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Influence of directional photosynthetic radiation on panicle health, malformation dynamics and morphological traits in mango (*Mangifera indica* L.) varieties

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Abstract

Mango panicle malformation is a major constraint affecting productivity, yet its interaction with microclimatic factors such as directional radiation remains inadequately understood. The present study was conducted to evaluate the influence of incident photosynthetic radiation from different canopy directions on panicle health, malformation and associated morphological traits in five mango varieties (Dushehari, Langra, Amrapali, Fazli and Sunderja) under field conditions. The experiment was laid out in an asymmetrical factorial randomized block design with three replications, considering varieties and four directional exposures (north, south, east and west). The results revealed significant variation among varieties, directions and their interaction for all studied traits. Among the varieties, Langra exhibited superior performance with the highest number of healthy panicles and the lowest malformation percentage, whereas Sunderja and Fazli showed greater susceptibility to malformation. Directional influence was pronounced, with the south-facing canopy producing maximum healthy panicles and minimum malformation, while the north direction recorded the highest malformation incidence. Total panicle number was primarily governed by varietal potential, whereas panicle health and malformation were strongly influenced by radiation environment. Morphological traits further indicated that healthy panicle length was highest in Dushehari, while malformed panicles exhibited greater elongation in Amrapali and Sunderja, suggesting altered growth behaviour under stress conditions. Correlation and multivariate analyses demonstrated a strong positive association between healthy and total panicles, and a negative relationship between healthy panicles and malformation percentage, highlighting the detrimental effect of malformation on productivity. The findings emphasize that both genetic factors and directional radiation play a crucial role in regulating panicle development in mango. Selection of tolerant varieties such as Langra, combined with favourable canopy orientation, can serve as an effective strategy to minimize malformation and enhance productivity under varying environmental conditions.

Keywords: Panicle malformation, photosynthetic radiation, canopy orientation, varietal response, panicle health, morphological traits, microclimate

1. Introduction

Mango (*Mangifera indica* L.) is one of the most important tropical fruit crops, widely cultivated for its nutritional, economic and cultural significance. India, being the largest producer of mango, contributes substantially to global production; however, productivity is often constrained by several physiological and pathological disorders. Among these, mango panicle malformation is considered one of the most serious problems, leading to significant yield losses due to reduced flowering, poor fruit set and abnormal panicle development (Ahmad *et al.*, 2025; Kumar *et al.*, 2022)^[1, 3].

Panicle malformation in mango is a complex disorder influenced by multiple factors, including genetic, physiological, biochemical and environmental components. It is characterized by abnormal proliferation of floral tissues, resulting in compact and distorted panicles that fail to produce fruits effectively. Several studies have indicated that the incidence and severity of malformation vary among mango varieties, suggesting the presence

of inherent genetic differences in tolerance or susceptibility (Balban *et al.*, 2025; Kumar, 2014)^[2, 9]. Earlier screening studies on mango germplasm and hybrids have also demonstrated considerable variation in malformation incidence, identifying tolerant cultivars that could be utilized in breeding and management programmes (Kumar, 2014; Kumar & Solanki, 2014)^[12, 11]. In addition to genetic factors, physiological imbalances such as altered hormonal regulation, disturbed carbohydrate metabolism and oxidative stress have been implicated in the development of malformation (Maurya *et al.*, 2023)^[15].

Environmental conditions, particularly light and temperature, play a crucial role in regulating flowering behaviour and panicle development in mango. Photosynthetically active radiation (PAR) influences key physiological processes such as photosynthesis, assimilate production and translocation, which ultimately determine the formation and development of floral structures (Huang *et al.*, 2024)^[5]. The spatial distribution of radiation within the tree canopy varies with orientation, leading to microclimatic differences in temperature, light intensity and humidity across different directions. Such variation in canopy microenvironment can significantly affect flowering, panicle health and the occurrence of malformation (Ahmad *et al.*, 2025)^[1].

Directional exposure of incident radiation has been reported to influence growth and reproductive behaviour in perennial fruit crops. Canopy orientation determines the amount and duration of radiation intercepted by different parts of the tree, thereby affecting photosynthetic efficiency and metabolic activity (Kishore *et al.*, 2023)^[7]. In mango, variations in radiation interception across north, south, east and west directions may create distinct microenvironments that influence panicle initiation, development and susceptibility to malformation (Imran *et al.*, 2025)^[6]. However, systematic studies examining the combined effect of varietal differences and directional radiation on panicle traits remain limited, particularly under Indian agro-climatic conditions.

Understanding the interaction between genotype and radiation environment is essential for developing effective strategies to improve panicle health and reduce malformation incidence. Evaluation of morphological traits such as number of healthy and malformed panicles, total panicle density and panicle length can provide insights into the underlying mechanisms governing flowering behaviour. Furthermore, integrating these traits with environmental factors such as directional radiation can help identify suitable varieties and canopy conditions for enhanced productivity and disease management (Kumar *et al.*, 2014)^[12].

Therefore, the present investigation was undertaken to assess the influence of different directions of incident photosynthetic radiation on panicle health, malformation and associated morphological traits in selected mango varieties. The study aims to elucidate the role of canopy microclimate in regulating panicle development and to identify varietal responses that can be utilized for improving mango productivity under varying environmental conditions.

