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Pawan Sharma
Master Scholar, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan, India

YA Tamboli
Assistant Professor, Department of Agronomy, School of Agriculture Sciences, Jaipur National University, Jaipur, Rajasthan, India

Ajeet Singh
Assistant Professor, Department of Agronomy, School of Agriculture Sciences, Jaipur National University, Jaipur, Rajasthan, India

RK Bansal
Director and Professor, Department of Plant Pathology, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan, India

GR Chaudhary
Department of Agronomy, School of Agriculture Sciences, Jaipur National University, Jaipur, Rajasthan, India

Corresponding Author:
Pawan Sharma
Master Scholar, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan, India

Interactive effects of lentil genotypes, fertilizer levels and crop geometry on growth and phenological development of lentil (*Lens culinaris Medik.*)

Pawan Sharma, YA Tamboli, Ajeet Singh, RK Bansal and GR Chaudhary

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Abstract
A field experiment was conducted during the Rabi season of 2024-25 at the School of Agricultural Sciences, Jaipur National University, Jaipur (Rajasthan) to study the effects of lentil genotypes, fertilizer levels and crop geometry on the growth and phenological development of lentil (*Lens culinaris* Medik.). The experiment was laid out in a split-plot design with twelve treatment combinations consisting of two varieties (KM-3 and DPL-62), two spacings (30 cm × 10 cm and 45 cm × 10 cm), and recommended fertilizer levels. The results showed that the application of 100% RDF (20:40:00 N P_2O_5 K_2O kg/ha) significantly improved growth parameters with the highest plant height at harvest (48.50 cm), number of branches per plant (11.64) and dry matter accumulation at maturity (9.98 g plant^{-1}), along with higher days to 50% flowering and maturity. However, plant population showed a non-significant effect on plant stand. The 45 cm × 10 cm spacing significantly improved plant height (44.72 cm), number of branches (11.04) and dry matter accumulation at maturity (9.20 g plant^{-1}), while plant population, days to 50% flowering and days to maturity showed a non-significant effect on plant stand. The DPL-62 genotype recorded the highest values for plant height at harvest (44.49 cm), number of branches per plant (10.99), and dry matter accumulation (9.15 g plant^{-1}), along with higher days to 50% flowering and maturity. However, plant population again showed a non-significant effect on plant stand. In conclusion, the study suggests that the application of 100% RDF combined with 45 cm × 10 cm spacing and the DPL-62 variety optimizes lentil growth, yield, quality, and economic returns under semi-arid conditions.

Keywords: Growth, phenology, fertilizer levels, genotypes, spacing, lentil

Introduction
Pulses are an essential global food source, particularly in India, where they contribute to national food security. They provide plant-based proteins, minerals and vitamins, making up about 10% of daily protein intake. Lentils (*Lens culinaris* Medik) are a key winter legume crop in India known for their high protein content and are important in many diets, especially in the Middle East and South Asia. India leads both in production and consumption of pulses globally. Lentils are primarily grown in Asia with India, Canada and Turkey being top producers. Lentils are mainly grown in Asia, which accounts for 80% of the global area and 75% of production. India is the largest producer followed by Canada. In the 2023-24 season, lentils were cultivated on 1.4 million hectares in India, yielding 1.3 million tonnes at an average productivity of 926 kg/ha. In Rajasthan, lentils were grown on 0.19 million hectares, producing 0.18 million tonnes at a productivity of 925 kg/ha (Anonymous, 2023) [2]. Lentils are a rich source of protein, carbohydrates, fats, vitamins and minerals, making them versatile in cooking and nutrition. They also fix nitrogen in the soil, support human diets with essential amino acids, and serve as fodder and cover crops.

The low productivity of lentils in India is mainly due to marginal soils, inadequate irrigation, poor management practices and pest susceptibility. Fertilization plays a crucial role in improving yields, particularly in semi-arid, nutrient-poor soils. While lentils fix nitrogen, they still require supplemental phosphorus, potassium and micronutrients for optimal growth. Proper fertilization, including phosphorus and potassium, enhances root development, drought tolerance and disease resistance. Studies show that appropriate fertilizer applications significantly improve lentil yield and growth, boosting productivity and net returns (Anchra *et al*., 2023, Singh *et al*., 2016 and Philip *et al*., 2021) [1, 11. 18],

Crop geometry including row spacing and plant density is key to optimizing sunlight capture, water use and minimizing competition. Proper spacing enhances germination, growth and yield by reducing competition for resources. Wider spacing improves individual plant yield but lowers total yield, while closer spacing increases competition and affects quality. Research shows that a 30 cm row spacing optimizes seed yield, and wider spacing (40 cm × 10 cm) promotes better growth and nodulation (Singh *et al*., 2009 and Swargiary *et al.* 2021) [22, 24].

