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Performance of tree canopy architecture of bael (*Aegle marmelos* L. Correa) on leaf traits under rainfed condition of Central India

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Abstract
The field study was carried out at Central Research Farm of the ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, during 2023-24 and 2024-25 in a 15-year-old Bael orchard. The study was carried out in factorial randomized block design with two varieties (V_1: CISHB-2 and V_2: NB-9) and four canopy architectures (C_1: Central leader system, C_2: Modified leader system, C_3: Open centre system and C_4: Untrained system). The results indicated that cultivar CISHB-2 recorded larger leaf area (95.63 cm^2) and fresh leaf weight (3.46 g), whereas NB-9 was superior in terms of leaf chlorophyll content (53.57 SPAD). The Open Center System performed better with higher fresh leaf weight (3.67 g), leaf moisture content (72.33%), leaf area (103.76 cm^2), and leaf chlorophyll content (58.66 SPAD unit) compared to Untrained trees. Overall, results indicated that trees with the Open Centre System canopy architecture improved leaf weight, moisture, area, and chlorophyll content.

Keywords: Bael (*Aegle marmelos*), canopy architecture, leaf weight, moisture, leaf area and chlorophyll

Introduction
One of the most significant underutilized native fruit crop of India is bael (*Aegle marmelos*). Its fruit is well known as “Amrit Phal”, and is well liked for its nutritional and medicinal qualities. A wide range of illness, including diarrhea, dysentery, malaria, fever, jaundice cancer, ulcers, and urticaria are treated with medicines in the Ayurvedic and Siddha systems (Venudevan and Srimathi, 2013) [1]. The ripe fruits are sweet, astringent, and aromatic, which help in skin regeneration, act as a coolant, laxative, febrifuge, and are beneficial for the heart, brain, and dyspepsia (Raju *et al.*, 2014) [2]. It is mostly grown close to temples because of its mythological significance. It can be grown with ease on eroded soils and in unfavorable climates where other fruit crops can’t be grown (Kumar *et al.*, 1994) [3]. There is no precise data on production and acreage. However, according to Singh *et al.* (2018) [4], approximately 1,000 hectares of bael cultivation existed in 2008. The country has produced about 70000 tonnes of fruits with the development of improved cultivars like Goma Yashi, NB-5, NB-9 and CISHB-2 which have increased the acreage of bael cultivation (Singh *et al.*, 2021) [5]. The bael gene pool varies greatly in both qualitative and quantitative characteristics and is dispersed across the country. The bael cultivars varied in morphological characteristics such as leaf weight, size, shape and chlorophyll content (Nagar *et al.*, 2018) [6]. The photosynthesis of a tree strongly depends on the light, plant training, which determines the ratio and spatial distribution of the various shoot categories, including vegetative versus fruiting shoots (Lakso, 1980) [7]. According to Taiz and Zeiger (2010) [8], leaves with a larger surface area tend to absorb more sunlight, which boosts biomass growth and chlorophyll activity. Chlorophyll is a crucial component of photosynthesis in plants. According to Wang *et al.* (2024) [17], the enzyme light-dependent protochlorophyllide oxidoreductase (LPOR) is essential to the process of chlorophyll production.
The suitable canopy architecture is important for improved tree performance. Unmanaged trees show excessive vegetative growth and reduced photosynthetically active radiation,

which negatively impact production and fruit quality. Therefore, this study was undertaken to assess the effect of tree canopy architecture on leaf attributes in bael (*Aegle marmelos* L. Correa).

Materials and Methods

Experimental Site: The study was carried out at Central Research Farm of the ICAR-Indian Grassland and Fodder Research Institute in Jhansi, Uttar Pradesh, which is located at latitude 24º11′-26º27′ N and longitude 78º17′-81º34′ at about 275 m above mean sea level. Geologically, it is part of the Bundelkhand region of central India, which is distinguished by an extreme climate, barren soil, and severe drought. This tract contains basic igneous intrusions and rocks with highly ferruginous beds, such as granites and gneisses. Bundelkhand is a semi-arid, subtropical region that experiences harshly hot summers and cold winters. The Southwest monsoon season runs from July to September. The average annual rainfall of this area is 850.1 mm. The region has a sub-humid climate marked by a hot dry summer and cold winter. About 91% of rainfall occurs between June and September. Frequent droughts in the Bundelkhand region are a result of the unpredictable rainfall patterns of this region.

