

RESPONSE OF SEED CORIANDER (*CORIANDRUM SATIVUM* L.) VAR. VARADEVI 1 TO NITROGEN AND PHOSPHORUS LEVELS: GROWTH, SEED YIELD, SEED QUALITY, NUTRIENT UPTAKE AND ECONOMICS IN THE NORTHERN DRY ZONE OF KARNATAKA

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ABSTRACT

Nitrogen and phosphorus are the main nutrients that limit the production of seed coriander, but location-specific information on their combined effect on seed yield and physiological seed quality is scarce for the Northern Dry Zone of Karnataka, India. A factorial randomized block design experiment with three replications was conducted during rabi 2024-25 and 2025-26 at the College of Horticulture, Bagalkot, to evaluate four levels of nitrogen (20, 30, 40 and 50 kg ha⁻¹) and four levels of phosphorus (20, 30, 40 and 50 kg P₂O₅ ha⁻¹) on coriander var. Varadevi 1. Pooled over the two seasons, growth, yield attributes, seed yield, seed quality, essential oil and oleoresin content and crop nutrient uptake increased significantly with each increment of nitrogen and phosphorus and the nitrogen × phosphorus interaction was significant for most characters. Flowering was delayed slightly (by less than three days). The combination of 50 kg N and 50 kg P₂O₅ ha⁻¹ (N₄P₄) gave the highest seed yield (825.69 kg ha⁻¹), which was 76.6 % higher than the lowest combination (467.44 kg ha⁻¹) and 35.1 % higher than the recommended dose of 30:40 kg N:P₂O₅ ha⁻¹ (611.26 kg ha⁻¹). The treatment combination of N₄P₄ also produced the heaviest seeds (14.62 g per 1000 seeds), the highest seedling vigor indices (1694 and 1983) and oleoresin content (9.11 %) and the highest net returns (₹ 87,070 ha⁻¹) and benefit:cost ratio (3.37:1). Available soil nitrogen and phosphorus after harvest declined as fertilizer levels increased, whereas crop uptake increased. The response had not leveled off at the highest level tested, so the optimum dose may lie above 50:50 kg ha⁻¹.

KEYWORDS: Coriander; nitrogen; phosphorus; seed yield; seed quality; oleoresin; economics

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is an important seed spice valued for its culinary, medicinal and industrial uses. India produced about 0.824 million metric tons of coriander seed from 0.639 million hectares in 2024-25, an average productivity of 1.29 t ha⁻¹ [1]. Production is concentrated in Madhya Pradesh, Gujarat and Rajasthan, and the relative shares of the states have shifted over time [2]. The seed is a source of essential oil, in which linalool is the major constituent, and of oleoresin used in the food, flavor and pharmaceutical industries, and coriander shows antioxidant and antimicrobial properties [3].

Nutrient management is among the most important agronomic practices governing the growth, seed yield and quality of coriander. Nitrogen and phosphorus are of particular importance because of their direct involvement in key physiological and biochemical processes [4]. Nitrogen is a constituent of chlorophyll, amino acids, proteins and nucleic acids and promotes vegetative growth, leaf area development and photosynthetic efficiency. Phosphorus supports root development, energy transfer, cell division, flowering and seed formation and it aids the translocation of photosynthates from source to sink [5].

Positive responses of coriander to nitrogen and phosphorus have been reported from several regions of India [6–10]. However, the optimum dose varies with cultivar, soil fertility and environment. Excess fertilizer raises the cost of production and lowers nutrient-use efficiency, whereas too little limits growth and yield, so location-specific recommendations are needed.

Most studies report growth, yield attributes, seed yield, oil content or economics and fewer evaluate the physiological quality of the harvested seed, such as thousand seed weight, germination and seedling vigor [11].

Information on the response of the variety Varadevi 1 to nitrogen and phosphorus in the Northern Dry Zone of Karnataka is also limited. A fertilizer treatment that raises seed yield does not necessarily give the best seed quality, and the economics of higher doses must be checked. This study therefore evaluated four levels each of nitrogen and phosphorus and their interaction, on growth, flowering, yield attributes, seed yield, seed quality, essential oil and oleoresin content, soil nutrient status, nutrient uptake and economics of seed coriander var. Varadevi 1.

2. MATERIALS AND METHODS

2.1. Site, climate and soil

The field experiment was conducted during rabi 2024-25 and 2025-26 at the Experimental Research Field of the Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Bagalkot, in the Northern Dry Zone of Karnataka (Agro-climatic Zone III, Region II), at 16°18' N latitude and 75°69' E longitude, at about 542 m above mean sea level. During the study period temperatures ranged from 11.4 to 38.9 °C, morning relative humidity from 62 to 97 % and afternoon relative humidity from 19 to 74 %. The highest monthly rainfall was 222.1 mm in September 2025, followed by 109.7 mm in October 2024. Composite soil samples taken before sowing showed that the soil was moderately alkaline (pH 8.35) and non-saline (EC 0.38 dS m⁻¹), with an organic carbon content of 0.54 % and available nitrogen, phosphorus and potassium of 210, 23 and 285.8 kg ha⁻¹, respectively (methods in Section 2.5).

2.2. Experimental design and treatments

The experiment was laid out in a factorial randomized block design with three replications and 16 treatment combinations of four levels of nitrogen (N₁, N₂, N₃ and N₄: 20, 30, 40 and 50 kg N ha⁻¹) and four levels of phosphorus (P₁, P₂, P₃ and P₄: 20, 30, 40 and 50 kg P₂O₅ ha⁻¹). The treatments were allotted at random within each replication. The gross plot size was 3 × 3 m (9 m²) and the net plot size was 2.4 × 2.7 m (6.48 m²). With a spacing of 30 × 15 cm, each gross plot had 200 plants and each net plot 144 plants. All plots received farmyard manure at 6 t ha⁻¹ and potassium at 20 kg K₂O ha⁻¹. The treatment N₂P₃ (30:40:20 kg N:P₂O₅:K₂O ha⁻¹), the dose recommended in the package of practices [12], served as the control.

2.3. Crop management

The land was plowed and harrowed to a fine tilth, weeds and residues were removed, and well-decomposed farmyard manure was incorporated during final land preparation. Seeds of var. Varadevi 1, obtained from the Horticulture Research and Extension Centre, Devihosur, Haveri (University of Horticultural Sciences, Bagalkot), were sown at 30 × 15 cm. A pre-sowing irrigation was given, followed by irrigation immediately after sowing and at regular intervals until maturity. Plots were thinned at 30 days after sowing (DAS) to one seedling per hill. Pendimethalin (38.7 %) at 1.0 kg ha⁻¹ in 1000 L of water was sprayed 10–15 days before sowing, followed by hand weeding at regular intervals. Powdery mildew was managed with myclobutanil (0.5 g L⁻¹) sprayed at disease onset and repeated at 10–15 day intervals, and aphids with Confidor Super (0.5 mL L⁻¹). All operations followed the package of practices of the University of Horticultural Sciences, Bagalkot [12]. The crop was harvested at maturity. The five marked plants of each plot were harvested separately for observations, the remaining plants were harvested together and the produce was sun-dried for two to four days and threshed and cleaned manually.

2.4. Observations

Growth and yield attributes were recorded on five tagged plants per plot, excluding border rows. Plant height and the numbers of primary and secondary branches were recorded at 30 and 60 DAS and at harvest. Leaf area (leaf area meter) and leaf area index (LAI) were recorded at 60 DAS. Chlorophyll content was measured with a SPAD-502 meter at 30 DAS, 60 DAS and harvest and dry matter was determined at the same stages after oven drying at 65 ± 5 °C. Days to flower initiation and to 50% flowering were recorded per plot. At maturity, the numbers of umbels per plant, umbellate per umbel, seeds per umbel and seeds per umbellate were counted and seed yield per plant, per net plot and per hectare was determined.

Seed quality was assessed as thousand seed weight, germination (paper towel method, ISTA rules [13]), seedling length, seedling dry weight (80 ± 2 °C for 24 h) and seedling vigor indices I and II [14], following Kumar et al. [15]. Essential oil was extracted from 250 g of crushed seed by hydro-distillation for 3 h in a Clevenger-type apparatus [16]. Oleoresin was extracted from 5 g of powdered seed with hexane in a Soxhlet apparatus and expressed as a percentage of sample weight.