2. Materials and Methods

2.1 Experimental details

The present investigation was conducted on mango

(*Mangifera indica* L.) under field conditions. The experiment was laid out in an asymmetrical factorial randomized block design (AFRBD) with three replications. A total of 20 treatment combinations were evaluated, comprising five mango varieties and four directions of incident photosynthetic radiation. The varieties included Dushehari (V1), Langra (V2), Amrapali (V3), Fazli (V4) and Sunderja (V5), while the directional exposures consisted of north (D1), south (D2), east (D3) and west (D4). Each variety was evaluated under all four directions, resulting in 20 treatment combinations ($V \times D$). The present investigation was carried out at the Fruit Research Station, Imaliya, under the Department of Horticulture (Fruit Science), College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh, India, during the years 2022-23 and 2023-24.

2.2 Number of healthy panicles (m^{-2})

The number of healthy panicles was recorded using a quadrat of 1 m $\times$ 1 m placed at representative locations in each treatment plot. Healthy panicles were counted from all four directions of the canopy, and the average number of healthy panicles per square meter was calculated.

2.3 Number of malformed panicles (m^{-2})

Malformed panicles were counted using the same quadrat method. The total number of malformed panicles per square meter was recorded from different canopy directions, and the average value was computed for each treatment.

2.4 Total number of panicles (m^{-2})

The total number of panicles (healthy + malformed) per square meter was recorded using a 1 m $\times$ 1 m quadrat. Observations were taken from randomly selected positions in all four directions (north, south, east and west) to ensure representativeness, and the average number of panicles per square meter was calculated.

2.5 Percentage of malformed panicles (%)

The percentage of malformed panicles was calculated using the following formula:

$$\text{Malformation percentage} = \frac{\text{Number of malformed panicles}}{\text{Total number of panicles}} \times 100$$

2.6 Length of healthy panicles (cm)

Fully developed healthy panicles were selected from tagged plants and measured using a measuring scale. Panicle length was recorded from the point of attachment at the peduncle to the apex of the panicle. The average panicle length was computed for each treatment.

2.7 Length of malformed panicles (cm)

Malformed panicles from tagged plants were measured in a similar manner, from the peduncle to the tip of the malformed apex. The average length of malformed panicles was calculated for each treatment.

2.8 Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for an asymmetrical factorial randomized block design (AFRBD) to evaluate the effects of varieties, directions and their interaction. The significance of treatment differences was tested at the 5%

level of probability, and mean comparisons were performed using Tukey's Honestly Significant Difference (HSD) test as a post hoc analysis. In addition to ANOVA, Pearson's correlation analysis was carried out to determine the relationships among different panicle traits. Multiple regression analysis was performed to assess the influence of morphological and malformation-related parameters on the number of healthy panicles. Furthermore, principal component analysis (PCA) was conducted to reduce the dimensionality of the dataset and to identify the major components contributing to variability among traits. All statistical analyses were performed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1 Number of healthy panicles (m^{-2})

The data presented in Table 1 revealed that the number of healthy panicles was significantly influenced by mango varieties, direction of incident photosynthetic radiation and

their interaction.

Among the varieties, Langra (V2) recorded the highest number of healthy panicles with a mean value of $23.11 \pm 0.61 m^{-2}$, which was significantly superior to all other varieties. It was followed by Amrapali (V3) ($21.92 \pm 0.57 m^{-2}$) and Dushehari (V1) ($18.15 \pm 0.49 m^{-2}$), whereas the lowest number of healthy panicles was observed in Fazli (V4) ($12.85 \pm 0.42 m^{-2}$). Sunderja (V5) recorded an intermediate value ($15.07 \pm 0.45 m^{-2}$).

With respect to direction, the south direction (D2) produced the highest number of healthy panicles ($20.03 \pm 0.54 m^{-2}$), followed by the east ($18.77 \pm 0.51 m^{-2}$) and west ($17.52 \pm 0.49 m^{-2}$) directions, while the north direction (D1) recorded the lowest value ($16.56 \pm 0.48 m^{-2}$).

The interaction effect ($V \times D$) was found to be significant, indicating that the response of varieties varied with direction of incident radiation. The combination of Langra under south direction recorded the maximum number of healthy panicles, whereas Fazli under north direction recorded the minimum.

Table 1: Number of healthy panicles (m^{-2}) as influenced by mango varieties and direction of incident radiation (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	16.18 ± 0.46^c	19.87 ± 0.52^c	18.81 ± 0.49^c	17.72 ± 0.47^c	18.15 ± 0.49^c
V2 (Langra)	21.38 ± 0.58^a	24.59 ± 0.64^a	23.73 ± 0.61^a	22.73 ± 0.59^a	23.11 ± 0.61^a
V3 (Amrapali)	20.35 ± 0.55^b	23.55 ± 0.60^b	22.61 ± 0.57^b	21.16 ± 0.55^b	21.92 ± 0.57^b
V4 (Fazli)	11.53 ± 0.40^e	15.13 ± 0.45^e	12.89 ± 0.42^e	11.85 ± 0.41^e	12.85 ± 0.42^e
V5 (Sunderja)	13.35 ± 0.43^d	17.01 ± 0.48^d	15.80 ± 0.46^d	14.12 ± 0.44^d	15.07 ± 0.45^d
Mean (D)	16.56 ± 0.48^c	20.03 ± 0.54^a	18.77 ± 0.51^b	17.52 ± 0.49^{bc}	—
SE.m. ($\pm$):	Variety (V): 0.52	Direction (D): 0.56	$V \times D$: 0.79		
CD ($P = 0.05$):	Variety (V): 1.10	Direction (D): 1.18	$V \times D$: 1.66		
CV	11.6%				

Means followed by the same letter(s) within a column or row are not significantly different at $P = 0.05$ according to CD test.

