sprayed plants achieving the lowest average trait length of 184.42 cm as compared with the branching stage-sprayed plants (Table 1). The recorded highest average plant height was at 195.75 cm. The physiological efficacy of growth retardants, such as ethephon, when sprayed at the right period of plant growth, may be the cause of the noted break in apical dominance. Ethephon inhibited auxin's polar transport in plant tissues, which reduces its potency and controls elongation. When spraying, ethephon

Table 1. Effect of topping and Ethephon with growth phases and their interaction on the plant height in rapeseed.

Ethephon Treatments	Growth stages			Means (cm)
	S1	S2	S3	
E0	208.00	211.00	219.33	212.78
T	175.67	179.00	186.33	180.33
E1	183.00	186.67	192.00	187.22
E2	171.00	177.33	185.33	177.89
Means (cm)	184.42	188.50	195.75	

$LSD_{0.05}$ Ethephon: 3.30, Growth stages: 3.36, Interaction: N.S.

Table 2. Effect of topping and Ethephon with growth phases and their interaction on the branch per plant in rapeseed.

Treatments	Stages			Means (branches plant^{-1})
	S1	S2	S3	
E0	58.67	59.00	62.67	60.11
T	89.00	79.00	72.33	80.11
E1	79.67	75.00	72.00	75.56
E2	90.67	80.33	76.33	82.33
Means(branches plant^{-1})	79.50	73.33	70.75	
$LSD_{0.05}$ Ethephon: 7.86, Growth stages: 2.16, Interaction: 8.13				

Table 3. Effect of topping and Ethephon with growth phases and their interaction on the leaf area in rapeseed.

Treatments	Stages			Means (cm^2)
	S1	S2	S3	
E0	2505.1	2722.2	2836.3	2688.7
T	5177.0	4316.7	3752.5	4415.6
E1	5397.3	4896.8	4574.8	4956.4
E2	5994.6	5777.2	5430.0	5734.3
Means (cm^2)	4768.4	4428.3	4148.5	
$LSD_{0.05}$ Ethephon: 427.5, Growth stages: 266.7, Interaction: 562.9				

breaks down auxin and releases ethylene. The subapical meristematic region's inhibition of cell division and elongation leads to the terminal phalanx (Dahnous *et al*., 1982 and Suh and Lee, 1997). Plant height incurred no effects by the interactions between the treatments under study.

Branches per plant

The ethephon spraying treatment at a concentration of 2 ml L^{-1} recorded with the utmost average for the trait, reaching 82.33 branches plant^{-1}, but did not significantly differ from the topping treatment at 80.11 branches plant^{-1} (Table 2). Obtaining the lowest average plant height, the plants sprayed with a concentration of 2 ml showed superiority (Table 1). It is because auxin, a plant hormone regulating the process of lateral branch appearance and growth in rape plants, correlated to the phenomena of apical dominance. Hence, emphasis on growth retardants, such as ethephon, are physiologically efficacious when sprayed at the right amount by decreasing the concentrations of non-polar amino acids, which functions as anti-auxin chemicals. Tryptophan is the basic component needed for the production of auxin (Suh and Lee, 1997; Mahmoud, 2016). The ethephon spraying phase had a significant effect on the number of branches. The S1 stage recorded the highest number (79.50 branches plant^{-1}), while S3 achieved the lowest number (70.75 branches plant^{-1}). The reason for this may be that spraying growth retardants in the early stages has led to a reduction in the capacity of the stem as an outlet and a decrease in the number of branches. Moreover, the role of ethephon stimulates the growth of lateral branches and activates them, thus increasing the number of branches in the plant (Bora and Sarma, 2004). The interaction S1×E2 gave the maximum average of 90.67 branches plant^{-1}, with no significant difference to the interaction S1×T, recording an average of 89.00 branches plant^{-1}. Meanwhile, the S1×E0 gave the lowest at 58.67 branches plant^{-1}.

Leaf area

Both factors revealed significantly varied mean values of leaf area in rapeseed (Table 3). The comparison treatment recorded the lowest average of 2688.7 cm^2 per plant, whereas the

E2 treatment gave the highest mean of 5734.3 cm^2 per plant. The leaf area is one of the crucial characteristics that express the plant's ability to grow and develop. The reason for the superiority of E2 treatment in this characteristic is due to the role of the ethephon in physiological activities related to plant growth, through its action on inhibiting apical dominance and reducing plant height (Table 1). Increased number of branches and directing growth factors toward encouraging cell division, as well as, enhanced physiological processes are responsible for promoting vegetative growth, such as the number of leaves in the plant and leaf area.