2.5. Soil and plant analysis

Composite soil samples were collected before sowing, and treatment-wise samples were collected after harvest at 15 cm depth, air dried in shade, ground and passed through a 2 mm sieve. Soil pH and electrical conductivity were determined in a 1:2.5 soil:water suspension with a digital pH meter and a conductivity meter (at 25 °C), respectively [17]. Organic carbon was determined by the Walkley and Black wet oxidation method [18], available nitrogen by the alkaline permanganate method [19], available phosphorus by Olsen's extraction with the chloromolybdophosphoric blue color method read at 660 nm [20,21], and available potassium by extraction with 1 N ammonium acetate and flame photometry [17].

Leaf, stem, inflorescence and root samples were washed with dilute detergent (0.2 %) and hydrochloric acid (0.1 %), rinsed with distilled water, dried in a hot-air oven at 65–70 °C for 48 h and powdered. Total nitrogen was determined by micro-Kjeldahl digestion and distillation, and phosphorus in a di-acid (HNO₃:HClO₄, 9:4) digest

by the vanadomolybdate yellow color method read at 430 nm [17]. Nutrient uptake (kg ha^{-1}) was calculated as nutrient content (%) $\times$ dry matter yield (kg ha^{-1}) / 100, summed over the plant parts [22].

2.6. Economics and statistical analysis

Cost of cultivation was worked out from prevailing input and labor prices. Gross returns were calculated at a seed price of ₹ 150 kg^{-1} , net returns as gross returns minus cost of cultivation, and the benefit:cost (B:C) ratio as gross returns divided by cost of cultivation. Data were analyzed by analysis of variance for a factorial randomized block design [23], separately for each season and pooled over the two seasons. Treatment effects were tested by the F-test at the 5% level. Where the F-test was significant, treatment means were compared using Duncan's multiple range test (DMRT) at the 5% level [24], and means followed by the same letter do not differ significantly. S.Em $\pm$ and critical difference (CD) at 5% are also reported.

3. RESULTS

Pooled means over the two seasons are presented in Tables 1–6 and Figures 1–3, with S.Em $\pm$ and CD at 5% from the analysis of the pooled data. In each table, N_1P_1 is the lowest combination, N_2P_3 the recommended dose (control) and N_4P_4 the highest combination.

3.1. Growth

Plant height, branching, leaf area, LAI, chlorophyll content and dry matter production at every stage increased significantly with each increment of nitrogen and phosphorus (Tables 1 and 2). Nitrogen at 50 kg ha^{-1} (N_4) gave the highest value of every growth character. Plant height under N_4 was 15.42, 56.42 and 59.01 cm at 30 DAS, 60 DAS and harvest, against 10.72, 47.92 and 51.33 cm under N_1 ; secondary branches at harvest were 13.84 against 11.99; leaf area at 60 DAS was 267.13 against 241.98 $\text{cm}^2 \text{ plant}^{-1}$; the SPAD value at 60 DAS was 53.76 against 39.06; and dry matter at harvest was 11.17 against 9.48 g plant^{-1} . Phosphorus followed the same trend: P_4 gave 57.04 cm plant height, 13.82 secondary branches, 258.46 cm^2 leaf area and 10.74 g dry matter at harvest or 60 DAS, against 54.54 cm, 12.06, 248.75 cm^2 and 9.90 g under P_1 . The $\text{N} \times \text{P}$ interaction was significant for every growth character. N_4P_4 produced the most vigorous plants (60.64 cm at harvest; 7.26 primary and 15.24 secondary branches; 282.87 cm^2 leaf area; 11.71 g dry matter), whereas N_1P_1 was the poorest (48.92 cm; 5.82 and 11.40 branches; 239.65 cm^2 ; 9.13 g). Compared with the recommended dose (N_2P_3), N_4P_4 increased plant height at harvest from 55.74 to 60.64 cm and dry matter at harvest from 10.13 to 11.71 g plant^{-1} .

Table 1. Plant height and number of branches of seed coriander var. Varadevi 1 as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	Plant height 30 DAS (cm)	Plant height 60 DAS (cm)	Plant height at harvest (cm)	Primary branches 60 DAS	Primary branches at harvest	Secondary branches 60 DAS	Secondary branches at harvest
Nitrogen (N)							
N_1 (20 kg ha^{-1})	10.72 ^d	47.92 ^d	51.33 ^d	4.87 ^d	6.21 ^d	10.16 ^d	11.99 ^d
N_2 (30 kg ha^{-1})	12.16 ^c	51.98 ^c	55.55 ^c	5.33 ^c	6.34 ^c	10.87 ^c	12.61 ^c
N_3 (40 kg ha^{-1})	13.85 ^b	54.15 ^b	56.90 ^b	5.66 ^b	6.58 ^b	11.42 ^b	13.41 ^b
N_4 (50 kg ha^{-1})	15.42 ^a	56.42 ^a	59.01 ^a	6.00 ^a	6.90 ^a	11.70 ^a	13.84 ^a
F test	S	S	S	S	S	S	S
S.Em $\pm$	0.030	0.042	0.063	0.061	0.024	0.050	0.009
CD at 5%	0.086	0.121	0.183	0.178	0.070	0.145	0.027
Phosphorus (P)							
P_1 (20 kg ha^{-1})	12.42 ^d	51.61 ^d	54.54 ^d	4.91 ^d	6.05 ^d	10.31 ^d	12.06 ^d
P_2 (30 kg ha^{-1})	12.85 ^c	52.22 ^c	55.11 ^c	5.28 ^c	6.32 ^c	10.81 ^c	12.74 ^c
P_3 (40 kg ha^{-1})	13.27 ^b	52.95 ^b	56.11 ^b	5.66 ^b	6.79 ^b	11.30 ^b	13.22 ^b
P_4 (50 kg ha^{-1})	13.61 ^a	53.67 ^a	57.04 ^a	6.02 ^a	6.87 ^a	11.74 ^a	13.82 ^a
F test	S	S	S	S	S	S	S
S.Em $\pm$	0.030	0.042	0.063	0.061	0.024	0.050	0.009
CD at 5%	0.086	0.121	0.183	0.178	0.070	0.145	0.027
Interaction (N $\times$ P)							
N_1P_1	10.01 ^o	46.29 ^p	48.92 ^m	4.62 ^h	5.82 ^j	9.85 ^j	11.40 ⁿ
N_1P_2	10.69 ⁿ	47.08 ^o	50.18 ^l	4.81 ^{gh}	6.29 ^{fg}	10.07 ^{ij}	11.73 ^l
N_1P_3	10.92 ^m	48.43 ⁿ	52.24 ^k	4.96 ^{gh}	6.34 ^f	10.25 ^{hi}	12.10 ^k
N_1P_4	11.25 ^l	49.86 ^m	53.96 ^j	5.10 ^{fg}	6.39 ^f	10.45 ^{gh}	12.71 ⁱ

Treatment	Plant height 30 DAS (cm)	Plant height 60 DAS (cm)	Plant height at harvest (cm)	Primary branches 60 DAS	Primary branches at harvest	Secondary branches 60 DAS	Secondary branches at harvest
N ₂ P ₁	11.60 ^k	51.22 ^l	55.06 ⁱ	4.84 ^{gh}	5.94 ^{ij}	10.20 ^{hi}	11.51 ^m
N ₂ P ₂	11.75 ^k	51.65 ^k	55.33 ⁱ	5.20 ^{efg}	6.02 ^{hi}	10.65 ^g	12.36 ^j
N ₂ P ₃	12.45 ^j	52.36 ^j	55.74 ^h	5.50 ^{de}	6.66 ^e	11.13 ^f	12.85 ^h
N ₂ P ₄	12.84 ⁱ	52.68 ⁱ	56.09 ^{gh}	5.79 ^{cd}	6.75 ^{de}	11.51 ^{de}	13.71 ^c
N ₃ P ₁	13.16 ^h	53.35 ^h	56.40 ^{fg}	5.00 ^{gh}	6.11 ^h	10.46 ^{gh}	13.19 ^g
N ₃ P ₂	13.73 ^g	53.82 ^g	56.67 ^f	5.45 ^{def}	6.16 ^{gh}	11.12 ^f	13.35 ^f
N ₃ P ₃	14.18 ^f	54.41 ^f	57.05 ^e	5.90 ^c	6.99 ^c	11.77 ^{cd}	13.48 ^e
N ₃ P ₄	14.35 ^e	55.02 ^e	57.46 ^d	6.28 ^b	7.08 ^{bc}	12.34 ^b	13.63 ^d
N ₄ P ₁	14.92 ^d	55.58 ^d	57.76 ^d	5.17 ^{efg}	6.32 ^f	10.73 ^g	12.14 ^k
N ₄ P ₂	15.25 ^c	56.35 ^c	58.24 ^c	5.67 ^{cd}	6.83 ^d	11.39 ^{ef}	13.53 ^c
N ₄ P ₃	15.52 ^b	56.61 ^b	59.41 ^b	6.27 ^b	7.17 ^{ab}	12.04 ^c	14.44 ^b
N ₄ P ₄	16.00 ^a	57.13 ^a	60.64 ^a	6.91 ^a	7.26 ^a	12.66 ^a	15.24 ^a
F test	S	S	S	S	S	S	S
S.Em±	0.059	0.083	0.126	0.123	0.049	0.100	0.019
CD at 5%	0.172	0.241	0.366	0.356	0.141	0.291	0.055