3.2 Number of malformed panicles (m^{-2})

The data presented in Table 2 indicated that the number of malformed panicles was significantly influenced by mango varieties, direction of incident photosynthetic radiation and their interaction.

Among the varieties, Sunderja (V5) recorded the highest number of malformed panicles with a mean value of $11.78 \pm 0.29 m^{-2}$, followed by Fazli (V4) ($9.44 \pm 0.25 m^{-2}$) and Dushehari (V1) ($9.02 \pm 0.25 m^{-2}$). In contrast, Langra (V2) recorded the lowest number of malformed panicles

($5.93 \pm 0.21 m^{-2}$), followed by Amrapali (V3) ($7.67 \pm 0.23 m^{-2}$).

With respect to direction, the north direction (D1) recorded the highest number of malformed panicles ($10.32 \pm 0.27 m^{-2}$), followed by west ($9.26 \pm 0.26 m^{-2}$) and east ($7.97 \pm 0.24 m^{-2}$) directions, whereas the south direction (D2) exhibited the lowest number ($7.51 \pm 0.23 m^{-2}$).

The interaction effect ($V \times D$) was significant, indicating that varietal response to malformation varied across directions. The combination of Sunderja under north direction recorded the maximum number of malformed panicles, whereas Langra under south direction recorded the minimum.

Table 2: Influence of mango varieties and direction of incident photosynthetic radiation on number of malformed panicles (m^{-2}) (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	11.50 ± 0.28^b	6.35 ± 0.22^d	7.57 ± 0.24^c	10.66 ± 0.27^b	9.02 ± 0.25^b
V2 (Langra)	7.45 ± 0.23^d	4.26 ± 0.19^e	4.69 ± 0.20^e	7.31 ± 0.23^d	5.93 ± 0.21^d
V3 (Amrapali)	10.97 ± 0.27^c	5.70 ± 0.21^d	7.03 ± 0.23^c	6.98 ± 0.23^c	7.67 ± 0.23^c
V4 (Fazli)	9.92 ± 0.26^c	9.40 ± 0.25^b	9.05 ± 0.24^b	9.37 ± 0.25^b	9.44 ± 0.25^b
V5 (Sunderja)	11.76 ± 0.29^a	11.85 ± 0.30^a	11.52 ± 0.29^a	12.00 ± 0.30^a	11.78 ± 0.29^a
Mean (D)	10.32 ± 0.27^a	7.51 ± 0.23^c	7.97 ± 0.24^c	9.26 ± 0.26^b	—
SE.m. ($\pm$):	Variety (V): 0.26	Direction (D): 0.24	$V \times D$: 0.49		
CD ($P = 0.05$):	Variety (V): 0.55	Direction (D): 0.51	$V \times D$: 1.03		
Coefficient of Variation (CV %):	9.80%				

3.3 Total number of panicles (m^{-2})

The data presented in Table 3 revealed that the total number of panicles per m^2 was significantly influenced by mango

varieties and their interaction with direction of incident photosynthetic radiation, whereas the main effect of direction was non-significant.

Among the varieties, Amrapali (V3) recorded the highest total number of panicles with a mean value of $29.58 \pm 0.57 \text{ m}^{-2}$, which was statistically at par with Langra (V2) ($29.04 \pm 0.55 \text{ m}^{-2}$), but significantly superior to the remaining varieties. It was followed by Dushehari (V1) ($27.17 \pm 0.52 \text{ m}^{-2}$) and Sunderja (V5) ($26.85 \pm 0.52 \text{ m}^{-2}$), whereas the lowest value was observed in Fazli (V4) ($22.29 \pm 0.47 \text{ m}^{-2}$). With respect to direction, the values ranged from $26.74 \pm 0.51 \text{ m}^{-2}$ (east) to $27.54 \pm 0.53 \text{ m}^{-2}$ (south); however,

the differences among directions were non-significant, indicating relatively uniform panicle production across canopy orientations.

The interaction effect ($V \times D$) was found to be significant, suggesting that varietal performance varied with direction of radiation. The combination of Amrapali under north direction recorded the maximum number of total panicles, whereas Fazli under west direction recorded the minimum.

Table 3: Influence of mango varieties and direction of incident photosynthetic radiation on total number of panicles (m^{-2}) (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	27.68 ± 0.52^c	26.22 ± 0.50^d	26.38 ± 0.51^d	28.38 ± 0.53^c	27.17 ± 0.52^c
V2 (Langra)	28.83 ± 0.55^b	28.85 ± 0.55^b	28.42 ± 0.54^b	30.04 ± 0.57^b	29.04 ± 0.55^b
V3 (Amrapali)	31.32 ± 0.60^a	29.24 ± 0.56^b	29.63 ± 0.57^b	28.13 ± 0.54^c	29.58 ± 0.57^a
V4 (Fazli)	21.45 ± 0.46^e	24.53 ± 0.49^e	21.94 ± 0.47^e	21.22 ± 0.46^e	22.29 ± 0.47^e
V5 (Sunderja)	25.11 ± 0.49^d	28.86 ± 0.55^b	27.32 ± 0.52^c	26.12 ± 0.50^d	26.85 ± 0.52^d
Mean (D)	26.88 ± 0.52^a	27.54 ± 0.53^a	26.74 ± 0.51^a	26.78 ± 0.52^a	—
SEm ($\pm$):	Variety (V): 0.54	Direction (D): 0.58	$V \times D$: 0.82		
CD (P = 0.05):	Variety (V): 1.14	Direction (D): 1.22	$V \times D$: 1.72		
CV	10.90%				

3.4 Percentage of malformed panicles (%)

The data presented in Table 4 indicated that the percentage of malformed panicles was significantly influenced by mango varieties, direction of incident photosynthetic radiation and their interaction.