Plant Materials: The experiment was carried out during 2023-24 and 2024-25 in a 15 years old bael orchard with uniform, healthy, insect, pest and disease free two cultivars (CISHB-2 and NB-9). The bael plant was planted at 6 m apart in the year of 2008. A total of seventy-two uniform, healthy, insect, pest, and disease-free trees were marked for study. Initially, the orchard was grown naturally without any training or pruning. Later the experimental trees were pruned according to different types of canopy architecture, i.e., central leader system, modified leader system, open centre system and untrained system.

Treatments: This experiment conducted under factorial randomized block design which consist two factors (Factor A: Variety and factor B: Canopy architecture) with three replications. Factor A had two varieties (V_1: CISHB-2 and V_2: NB-9) and factor B had four canopy architectures (C_1: Central leader system, C_2: Modified leader system, C_3: Open centre system and C_4: Untrained system). This experiment was composed total 8 treatment combinations i.e., T_1: V_1C_1 (CISHB-2 + Central leader system), T_2: V_2C_1 (NB-9 + Central leader system), T_3: V_1C_2 (CISHB-2 + Modified leader system), T_4: V_2C_2 (NB-9 + Modified leader system), T_5: V_1C_3 (CISHB-2 + Open centre system), T_6: V_2C_3 (NB-9 + Open centre system), T_7: V_1C_4 (CISHB-2 + Untrained system) and T_8: V_2C_4 (NB-9 + Untrained system). In each treatment three trees of each cultivars were selected with similar tree growth. Each replication contain 24 trees and total 72 tress were marked for study. The different parmeters were recorded from marked trees.

Data Collection

In last week of November, randomly chosen leaves from each direction of the middle and lower canopy portion of the plant were measured for chlorophyll content using a SPAD-502 meter across all treatments. The leaf area was measured with the help of Biovis digital leaf area meter Model PSM-L3000, 5 trifoliate leaves were taken to record leaf area, and the average value was expressed in square centimeters. A digital weighing balance was used to obtain fresh leaf weight and expressed in grams. The leaf samples were placed in the brown paper bags and kept in the oven at 60 °C for 48 hours to get the constant leaf dry weight. Leaf moisture content was measured using the following formula and expressed as a percentage.

$$\text{Moisture (\%)} = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Fresh weight})} \times 100$$

Statistical Analysis: The recorded data were statistically analyzed using ANOVA, and the significance was tested by the least significant difference test at a 5 percent level of significance.

Results and Discussion

Fresh and Dry Leaf Weight (g)

The fresh leaf weight was influenced with cultivars. Table 1 revealed that the cultivar CISHB-2 (3.53v g, 3.39 g and 3.46 g in 2023-24, 2024-25 and in pooled data, respectively) showed significantly higher fresh leaf weight than NB-9 (3.42 g, 3.30 g and 3.36 g in 2023, 2024 and pooled value, respectively). Varietal variation in leaf characters seems to be a genetic trait of a variety. Among the canopy architectures, Open center system (3.74 g in 2023, 3.61 g in 2024 and 3.67 g in pooled analysis) exhibited significantly higher fresh leaf weight and lower in untrained system (3.20 g in 2023, 3.07 g in 2024 and 3.13 g in pooled analysis). Tree canopy architecture significantly influenced dry leaf weight during both consecutive years of experiments and pooled analysis (Table 1). The higher dry leaf weight was recorded in Modified leader system during both consecutive years and pooled data (1.02 g in 2023-24, 1.04 g in 2024-25 and 1.03 g in pooled data, respectively) compared to the other canopy architecture systems.