Note: DAS: days after sowing; S: significant; NS: non-significant. Nitrogen and phosphorus in kg ha⁻¹ (N:P₂O₅). Values are means; within each section, means followed by the same letter do not differ significantly according to Duncan's multiple range test (DMRT) at the 5% level.

Table 2. Leaf area, leaf area index, chlorophyll content and dry matter production of seed coriander var. Varadevi 1 as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	Leaf area 60 DAS (cm ² plant ⁻¹)	LAI 60 DAS	SPAD 30 DAS	SPAD 60 DAS	SPAD at harvest	Dry matter 30 DAS (g plant ⁻¹)	Dry matter 60 DAS (g plant ⁻¹)	Dry matter at harvest (g plant ⁻¹)
Nitrogen (N)								
N ₁ (20 kg ha ⁻¹)	241.98 ^d	0.538 ^d	26.82 ^d	39.06 ^d	30.85 ^d	0.202 ^d	6.05 ^d	9.48 ^d
N ₂ (30 kg ha ⁻¹)	247.82 ^c	0.551 ^c	31.61 ^c	44.50 ^c	35.74 ^c	0.288 ^c	6.67 ^c	10.00 ^c
N ₃ (40 kg ha ⁻¹)	254.04 ^b	0.565 ^b	35.24 ^b	49.53 ^b	40.30 ^b	0.394 ^b	7.36 ^b	10.57 ^b
N ₄ (50 kg ha ⁻¹)	267.13 ^a	0.594 ^a	37.62 ^a	53.76 ^a	43.23 ^a	0.522 ^a	7.92 ^a	11.17 ^a
F test	S	S	S	S	S	S	S	S
S.Em±	0.594	0.001	0.054	0.044	0.013	0.005	0.026	0.039
CD at 5%	1.725	0.004	0.157	0.127	0.038	0.015	0.076	0.120
Phosphorus (P)								
P ₁ (20 kg ha ⁻¹)	248.75 ^d	0.553 ^d	31.39 ^d	44.74 ^d	35.89 ^d	0.294 ^d	6.51 ^d	9.90 ^d
P ₂ (30 kg ha ⁻¹)	250.53 ^c	0.557 ^c	32.39 ^c	46.16 ^c	37.17 ^c	0.330 ^c	6.84 ^c	10.15 ^c
P ₃ (40 kg ha ⁻¹)	253.23 ^b	0.563 ^b	33.27 ^b	47.41 ^b	38.17 ^b	0.368 ^b	7.16 ^b	10.45 ^b
P ₄ (50 kg ha ⁻¹)	258.46 ^a	0.574 ^a	34.24 ^a	48.54 ^a	38.90 ^a	0.415 ^a	7.49 ^a	10.74 ^a
F test	S	S	S	S	S	S	S	S
S.Em±	0.594	0.001	0.054	0.044	0.013	0.005	0.026	0.039
CD at 5%	1.725	0.004	0.157	0.127	0.038	0.015	0.076	0.120
Interaction (N × P)								
N ₁ P ₁	239.65 ^m	0.533 ^k	24.75 ^o	36.55 ^p	28.52 ^o	0.163 ^l	5.72 ^l	9.13 ^l
N ₁ P ₂	241.33 ^{lm}	0.536 ^{jk}	26.10 ⁿ	38.61 ^o	30.40 ⁿ	0.191 ^{kl}	5.95 ^k	9.36 ^k
N ₁ P ₃	242.80 ^{klm}	0.540 ^{ijk}	27.48 ^m	39.92 ⁿ	31.69 ^m	0.217 ^{jk}	6.18 ^j	9.59 ^j
N ₁ P ₄	244.12 ^{jkl}	0.542 ^{ijk}	28.96 ^l	41.14 ^m	32.78 ^l	0.236 ^j	6.36 ⁱ	9.84 ^{hi}

Treatment	Leaf area 60 DAS (cm ² plant ⁻¹)	LAI 60 DAS	SPAD 30 DAS	SPAD 60 DAS	SPAD at harvest	Dry matter 30 DAS (g plant ⁻¹)	Dry matter 60 DAS (g plant ⁻¹)	Dry matter at harvest (g plant ⁻¹)
N ₂ P ₁	245.51 ^{ijk}	0.545 ^{hij}	29.67 ^k	42.47 ^l	33.93 ^k	0.241 ^{ij}	6.23 ^{ij}	9.62 ^{ij}
N ₂ P ₂	247.03 ^{hij}	0.549 ^{ghi}	31.31 ^j	43.99 ^k	35.27 ^j	0.268 ⁱ	6.52 ^h	9.87 ^h
N ₂ P ₃	248.64 ^{ghi}	0.553 ^{fgh}	32.30 ⁱ	45.16 ^j	36.37 ⁱ	0.304 ^h	6.82 ^g	10.13 ^g
N ₂ P ₄	250.10 ^{fgh}	0.556 ^{fg}	33.15 ^h	46.37 ⁱ	37.40 ^h	0.338 ^g	7.09 ^f	10.40 ^f
N ₃ P ₁	251.55 ^{efg}	0.559 ^{ef}	34.15 ^g	47.64 ^h	38.52 ^g	0.337 ^g	6.77 ^g	10.17 ^g
N ₃ P ₂	253.00 ^{ef}	0.562 ^{ef}	34.98 ^f	48.92 ^g	39.85 ^f	0.372 ^f	7.14 ^f	10.44 ^{ef}
N ₃ P ₃	254.86 ^{de}	0.566 ^{de}	35.58 ^e	50.35 ^f	41.04 ^e	0.410 ^e	7.56 ^d	10.69 ^d
N ₃ P ₄	256.72 ^d	0.571 ^d	36.25 ^d	51.21 ^e	41.80 ^d	0.458 ^d	7.98 ^b	11.00 ^c
N ₄ P ₁	258.30 ^{cd}	0.574 ^{cd}	36.98 ^c	52.30 ^d	42.60 ^c	0.434 ^{de}	7.30 ^c	10.66 ^{de}
N ₄ P ₂	260.74 ^c	0.580 ^c	37.17 ^c	53.12 ^c	43.14 ^b	0.487 ^c	7.74 ^c	10.94 ^c
N ₄ P ₃	266.62 ^b	0.592 ^b	37.71 ^b	54.20 ^b	43.59 ^a	0.540 ^b	8.07 ^b	11.36 ^b
N ₄ P ₄	282.87 ^a	0.629 ^a	38.61 ^a	55.42 ^a	43.60 ^a	0.627 ^a	8.54 ^a	11.71 ^a
F test	S	S	S	S	S	S	S	S
S.Em±	1.189	0.003	0.108	0.087	0.027	0.010	0.052	0.079
CD at 5%	3.450	0.008	0.313	0.253	0.077	0.029	0.151	0.240

Note: LAI: leaf area index; SPAD: chlorophyll content in SPAD units; S: significant; NS: non-significant. Values are means; within each section, means followed by the same letter do not differ significantly according to Duncan's multiple range test (DMRT) at the 5% level.