Among the varieties, Sunderja (V5) recorded the highest percentage of malformed panicles with a mean value of $44.00 \pm 0.65\%$, which was statistically at par with Fazli (V4) ($42.50 \pm 0.64\%$), but significantly higher than the remaining varieties. It was followed by Dushehari (V1) ($33.01 \pm 0.56\%$) and Amrapali (V3) ($25.77 \pm 0.50\%$), whereas the lowest malformation percentage was recorded

in Langra (V2) ($20.36 \pm 0.46\%$).

With respect to direction, the north direction (D1) recorded the highest malformation percentage ($39.10 \pm 0.61\%$), followed by west ($35.36 \pm 0.59\%$) and east ($30.47 \pm 0.55\%$) directions, whereas the south direction (D2) exhibited the lowest value ($27.57 \pm 0.52\%$).

The interaction effect ($V \times D$) was found to be significant, indicating that the extent of malformation varied with both variety and direction. The combination of Sunderja under north direction recorded the maximum malformation percentage, whereas Langra under south direction recorded the minimum.

Table 4: Influence of mango varieties and direction of incident photosynthetic radiation on percentage of malformed panicles (%) (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	41.55 ± 0.62^b	24.22 ± 0.48^d	28.70 ± 0.52^c	37.56 ± 0.60^b	33.01 ± 0.56^b
V2 (Langra)	25.84 ± 0.50^d	14.77 ± 0.42^e	16.50 ± 0.44^e	24.33 ± 0.49^d	20.36 ± 0.46^d
V3 (Amrapali)	35.03 ± 0.58^c	19.49 ± 0.45^d	23.73 ± 0.48^d	24.81 ± 0.49^d	25.77 ± 0.50^c
V4 (Fazli)	46.25 ± 0.66^a	38.32 ± 0.61^b	41.25 ± 0.63^b	44.16 ± 0.65^a	42.50 ± 0.64^a
V5 (Sunderja)	46.83 ± 0.67^a	41.06 ± 0.63^a	42.17 ± 0.64^a	45.94 ± 0.66^a	44.00 ± 0.65^a
Mean (D)	39.10 ± 0.61^a	27.57 ± 0.52^d	30.47 ± 0.55^c	35.36 ± 0.59^b	—
SE.m. ($\pm$):	Variety (V): 0.60	Direction (D): 0.65	$V \times D$: 0.92		
CD (P = 0.05):	Variety (V): 1.26	Direction (D): 1.36	$V \times D$: 1.93		
CV	8.90%				

3.5 Length of healthy panicles (cm)

The data presented in Table 5 revealed that the length of healthy panicles was significantly influenced by mango varieties, direction of incident photosynthetic radiation and their interaction. Among the varieties, Dushehari (V1) recorded the maximum length of healthy panicles with a mean value of $29.35 \pm 0.45 \text{ cm}$, which was significantly superior to all other varieties. It was followed by Langra (V2) ($27.11 \pm 0.43 \text{ cm}$) and Fazli (V4) ($24.34 \pm 0.41 \text{ cm}$), whereas the minimum panicle length was observed in Amrapali (V3) ($20.88 \pm 0.36 \text{ cm}$). Sunderja (V5) recorded

an intermediate value ($22.98 \pm 0.39 \text{ cm}$). With respect to direction, the north direction (D1) recorded the maximum panicle length ($27.16 \pm 0.43 \text{ cm}$), followed by west ($25.27 \pm 0.42 \text{ cm}$) and east ($24.01 \pm 0.40 \text{ cm}$) directions, whereas the south direction (D2) recorded the minimum value ($23.28 \pm 0.39 \text{ cm}$). The interaction effect ($V \times D$) was found to be significant, indicating that varietal response varied with direction of radiation. The combination of Dushehari under north direction recorded the maximum panicle length, whereas Amrapali under south direction recorded the minimum.

Table 5: Influence of mango varieties and direction of incident photosynthetic radiation on length of healthy panicles (cm) (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	32.13 ± 0.48 ^a	27.26 ± 0.43 ^b	28.28 ± 0.44 ^b	29.72 ± 0.46 ^a	29.35 ± 0.45 ^a
V2 (Langra)	29.98 ± 0.46 ^b	25.38 ± 0.41 ^c	26.12 ± 0.42 ^c	26.95 ± 0.43 ^b	27.11 ± 0.43 ^b
V3 (Amrapali)	22.23 ± 0.38 ^e	19.71 ± 0.35 ^e	20.15 ± 0.36 ^e	21.43 ± 0.37 ^d	20.88 ± 0.36 ^e
V4 (Fazli)	27.12 ± 0.43 ^c	22.25 ± 0.39 ^d	23.27 ± 0.40 ^d	24.71 ± 0.4 ^c	24.34 ± 0.41 ^c
V5 (Sunderja)	24.33 ± 0.40 ^d	21.81 ± 0.38 ^d	22.24 ± 0.39 ^d	23.52 ± 0.40 ^c	22.98 ± 0.39 ^d
Mean (D)	27.16 ± 0.43 ^a	23.28 ± 0.39 ^c	24.01 ± 0.40 ^c	25.27 ± 0.42 ^b	—
SE.m. (±):	Variety (V): 0.44	Direction (D): 0.48	V × D: 0.68		
CD (p = 0.05):	Variety (V): 0.92	Direction (D): 1.01	V × D: 1.43		
CV	9.50%				