The plant's leaf area grew when reducing the growth of the growing stem top (Al-Darraji and Al-Jumaily, 2020). The results of Table 3 reveal the S1 stage had the supreme leaf area (4768.4 cm $plant^{-1}$), while the S3 treatment had the littlest average of 4148.5 cm $plant^{-1}$. The reason for this increase refers to plants treated with ethephon during the S1 stage are wider, and their leaves are broader. This increases light reception and, thus, enriches the period of vegetative growth by boosting plant growth-related physiological activities and expanding leaf area (Atiyah *et al*., 2010). The combination E2×S1 resulted in the greatest leaf area value of 5994.6 cm^2 per plant, while E0×S1 yielded the lowest average of 2505.1 cm^2 per plant.

Capsules per plant

The E2 treatment achieved the highest average of 885.3 capsules $plant^{-1}$ without a significant difference from the T treatment, which recorded 875.7 capsules $plant^{-1}$, with an increase of 72.6% and 70.7%, respectively, compared with the control treatment (513.0 capsules $plant^{-1}$) (Table 4). Results related to the superiority of the E2 treatment, which gave the optimum outcomes for the number of branches and leaf area (Tables 2 and 3). It resulted in an increase in the rate of photosynthesis and its metabolites, boosting the accumulation of dry matter, with the beneficial effect of raising the number of flowers in the plant. The role of ethylene created by spraying the ethephon in early pod development came from reduced flowering and formed pod, which promotes greater plant growth (Al-Zubaidi, 2022; Al-Darraji, 2019).

The growth impediments including ethephon work to cancel apical dominance and, thus, regulate plant growth through a decreased plant height and an increased number of branches. Consequently, it caused to raise the number of flowers in the plant, as well as, the fragmentation of photosynthesis products in a balanced manner between the different plant parts (Darginavičienė *et al*. 2011; Devi *et al*. 2011; Mahmoud, 2016). The S1 stage had a 19% higher average of 822.9

Table 4. Effect of topping and Ethephon with growth phases and their interaction on the number of pods per plant in rapeseed.

Treatments	Stages			Means (pods $plant^{-1}$)
	S1	S2	S3	
E0	518.1	505.4	515.3	513.0
T	966.1	871.1	790.1	875.7
E1	814.8	796.9	662.3	758.0
E2	922.7	871.9	791.2	885.3
Means (pods $plant^{-1}$)	822.9	761.3	689.7	
$LSD_{0.05}$ Ethephon: 37.88, Growth stages: 24.53, Interaction: 550.91				

capsules plant^{-1} than the S3 stage, which had the lowest average of 689.7 pods plant^{-1}. The combinations of S1×T and S1×E2 had the highest number of capsules (966.1 and 992.7 pods plant^{-1}, respectively), with a 99% and 96% increase over the combination S2×E2, which had 505.4 capsules plant^{-1}.

The reason for this is due to the role of the ethephon and the distortion at the stage of elongation to the role of the ethephon in the mutation of plant growth by reducing the height of the plant (Table 1). It increased the number of branches in the plant besides enhancing germination of pollen grains and the growth of pollen tubes, raising the number of active branches, and, thus, boosting the number of capsules (Attia and Jaddou, 1999). Aside from the accumulated dry matter's balanced distribution between the different plant parts, it directed growth factors toward increasing the plant's number of flowers, with ethylene's physiological role released from the ethephon reducing flower fall and encouraging mustard (Abbas, 1991; Cherkasova *et al*., 2024). According to Mir *et al*. (2010), the ethephon engages in the plant's various cellular and developmental functions, where the most important is reducing pod damage and increasing capsule number in the plant by reducing flower and capsule abortion.

The effect of the interaction was noteworthy on the number of capsules per plant. The interaction S1×E2 and S1×T recorded the most number of capsules, about 992.7 and 976.1 capsules plants^{-1}, respectively, with an increase rate of 99% and 96% compared with the interaction S2×E0, with 505.4 capsules plant^{-1}.

Seeds per capsule

The results revealed nonsignificant effect of both factors and their interactions on the seeds per pod in rapeseed (Table 5).

1000-seed weight

The results revealed the rapeseed plants in the E2 treatment had the lowest average for the trait at 2.017 g, a decrease of 43% from E0, which had the highest average of 3.593 g (Table 6). Ethephon role in canceling apical sovereignty is responsible for an increase in the number of branches in the plant (Table 2) and capsules (Table 5), boosting competition for carbon-metabolized components and their dispersion to more places. This reduces the amount of dry materials that reaches the seed at the full stage. It occurred by reducing the weight of one seed. Furthermore, the low 1000-seed weight could be because of the sensitivity of plant tissues and the speed of their response to the ethephon resulted in a modification of plant growth through an increase in the number of branches (Table 2). The fragmentation of photosynthetic products and their distribution to a larger number of sinks positively affected the increase in the number of pods, decreasing the weight of the seeds (Saxena *et al*., 2007). The results indicated that the stages and the interaction between treatments had no significant effect on the 1000-seed weight.

