



AGRONOMY

EFFECT OF NITROGEN SOURCE AND APPLICATION SCHEDULE ON PRODUCTIVITY AND PROFITABILITY OF BLACK CUMIN (*NIGELLA SATIVA* L.)

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ABSTRACT

Efficient nitrogen (N) management through its appropriate source and timing of application is essential for enhancing crop yield. A field study was conducted during the winter growing seasons 2021–22 and 2022–23 at Agronomic Research Station, Khanewal, Punjab-Pakistan to most suitable source and application time of N on growth and yield of black cumin. Ammonium sulfate, ammonium nitrate and urea were used as different N sources and whole N application at sowing, 1/2 N at sowing + 1/2 N at branching, 1/3 N at sowing + 1/3 at branching + 1/3 at flowering as variable N application timings. Results showed that ammonium sulfate consistently outperformed all other N sources. Relative to urea, ammonium sulfate increased plant height by 18% and 4%, branches per plant by 33% and 25% during 2021–22 and 2022–23, respectively. The number of capsules per plant improved by 8% and 7% in the respective years. Likewise, ammonium sulfate increased the number of seeds per capsule by 12% and 5% and boosted seed yield by 7% and 9% across the two years. Among N split-application treatments, the three-split application of 18.3 kg N ha⁻¹ at sowing, branching and flowering proved the most effective. Compared with the control, said treatment increased plant height by 90% and 18% during 2021–22 and 2022–23, respectively. The number of branches per plant improved by 150% and 57%, while the number of capsules per plant increased by 17% and 33% across the two years. Similarly, said treatment enhanced the number of seeds per capsule by 94% and 16%, and increased 1000-seed weight by 84% and 53% in the respective years. Seed yield was also substantially higher, with gains of 67% and 50% over the control. A significant interaction between N source and N split-application was observed. Among all combinations, ammonium sulfate applied in three splits produced the highest values. Compared with the lowest-performing combination; urea with no N application (control); this treatment increased plant height by 114% and 23% in 2021–22 and 2022–23, respectively. The number of branches per plant increased by 200% and 67%, while the number of capsules per plant improved by 22% and 44% across the two years. Thousand-seed weight was enhanced by 112% and 49%, and seed yield was boosted by 70% and 68%, respectively. Economic analysis revealed that ammonium sulfate applied in three splits gave the highest net income (Rs. 301044 and 301044 during 2021-22 and 2022-23 respectively) and benefit-cost ratio (2.41 and 1.99) during respective years. It is concluded that the application of ammonium sulfate in three equal splits at sowing, branching, and flowering is the most effective N management strategy for black cumin.

KEYWORDS: *Nigella sativa* L.; nitrogen sources; ammonium sulfate; ammonium nitrate; benefit-cost ratio; yield; Pakistan

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INTRODUCTION

Black cumin or black seed (*Nigella sativa* L.), locally known as *Kalonji*, belongs to the *Ranunculaceae* family and has traditionally been appreciated for centuries as both a culinary spice and a food ingredient (Alberts *et al.*, 2024). Originating from Southern Europe, North Africa, and Southwest Asia, its cultivation has spread to various parts of the world, notably the

Middle East, Mediterranean region, Southern Europe and nations like India, Pakistan, Syria, Turkey and Saudi Arabia (Khare, 2004; Prajapati *et al.*, 2023). Widespread research highlights its remarkable pharmacological properties, placing it medicinally as an important herb with profound historical and religious significance (Prajapati *et al.*, 2023). The presence of bioactive molecules such as thymoquinone, alkaloids,

saponins, flavonoids, proteins and fatty acids makes its seed effective remedy for treating a variety of health disorders (Prajapati *et al.*, 2023) including pain, diarrhea, rheumatism, backache, hypertension, diabetes, respiratory disorders, gastrointestinal problems, cancer and migraine (Alberts *et al.*, 2024). In Pakistan, black cumin has been traditionally used for multiple purposes; however, its large-scale commercial cultivation has not yet been developed (Iqbal *et al.*, 2010). Given the increasing demand for medicinal plants, black cumin offers significant potential as an alternative crop, supporting crop diversification to reduce the risk of crop failure, improve farm productivity and boost farmers' income, especially for smallholders (Rabbani *et al.*, 2011; Mehmood *et al.*, 2018; Rehman *et al.*, 2022). The commercial cultivation of black cumin depends on multiple factors such as climate, sowing time, soil fertility, nutrient management, irrigation, planting geometry and other agronomic practices (Sen *et al.*, 2019). Among these, soil nutrient availability and external fertilization are key determinants of yield potential (Ayub *et al.*, 2020).