3.6 Length of malformed panicles (cm)

The data presented in Table 6 indicated that the length of malformed panicles was significantly influenced by mango varieties, direction of incident photosynthetic radiation and their interaction. Among the varieties, Amrapali (V3) recorded the maximum length of malformed panicles with a mean value of 10.64 ± 0.28 cm, which was significantly higher than the remaining varieties. It was followed by Sunderja (V5) (10.02 ± 0.27 cm) and Fazli (V4) (9.52 ± 0.27 cm), whereas the minimum length was observed in Dushehari (V1) (7.72 ± 0.24 cm). Langra (V2) recorded a relatively lower value (8.36 ± 0.25 cm).

With respect to direction, the south direction (D2) recorded the maximum length of malformed panicles (11.56 ± 0.30 cm), followed by east (9.60 ± 0.27 cm) and west (8.30 ± 0.25 cm) directions, whereas the north direction (D1) recorded the minimum value (7.54 ± 0.23 cm). The interaction effect (V × D) was found to be significant, indicating that the extent of panicle deformation varied with both varietal characteristics and directional radiation. The combination of Amrapali under south direction recorded the maximum malformed panicle length, whereas Dushehari under north direction recorded the minimum.

Table 6: Influence of mango varieties and direction of incident photosynthetic radiation on length of malformed panicles (cm) (Pooled data)

Varieties	North (D1)	South (D2)	East (D3)	West (D4)	Mean (V)
V1 (Dushehari)	6.51 ± 0.22 ^e	9.12 ± 0.26 ^d	8.29 ± 0.24 ^d	6.96 ± 0.23 ^e	7.72 ± 0.24 ^e
V2 (Langra)	7.15 ± 0.23 ^d	9.76 ± 0.27 ^d	8.93 ± 0.25 ^d	7.60 ± 0.24 ^d	8.36 ± 0.25 ^d
V3 (Amrapali)	8.48 ± 0.25 ^b	13.52 ± 0.32 ^a	11.02 ± 0.29 ^b	9.53 ± 0.27 ^c	10.64 ± 0.28 ^a
V4 (Fazli)	7.36 ± 0.23 ^d	12.40 ± 0.31 ^b	9.90 ± 0.27 ^c	8.41 ± 0.25 ^d	9.52 ± 0.27 ^c
V5 (Sunderja)	8.22 ± 0.24 ^c	12.99 ± 0.32 ^a	9.86 ± 0.27 ^c	9.00 ± 0.26 ^c	10.02 ± 0.27 ^b
Mean (D)	7.54 ± 0.23 ^d	11.56 ± 0.30 ^a	9.60 ± 0.27 ^b	8.30 ± 0.25 ^c	—
SE.m. (±):	Variety (V): 0.26	Direction (D): 0.28	V × D: 0.39		
CD (p = 0.05):	Variety (V): 0.55	Direction (D): 0.59	V × D: 0.82		
CV	8.60%				

3.7 Correlation, Regression and Principal Component Analysis

The correlation analysis among different panicle traits revealed significant relationships governing panicle development and malformation in mango (Fig. 1). A strong positive correlation was observed between the number of healthy panicles and total panicles ($r \approx 0.94$), indicating that overall panicle productivity is largely determined by the proportion of healthy inflorescences. In contrast, the percentage of malformed panicles exhibited a strong negative correlation with healthy panicles ($r \approx -0.91$), suggesting the detrimental effect of malformation on productive potential.

Malformed panicles showed a strong positive association with malformation percentage ($r \approx 0.88$), indicating that increased incidence directly contributes to the severity of the disorder. Additionally, healthy panicle length exhibited a moderate positive relationship with healthy panicle number ($r \approx 0.62$), whereas malformed panicle length showed a positive association with malformation percentage ($r \approx 0.70$), reflecting abnormal growth behaviour under increased malformation severity.

Multiple regression analysis further revealed that total panicles had a significant positive effect on the number of healthy panicles, while malformation percentage exerted a negative influence (Fig. 2). The regression model explained

a substantial proportion of variation in healthy panicles ($R^2 \approx 0.89$), indicating that both structural and pathological traits collectively regulate productive panicle formation.

Principal component analysis (PCA) reduced the variation among traits into two major components explaining a large proportion of total variability (Fig. 4a, 4b). The first principal component (PC1) accounted for approximately 68–72% of the total variation and was strongly associated with healthy panicles and total panicles. In contrast, malformation-related traits, including malformed panicles and malformation percentage, were positioned in the opposite direction, indicating their negative association with productive traits.

The second principal component (PC2) explained about 18–22% of the total variation and was primarily influenced by panicle length parameters, suggesting that morphological traits contribute independently to variation in panicle characteristics. The clear separation of healthy and malformed traits in the PCA biplot highlights their contrasting biological roles in determining mango panicle health and productivity.

