



RESEARCH ARTICLE

Systems-level analysis of growth, yield architecture and profitability of ginger genotypes (*Zingiber officinale* Rosc.) across sequential sowing patterns

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Abstract

Ginger (*Zingiber officinale* Rosc.) is an economically important spice crop valued for its culinary, medicinal and industrial uses. Its productivity is highly influenced by agronomic factors, particularly planting time and selection of suitable varieties, which can significantly affect growth and yield performance under varying environmental conditions. The study aimed to evaluate the effect of different planting dates and ginger varieties on growth, yield and economic returns to determine the most suitable combination for enhanced productivity. A field experiment was laid out in randomised block design with dates of planting (25th April, 15th May and 5th June) as the main plot treatments and three varieties as subplot treatments (Rajgarh local, Sirmaur local and Himgiri) with 3 replications. Growth parameters, rhizome yield and economic returns were recorded and analysed over two consecutive years. During both years, 5th June planting and the Himgiri variety showed the significantly highest growth and yield parameters, while the lowest growth and yield parameters were observed on 25th April planting and Sirmaur variety. Sowing of ginger on 15th May and 5th June produced significantly higher rhizome yield than sowing on 25th April. During both years, the maximum rhizome yield (193.18 q/ha) was recorded when sowing was done on 5th June, but it was at par with sowing on 15th May (182.32 q/ha). Sowing on 5th June recorded mean net returns of Rs. 451034 with benefit-cost ratio of 2.80. There was no significant difference among the genotypes evaluated. Himgiri gave the highest yield of 181 q/ha, followed by Rajgarh and Sirmaur. Planting ginger in early June or mid-May significantly enhances yield and profitability compared to late April planting. Although varietal differences were not significant, Himgiri showed superior performance and can be recommended for higher productivity under similar agro-climatic conditions.

Keywords: economics; genotype; ginger; planting date; yield

Introduction

Ginger (*Zingiber officinale* Rosc.) is an important spice crop grown in India, the rhizomes of which are used as a spice either fresh or after drying. It is used in foods, beverages, preservatives, medicines and perfumery industries. There is an increasing trend in the export ginger oils and oleoresin (1). Ginger is a shade-tolerant crop. India occupies a unique position as the largest producer and exporter of ginger in the world (2). Indian ginger, popularly known as Cochin ginger, mainly comes from Kerala and is known for its quality in the world market (3). In India, it is grown over an area of 162 thousand hectares with an annual production of 1131 thousand metric tonnes and productivity of 6.98 MT ha⁻¹ (4). The average productivity of the crop at present is very low (6.98 MT ha⁻¹).

There is tremendous scope to increase the yield per unit area and thereby the total production. In South India, it is widely grown as an intercrop in coconut plantations (5). Punjab has an area of 18.88 thousand ha (0.37 % of total geographical area) under

agroforestry plantations, mainly comprising Poplar, Safeda (*Eucalyptus*), Drek (*Melia azaderach*) and Sheesham/Tahli (*Dalbergia sissoo*), out of which 0.13 % area is under poplar plantation (6). Promotion of ginger cultivation in agroforestry systems would help in crop diversification and supplement the income of the farmers in Punjab (7).

Proper planting time is an important non-monetary input in crop production, which affects crop growth, yield and quality to a greater extent. Delayed or early planting results in reduced growth and yield (8). A small change in planting time leads to a significant change in crop performance. A considerable amount of genetic variability has been reported among different varieties with regard to growth, yield and quality parameters under different agro-climatic conditions. Several cultivars of ginger are grown in different ginger-growing areas of India (9). They are generally named after the localities or places where they are grown. These local cultivars have been selected, domesticated and planted for a long time under local natural conditions (10). They generally have greater adaptability,

higher yield, better quality and unique use value. The available germplasm serves as a valuable natural reservoir for providing donor parents to improve particular traits (11). Therefore, the experiment was conducted to study the effect of planting dates on the growth and yield of ginger genotypes (12).