Seed yield

The findings showed the E2 treatment gave the ultimate mean for the trait, which reached 21.38 g plant^{-1}, but differing nonsignificantly from T (20.75 g plant^{-1}). These had an increase of 57.55% and 52.91%, respectively, compared with the E0 treatment, recording the lowest average of 13.57 g plant^{-1} (Table 7). The increase in seed yield might refer to the effect of growth inhibitors in reducing apical dominance, leading to an increase in the number of branches per plant, leaf area, and pods per plant per unit area (Tables 2, 3, and 4). All these reflected positively on total seed yield. The result further revealed the spraying stage had significant effects on seed yield, with the S1 stage recording the highest average at about 19.26 g plant^{-1}, a 13% increase compared with the S3 stage. The latter recorded the lowest average of 17.00 g plant^{-1} and did not differ yet significantly higher than S2 (17.68 g plant^{-1}).

The increase in seed yield, especially at this stage (S1), can be attributable to the increased number of pods per plant (Table 4). The increase in seed yield at stage S1 may be due to an increase in the number of pods per

Table 5. Effect of topping and Ethephon with growth phases and their interaction on the seeds per pod in rapeseed.

Treatments	Stages			Means (seeds pod^{-1})
	S1	S2	S3	
E0	7.817	7.850	7.847	7.838
T	7.847	7.843	7.842	7.844
E1	7.850	7.850	7.840	7.848
E2	7.837	8.077	7.837	7.917
Means (seeds pod^{-1})	7.838	7.905	7.843	
$LSD_{0.05}$ Ethephon: N.S, Growth stages: N.S, Interaction: N.S				

Table 6. Effect of topping and Ethephon with growth phases and their interaction on 1000-seed weight in rapeseed.

Treatments	Stages			Means (g)
	S1	S2	S3	
E0	3.629	3.583	3.568	3.593
T	2.553	2.535	2.553	2.547
E1	2.402	2.404	2.405	2.404
E2	2.011	2.017	2.024	2.017
Means (g)	2.649	2.635	2.637	
$LSD_{0.05}$ Ethephon: 0.025, Growth stages: N.S., Interaction: N.S.				

Table 7. Effect of topping and Ethephon with growth phases and their interaction on the seed yield in rapeseed.

Treatments	Stages			Means (g plant^{-1})
	S1	S2	S3	
E0	13.57	13.63	13.64	13.46
T	20.75	19.31	19.91	19.99
E1	16.23	15.77	16.37	16.54
E2	21.38	19.30	20.82	20.50
Means (g plant^{-1})	19.26	17.68	17.00	
$LSD_{0.05}$ Ethephon:0.73, Growth stages: 0.69 Interaction: 1.31				

plant (Table 4). Several studies indicated an increase in seed production might compensate for the number of pods in the plant even with reduced two yield components, especially the number of seeds per pod and the 1000-seed weight (Attiyah and Jadoua, 1999; Zubkova *et al*., 2022). The combination S1×E2 gave the highest yield value of 24.03 g plant^{-1}, compared with the combination S1×E0, which gave the lowest average of 13.46 g plant^{-1}.

Harvest Index

The treatment E2 emerged superior, with the maximum average of 22.51%, yet did not differ significantly from treatment T (21.77%), with an increase rate of 39% and 34%, respectively, versus the treatment E0 with the minimum average of 16.19%. The increase could refer to the effect of growth inhibitors in increasing the yield of seeds (Table 7). The rise in harvest index in this study confirmed what several studies reported. These are large amounts of carbon metabolism products in the treated plants directed to mustard, with a decrease in the stem's storage capacity. It resulted from the elimination of apical dominance (the effect of ethephon and topping) and, thus, a shortening. This also changes the distribution of dry matter within the crop, favoring economic yield with an increase in the harvest index (Mustafa *et al*., 2022; Zaibel, 2022).

Table 8. Effect of topping and Ethephon with growth phases and their interaction on the harvest index in rapeseed.

Treatments	Stages			Means (%)
	S1	S2	S3	
E0	16.69	15.80	16.08	16.19
T	23.53	21.23	20.56	21.77
E1	17.778	17.85	17.18	17.60
E2	24.81	22.19	20.54	22.51
Means (%)	20.70	19.27	18.59	
$LSD_{0.05}$ Ethephon:0.01, Growth stages: 0.66 Interaction: 1.37				

The spraying stage has a significant effect on the harvest index. The S1 stage gave the highest average of 20.70% compared with the S3 stage, which had the lowest average of 18.59% (Table 8). The increase can refer to S1's superiority in both branch count and seed yield (Tables 2 and 7). Interference had a significant effect on the Harvest Index. The combination S1×E2 gave the maximum amount of interaction (24.81%), while the combination S2×E0 gave the minimum average of 15.80%.

CONCLUSIONS

Ethephon (2 ml L^{-1}) foliar application and topping at the stage of elongation showed better results. These processes also managed the dry matter, with a distribution in a way that affects seed and biological yield.

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