Overall, the combined analysis of correlation, regression and PCA demonstrated that healthy panicle production is positively associated with total panicle density and favourable growth conditions, whereas malformation traits negatively influence productivity.

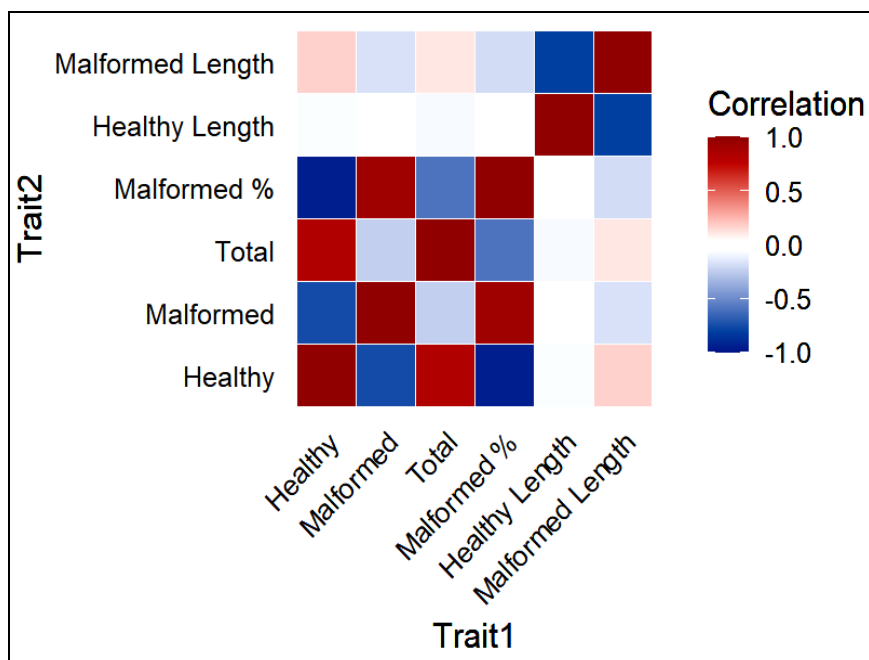


Fig 1: Correlation matrix of panicle traits in mango showing the relationships among healthy panicles, malformed panicles, total panicles, malformation percentage and panicle length parameters.

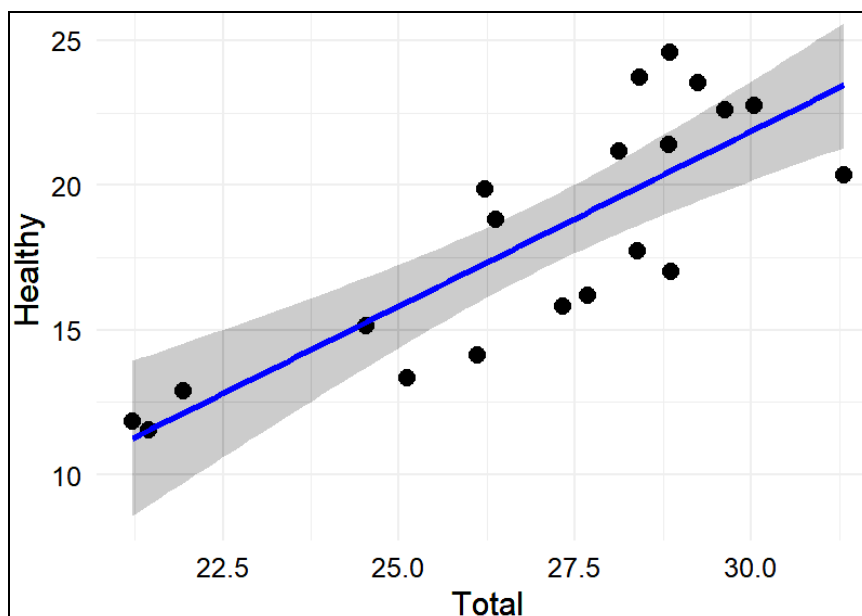


Fig 2: Scatter plot showing the relationship between total number of panicles and healthy panicles with a fitted regression line.

4. Discussion

The present investigation demonstrated that mango panicle development is significantly influenced by both varietal characteristics and directional variation in incident photosynthetic radiation. The significant differences observed among varieties for all studied traits indicate a strong genetic basis governing flowering behaviour, panicle development and susceptibility to malformation (Yadav *et al.*, 2020) [21].

Among the evaluated varieties, Langra exhibited superior performance with a higher number of healthy panicles and lower malformation percentage, indicating its relative tolerance to mango malformation. In contrast, Sunderja and Fazli showed greater susceptibility, as reflected by higher malformed panicle incidence and percentage. Such varietal differences may be attributed to inherent genetic variability affecting physiological processes such as carbohydrate

accumulation, hormonal balance and metabolic regulation during floral differentiation (Brito Vera & Pérez, 2024) [3]. Efficient mobilization of assimilates from vegetative tissues to developing reproductive structures is known to promote healthy panicle formation, whereas any disruption in these processes may favour abnormal growth and malformation (Ullah *et al.*, 2024) [20].