Among essential plant nutrients, nitrogen (N) is often considered the most restrictive playing a critical role in determining the growth, yield and quality of black cumin. As a vital constituent of protein, nucleic acid, chlorophyll and enzymes, N plays a crucial role in photosynthesis, metabolic activities and overall plant development (Verma *et al.*, 2022; Wang *et al.*, 2024). Sufficient N supply promotes vigorous vegetative growth, efficient nutrient uptake, improved seed development and enhanced stress tolerance (Verma *et al.*, 2022). However, the efficiency of N in boosting productivity depends not only on the total amount applied but also on the timing and the form of fertilizer used (Nasielski *et al.*, 2020). Aligning N application with the crop's key growth stages improves uptake and utilization while the selection of an appropriate fertilizer source affects nutrient release dynamics and soil health (Singh *et al.*, 2024). Therefore, optimizing both the timing and source of N application is crucial to achieve higher yield, better quality and improved resource-use efficiency in black cumin cultivation.

Limited research exists on the agronomic management practices required to achieve maximum yield of black cumin. In an earlier study, we identified November 1st as the optimal sowing date and 7 kg/ha as the most suitable seed rate for enhancing its productivity (Ullah *et al.*, 2024). Nevertheless, limited information is available on the critical growth stages for N application and the most efficient nitrogen source for black cumin. Hence, this study was designed to assess suitable nitrogen sources and application timings to enhance

the crop's growth, yield, and profitability.

MATERIALS AND METHODS

The field trial was carried out at the Agronomic Research Station, Khanewal, over two consecutive winter (Rabi) seasons (2021–2023). The physico-chemical characteristics of soil are presented in table 1. The experiment followed a randomized complete block design with three replications; the dimensions of each net plot were 3.5 m × 7.0 m. Experimental treatments comprised of two factors, i.e., three N sources (ammonium sulfate, ammonium nitrate, and urea) and three N split applications (whole N at sowing, 1/2 N at sowing + 1/2 N at branching, 1/3 N at sowing + 1/3 at branching + 1/3 at flowering). N application rate was 55 kg ha⁻¹ while a 0 kg ha⁻¹ N was kept as control. A basal dose of phosphorus (P) at 25 kg ha⁻¹ was incorporated at sowing. In both years, sowing was performed on November 1st. The dry soil was prepared through one rotavation, a cultivation, laser leveling and another cultivation, after which beds were formed. Each bed had a 45 cm width and a 45 cm furrow, made with a bed shaper. Manual line sowing was done on both sides of the beds. Just after sowing, irrigation was applied, and pre-emergence weedicide pendimethalin was applied. In total, four irrigations were applied during the growing season. Weeds were controlled manually by hoeing. The crop was harvested on the 15th of April during both years. Measurements were recorded for plant height, branches per plant, capsules per plant, seeds per capsule, 1000-seed weight (g) and seed yield (kg/ha). To assess profitability, the benefit–cost ratio (BCR) was calculated.

Table 1: Physico-chemical properties of experimental soil

Parameters	Results
Texture	Loam
EC (ds cm ⁻¹)	4.1
pH	8.4
Organic matter (%)	0.5
Total nitrogen (mg kg ⁻¹)	24
Available Phosphorous (mg kg ⁻¹)	6.8
Available Potassium (mg kg ⁻¹)	203.8

Statistical analysis: Data were subjected to analysis of variance (ANOVA) and treatment means were compared using the least significant difference (LSD) test at the 5% probability level with Statistix 8.1.

RESULTS AND DISCUSSION

Among N sources, the highest plant height (64 cm)

was recorded with the ammonium sulfate (Table 2). Similarly, the number of branches per plant (4-10) was highest with ammonium sulfate and ammonium nitrate (Table 2). The maximum number of capsules per plant (26 and 30) was also obtained with ammonium sulfate (Table 2). The highest number of seeds per capsule was recorded with ammonium sulfate (75 in 2021–22 and 64 in 2022–23) (Table 3). Seed yield was also significantly influenced by N sources, where ammonium sulfate produced the highest yield (553 and 754 kg/ha) (Table 3).