Materials and Methods

Experimental site and treatment details

The experiment was carried out in the field to determine the effect of planting dates and cultivars on ginger growth, yield and economic viability of ginger in the Kandi region of Punjab, India. The experimental site was geographically situated at Ballawal Saunkhri, Shaheed Bhagat Singh Nagar, Punjab, India (31°6'5" N latitude, 76°23' 26" E longitude) at an altitude of approximately 346 m above mean sea level. The region falls under a sub-humid climate characterised by hot summers and cold winters. The average annual rainfall of the region is around 1000–1200 mm, of which nearly 80 % is received during the monsoon period (mid-June to mid-September). During the experimental period, the rainfall distribution was adequate for crop growth. The mean monthly minimum and maximum temperatures ranged from approximately 6 °C to 25 °C and 19 °C to 39 °C respectively. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 8.1), low in organic carbon (0.40 %) and available nitrogen (224 kg ha⁻¹) and medium in available phosphorus (13 kg ha⁻¹) and potassium (192 kg ha⁻¹).

The experiment was conducted in a randomised block design with 3 replications. The main plot treatments consisted of three planting dates: D₁ (25th April), D₂ (15th May) and D₃ (5th June), whereas the subplot treatments comprised three ginger varieties (Rajgarh, Sirmaur and Himgiri). Thus, a total of 9 treatment combinations were evaluated. The ginger variety "Himgiri" was procured from Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh), India, whereas the varieties "Rajgarh" and "Sirmaur" were collected from progressive farmers of the same region.

Field preparation and planting

Beds of 3 × 1 m and a height of 15 cm were constructed and a total of nine beds were prepared in each replication. Healthy seed rhizomes of all three varieties were treated with Mancozeb at 0.3 % for 30 min before planting. The treated rhizomes were planted on the respective dates at a spacing of 20 cm between plants and 30 cm between rows, and the beds were covered with soil.

Observations recorded

Growth attributes

The growth parameters were measured on representative plants randomly selected from each treatment plot at appropriate stages of crop development and at harvest. Plant height (cm) was measured as the distance between the soil surface and the tip of the highest fully developed leaf using a measuring scale. The number of tillers per plant was recorded by counting the effective tillers emerging from the base of each selected plant. The average values were calculated and used for statistical analysis to determine the influence of sowing dates and varieties on vegetative growth.

Yield and yield attributes

At harvest, representative plants from each plot were evaluated for yield and its attributes. The number of rhizomes per plant was determined by counting all marketable rhizomes produced per plant. The rhizomes were measured for length and width (cm) using a scale or digital vernier caliper at the respective points of each

rhizome. The weight of the rhizomes per rhizome (g) was measured using a digital balance by weighing each rhizome separately. Fresh rhizome yield (q ha⁻¹) was estimated by recording the total fresh rhizome weight in each plot and converting it to yield per hectare based on the plot area. Subsequent analysis was carried out using the mean values.

Economic analysis

The yield of fresh rhizomes and the current market price of ginger were used to calculate the gross monetary returns (Rs ha⁻¹). The price of growing per treatment was determined using all operation costs from land preparation to harvesting. Net returns (Rs ha⁻¹) were calculated as the difference between the gross returns and the cost of cultivation, while the benefit-cost ratio was calculated as a ratio of the gross returns to the cost of cultivation.

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) using R software with the "agricolae" package. Treatment means were compared using the least significant difference (LSD) test at the 5 % level of significance. Economic analysis was carried out by computing the benefit-cost ratio (B:C ratio) based on prevailing market prices and actual input costs.

Results

Effect of sowing dates and varieties on growth parameters

Table 1 presents the data on plant height and number of tillers per plant. Among the planting dates, significantly higher plant height (86.04 cm) and number of tillers per plant (11.30) were observed on the 5th June planting, whereas the lowest values were recorded in the 25th April planting (77.03 cm and 9.60 respectively). With respect to cultivars, Himgiri had the significant highest number of tillers per plant (10.60) and plant height (84.03 cm) than Sirmaur, however with Rajgarh no significant differences were found.