The directional effect of incident radiation further highlighted the importance of canopy microclimate in regulating panicle development. The south-facing direction consistently produced a higher number of healthy panicles and lower malformation percentage, which may be attributed to enhanced solar radiation interception and favourable thermal conditions. Increased radiation availability improves photosynthetic efficiency and carbohydrate synthesis, thereby supporting floral bud differentiation and panicle development (Rossouw *et al.*,

2024)^[18]. Conversely, the north direction recorded higher malformation incidence, which may be associated with relatively lower light intensity and cooler microclimatic conditions that reduce photosynthetic activity and disturb hormonal regulation, thereby promoting malformation (Balban *et al.*, 2025)^[12]. Similar directional effects on flowering behaviour and malformation incidence have been reported in mango and other perennial fruit crops (Hammad *et al.*, 2025)^[14].

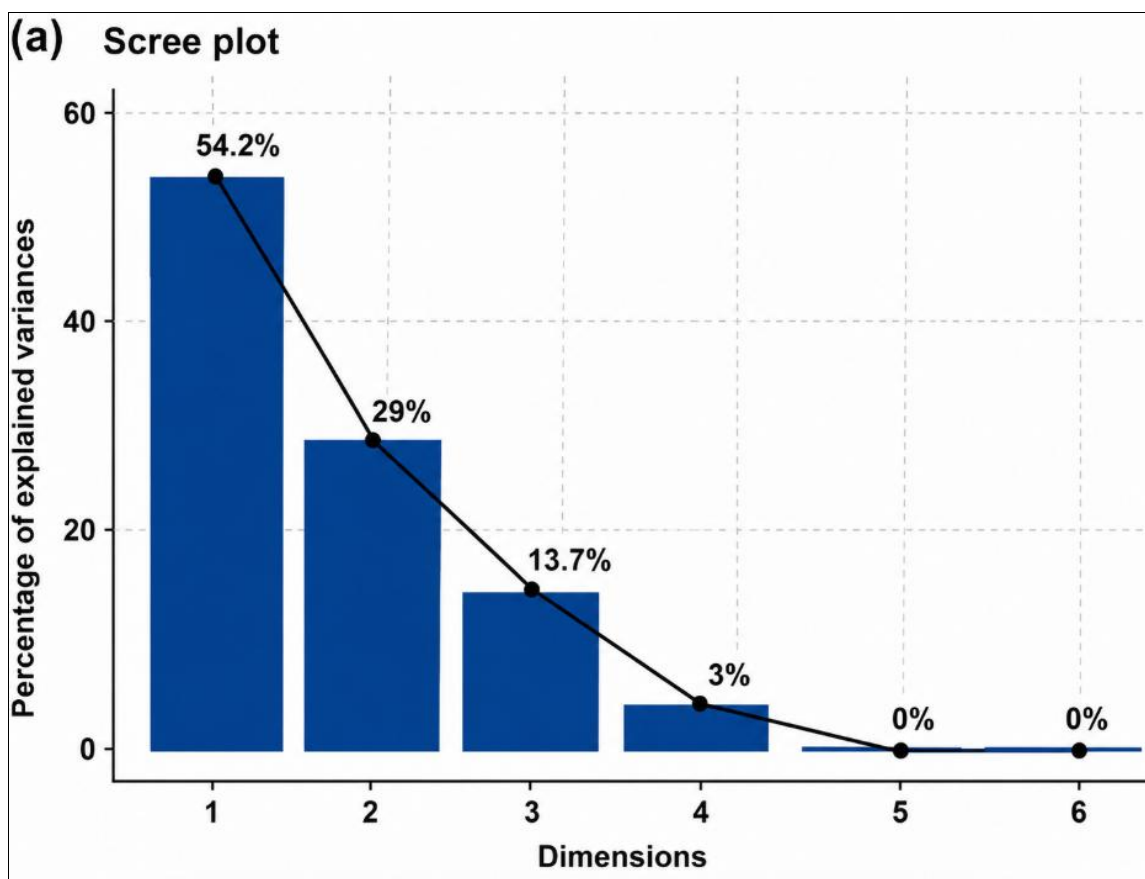
The total number of panicles was largely governed by varietal potential, with Amrapali and Langra producing a higher panicle density. This suggests that panicle initiation is primarily controlled by genetic factors, whereas the proportion of healthy and malformed panicles is more sensitive to environmental conditions. The relatively non-significant variation in total panicle number across directions further indicates that radiation environment plays a greater role in determining panicle quality rather than quantity (Kishore *et al.*, 2023)^[7].

Panicle length also exhibited significant variation among varieties and directions, reflecting differences in growth dynamics of floral structures. The greater length of healthy panicles observed in Dushehari may be attributed to enhanced assimilate supply and hormonal balance promoting elongation of the rachis and panicle branches (Singh *et al.*, 2025)^[19]. The increased panicle length observed under the north direction may be associated with reduced light intensity favouring elongation growth as a

physiological adaptation. Under relatively shaded conditions, plants often exhibit increased elongation due to altered growth regulation mechanisms (Kuldeep *et al.*, 2025)^[8].

In contrast, malformed panicles exhibited greater elongation in Amrapali and Sunderja, particularly under the south direction. This abnormal elongation may be associated with disturbed metabolic activity and hormonal imbalance within malformed tissues. Higher radiation exposure may enhance metabolic processes, leading to excessive and disorganized growth patterns in malformed panicles (Perveen *et al.*, 2025)^[16]. Such responses reflect the altered physiological status of affected tissues under stress conditions (Léchaudel *et al.*, 2013)^[14].