Regarding N split application treatments, the tallest plants were observed where 18.3 kg N/ha each at sowing + branching + flowering was applied (72 cm in 2021–22; 52 cm in 2022–23) (Table 2). Similarly, the highest number of branches per plant was recorded where 18.3 kg N/ha each at sowing + branching + flowering was applied (5 and 11) (Table 2). For number of capsules per plant, the treatment where 18.3 kg N/ha each at sowing + branching + flowering was applied again showed superiority (27 and 32) (Table 2). Similarly, the highest number of seeds per capsule was obtained where 18.3 kg N/ha each at sowing + branching + flowering (89 and 67) was applied (Table 3). Similarly, the treatment where 18.3 kg N/ha each at sowing + branching + flowering was applied also produced the highest 1000-seed weight (6.80 g and 5.50 g) (Table 3). Seed yield was also maximum in the treatment where 18.3 kg N/ha each at sowing + branching + flowering was applied (712 and 838 kg/ha) (Table 3).

The interaction of nitrogen source and application timing significantly influenced plant height. Ammonium sulfate applied in three splits (sowing, branching, and flowering) produced the tallest plants (77 cm in 2021–22 and 54 cm in 2022–23) which did not differ significantly from ammonium nitrate in three splits (75 and 52 cm) and ammonium sulfate in two splits (sowing and branching) (75 and 52 cm) (Table 2). The highest number of branches per plant was recorded with ammonium sulfate applied in three splits (6 and 12) and ammonium nitrate in three splits (6 and 11) (Table 2). Similarly, the highest number of capsules per plant was obtained from ammonium sulfate in three splits (28 and 33) (Table 2). For the number of seeds per capsule, the maximum was produced by ammonium sulfate in three splits (96 and 68) (Table 3). The highest 1000-seed weight was also achieved with ammonium sulfate in three splits (6.97 g and 5.5 g) ammonium nitrate in three splits (6.73 g and 5.40 g) and urea in three splits (6.73 g and 5.70 g) (Table 3). Similarly, the maximum seed yield was obtained with ammonium sulfate in three splits (761 and 874 kg/ha) (Table 3).

The economic evaluation of black cumin production under different N sources and application timings during 2021–22 and 2022–23 revealed significant variations in the cost of production, gross income, net income and BCR. During 2021–22, among N sources, the maximum profitability was achieved with ammonium sulfate applied in three splits, which recorded the highest gross income (Rs. 380500/ha) net income (Rs. 301044/ha) and BCR (2.41) (Fig. 1). During 2022–23, a similar trend was observed (Fig. 1). Ammonium sulfate applied in three splits again proved most profitable, producing the highest gross income (Rs. 314640/ha) net income (Rs. 156604/ha) and BCR (1.99) (Fig. 1). Ammonium nitrate and urea applied in three splits also remained highly profitable, with net incomes of Rs. 149344 and Rs. 145104/ha and BCR values of 1.99 and 2.00, respectively.

Results indicated significant effects of nitrogen sources and timings on the growth, yield traits, seed yield, and economic returns of black cumin. Compared with ammonium nitrate and urea, ammonium sulfate consistently produced better growth and yield performance, including taller plants, increased branching, higher capsule and seed numbers and maximum seed yield. Ammonium sulfate is often considered a better N fertilizer than urea and ammonium nitrate for improving crop productivity because of both its chemical form and additional nutrient supply (Chien *et al.*, 2011). Urea often incurs high nitrogen losses due to ammonia volatilization during hydrolysis (Motasim *et al.*, 2024). By comparison, ammonium sulfate releases nitrogen in the ammonium (NH_4^+) form, which is more stable in soils and less prone to rapid volatilization owing to its adsorption onto negatively charged soil particles (Li *et al.*, 2017). Moreover, the acidifying effect of ammonium sulfate during nitrification reduces ammonia volatilization compared to urea. Compared to ammonium nitrate, which contains a large fraction of nitrate (NO_3^-) that is highly mobile and easily lost through leaching or denitrification (Wang and Li, 2019) ammonium sulfate provides N in a less leachable form that remains available longer in the root zone (Nadarajan and Sukumaran, 2021). Besides supplying nitrogen, ammonium sulfate contains about 24% sulfur (S) (Chien *et al.*, 2011) which plays a critical role in enhancing nitrogen uptake, protein formation, and enzyme activity (Narayan *et al.*, 2022; Yan *et al.*, 2024). The combined availability of N and S not only boosts nitrogen-use efficiency but also promotes better crop growth and productivity. Supporting evidence from earlier studies indicates that ammonium sulfate outperforms conventional urea by improving nitrogen-use efficiency, increasing grain nitrogen uptake, and producing higher maize yields (Swify *et al.*, 2022).