Selecting resilient lentil genotypes that can withstand heat, drought, and fertility stress is crucial for optimizing crop performance and ensuring stable yields, especially with climate change. Variety selection plays a key role in adapting to specific soil and climatic conditions, improving growth and yield. Studies by Yadav *et al.* (2017) [27] and Reja *et al.* (2017) [13] highlighted that the DPL-62 variety performs well in terms of test weight, yield and phenological traits. Based on these factors, a field experiment was designed to investigate the effects of optimal variety selection, fertilizer levels and crop geometry on the growth and phenological development of lentil.

Materials and Methods

Experimental Site

The study was conducted at the Research Farm of the School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan located at 26°85' N latitude and 75°87' E longitude with an elevation of 390 m. The site lies within the NARP agro-climatic zone IIIa, which corresponds to the Semi-Arid Eastern Plain Zone of Rajasthan.

Weather

The region experiences a hot semi-arid climate with extreme temperatures and moderate rainfall. Summer highs can reach 45 °C, while winter lows dip to 5 °C. The average annual rainfall is 527 mm, with humidity ranging from 20-30% in summer to 60-80% during the monsoon. Winds typically blow at 5-15 km/h, gusting up to 40 km/h during dust storms. Sunshine duration ranges from 8-10 hours in summer, 6-8 hours in winter and 4-6 hours during the monsoon. In the 2024-25 *rabi* season, temperatures fluctuated between 33.8 °C and 8.6 °C with occasional rainfall.

Sampling and analyses

The soil in the experimental area is sandy loam of Gangetic alluvial origin, with 66.50% sand, 23.96% silt, and 9.54% clay. It has an alkaline pH of 7.94, low organic carbon (0.40%), and moderate levels of nitrogen (146.45 kg/ha), phosphorus (18.70 kg/ha) and high potassium (245.29 kg/ha). Physical analysis showed a bulk density of 1.59 Mg/m³, particle density of 2.55 Mg/m³, and porosity of 39.90%. The soil was analyzed using methods like the International Pipette Method and techniques for pH, conductivity, and nutrient analysis, as per established research standards. The procedures used were based on Piper (1950) [12] and Black (1950) [3], Olsen *et al*. (1954) [8], Richards (1954) [14], Subbaiah and Asija (1956) [23] and Jackson (1973) [6].

Experimental setup

The experiment was designed in a Split Plot Design with twelve treatment combinations, consisting of three fertilizer levels (F_2: Control, F_2: 50% RDF and F_3: 100% RDF), two spacings (S_1: 30 cm × 10 cm and S_2: 45 cm × 10 cm) and two varieties (G_1: KM-3 and G_2: DPL-62). All standard agronomic practices were followed and observations were taken from five randomly selected plants in each plot to evaluate various growth attributes and dry matter from the gross plot. The number of days from sowing to 50 % flowering and physiological maturity was also recorded. Statistical analysis of the data for each character was performed following the experimental design and the simple correlation coefficient ('r') for each character was calculated (Gomez and Gomez1984) [4].

Result and Discussion

Effect of Fertilizer Levels

The data presented in Table 1 and 2 reveal that different RDF levels significantly increased plant height, days to 50% flowering, days to maturity, number of branches per plant at maturity and dry matter accumulation (g per plant). However, plant population showed a non-significant effect on plant stand at both 20 DAS and the maturity stage of lentil. The application of 100% RDF (F_3) significantly enhanced the growth and phenological parameters of lentil compared to Control (F_2) and 50% RDF (F_2). At 20 DAS, the highest plant population was recorded under 100% RDF (F_3), showing a 7.58% increase over 50% RDF (F_2) and a 14.64% increase over Control (F_2). In terms of plant height, 100% RDF (F_3) resulted in the tallest plants at 45 DAS (31.99 cm), a 4.29% increase over F_2 (50% RDF) and a substantial 33.25% improvement over Control (F_2). 100% RDF (F3) also led to the earliest flowering, with 65.17 days to reach 50% flowering, which was 4.49% earlier than F_2 and 14.53% earlier than F_2. Similarly, 100% RDF (F_3) reduced the days to maturity to 111.55 days, which was 4.35% earlier than F_2 (50% RDF) and 13.34% earlier than F_2 (Control). These results highlight that the application of 100% RDF is crucial for improving plant growth, accelerating flowering, and ensuring earlier maturity.