The CISHB-2 had a higher fresh leaf weight than NB-9, which might be due to the genotypic characteristics of the variety and adaptation to agroclimatic conditions. Nagar *et al.* (2018) [6] also reported variation in leaf weight in different genotypes of Bael. In the present investigation, canopy architecture significantly affected leaf weight. It might be due to greater light penetration and enhanced air circulation within the plant canopy, encouraged by the Open-Center canopy architecture system, which increased photosynthetic activity and overall leaf growth. On the other hand, untrained trees had a dense canopy that restricted light penetration and reduced photosynthetic activity, limiting the ability of leaves to grow fully and accumulate fresh weight.

Leaf Moisture Content

Canopy architectures significantly affected leaf moisture content. The Open Centre System recorded significantly higher leaf moisture content (Table 1) during both consecutive years and pooled data (73.43% in 2023-24, 71.22% in 2024-25 and 72.33% in pooled data, respectively) compared to Untrained trees.

The Open Center System had higher leaf moisture content might be attributed to its higher leaf area. Pangano *et al.* (2019) reported a strong correlation between leaf surface area with the leaf water mass for all the studied species (*Corylus avellana* L., *Ostrya carpinifolia* Scop. and *Vitis vinifera* L.). Hughes *et al.* (1970) [10] also found linear function with leaf area and leaf water content and also reported that morphologically dissimilar leaves had different specific leaf water contents (water/dry matter).

Leaf Area (cm^2)

The leaf area significantly influenced with cultivars and canopy architectures. The Figure 1 showed that in year 2023-24, cultivar CISHB-2 recorded significantly higher leaf area (97.21 cm^2) as compared to NB-9 (92.14 cm^2). Among the canopy architectures, open center system exhibited significantly maximum leaf area (105.93 cm^2) followed by modified leader system (98.37 cm^2). The interactive effect also showed significantly higher leaf area in V_1C_3 (114.62 cm^2) than other combinations. Similar trend was also noticed in second year, cultivar CISHB-2 showed significantly higher leaf area (94.05 cm^2) than NB-9 (86.80 cm^2). Among canopy architectures, Open center system exhibited significantly maximum leaf area (101.59 cm^2) and modified leader system (94.70 cm^2) was statistically at par. However, untrained system exhibited significantly lower leaf area (80.12 cm^2) than trained systems. The interactive effect showed significantly higher in V_1C_3 (111.28 cm^2) as compared to other combinations. The pooled analysis revealed significantly maximum leaf area in CISHB-2 (95.63 cm^2) than NB-9 (89.47 cm^2). Open center system (103.76 cm^2) recorded significantly higher leaf area than untrained system and V_1C_3 (112.95 cm^2) recorded significant increase in leaf area than V_1C_4 (80.14 cm^2).

The cultivars CISHB-2 recorded higher leaf area than NB-9. It might be due to the variation agroclimatic condition and inherent characteristics of cultivar. Patil *et al.* (2025) [11] also found that leaf area had significant difference among the evaluated mango cultivars. Bhawna and Misra (2011) [12], observed maximum (144.20 cm²) leaf area in Pant Vishal, whereas it was minimum (35.75 cm^2) in Pant Bael-10. Nicotra *et al.* (2011) [13] reported the leaf shapes can differ in association with variation in other leaf traits due to different climatic factors. Vasconcelos and Castagnoli (2000) [14] also noted that the removal of shoots by pruning supported to increasing leaf area. Yilmaz *et al.* (2023) [15] noted that leaf area influenced Individually and interactive with different training systems as well as root stock in sweet cherry.

Leaf Chlorophyll

The leaf chlorophyll content significantly influenced with cultivars, canopy architectures and their interaction too. Leaf chlorophyll content (Table 1) showed that in 2023-24, cultivar NB-9 (54.61 SPAD unit) showed significantly higher chlorophyll content than CISHB-2 (51.59 SPAD unit). The Open center system (58.66 SPAD unit) recorded significantly higher leaf chlorophyll content followed by Modified leader system (55.48 SPAD unit) and lowest chlorophyll content exhibited in Untrained system (46.88 SPAD unit). Interactive effect V_2C_3 (59.67 SPAD unit) had significant higher leaf chlorophyll content and was lower in V_1C_4 (43.87 SPAD unit). Similar trend was followed by second year of study. It was significantly maximum in cv. NB-9 (52.53 SPAD unit) and Open center system (58.65 SPAD unit). Interactive effect recorded significant impact on leaf chlorophyll content, it exhibited maximum in V_2C_3 (59.50 SPAD unit) and least in V_2C_4 (43.79 SPAD unit). Similarly, pooled analysis revealed significantly higher leaf chlorophyll content in cv. NB-9 (53.57 SPAD unit) followed by Open Center System (58.66 SPAD unit). The interactive effect of varieties and canopy architectures recorded significant impact.