Table 2: Effect of nitrogen fertilizer sources and split applications on plant height, number of branches per plant, and number of capsules per plant of black cumin (*Nigella sativa* L.)

Treatments	Plant height (cm)		Number of branches per plant		Number of capsules per plant	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Nitrogen sources (S)						
Ammonium Sulfate (S ₁)	64 A	50	4 A	10 A	26 A	30 A
Ammonium Nitrate (S ₂)	61 B	49	4 A	9 B	25 AB	29 B
Urea (S ₃)	54 C	48	3 B	8 C	24 B	28 C
LSD α 0.05	2	ns	0.4	0.4	1	0.2
Nitrogen split application treatments (T)						
Control (T ₁)	38 C	44 C	2 D	7 D	23 D	24 D
55 kg N ha ⁻¹ at sowing (T ₂)	57 B	48 B	3 C	8 C	25 C	29 C
27.5 Kg N ha ⁻¹ at sowing and branching (T ₃)	70 A	51 A	4 B	10 B	26 B	31 B
18.3 Kg N ha ⁻¹ at sowing + branching + flowering (T ₄)	72 A	52 A	5 A	11 A	27 A	32 A
LSD α 0.05	2.0	1.0	0.5	0.6	1	0.4
Nitrogen sources $\times$ Nitrogen application time (S$\times$T)						
S ₁ $\times$ T ₁	39 e	45	2	8 e	23	25 g
S ₁ $\times$ T ₂	64 b	49	4	9 cd	25	30 d
S ₁ $\times$ T ₃	75 a	52	5	10 bc	27	32 b
S ₁ $\times$ T ₄	77 a	54	6	12 a	28	33 a
S ₂ $\times$ T ₁	38 e	44	2	6 f	23	24 h
S ₂ $\times$ T ₂	56 c	48	3	8 de	25	29 e
S ₂ $\times$ T ₃	73 a	51	4	10 bc	26	31 c
S ₂ $\times$ T ₄	75 a	52	6	11 b	28	32 b
S ₃ $\times$ T ₁	36 e	44	2	6 f	23	23 i
S ₃ $\times$ T ₂	51 d	46	2	7 ef	24	28 f
S ₃ $\times$ T ₃	63 b	51	4	9 cd	25	30 d
S ₃ $\times$ T ₄	65 b	52	4	10 bc	27	31 c
LSD α 0.05	4	ns	ns	1	ns	0.7

Means sharing the same case letter do not differ significantly at $p \leq 0.5$

ns= non-significant

Table 3: Effect of nitrogen fertilizer sources and split application on number of seeds per capsule, 1000-seed weight, and yield of black cumin (*Nigella sativa* L.)

Treatments	Number of seeds per capsule		1000-seed weight (g)		Yield (kg/ha)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Nitrogen sources (S)						
Ammonium Sulfate (S ₁)	75 A	64 A	5.20	4.60	553 A	754 A
Ammonium Nitrate (S ₂)	67 B	62 B	5.20	4.60	524 B	731 B
Urea (S ₃)	67 B	61 B	5.20	4.70	519 B	694 C
LSD α 0.05	4	1.6	ns	ns	16	12
Nitrogen split application treatments (T)						
Control (T ₁)	46 D	58 D	3.70 C	3.60 D	427 D	558 D
55 kg N ha ⁻¹ at sowing (T ₂)	65 C	61 C	4.90 B	4.50 C	469 C	720 C
27.5 Kg N ha ⁻¹ at sowing and branching (T ₃)	79 B	64 B	5.30 B	4.90 B	520 B	789 B
18.3 Kg N ha ⁻¹ at sowing + branching + flowering (T ₄)	89 A	67 A	6.80 A	5.50 A	712 A	838 A
LSD α 0.05	2	1.5	0.5	0.2	19	9
Nitrogen sources $\times$ Nitrogen application time (S$\times$T)						
S ₁ $\times$ T ₁	48	60	3.33	3.50 d	416 h	581 h
S ₁ $\times$ T ₂	67	62	5.10	4.50 bc	488 ef	735 ef
S ₁ $\times$ T ₃	88	65	5.33	4.90 b	545 d	824 bc
S ₁ $\times$ T ₄	96	68	6.97	5.50 a	761 a	874 a
S ₂ $\times$ T ₁	46	58	3.90	3.60 d	417 h	571 h
S ₂ $\times$ T ₂	63	60	4.83	4.40 c	462 fg	731 f
S ₂ $\times$ T ₃	74	64	5.33	5.00 b	506 e	789 d
S ₂ $\times$ T ₄	87	66	6.73	5.40 a	708 b	833 b
S ₃ $\times$ T ₁	44	57	3.93	3.70 d	447 gh	520 i
S ₃ $\times$ T ₂	66	59	4.73	4.40 c	457 fg	693 g
S ₃ $\times$ T ₃	76	63	5.27	4.90 b	508 e	753 e
S ₃ $\times$ T ₄	83	65	6.73	5.70 a	666 c	807 c
LSD α 0.05	ns	ns	ns	0.3	33	16