3.2. Flowering

Days to flower initiation and to 50% flowering increased significantly with nitrogen and phosphorus (Table 3). The treatment N₄ took 49.59 days to flower initiation and 52.91 days to 50% flowering, against 47.71 and 50.26 days under N₁ and P₄ took 49.07 and 52.00 days against 48.24 and 51.13 days under P₁. The interaction was significant for flower initiation, ranging from 47.31 days under N₁P₁ to 49.97 days under N₄P₄ (on par with N₄P₃), but not for 50% flowering.

3.3. Yield attributes

The numbers of umbels per plant, umbellate per umbel, seeds per umbel and seeds per umbellate all increased significantly with nitrogen and phosphorus (Table 3). The treatment N₄ gave 30.12 umbels, 5.55 umbellate, 14.75 seeds per umbel and 7.60 seeds per umbellate, against 23.87, 4.23, 10.90 and 5.42 under N₁. The treatment P₄ gave 27.85, 5.16, 13.44 and 6.88, against 26.26, 4.79, 12.22 and 6.23 under P₁. The interaction was significant for all four attributes, with N₄P₄ recording 31.57 umbels, 5.74 umbellate, 15.80 seeds per umbel and 7.92 seeds per umbellate and N₁P₁ the lowest values (23.02, 3.97, 10.40 and 4.97).

3.4. Seed yield

Seed yield per plant, per plot and per hectare increased significantly and progressively with nitrogen and phosphorus (Table 3 and Figure 1). The treatment N₄ gave 5.20 g per plant, 476.27 g per plot and 734.97 kg ha⁻¹, against 3.18 g, 335.52 g and 517.78 kg ha⁻¹ under N₁ (a 42% increase per hectare). The treatment P₄ gave 4.45 g, 451.81 g and 697.23 kg ha⁻¹, against 3.76 g, 364.65 g and 562.72 kg ha⁻¹ under P₁ (a 24% increase). The interaction was significant: N₄P₄ gave the highest yield (5.59 g, 535.06 g and 825.69 kg ha⁻¹) and N₁P₁ the lowest (2.93 g, 302.90 g and 467.44 kg ha⁻¹), a difference of 76.6%. The treatment N₄P₄ yielded 35.1% more than the recommended dose N₂P₃ (611.26 kg ha⁻¹). The response to phosphorus was larger at higher nitrogen: increasing phosphorus from 20 to 50 kg ha⁻¹ raised seed yield by about 108 kg ha⁻¹ at N₁ (467.44 to 575.31) and by about 178 kg ha⁻¹ at N₄ (647.22 to 825.69), which is the positive interaction that the significant N × P term indicates.

Table 3. Flowering, yield attributes and seed yield of seed coriander var. Varadevi 1 as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	Days to flower initiation	Days to 50% flowering	Umbels per plant	Umbella te per umbel	Seeds per umbel	Seeds per umbella te	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per ha (kg)
Nitrogen (N)									
N ₁ (20 kg ha ⁻¹)	47.71 ^d	50.26 ^d	23.87 ^d	4.23 ^d	10.90 ^d	5.42 ^d	3.18 ^d	335.52 ^d	517.78 ^d
N ₂ (30 kg ha ⁻¹)	48.36 ^c	51.10 ^c	26.45 ^c	4.89 ^c	12.17 ^c	6.28 ^c	3.82 ^c	382.13 ^c	589.70 ^c

Treatment	Days to flower initiation	Days to 50% flowering	Umbels per plant	Umbella te per umbel	Seeds per umbel	Seeds per umbella te	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per ha (kg)
N ₃ (40 kg ha ⁻¹)	48.97 ^b	51.96 ^b	27.85 ^b	5.24 ^b	13.35 ^b	6.93 ^b	4.24 ^b	433.37 ^b	668.78 ^b
N ₄ (50 kg ha ⁻¹)	49.59 ^a	52.91 ^a	30.12 ^a	5.55 ^a	14.75 ^a	7.60 ^a	5.20 ^a	476.27 ^a	734.97 ^a
F test	S	S	S	S	S	S	S	S	S
S.Em±	0.08	0.07	0.090	0.014	0.011	0.008	0.008	1.18	1.83
CD at 5%	0.23	0.20	0.262	0.039	0.033	0.023	0.023	3.43	5.31
Phosphorus (P)									
P ₁ (20 kg ha ⁻¹)	48.24 ^d	51.13 ^d	26.26 ^d	4.79 ^d	12.22 ^d	6.23 ^d	3.76 ^d	364.65 ^d	562.72 ^d
P ₂ (30 kg ha ⁻¹)	48.53 ^c	51.41 ^c	26.73 ^c	4.93 ^c	12.55 ^c	6.45 ^c	3.98 ^c	390.27 ^c	602.26 ^c
P ₃ (40 kg ha ⁻¹)	48.80 ^b	51.69 ^b	27.46 ^b	5.02 ^b	12.97 ^b	6.66 ^b	4.25 ^b	420.57 ^b	649.02 ^b
P ₄ (50 kg ha ⁻¹)	49.07 ^a	52.00 ^a	27.85 ^a	5.16 ^a	13.44 ^a	6.88 ^a	4.45 ^a	451.81 ^a	697.23 ^a
F test	S	S	S	S	S	S	S	S	S
S.Em±	0.08	0.07	0.090	0.014	0.011	0.008	0.008	1.18	1.83
CD at 5%	0.23	0.20	0.262	0.039	0.033	0.023	0.023	3.43	5.31
Interaction (N × P)									
N ₁ P ₁	47.31 ⁱ	49.84	23.02 ^j	3.97 ^m	10.40 ^p	4.97 ^p	2.93 ^p	302.90 ^k	467.44 ^k
N ₁ P ₂	47.57 ^{hi}	50.12	23.67 ⁱ	4.17 ^l	10.71 ^o	5.28 ^o	3.07 ^o	321.54 ^j	496.20 ^j
N ₁ P ₃	47.83 ^{gh}	50.39	24.27 ^h	4.31 ^k	11.09 ⁿ	5.58 ⁿ	3.28 ⁿ	344.84 ⁱ	532.16 ⁱ
N ₁ P ₄	48.12 ^{fg}	50.67	24.52 ^h	4.47 ^j	11.41 ^m	5.85 ^m	3.42 ^m	372.80 ^h	575.31 ^h
N ₂ P ₁	47.94 ^{gh}	50.68	25.73 ^g	4.67 ⁱ	11.69 ^l	5.96 ^l	3.49 ^l	344.84 ⁱ	532.16 ⁱ
N ₂ P ₂	48.24 ^{fg}	50.96	26.18 ^g	4.85 ^h	11.97 ^k	6.20 ^k	3.71 ^k	368.14 ^h	568.11 ^h
N ₂ P ₃	48.49 ^{ef}	51.24	26.90 ^f	4.95 ^g	12.38 ^j	6.35 ^j	3.93 ⁱ	396.10 ^g	611.26 ^g
N ₂ P ₄	48.78 ^{de}	51.51	26.98 ^f	5.07 ^f	12.64 ⁱ	6.59 ⁱ	4.16 ^g	419.44 ^f	647.27 ^f
N ₃ P ₁	48.54 ^{ef}	51.55	27.44 ^f	5.14 ^{ef}	12.76 ^h	6.69 ^h	3.81 ^j	391.44 ^g	604.07 ^g
N ₃ P ₂	48.83 ^{de}	51.83	27.45 ^f	5.20 ^{de}	13.16 ^g	6.80 ^g	4.07 ^h	414.74 ^f	640.03 ^f
N ₃ P ₃	49.11 ^{cd}	52.10	28.20 ^e	5.24 ^d	13.57 ^f	7.06 ^f	4.43 ^f	447.36 ^e	690.37 ^e
N ₃ P ₄	49.39 ^{bc}	52.38	28.31 ^e	5.36 ^c	13.92 ^e	7.17 ^e	4.64 ^e	479.94 ^c	740.64 ^c
N ₄ P ₁	49.18 ^{cd}	52.45	28.83 ^d	5.38 ^c	14.04 ^d	7.28 ^d	4.81 ^d	419.40 ^f	647.22 ^f
N ₄ P ₂	49.48 ^{bc}	52.73	29.60 ^c	5.51 ^b	14.35 ^c	7.54 ^c	5.06 ^c	456.66 ^d	704.71 ^d
N ₄ P ₃	49.75 ^{ab}	53.01	30.47 ^b	5.58 ^b	14.83 ^b	7.65 ^b	5.34 ^b	493.96 ^b	762.28 ^b
N ₄ P ₄	49.97 ^a	53.45	31.57 ^a	5.74 ^a	15.80 ^a	7.92 ^a	5.59 ^a	535.06 ^a	825.69 ^a
F test	S	NS	S	S	S	S	S	S	S
S.Em±	0.16	0.14	0.181	0.027	0.023	0.016	0.016	2.36	3.66
CD at 5%	0.47	NS	0.525	0.079	0.066	0.047	0.045	6.85	10.63

Note: S: significant; NS: non-significant. Values are means; within each section, means followed by the same letter do not differ significantly according to Duncan's multiple range test (DMRT) at the 5% level.