Effect on rhizome characters and fresh rhizome yield

Table 1 presents the effects of sowing dates and varieties on the number of rhizomes per plant, rhizome length, width and weight and fresh rhizome yield. Planting on 5th June resulted in significantly higher values than the other planting dates, recording the highest number of rhizomes per plant (4.53), rhizome length (9.30 cm), rhizome width (5.60 cm), rhizome weight (78.67 g), and fresh rhizome yield (193.18 q ha⁻¹). These results may be attributed to the prevalence of favourable environmental conditions during the crop growth period, particularly optimum temperature and moisture availability which enhanced vegetative growth, efficient assimilate partitioning and better rhizome development. In contrast, the lowest values of these parameters were obtained with planting on 25th April, where the fresh rhizome yield was limited to 154.96 q ha⁻¹.

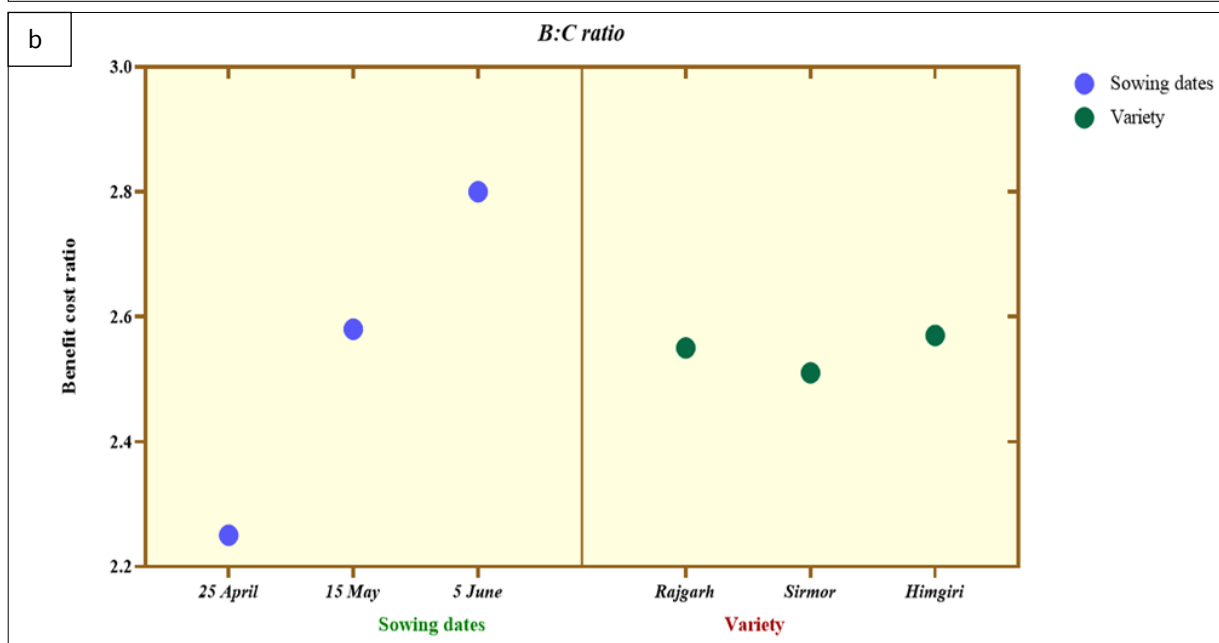
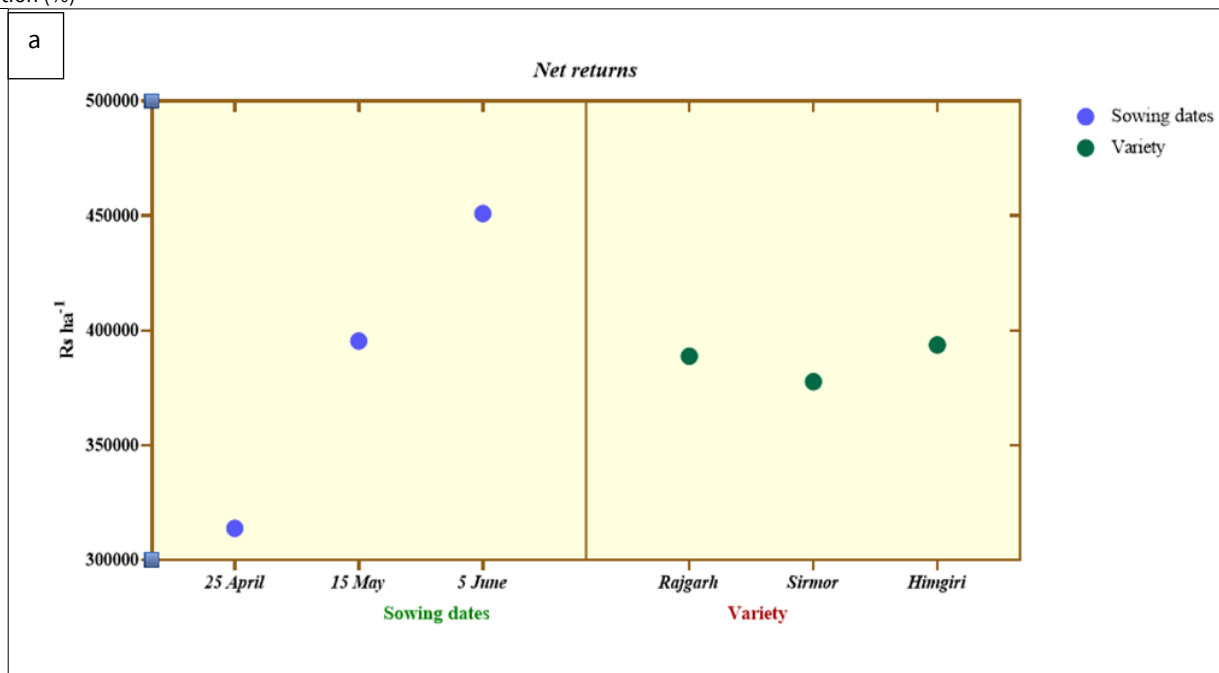
Himgiri was found to be the best-performing variety, recording a higher number of rhizomes per plant (4.50), rhizome length (8.80 cm), rhizome width (5.30 cm), rhizome weight (76.97 g) and fresh rhizome yield (181.32 q ha⁻¹). Sirmaur recorded the lowest values for most rhizome characteristics and yield, whereas Rajgarh recorded the lowest rhizome length (8.50 cm).