Means sharing the same case letter do not differ significantly at $p \leq 0.5$

ns= non-significant

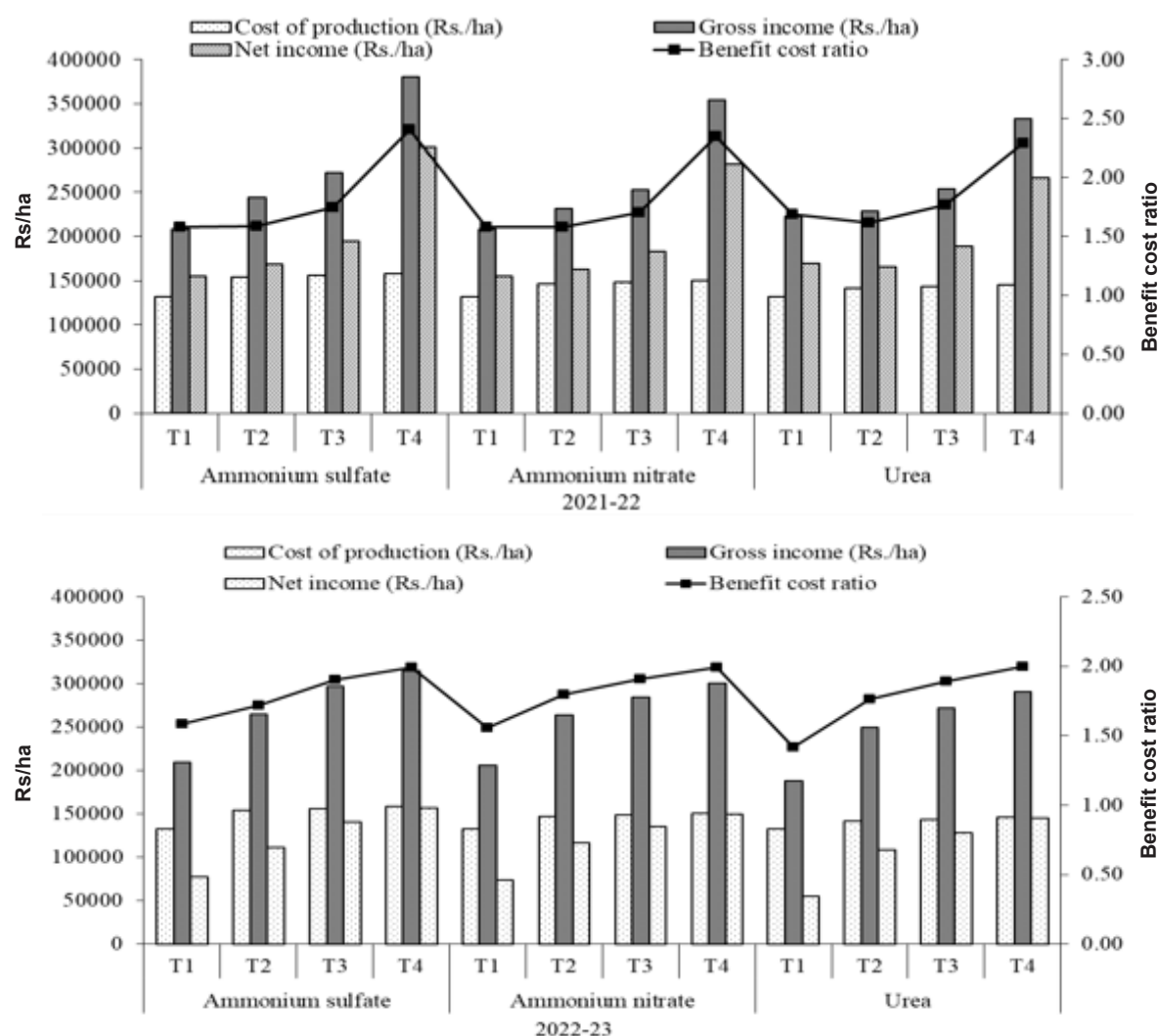


Fig. 1: Economic analysis of nitrogen fertilizer sources and split application for black cumin (*Nigella sativa* L.) cultivation

Likewise, a recent study demonstrated its superiority over urea in rice, where it significantly increased growth, grain yield, and nitrogen-use efficiency (Rushtha *et al.*, 2024).

Application timing was also critical in maximizing crop performance. Split application of nitrogen at sowing, branching and flowering produced superior growth and yield traits, including taller plants, increased branching, higher capsule numbers, and more seeds per capsule, culminating in the highest seed yield and 1000-seed weight. These results support the principle of synchronizing N application with the critical growth stages of the crop, ensuring improved N use efficiency and reduced losses through volatilization or leaching (Singh *et al.*, 2024; Lee and Ku, 2025). As N is one

of the most essential inputs for crop production, its improper or uneven application at unsuitable growth stages often leads to poor N use efficiency and does not contribute to yield improvement (Bhatt *et al.*, 2024). In contrast, timely and well-planned split applications of N enhance nutrient availability during critical growth phases, ensuring efficient uptake and reducing nitrogen losses (Sajjad *et al.*, 2025). Properly scheduled split applications help meet crop demand during peak growth, support balanced vegetative and reproductive development (Kamruzzaman *et al.*, 2013) and minimize risks such as lodging, pest infestation, and disease susceptibility that may arise from excessive or poorly managed nitrogen supply (Nurulnihar *et al.*, 2023). Earlier studies have