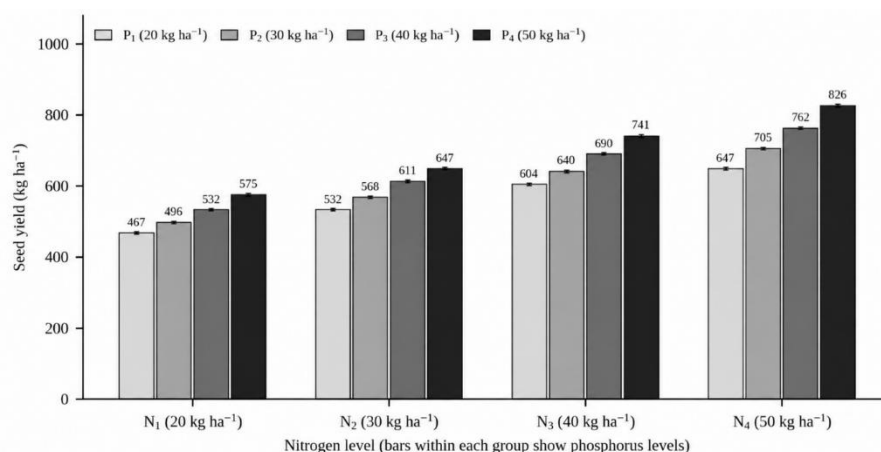


Figure 1. Seed yield (kg ha⁻¹) of seed coriander var. Varadevi 1 under the 16 combinations of nitrogen and phosphorus (pooled over two seasons). Bars show means with $\pm$ S.E.m error bars. The hatched bar is the recommended dose (N₂P₃). CD at 5% for the N $\times$ P interaction = 10.63 kg ha⁻¹.

3.5. Seed quality

All seed quality attributes increased significantly with nitrogen and phosphorus (Table 4 and Figure 2). The N₄ gave the highest thousand seed weight (13.18 g), germination (80.60 %), seedling length (19.76 cm), seedling dry weight (23.97 mg) and vigor indices I and II (1596 and 1935), against 11.59 g, 75.48%, 15.68 cm, 20.75 mg, 1186 and 1569 under N₁. The treatment P₄ gave 12.97 g, 79.07%, 18.11 cm, 22.76 mg, 1438 and 1805, against 11.84 g, 77.41 %, 17.14 cm, 21.88 mg, 1332 and 1699 under P₁. The interaction was significant for all six attributes. The interaction N₄P₄ recorded the highest values (14.62 g, 80.99 %, 20.88 cm, 24.44 mg, 1694 and 1983) and N₁P₁ the lowest (11.29 g, 74.10 %, 15.26 cm, 20.43 mg, 1133 and 1516). Compared with the recommended dose N₂P₃, N₄P₄ increased thousand seed weight from 12.21 to 14.62 g and vigor index II from 1710 to 1983. The interaction was most marked for thousand seed weight, which at N₄ rose by 1.48 g between P₃ and P₄ but by only 0.09–0.28 g at the lower nitrogen levels (Figure 2a).

3.6. Essential oil and oleoresin

Essential oil and oleoresin contents increased significantly with nitrogen and phosphorus (Table 4 and Figure 2c). The treatment N₄ gave 0.32 % essential oil and 8.52 % oleoresin, against 0.14 % and 4.52 % under N₁ and P₄ gave 0.25 % and 7.17 %, against 0.21 % and 5.88 % under P₁. The interaction was significant for oleoresin but not for essential oil. The treatment combination of N₄P₄ gave the highest oleoresin (9.11 %) and N₁P₁ the lowest (3.84 %).

Table 4. Seed quality, essential oil and oleoresin content of seed coriander var. Varadevi 1 as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	Thousand seed weight (g)	Germination (%)	Seedling length (cm)	Seedling dry weight (mg)	Seedling vigor index I	Seedling vigor index II	Essential oil (%)	Oleoresin (%)
Nitrogen (N)								
N ₁ (20 kg ha ⁻¹)	11.59 ^d	75.48 ^d	15.68 ^d	20.75 ^d	1186 ^d	1569 ^d	0.14 ^d	4.52 ^d
N ₂ (30 kg ha ⁻¹)	12.07 ^c	77.79 ^c	17.02 ^c	21.72 ^c	1327 ^c	1692 ^c	0.20 ^c	6.09 ^c
N ₃ (40 kg ha ⁻¹)	12.53 ^b	79.27 ^b	18.37 ^b	22.69 ^b	1460 ^b	1802 ^b	0.26 ^b	7.01 ^b
N ₄ (50 kg ha ⁻¹)	13.18 ^a	80.60 ^a	19.76 ^a	23.97 ^a	1596 ^a	1935 ^a	0.32 ^a	8.52 ^a
F test	S	S	S	S	S	S	S	S
S.E.m $\pm$	0.066	0.010	0.053	0.029	4.40	2.61	0.001	0.002
CD at 5%	0.190	0.030	0.155	0.083	12.76	7.56	0.003	0.005
Phosphorus (P)								
P ₁ (20 kg ha ⁻¹)	11.84 ^d	77.41 ^d	17.14 ^d	21.88 ^d	1332 ^d	1699 ^d	0.21 ^d	5.88 ^d
P ₂ (30 kg ha ⁻¹)	12.12 ^c	78.00 ^c	17.69 ^c	22.10 ^c	1386 ^c	1729 ^c	0.22 ^c	6.33 ^c
P ₃ (40 kg ha ⁻¹)	12.44 ^b	78.65 ^b	17.89 ^b	22.38 ^b	1413 ^b	1765 ^b	0.24 ^b	6.76 ^b
P ₄ (50 kg ha ⁻¹)	12.97 ^a	79.07 ^a	18.11 ^a	22.76 ^a	1438 ^a	1805 ^a	0.25 ^a	7.17 ^a
F test	S	S	S	S	S	S	S	S