Economics of ginger cultivation

Data regarding the economics of ginger cultivation are presented in Fig. 1a and b. The 5th June planting treatment recorded the highest net returns of Rs. 451034 with B:C ratio of 2.80. The minimum net

Table 1. Effect of planting dates on the growth, yield attributes and yield of ginger genotypes (averaged across two years)

Treatments	Plant height (cm)	No of tillers/ plant	No. of rhizomes/ plant	Length of rhizome (cm)	Width of rhizome (cm)	Weight/rhizome (g)	Fresh rhizome yield (q/ha)
Sowing date							
D ₁ : 25 th April	77.03 ± 2.04 ^b	9.60 ± 0.38 ^c	3.80 ± 0.26 ^c	7.80 ± 0.20 ^b	4.70 ± 0.26 ^c	68.00 ± 1.24 ^c	154.96 ± 4.42 ^c
D ₂ : 15 th May	84.07 ± 2.93 ^a	10.60 ± 0.40 ^b	4.40 ± 0.29 ^b	8.90 ± 0.40 ^a	5.30 ± 0.26 ^b	75.05 ± 1.66 ^b	182.16 ± 8.65 ^b
D ₃ : 5 th June	86.04 ± 1.04 ^a	11.30 ± 0.43 ^a	4.53 ± 0.27 ^a	9.30 ± 0.35 ^a	5.60 ± 0.20 ^a	78.67 ± 1.47 ^a	193.18 ± 5.06 ^a
Mean	82.06 ± 1.05	10.50 ± 0.43	4.30 ± 0.26	8.70 ± 0.40	5.20 ± 0.35	74.00 ± 1.13	176.88 ± 3.57
Critical difference at 5 %	3.71	0.11	0.06	0.47	0.13	0.83	8.98
Coefficient of variation (%)	2.98	1.47	1.59	2.40	1.11	0.49	3.24
Variety							
Rajgarh	83.05 ± 2.35 ^a	10.50 ± 0.52 ^a	4.20 ± 0.26 ^b	8.50 ± 0.35 ^a	5.20 ± 0.26 ^a	74.00 ± 2.40 ^b	175.75 ± 3.69 ^{ab}
Sirmaur	80.04 ± 2.19 ^b	10.60 ± 0.46 ^a	4.10 ± 0.29 ^c	8.70 ± 0.17 ^a	5.10 ± 0.14 ^a	71.00 ± 1.10 ^c	171.85 ± 5.93 ^b
Himgiri	84.03 ± 1.18 ^a	10.50 ± 0.38 ^a	4.50 ± 0.26 ^a	8.80 ± 0.23 ^a	5.30 ± 0.20 ^a	76.97 ± 1.88 ^a	181.32 ± 8.17 ^a
Mean	82.05 ± 1.72	10.50 ± 0.46	4.30 ± 0.23	8.70 ± 0.23	5.20 ± 0.32	74.00 ± 1.76	176.92 ± 4.85
Critical difference at 5 %	2.49	0.29	0.07	0.35	0.23	2.56	8.89
Coefficient of variation (%)	1.33	1.19	1.67	2.76	2.92	2.53	3.22