Overall, the results revealed a clear inverse relationship between healthy panicle production and malformation incidence, indicating that factors promoting normal floral development simultaneously suppress malformation. The combined influence of varietal traits and radiation environment determines the balance between healthy and malformed panicles, thereby influencing overall productivity (Ahmad *et al.*, 2025)^[1]. Varieties such as Langra, which maintain higher healthy panicle numbers with lower malformation under favourable radiation conditions, may therefore be considered more suitable for cultivation under similar agro-climatic conditions (Premalatha, 2023)^[17].



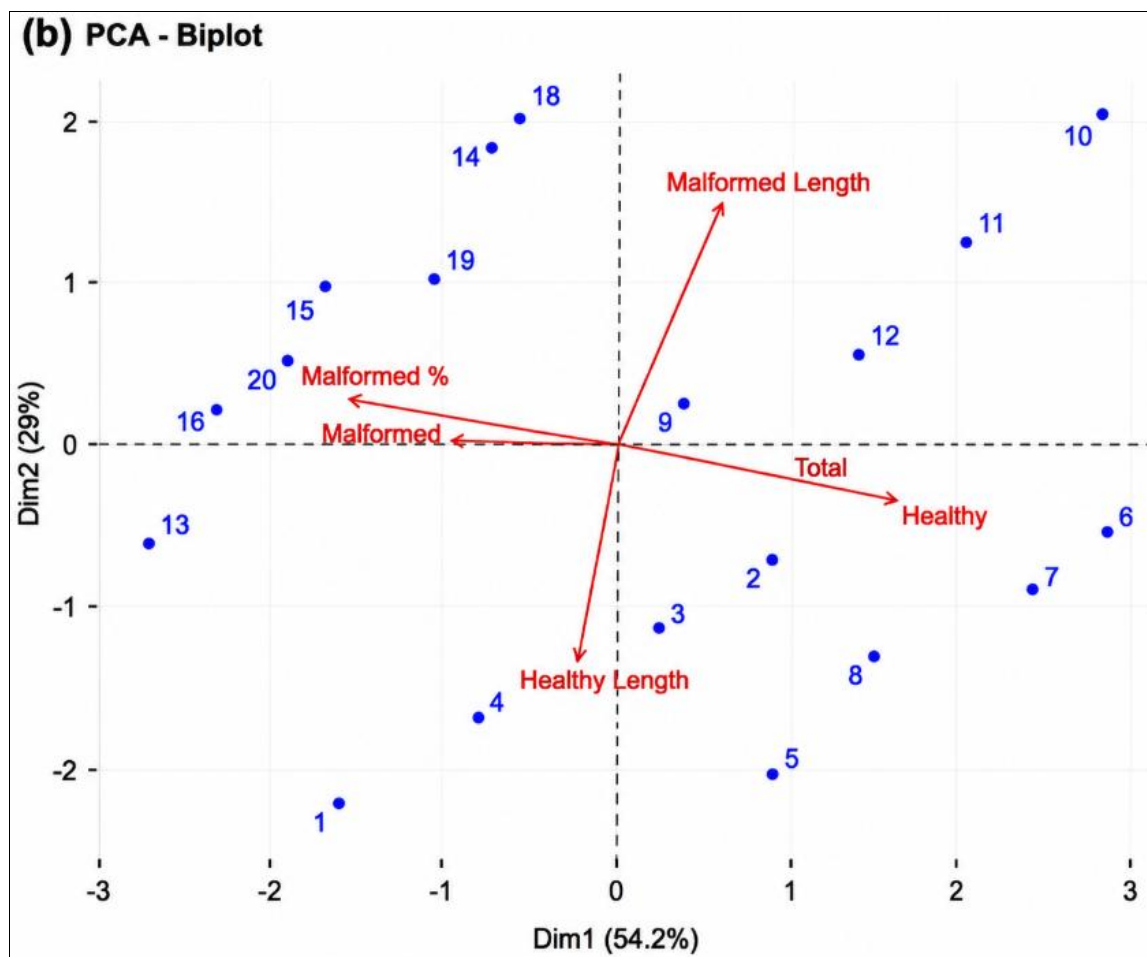


Fig 4: Principal component analysis (PCA) of panicle traits in mango: (a) biplot showing the distribution and association of variables, and (b) contribution of individual traits to principal components

5. Conclusion

The present study demonstrated that mango panicle development is significantly influenced by varietal characteristics and the direction of incident photosynthetic radiation. Among the evaluated varieties, Langra exhibited superior performance with a higher number of healthy panicles and lower malformation percentage, indicating its relative tolerance to mango malformation. In contrast, Sunderja and Fazli showed greater susceptibility, as evidenced by higher malformed panicle incidence and percentage. Directional variation in radiation also played a crucial role in determining panicle health and morphology. The south-facing direction proved most favourable for healthy panicle production and reduced malformation, likely due to enhanced radiation interception and improved microclimatic conditions. Conversely, the north direction was associated with higher malformation incidence, suggesting that reduced light availability adversely affects normal panicle development.

The study further revealed that while total panicle production is largely governed by varietal potential, the proportion of healthy and malformed panicles is strongly influenced by environmental conditions, particularly radiation exposure. Additionally, variations in panicle length indicate that both genetic factors and microclimatic conditions regulate growth behaviour of healthy and malformed panicles.

Overall, the findings highlight that selection of tolerant varieties such as Langra, along with consideration of canopy orientation and radiation exposure, can significantly

improve panicle health and productivity in mango orchards. These results provide valuable insights for developing management strategies aimed at minimizing malformation and enhancing yield under varying environmental conditions.

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