Treatment	Thousand seed weight (g)	Germination (%)	Seedling length (cm)	Seedling dry weight (mg)	Seedling vigor index I	Seedling vigor index II	Essential oil (%)	Oleoresin (%)
S.Em±	0.066	0.010	0.053	0.029	4.40	2.61	0.001	0.002
CD at 5%	0.190	0.030	0.155	0.083	12.76	7.56	0.003	0.005
Interaction (N × P)								
N ₁ P ₁	11.29 ^k	74.10 ^o	15.26 ^l	20.43 ⁿ	1133 ^m	1516 ^o	0.12	3.84 ^p
N ₁ P ₂	11.47 ^{jk}	75.07 ⁿ	15.73 ^k	20.63 ^m	1183 ^l	1552 ⁿ	0.13	4.30 ^o
N ₁ P ₃	11.75 ^{hij}	76.05 ^m	15.63 ^k	20.85 ^l	1191 ^l	1588 ^m	0.15	4.75 ⁿ
N ₁ P ₄	11.84 ^{ghij}	76.70 ^l	16.10 ^j	21.08 ^k	1237 ^k	1619 ^l	0.16	5.18 ^m
N ₂ P ₁	11.65 ^{ijk}	76.83 ^k	16.47 ⁱ	21.32 ^j	1268 ^j	1641 ^k	0.17	5.45 ^l
N ₂ P ₂	11.93 ^{fghi}	77.55 ^j	17.20 ^{gh}	21.57 ⁱ	1337 ⁱ	1676 ^j	0.19	5.89 ^k
N ₂ P ₃	12.21 ^{efg}	78.19 ⁱ	17.48 ^g	21.83 ^h	1370 ^h	1710 ⁱ	0.20	6.32 ⁱ
N ₂ P ₄	12.49 ^{de}	78.58 ^h	16.93 ^h	22.14 ^g	1333 ⁱ	1743 ^h	0.22	6.72 ^h
N ₃ P ₁	12.12 ^{efgh}	78.58 ^h	17.95 ^f	22.22 ^g	1413 ^g	1749 ^h	0.23	6.31 ^j
N ₃ P ₂	12.39 ^{de}	78.91 ^g	18.41 ^e	22.42 ^f	1456 ^f	1772 ^g	0.25	6.80 ^g
N ₃ P ₃	12.67 ^{cd}	79.56 ^f	18.59 ^{de}	22.75 ^e	1482 ^e	1813 ^f	0.27	7.26 ^f
N ₃ P ₄	12.95 ^{bc}	80.02 ^e	18.54 ^e	23.39 ^d	1487 ^e	1874 ^e	0.28	7.67 ^e
N ₄ P ₁	12.30 ^{def}	80.15 ^d	18.87 ^d	23.55 ^d	1516 ^d	1890 ^d	0.30	7.91 ^d
N ₄ P ₂	12.67 ^{cd}	80.47 ^c	19.42 ^c	23.78 ^c	1566 ^c	1917 ^c	0.31	8.32 ^c
N ₄ P ₃	13.14 ^b	80.79 ^b	19.86 ^b	24.11 ^b	1608 ^b	1951 ^b	0.32	8.73 ^b
N ₄ P ₄	14.62 ^a	80.99 ^a	20.88 ^a	24.44 ^a	1694 ^a	1983 ^a	0.34	9.11 ^a
F test	S	S	S	S	S	S	NS	S
S.Em±	0.131	0.021	0.107	0.057	8.80	5.21	0.002	0.003
CD at 5%	0.380	0.060	0.310	0.166	25.52	15.12	NS	0.010

Note: S: significant; NS: non-significant. Values are means; within each section, means followed by the same letter do not differ significantly according to Duncan's multiple range test (DMRT) at the 5% level.

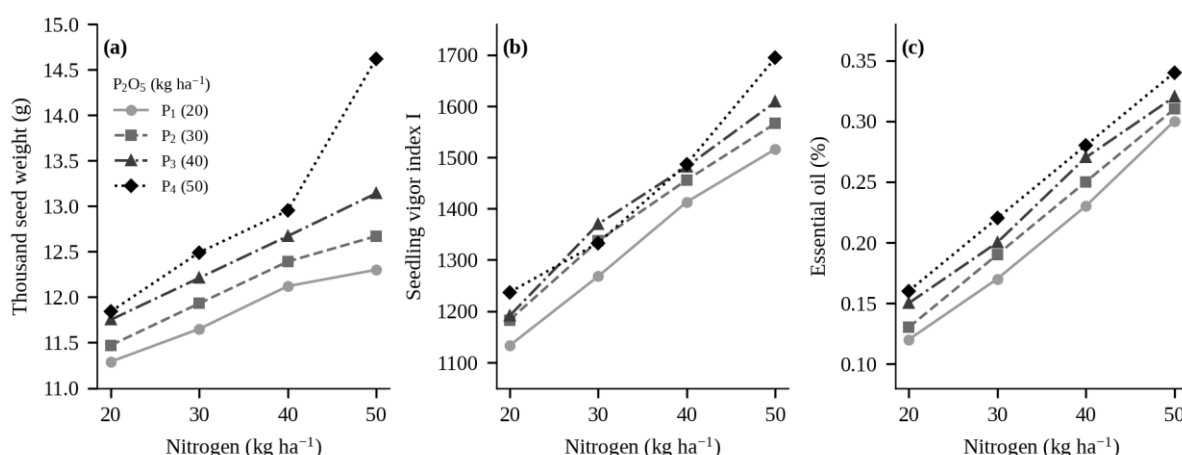


Figure 2. Effect of nitrogen and phosphorus on (a) thousand seed weight, (b) seedling vigor index I and (c) essential oil content of seed coriander var. Varadevi 1 (pooled means of the 16 combinations). Lines show phosphorus levels (kg P₂O₅ ha⁻¹). CD at 5% for the N × P interaction: 0.380 g in (a) and 25.52 in (b); the interaction was not significant for essential oil (c).

3.7. Soil nutrient status after harvest and nutrient uptake

Soil pH and organic carbon after harvest were not affected by nitrogen, phosphorus or their interaction (Table 5). Electrical conductivity was affected significantly by nitrogen alone, falling from 0.426 dS m⁻¹ under N₁ to 0.387 dS m⁻¹ under N₄ and by the N × P interaction (highest, 0.436 dS m⁻¹, under N₁P₁). Available nitrogen and phosphorus in the soil declined significantly as fertilizer levels increased, from 236.77 kg N ha⁻¹ and 35.64 kg P ha⁻¹ under N₁ to 201.42 and 19.18 kg ha⁻¹ under N₄ with 246.76 and 39.31 kg ha⁻¹ under N₁P₁ and 195.77 and

16.57 kg ha⁻¹ under N₄P₄. Crop uptake of nitrogen and phosphorus increased significantly with fertilizer level, from 21.09 and 2.73 kg ha⁻¹ under N₁P₁ to 36.38 and 6.39 kg ha⁻¹ under N₄P₄.

Table 5. Soil properties after harvest and nutrient uptake as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	Soil pH	EC (dS m ⁻¹)	Organic carbon (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Uptake of N (kg ha ⁻¹)	Uptake of P (kg ha ⁻¹)
Nitrogen (N)							
N ₁ (20 kg ha ⁻¹)	8.51	0.426 ^a	0.566	236.77 ^a	35.64 ^a	22.96 ^d	3.15 ^d
N ₂ (30 kg ha ⁻¹)	8.51	0.408 ^b	0.570	227.75 ^b	30.01 ^b	26.65 ^c	3.90 ^c
N ₃ (40 kg ha ⁻¹)	8.51	0.394 ^c	0.572	214.97 ^c	23.72 ^c	30.33 ^b	4.79 ^b
N ₄ (50 kg ha ⁻¹)	8.51	0.387 ^c	0.576	201.42 ^d	19.18 ^d	34.01 ^a	5.68 ^a
F test	NS	S	NS	S	S	S	S
S.Em±	0.010	0.003	0.003	0.43	0.030	0.011	0.081
CD at 5%	NS	0.007	NS	1.25	0.086	0.033	0.234
Phosphorus (P)							
P ₁ (20 kg ha ⁻¹)	8.51	0.407	0.570	226.38 ^a	29.28 ^a	26.36 ^d	3.93 ^c
P ₂ (30 kg ha ⁻¹)	8.51	0.406	0.571	223.62 ^b	27.60 ^b	27.78 ^c	4.26 ^b
P ₃ (40 kg ha ⁻¹)	8.51	0.401	0.571	216.81 ^c	26.92 ^c	29.19 ^b	4.60 ^a
P ₄ (50 kg ha ⁻¹)	8.51	0.401	0.573	214.10 ^d	24.74 ^d	30.61 ^a	4.73 ^a
F test	NS	NS	NS	S	S	S	S
S.Em±	0.010	0.003	0.003	0.43	0.030	0.011	0.081
CD at 5%	NS	NS	NS	1.25	0.086	0.033	0.234
Interaction (N × P)							
N ₁ P ₁	8.51	0.436 ^a	0.564	246.76 ^a	39.31 ^a	21.09 ^p	2.73 ^g
N ₁ P ₂	8.53	0.428 ^{ab}	0.565	240.47 ^b	35.99 ^b	22.34 ^o	3.19 ^f
N ₁ P ₃	8.50	0.425 ^{abc}	0.566	231.81 ^{cd}	34.41 ^c	23.58 ⁿ	3.29 ^f
N ₁ P ₄	8.52	0.416 ^{bcd}	0.567	228.02 ^e	32.84 ^d	24.84 ^l	3.38 ^f
N ₂ P ₁	8.51	0.417 ^{bcd}	0.568	230.73 ^d	31.18 ^c	24.61 ^m	3.48 ^f
N ₂ P ₂	8.51	0.410 ^{cde}	0.569	234.00 ^c	30.71 ^f	25.97 ^k	3.57 ^f
N ₂ P ₃	8.51	0.407 ^{de}	0.570	223.51 ^f	30.35 ^g	27.33 ^j	4.21 ^e
N ₂ P ₄	8.50	0.397 ^{ef}	0.571	222.74 ^{fg}	27.80 ^h	28.68 ^h	4.32 ^{de}
N ₃ P ₁	8.52	0.399 ^{ef}	0.572	220.86 ^g	25.44 ⁱ	28.12 ⁱ	4.68 ^{cde}
N ₃ P ₂	8.51	0.398 ^{ef}	0.572	214.82 ^h	23.23 ^k	29.59 ^g	4.79 ^{cd}
N ₃ P ₃	8.52	0.389 ^{fg}	0.572	214.33 ^h	24.42 ^j	31.06 ^f	4.90 ^c
N ₃ P ₄	8.50	0.390 ^{fg}	0.574	209.89 ⁱ	21.77 ^l	32.53 ^d	4.80 ^{cd}
N ₄ P ₁	8.51	0.375 ^g	0.575	207.17 ^j	21.18 ^m	31.64 ^e	4.84 ^c
N ₄ P ₂	8.49	0.387 ^{fg}	0.576	205.17 ^j	20.45 ⁿ	33.22 ^c	5.48 ^b
N ₄ P ₃	8.52	0.384 ^{fg}	0.577	197.58 ^k	18.50 ^o	34.80 ^b	6.00 ^a
N ₄ P ₄	8.50	0.399 ^{ef}	0.578	195.77 ^k	16.57 ^p	36.38 ^a	6.39 ^a
F test	NS	S	NS	S	S	S	S
S.Em±	0.021	0.005	0.007	0.86	0.059	0.023	0.161
CD at 5%	NS	0.015	NS	2.51	0.172	0.065	0.468