Table 1: Effect of bael (*Aegle marmelos* L. Correa) tree canopy architecture on fresh leaf weight, dry leaf weight and moisture content of leaves.

Treatments	Fresh leaf weight (g)			Dry leaf weight (g)			Leaf moisture content (%)			Leaf chlorophyll content (SPAD)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Cultivars												
V_1	3.53^a	3.39^a	3.46^a	0.97^a	1.01^a	0.99^a	72.50^a	70.21^a	71.31^a	51.59^b	50.88^b	51.24^b
V_2	3.42^b	3.30^b	3.36^b	0.96^a	0.98^a	0.97^a	71.87^a	70.12^a	71.04^a	54.61^a	52.53^a	53.57^a
SE ± (m)	0.03	0.03	0.02	0.01	0.01	0.01	0.41	0.35	0.27	0.42	0.41	0.29
LSD ($p\leq0.05$)	0.08	0.08	0.05	NS	NS	NS	NS	NS	NS	1.26	1.26	0.85
Canopy architecture												
C_1	3.27^b	3.13^b	3.20^b	0.91^b	0.93^b	0.92^b	72.23^{ab}	70.10^a	71.16^b	51.40^c	48.81^c	50.10^c
C_2	3.70^a	3.58^a	3.64^a	1.02^a	1.04^a	1.03^a	72.44^a	70.89^a	71.66^{ab}	55.48^b	54.81^b	55.15^b
C_3	3.74^a	3.61^a	3.67^a	0.99^a	1.04^a	1.02^a	73.43^a	71.22^a	72.33^a	58.66^a	58.65^a	58.66^a
C_4	3.20^b	3.07^b	3.13^b	0.94^b	0.97^b	0.95^b	70.66^b	68.47^b	69.56^c	46.88^d	44.55^d	45.71^d
SE ± (m)	0.04	0.05	0.03	0.02	0.01	0.01	0.58	0.50	0.39	0.59	0.59	0.41
LSD ($p\leq0.05$)	0.11	0.15	0.07	0.05	0.04	0.03	1.77	1.53	1.12	1.78	1.78	1.20
Cultivars × Canopy architecture												
V_1C_1	3.32^a	3.17^a	3.25^a	0.94^a	0.93^a	0.94^a	71.72^a	70.44^a	71.08^a	49.87^e	47.52^e	48.70^e
V_1C_2	3.77^a	3.65^a	3.71^a	1.03^a	1.07^a	1.05^a	72.79^a	70.69^a	71.74^a	54.98^{cd}	52.88^c	53.93^c
V_1C_3	3.83^a	3.68^a	3.75^a	1.00^a	1.06^a	1.03^a	73.81^a	71.10^a	72.46^a	57.65^{ab}	57.81^{ab}	57.73^b
V_1C_4	3.19^a	3.07^a	3.13^a	0.90^a	0.97^a	0.94^a	71.70^a	68.26^a	69.98^a	43.87^f	45.31^{ef}	44.59^g
V_2C_1	3.21^a	3.08^a	3.14^a	0.88^a	0.93^a	0.91^a	72.73^a	69.75^a	71.24^a	52.92^d	50.10^d	51.51^d
V_2C_2	3.62^a	3.50^a	3.56^a	1.01^a	1.01^a	1.01^a	72.08^a	71.08^a	71.58^a	55.98^{bc}	56.74^b	56.36^b
V_2C_3	3.66^a	3.54^a	3.60^a	0.98^a	1.01^a	1.00^a	73.04^a	71.35^a	72.19^a	59.67^a	59.50^a	59.59^a
V_2C_4	3.19^a	3.07^a	3.13^a	0.97^a	0.96^a	0.96^a	69.63^a	68.67^a	69.15^a	49.88^e	43.79^f	46.84^f
SE ± (m)	0.05	0.05	0.04	0.02	0.02	0.02	0.83	0.71	0.55	0.83	0.82	0.59
LSD ($p\leq0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.52	2.51	1.67