**Fig. 1.** Economic performance of ginger as influenced by sowing dates and varieties (mean of two years). a: Nested distribution of net returns (Rs ha⁻¹) under different sowing dates and ginger varieties; b: nested distribution of benefit-cost ratio under different sowing dates and ginger varieties.

returns of Rs. 313892 and a B:C ratio of 2.25 was recorded from the treatment with the 25th April planting date. The variety Himgiri gave the highest net returns of Rs. 393792 with B:C ratio of 2.57. The minimum net returns of Rs. 377767 and a B:C ratio 2.51 were obtained with the Sirmaur variety.

Phenotypic path coefficient analysis of fresh rhizome yield under different sowing dates and varietal regimes

Phenotypic path analysis revealed that rhizome weight was the most influential trait determining fresh rhizome yield across sowing dates, exhibiting a strong positive direct effect (0.895–0.933). This indicates that yield improvement is primarily driven by increased rhizome mass. The positive direct effect of rhizome length (0.347) and plant height (0.323) also showed moderate positive effects and it suggests that improved vegetative growth and rhizome elongation have a collaborative effect on the formation of yield.

Similarly, phenotypic path analysis across varieties (Table 2) indicated that rhizome width exerted the highest positive direct influence on fresh rhizome yield, with path coefficients greater than unity (1.034), highlighting the importance of rhizome thickness as a major determinant of varietal yield differences. Plant height also showed a positive and moderate direct effect (0.481), indicating the contribution of plant vigour to yield potential.

Comparative correlation analysis under sowing dates and varietal conditions

Phenotypic correlation analysis showed that the interrelationships between fresh rhizome yield and its component traits were significantly influenced by sowing dates as well as varietal differences (13). Under different sowing dates, fresh rhizome yield exhibited consistently high and significant positive correlations with plant height ($r = 0.98$), number of tillers per plant ($r = 1.00$), number of rhizomes per plant ($r = 1.00$), rhizome length, rhizome width ($r = 0.99$ each) and rhizome weight ($r = 1.00$). On the other hand, among varieties, fresh rhizome harvest was distinguished by negative plant height ($r = -0.97$), positive number of tillers in one plant ($r = 0.84$) and rhizome morphology properties such as length ($r = 0.96$), breadth ($r = 0.96$) and weight ($r = 0.93$) highlighting the importance of rhizome morphology in varietal yield expression. In both cases, rhizome length and width were strongly and significantly correlated ($r = 1.00$) and also showed strong correlations with rhizome weight ($r = 0.99$ – 1.00), indicating that sowing time and varietal characteristics largely influence the integrated development of rhizomes, as shown in Fig. 2a and b.