Note: EC: electrical conductivity; S: significant; NS: non-significant. Values are means; within each section, means followed by the same letter do not differ significantly according to Duncan's multiple range test (DMRT) at the 5% level.

3.8. Economics

The cost of cultivation rose with the fertilizer level, from ₹ 35,263 ha⁻¹ under N₁P₁ to ₹ 36,783 ha⁻¹ under N₄P₄, an increase of only ₹ 1,520 ha⁻¹ because fertilizer is a small part of the total cost (Table 6 and Figure 3). Gross returns rose from ₹ 70,116 to ₹ 123,853 ha⁻¹ and net returns from ₹ 34,853 to ₹ 87,070 ha⁻¹ and the B:C ratio rose

from 1.99:1 to 3.37:1. The recommended dose (N_2P_3) gave net returns of ₹ 55,529 ha^{-1} and a B:C ratio of 2.54:1. The combination of N_4P_4 therefore gave ₹ 31,541 ha^{-1} (57 %) more net return than the recommended dose, for an extra cost of ₹ 623 ha^{-1} . The B:C ratio exceeded unity at every level, so seed coriander was profitable across the range tested.

Table 6. Seed yield, cost of cultivation, gross returns, net returns and benefit:cost ratio of seed coriander var. Varadevi 1 as influenced by nitrogen and phosphorus levels (pooled data)

Treatment	N:P ₂ O ₅ :K ₂ O (kg ha^{-1})	Seed yield (kg ha^{-1})	Cost cultivation of (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T ₁ (N_1P_1)	20:20:20	467.44	35,263	70,116	34,853	1.99:1
T ₂ (N_1P_2)	20:30:20	496.20	35,653	74,430	38,777	2.09:1
T ₃ (N_1P_3)	20:40:20	532.16	36,043	79,824	43,781	2.21:1
T ₄ (N_1P_4)	20:50:20	575.30	36,433	86,295	49,862	2.37:1
T ₅ (N_2P_1)	30:20:20	532.16	35,380	79,824	44,444	2.26:1
T ₆ (N_2P_2)	30:30:20	568.11	35,770	85,217	49,447	2.38:1
T ₇ (N_2P_3) (control)	30:40:20	611.26	36,160	91,689	55,529	2.54:1
T ₈ (N_2P_4)	30:50:20	647.27	36,550	97,091	60,541	2.66:1
T ₉ (N_3P_1)	40:20:20	604.07	35,496	90,611	55,114	2.55:1
T ₁₀ (N_3P_2)	40:30:20	640.03	35,886	96,005	60,118	2.68:1
T ₁₁ (N_3P_3)	40:40:20	690.37	36,276	103,556	67,279	2.85:1
T ₁₂ (N_3P_4)	40:50:20	740.64	36,666	111,096	74,430	3.03:1
T ₁₃ (N_4P_1)	50:20:20	647.22	35,613	97,083	61,470	2.73:1
T ₁₄ (N_4P_2)	50:30:20	704.71	36,003	105,707	69,704	2.94:1
T ₁₅ (N_4P_3)	50:40:20	762.28	36,393	114,342	77,949	3.14:1
T ₁₆ (N_4P_4)	50:50:20	825.69	36,783	123,853	87,070	3.37:1

Note: Seed price ₹ 150 kg^{-1} . Control: recommended dose (30:40:20 kg N:P₂O₅:K₂O ha^{-1})

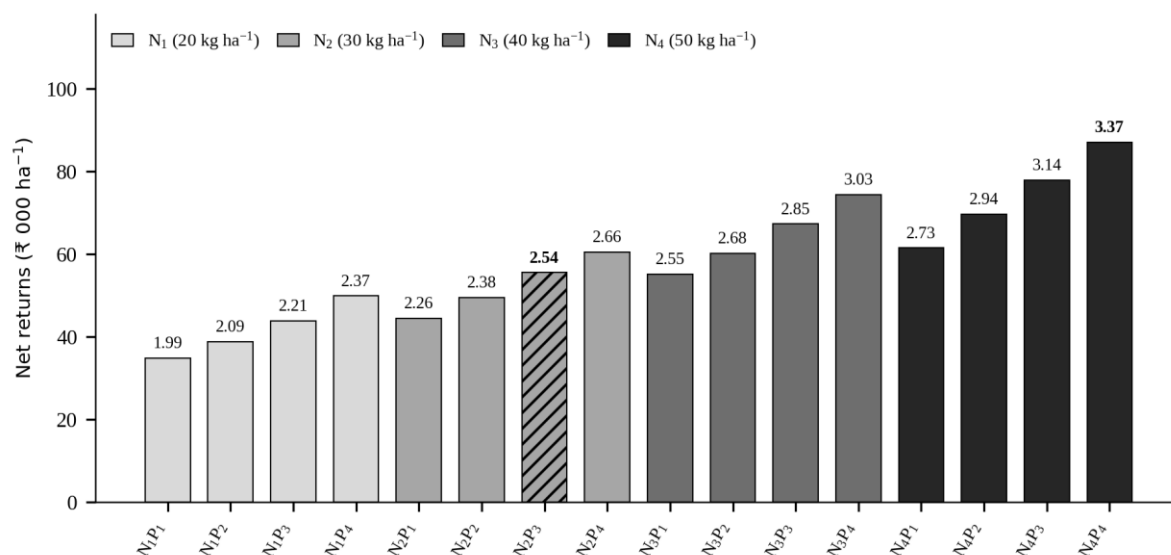


Figure 3. Net returns (₹ ha^{-1} , in thousands) and benefit:cost ratio (figures above the bars) of seed coriander var. Varadevi 1 under the 16 combinations of nitrogen and phosphorus. The hatched bar is the recommended dose (N_2P_3). Seed price ₹ 150 kg^{-1} .

4. DISCUSSION

4.1. Growth and flowering

The growth responses reflect the complementary roles of nitrogen and phosphorus. Nitrogen, as a constituent of amino acids, nucleic acids and chlorophyll, enhances meristematic activity at the shoot apex and axillary buds, giving taller plants, more branches and a larger photosynthetic surface, and it raises the chlorophyll density per unit leaf area. Phosphorus, as a component of ATP and nucleic acids, drives the energy transfer reactions of cell

division and promotes root proliferation, which improves the uptake of nitrogen and other nutrients. The interaction under N₄P₄ is consistent with each nutrient improving the uptake and use of the other. LAI is leaf area expressed per unit ground area and because the plant population was constant (30 × 15 cm), its response mirrors that of leaf area. SPAD readings are an indirect measure of leaf chlorophyll concentration [25], so the higher readings indicate greater chlorophyll density under higher nitrogen. The trends agree with the progressive increase in plant height, branching, chlorophyll status and dry matter reported for coriander with increasing nitrogen and phosphorus [5,6,26] with plant height and branching [7,8], with leaf area and LAI [27,28] and with the chlorophyll response to nitrogen [29].