Note: Mean data with different letters show significant differences at ($p\leq0.05$) among the treatments

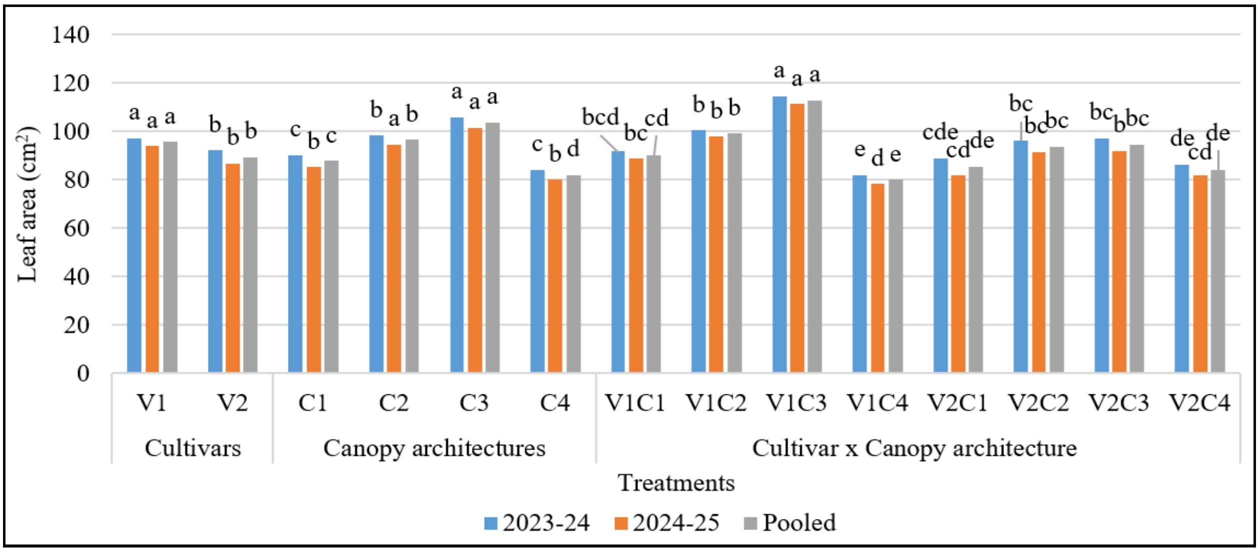

Fig. 1: Effect of cultivars and tree canopy architecture of bael on leaf area

Cultivar NB-9 showed higher leaf chlorophyll content than CISHB-2, might be due to the genotype of cultivar and their interaction with environment. Patil *et al.* (2025) [11] also noted that leaf chlorophyll had significant difference among the evaluated mango cultivars. Ali *et al.* (2023) [16] also reported that leaf chlorophyll content differed in different cultivars of apple. Open Center System recorded significantly higher chlorophyll content than untrained trees. Improvement in chlorophyll content may be due to openness of canopy that optimizes the penetration of light within the inner part of canopy that support to maximum production of chlorophyll. Wang *et al.* (2024) [17] also explained that chlorophyll production process, light-dependent protochlorophyllide oxidoreductase (LPOR) is a key enzyme in the chlorophyll biosynthesis pathway, catalyzing the conversion of Pchlide to Chlide. In photosynthetic organisms, the existence of various forms of LPOR guarantees the effective synthesis of chlorophyll during the dark-light transition. Feng *et al.* (2019) [18] reported that as light intensity increased, leaf chlorophyll, cytochrome content, net photosynthetic rate, and chlorophyll fluorescence also increased.

Conclusion

In the present investigation, the varietal performance for leaf traits was superior in the CISHB-2 cultivar, while the Open Center System performed better among the canopy architecture systems.

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