Discussion

The enhanced growth and yield observed under 5th June sowing can be attributed to the prevalence of favourable environmental conditions during the crop growth period, which facilitated improved vegetative development and greater yield potential (14). These findings indicate that yield variability in ginger is strongly influenced by plant vigour and rhizome development, which are regulated by the interaction between genetic constitution and environmental conditions (12). Even under the same agronomic conditions, the observed differences among cultivars highlight the dominant role of genetic factors in determining morphological and yield traits (15). The present results are in agreement with earlier reports in turmeric and in ginger-based intercropping systems, thereby reinforcing the consistency of genotype- and environment-driven yield responses in rhizomatous crops (16, 17).

Further, phenotypic path analysis provided critical insight into the mechanisms of yield determination. Although the number of tillers per plant and number of rhizomes per plant exhibited negative direct effects on yield, their positive indirect contributions via rhizome length and weight indicate that these traits influence yield indirectly by enhancing rhizome development (18, 19). The strong negative direct effect of rhizome number (-0.659) suggests the existence of intra-plant competition, wherein a higher number of rhizomes may limit assimilate availability per unit, thereby restricting individual rhizome growth (20). Moreover, despite the relatively lower or negative direct effects of weight per rhizome and tiller number in certain cases, their positive indirect effects through rhizome width emphasise that yield is ultimately governed by traits associated with rhizome size and sink strength (21). These findings clearly indicate that selection strategies should prioritise rhizome bulking traits rather than merely increasing rhizome number, as enhanced assimilate partitioning towards fewer but well-developed rhizomes is more conducive to higher yield realisation.

The present study indicates that planting date and varietal selection strongly influenced the growth, rhizome development and fresh rhizome yield of ginger grown in the Kandi region of Punjab. Among the planting dates, 5th June planting was found to be the most effective in promoting vegetative growth and rhizome size and overall yield performance, whereas the Himgiri variety displayed a better rhizome attributes and yield potential. Phenotypic correlation and path analyses revealed that rhizome size traits, particularly rhizome weight, width and length, are the major determinants of fresh rhizome yield, while other quantitative traits contribute mostly through indirect effects.

Table 2. Phenotypic pathway analysis of yield-contributing traits for fresh rhizome yield

Traits	Plant height	Tillers/plant	Rhizomes/plant	Length of rhizome	Width of rhizome	Weight/rhizome
(a) Trait-wise phenotypic path coefficients under sowing date regimes						
Plant height	0.323	-0.292	-0.215	0.33	-0.06	0.895
Tillers/plant	0.301	-0.313	-0.215	0.337	-0.061	0.929
Rhizomes/plant	0.312	-0.303	-0.222	0.34	-0.06	0.92
Length of rhizome	0.307	-0.304	-0.218	0.347	-0.059	0.917
Width of rhizome	0.314	-0.309	-0.218	0.335	-0.061	0.927
Weight/rhizome	0.309	-0.312	-0.219	0.341	-0.061	0.933
(b) Trait-wise phenotypic path coefficients across varietal differences						
Plant height	0.481	-0.105	-0.225	0.008	-0.328	0.076
Tillers/plant	-0.175	0.367	-0.254	-0.049	0.982	-0.086
Rhizomes/plant	0.209	0.142	-0.659	-0.041	0.467	-0.004
Length of rhizome	-0.071	0.257	-0.387	-0.071	1.034	-0.049
Width of rhizome	-0.179	0.323	-0.275	-0.065	1.116	-0.076
Weight/rhizome	-0.438	0.297	-0.025	-0.032	0.805	-0.106