The significant N × P interaction, with the highest value of every growth character under N₄P₄, may reflect each nutrient promoting the uptake and use of the other: phosphorus-driven root proliferation provides a larger absorptive surface for nitrogen, while nitrogen-driven protein synthesis supplies the enzymes needed to assimilate phosphorus. Dry matter production integrates the taller stature, more extensive branching, larger leaf surface and higher chlorophyll density described above. Nitrogen is also part of the structural basis of RuBisCO, and phosphorus supplies the ATP and NADPH needed for the light and dark reactions of photosynthesis and for the translocation of photosynthate to sink tissues, so an adequate supply of both would be expected to raise the photosynthetic capacity of the canopy.

The delay in flowering with higher nutrient levels can be explained by the carbon:nitrogen balance of the plant: ample nitrogen favors continued vegetative growth and delays the transition of the shoot apex to the reproductive phase, whereas nutrient-limited plants switch to reproduction earlier as a stress response [30]. A similar delay with higher nitrogen was reported earlier in coriander [8]. A delay of two to three days between the lowest and highest levels is agronomically acceptable, because flowering did not move into an unfavorable climatic window and the longer vegetative phase built up a larger reproductive sink, as shown by the higher umbel number, seeds per umbel and seed yield under the same treatments.

4.2. Yield attributes and seed yield

The umbel is the basic reproductive unit of coriander, and the larger number of branches under higher nutrient levels provided more umbel-bearing points. Seed-set attributes responded more strongly than umbel number: from N₁ to N₄, seeds per umbel and per umbellate increased by about 35% and 40%, against about 26% and 31% for umbels per plant and umbellate per umbel. This suggests that fertility influenced not only the number of reproductive structures initiated but even more the efficiency with which each structure set seed, most likely because more phosphorus was available for the energy-demanding processes of fertilization and early embryo development. Similar increases in umbel number and seed-set attributes with nitrogen and phosphorus were reported in coriander by Hossain and Pariari [8], Mahant et al. [6] and Choudhary et al. [5].

Seed yield is the cumulative expression of the growth and yield-attributing characters discussed above. Taller, more branched plants with larger leaf area and higher chlorophyll content produced and translocated more photosynthate, which was partitioned into more umbels, more seeds per umbel and heavier seeds. Nitrogen also sustains the source strength during seed filling by delaying leaf senescence, as seen in the higher chlorophyll content at harvest under N₄, while phosphorus supports root proliferation and so the water and nutrient supply of the larger canopy. These results agree with reports of a significant and progressive increase in coriander seed yield with nitrogen and phosphorus [5,6,9,26].

Figure 1 shows that the benefit of phosphorus depended on the nitrogen supply: raising phosphorus from P₁ to P₄ increased seed yield by about 108 kg ha⁻¹ at N₁ but by about 178 kg ha⁻¹ at N₄. This is the pattern expected if phosphorus-mediated root growth improves nitrogen uptake and nitrogen-driven protein synthesis in turn supports phosphorus assimilation. The response was also built up from gains in all the yield components, since N₄P₄ had the most umbels per plant, the most seeds per umbel and the heaviest seeds, rather than from any single component.

4.3. Seed quality, essential oil and oleoresin

Adequate nitrogen and phosphorus during the reproductive phase improves the translocation of photosynthate and minerals into the developing seed, giving heavier, better-filled seeds with a larger embryo and more stored reserves. Because early seedling growth depends on these reserves, the bolder seeds germinated more uniformly and gave longer and heavier seedlings, which raised the vigor indices, both of which are the product of germination percentage and seedling length or dry weight [14]. The findings agree with the improvement in test weight, germination, seedling length, seedling dry weight and vigor indices with better nutrient management in coriander [15] and with the increase in thousand seed weight with nitrogen and phosphorus [8]. Seed quality in some seed spices plateaus or declines beyond an optimum nitrogen level, because excessive vegetative growth competes with the developing seed for assimilates and delays maturity. No such decline occurred up to N₄P₄, so the crop remained within its efficient response range for seed quality over the levels tested.

Essential oil and oleoresin are secondary metabolites synthesized from photosynthate and stored in the vittae of the pericarp, so the larger photosynthetic surface, higher chlorophyll content and greater dry matter under higher nutrient levels supplied more precursors for terpenoid synthesis and phosphorus supports the pathways that generate the isoprenoid units of the oil constituents. The increases agree with the positive effect of phosphorus on essential oil content [28] and of nitrogen on essential oil yield [26,27]. Oil and oleoresin percentages are often reported to fall at very high nitrogen because extra dry matter dilutes them. Both kept rising up to N₄P₄, which suggests that the doses tested had not reached the point where dilution begins.

4.4. Soil nutrient status and nutrient uptake

The lack of effect of fertilizer on soil pH and organic carbon (Table 5) is expected, because these properties depend mainly on the parent material, clay mineralogy and long-term organic matter dynamics and change little in one season of fertilization. The falling electrical conductivity with nitrogen is consistent with the larger biomass and ion removal by the more vigorous crop. The significant $N \times P$ interaction for electrical conductivity points the same way: N_1P_1 , the combination with the lowest fertilizer input, crop biomass and uptake, had the highest value (0.436 dS m^{-1}). The decline in available nitrogen and phosphorus is the opposite of the residual build-up usually expected after higher fertilizer doses, and crop uptake alone does not account for it. The extra uptake under the highest levels (about 11 kg N and 2.5 kg P ha^{-1} more than under the lowest levels) was smaller than the extra amounts applied (30 kg N and $30 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) and available phosphorus was lower at the higher phosphorus levels (29.28 kg ha^{-1} under P_1 and 24.74 kg ha^{-1} under P_4). Losses by leaching or volatilization, microbial immobilization and fixation were not measured, so this result should be treated as provisional until a full nutrient balance is available. The analytical methods used are standard [19,21] and uptake was calculated as described by Millard and Marshall [22].

4.5. Economics

Fertilizer is a small part of the cost of cultivation, so the extra ₹ 1,520 ha^{-1} spent on N_4P_4 over N_1P_1 was repaid many times by extra gross returns of ₹ 53,737 ha^{-1} (Figure 3). The B:C ratio rose with each increment of either nutrient and stayed above unity even under N_1P_1 , with no turning point at which the marginal cost of additional fertilizer outweighed the marginal return.

These results agree with reports of better net returns and B:C ratio at higher nitrogen and phosphorus levels [10,31]. These returns depend on the assumed seed price of ₹ 150 kg^{-1} and the ratio of extra gross return to extra cost (about 52:1 for N_4P_4 over N_2P_3) would fall if seed prices dropped or fertilizer prices rose.

4.6. Practical implications and limitations

Seed yield, seed quality, oil and oleoresin content and net returns were all highest at the highest levels tested (N_4P_4) and no turning point was reached in any of them. The recommended dose is therefore not the optimum for this variety under these conditions, but the optimum itself is not defined by this study, because higher doses were not tested. The results come from one location over two seasons with potassium and farmyard manure held constant, and the unexpected soil nutrient results (Sections 3.7 and 4.4) call for a nutrient balance study. Further trials with doses above $50:50 \text{ kg N:P}_2\text{O}_5 \text{ ha}^{-1}$, at more locations and soil types are needed before a final recommendation.

5. CONCLUSION

Seed coriander var. Varadevi 1 responded significantly and positively to nitrogen and phosphorus in the Northern Dry Zone of Karnataka. Growth, yield attributes, seed yield, seed quality, essential oil and oleoresin content, crop nutrient uptake and economic returns all increased with each level of both nutrients and flowering was delayed only slightly. Nitrogen and phosphorus each at 50 kg ha^{-1} (N_4P_4) gave the highest seed yield ($825.69 \text{ kg ha}^{-1}$, 35.1% above the recommended dose), the best seed quality, the highest net returns (₹ 87,070 ha^{-1}) and the highest benefit:cost ratio (3.37:1). Because the response had not leveled off at the highest level, the economically optimum dose may be higher and should be tested.

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