Furthermore, 100% RDF (F_3) significantly enhanced the number of branches per plant and dry matter accumulation across all stages compared to Control (F_2) and 50% RDF (F_2). At maturity, F_3 (100% RDF) recorded the highest number of branches (11.98) and the highest dry matter accumulation (9.98 g per plant), showing an increase of 4.43% in branches and 4.49% in dry matter compared to F_2 (50% RDF) and 33.57% in branches and 33.72% in dry matter compared to F_2 (Control). This emphasizes the significant role of 100% RDF in promoting better vegetative growth and overall productivity of lentil. Such increases in growth parameters may be attributed to the significant role of applied NPK in enhancing metabolic activities, photosynthesis, root enlargement, and microbial activity. Nitrogen plays a vital role in plant metabolism and promotes increased plant height, while phosphorus is involved in photosynthesis, respiration, energy storage and transfer and cell division and enlargement. Potassium is crucial for nitrogen fixation in lentil. The varieties developed from different parental origins are also important factors influencing plant growth. These results are in close agreement with those of Saha *et al*. (2004) [15], Singh *et al*. (2011) [21], Saket *et al*. (2014) [16], Singh and Singh (2017) [20] and Patel *et al.* (2018) [10].

Effect of Spacing

The data presented in Table 1 and 2 reveal that different spacing significantly increased plant height, the number of branches per plant at maturity and dry matter accumulation (g per plant). However, plant population, days to 50% flowering, and days to maturity showed a non-significant effect on plant stand at both 20 DAS and the maturity stage of lentil. The effect of spacing on lentil growth was more pronounced in 45 cm x 10 cm (S_2)

compared to 30 cm x 10 cm (S_1). While S_1 showed a higher plant population at 20 DAS (556.67), S_2 exhibited better growth parameters, including plant height (29.49 cm at 45 DAS), which was 3.52% higher than S_1. The wider spacing in 45 cm x 10 cm (S_2) provided more room for plant growth, enhancing vegetative development, root expansion, and ultimately, plant height. Additionally, S2 resulted in better nodulation and overall vegetative growth. However, S_1 (closer spacing) led to higher plant density, which may have resulted in increased competition for resources, potentially affecting plant growth and quality.

The effect on phenological parameters showed that S_2 (45 cm x 10 cm) resulted in 60.08 days to 50% flowering, which was 3.21% longer than S_1 (59.14 days), indicating that wider spacing promotes better growth but slightly delays flowering. In terms of dry matter accumulation, S_2 (45 cm x 10 cm) recorded the highest value at 3.12 g per plant at 45 DAS, which was 3.68% higher than S_1 (30 cm x 10 cm). Additionally, the number of branches at maturity was higher in S_2 (11.04 branches), showing a 4.98% increase over S_1 (10.58 branches). These results suggest that wider spacing (S_2) allows better growth and development, leading to improved dry matter accumulation and branch formation. Superior plant growth at higher plant geometry may be ascribed to relatively lesser inter plant competition for moisture, soil nutrients and light interception. The effects also indicate that at higher plant geometry assimilates supplies to an individual plant was sufficiently high to sustain numerous vegetable sink. The present result is in close conformity with Singh and Singh (2014) [19], Khourgami *et al.* (2012) [7], Seyyed *et al.* (2014) [17] and Ouji *et al.* (2016) [9].

Effect of Genotypes

The data presented in Table 1 and 2 reveal that genotypes significantly influenced plant height, days to 50% flowering, days to maturity, number of branches per plant at maturity, and dry matter accumulation (g per plant). However, plant population showed a non-significant effect on plant stand at both 20 DAS and the maturity stage of lentil. Among the two lentil genotypes, DPL-62 (G_2) performed better across most parameters compared to KM-3 (G_1). The plant population in DPL-62 (G_2) was 463.33, which was 2.62% higher than KM-3 (G_1). At 45 DAS, DPL-62 (G_2) had a plant height of 29.34 cm, which was 3.19% higher than KM-3 (G_1), translating to better growth in terms of vegetative development. DPL-62 (G2) also flowered earlier, reaching 50% flowering in 59.78 days, which was 0.36% earlier than KM-3 (G_1). Additionally, DPL-62 (G_2) reached maturity faster, with 102.33 days, 0.76% earlier than KM-3 (G_1). These results suggest that DPL-62 (G_2) is better suited for higher yield and earlier maturity, making it a more efficient genotype for cultivation under the study conditions.