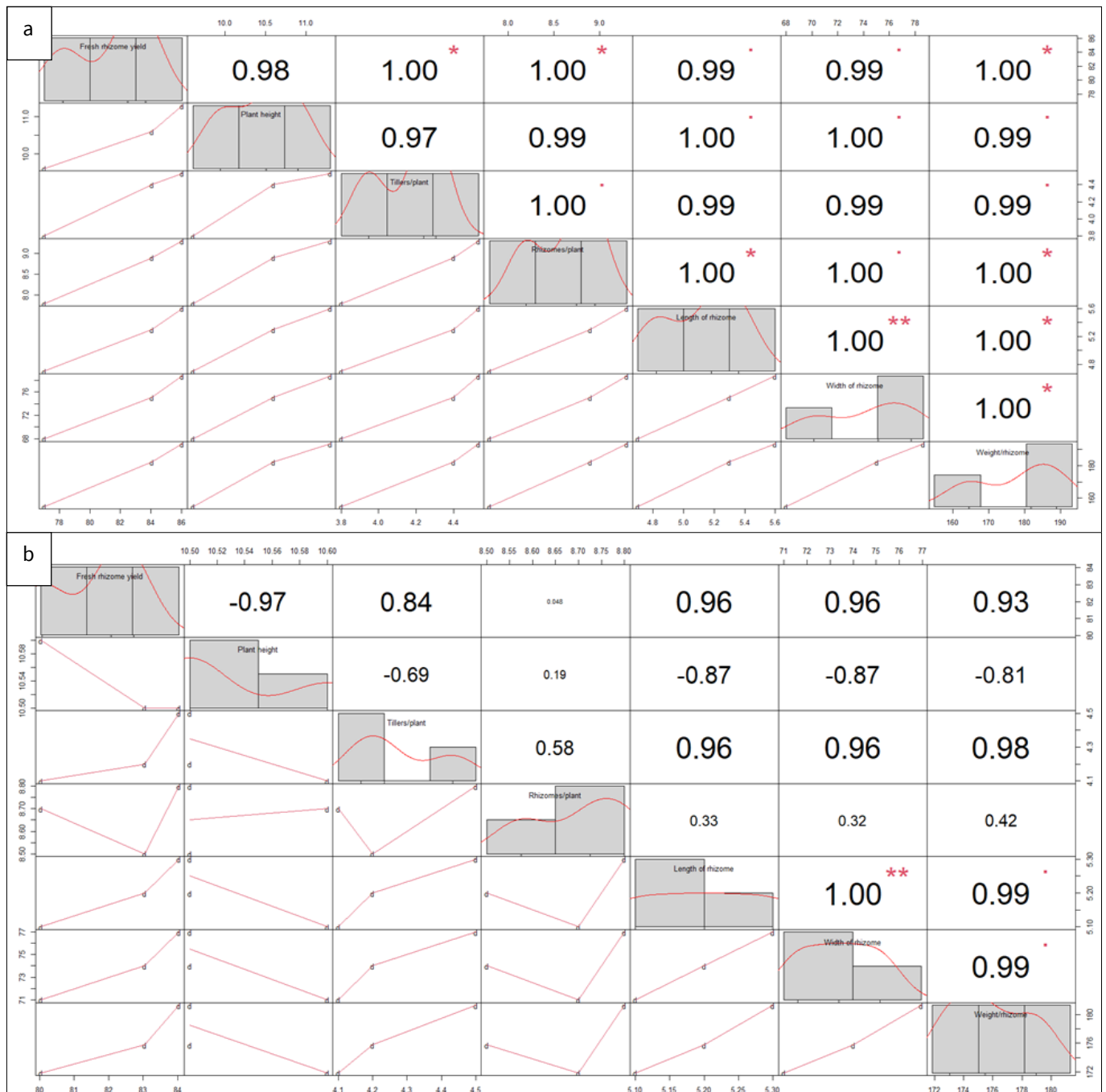


Fig. 2. Phenotypic relationships among yield and yield-contributing traits. a: Influence of sowing dates on trait inter-correlations; b: varietal influence on trait inter-correlations

Therefore, optimisation of sowing time along with the selection of varieties possessing superior rhizome morphology are critical factors for maximising yield and profitability in ginger cultivation under the region's agro-climatic conditions. From a practical perspective, these findings provide clear evidence-based recommendations for farmers, extension agencies and policymakers, suggesting that adoption of June sowing along with Himgiri variety can significantly enhance yield and economic returns in ginger cultivation under similar agro-climatic conditions.

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Authors' contributions

AK, PM and MS conceptualised and designed the study. AK and PM conducted the investigation, performed data curation and prepared the original draft of the manuscript. PM and B contributed to formal analysis, visualisation and assisted in data interpretation. MS supervised the research, provided overall project oversight and critically reviewed and edited the manuscript. B also contributed to interpretation of results and manuscript revision. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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