emphasized that split N applications enhance nutrient uptake and biomass allocation, thereby improving both yield components and final productivity. The findings from recent field trials emphasize that splitting N applications into three equal doses at basal, tillering and panicle initiation stages markedly enhances rice productivity and N use efficiency compared with conventional or control treatments (Sajjad *et al.*, 2025). The interaction between N sources and application timings further strengthened these trends, where ammonium sulfate applied in three splits gave the best performance across nearly all growth and yield parameters. This indicates that both the choice of nitrogen source and its proper scheduling are essential for maximizing yield potential. The economic analysis reinforced the agronomic findings, as ammonium sulfate applied in three splits provided the highest gross and net returns with superior BCR. Although ammonium nitrate and urea also improved profitability under split application, they were consistently inferior to ammonium sulfate. The poor performance of control plots across both years highlights the importance of N fertilization in black cumin cultivation, as N is the most yield-limiting nutrient in most soils (Redda *et al.*, 2022). Overall, the study determined that efficient N management, i.e. using ammonium sulfate as source of N and applying it as split application at sowing, branching and flowering, optimizes both crop productivity and profitability.

CONCLUSION

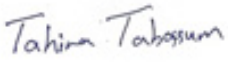
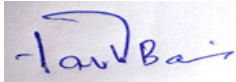
This study demonstrated that the performance of black cumin is strongly influenced by both the N source and its application timing. Moreover these findings highlight the importance of synchronizing N application with crop demand to maximize resource use efficiency. Therefore, for sustainable black cumin production, application of ammonium sulfate in three equal splits at sowing, branching, and flowering stages is recommended, as it ensures optimum growth, yield, and economic viability.

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4.	Naveed Akhtar	Proof read the manuscript	
5.	Arbab Jahangeer	Removal of plagiarism	
6.	Muhammad Arshad	Edited the manuscript	
7.	Tahira Tabassum	Assisted to write-up the manuscript	
8.	Ali Zohaib	Reviewed the manuscript and assisted in analyzing the data	
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