Regarding growth and dry matter accumulation, DPL-62 (G_2) exhibited superior performance compared to KM-3 (G_1). At maturity, DPL-62 (G_2) recorded 11.99 branches per plant, which was 3.39% higher than KM-3 (G_1). DPL-62 (G_2) also accumulated 9.15 g of dry matter per plant, a 3.24% increase over KM-3 (G_1). These results indicate that DPL-62 (G_2) is better suited for improved growth and higher yield under the given conditions. The growth attributes of lentil are significantly influenced by genotypes because each genotype possesses a distinct genetic potential that governs its growth behavior, physiology and adaptability to environmental conditions. Variations in plant height, branching pattern, leaf area, and biomass accumulation among genotypes arise due to differences in their genetic makeup, which determine their ability to utilize available resources efficiently and express superior growth performance under given conditions. The present result is in close conformity with Hamdi *et al.* (2004) [5] and Tariq *et al.* (2015) [25].

Table 1: Effect of fertilizer levels, spacing and genotypes on growth and phenological parameters of lentil

Treatments	Plant Population plot^{-1}		Plant height (cm)			Phenological parameters	
	20 DAS	At Maturity	30 DAS	45 DAS	At Maturity	Days to 50 % flowering	Days to taken maturity
Fertilizer Levels (F)							
F_2: Control	427.50	454.72	11.91	23.99	36.37	49.47	83.66
F_2: 50% RDF	455.00	481.53	15.20	30.53	46.43	62.38	106.78
F_3: 100% RDF	489.99	515.64	15.88	31.99	48.50	65.17	111.55
Sem ±	29.87	29.11	1.8	0.22	0.40	0.54	0.92
C.D (p=0.05)	NS	NS	NS	0.60	1.11	1.49	2.55
Spacing (S)							
S_1: 30 cm x 10 cm	556.67	580.63	14.02	28.18	42.82	59.14	101.01
S_2: 45 cm x 10 cm	358.33	387.29	14.64	29.49	44.72	60.08	102.13
Sem ±	9.64	9.40	0.29	0.18	0.28	0.54	0.65
C.D (p=0.05)	NS	NS	NS	0.39	0.58	NS	NS
Genotypes (G)							
G_1: KM-3	451.67	478.28	14.10	28.33	43.04	58.23	99.00
G_2: DPL-62	463.33	489.65	14.57	29.34	44.49	59.78	102.33
Sem ±	9.64	9.40	0.29	0.18	0.28	0.36	0.63
C.D (p=0.05)	NS	NS	NS	0.39	0.58	0.76	1.33

Table 2: Effect of fertilizer levels, spacing and genotypes on nnumber of branches plant^{-1} and dry matter accumulation of lentil

Treatments	Number of Branches plant^{-1} at maturity	Dry matter accumulation (g plant^{-1})		
		30 DAS	45 DAS	At Maturity
Fertilizer Levels (F)				
F_2: Control	8.98	0.98	2.54	7.48
F_2: 50% RDF	11.47	1.25	3.24	9.55
F_3: 100% RDF	11.98	1.31	3.39	9.98
SEm±	0.28	0.004	0.03	0.08
C.D (p=0.05)	0.1	0.015	0.07	0.23
Spacing (S)				
S_1: 30 cm x 10 cm	10.58	1.15	2.99	8.81
S_2: 45 cm x 10 cm	11.04	1.21	3.12	9.20
SEm±	0.14	0.01	0.02	0.06
C.D (p=0.05)	0.07	0.02	0.04	0.12
Genotypes (G)				
G_1: KM-3	10.63	1.16	3.01	8.85
G_2: DPL-62	10.99	1.20	3.11	9.15
SEm±	0.14	0.01	0.02	0.06
C.D (p=0.05)	0.07	0.02	0.04	0.12

Conclusion
Based on the one-year field study, it can be concluded that the combination of 100% RDF, 45 cm x 10 cm spacing, and DPL-62 genotype was the most effective for promoting higher growth parameters in lentil. 100% RDF enhanced plant height, flowering, maturity, branches, and dry matter accumulation, improving overall productivity. DPL-62 showed better growth, earlier flowering and faster maturity, while 45 cm x 10 cm spacing reduced competition for resources, supporting better plant development.

Future Prospects
Future prospects include exploring the long-term impact of 100% RDF on soil health, testing the DPL-62 genotype under different environmental conditions and optimizing spacing for better resource utilization. Integrating precision farming and sustainable irrigation practices will enhance water use efficiency and productivity, promoting more resilient and efficient lentil farming.

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