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Unraveling morpho-biochemical parameters and climatic factors associated with flowering in five Jamun (*Syzygium cumini* Skeels) varieties

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Abstract

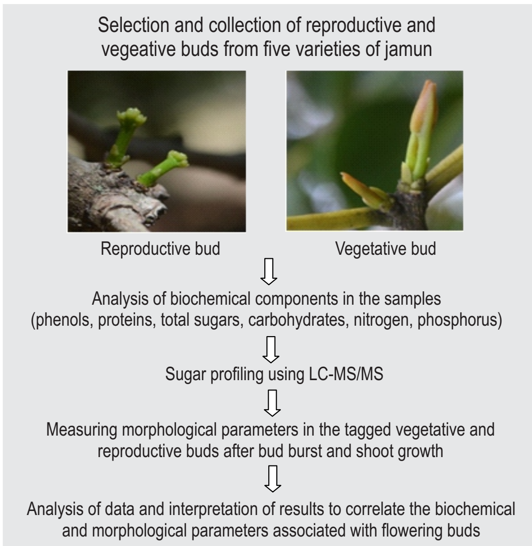
Aim: Identify key biochemical parameters involved in fruit bud formation in jamun varieties.

Methodology: Biochemical composition in vegetative and reproductive buds of five jamun varieties was analysed for carbohydrates, phenols, sugars, protein, chlorophyll, C/N ratio, nitrogen, and phosphorous along with vegetative parameters.

Results: The results revealed that, phenols (7.44 to 5.05 mg g^{-1} f.wt.), total sugars (27.58 to 22.75 mg g^{-1} f.wt.), phosphorous (0.097 to 0.084 %), carbohydrates (59.15 to 48.36 mg g^{-1} f.wt.), and C/N ratio (65.75 to 54.34) were higher in reproductive buds than vegetative buds *viz.*, phenols (3.42 to 3.79 mg g^{-1} f.wt.); total sugars (17.86 to 14.56 mg g^{-1} f.wt.); phosphorus (0.050-0.031 %); carbohydrates (59.15 to 48.36 mg g^{-1} f.wt.); CN ratio (49.43 to 34.15). However, vegetative buds recorded higher concentration of protein, chlorophyll and nitrogen than reproductive buds. Higher phenols in reproductive buds showed its significant role in bud formation as it is involved in morphogenesis along with favourable climatic conditions like high temperature and moderate rainfall. Sugar profiling revealed that maximum content glucose, fructose and sucrose, inositol, sorbitol contents were recorded in the reproductive buds than in the vegetative buds.

Interpretation: Varieties with higher phenols, carbohydrate and sugar contents, along with favourable responses of climatic conditions, may be utilized in breeding programs aimed at developing regular-bearing cultivars.

Key words: Climatic factors, Jamun varieties, Sugar profile, *Syzygium cumini*



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Introduction

In recent years, Jamun cultivation is gaining popularity due to its nutraceutical properties and high market value. It is highly recommended for marginal soils and drought prone areas. However, alternate bearing and erratic flowering is the problem faced by growers. Flowering behaviour is highly complex which is attributed to genetic, environmental and biochemical factors. Understanding factors influencing flowering may help in modification of cultural operations viz., pruning, and application of fertilizers and / or growth hormones to coincide with the flowering stage with desired environmental conditions. However, with changing climatic conditions, cultural operations coincide with the flowering time with desired climatic conditions may not be a feasible option. Biochemical composition of buds during differentiation may determine the fate of those buds to become either vegetative or reproductive. Flower development is one of the major phenological events in many fruit crops, and is a two-phase process that involves the formation of floral bud initiation and its conversion into a floral bud (Cevriye *et al.,* 2013).

In most perennial fruit trees including jamun, the flowering in the upcoming year depends on the cessation of previous year's fruiting, during which the induction of flower primordia access (Szot *et al.,* 2025). During the transition of buds into reproductive phase, some internal or external stimuli such as growth hormones, carbohydrates, day length, temperature, humidity may play a significant role. In jamun, the leaf buds may transform into reproductive buds depending on the degree of maturity. Moreover, temperature is the most crucial factor that affects the flowering at different phases starting from flower bud differentiation, anthesis and development of floral parts (Sharma *et al.,* 2019). The matured shoots showing reproductive bud burst depends on the carbohydrate reserves and the phase of the tree which is either in "on" or "off" year. High carbohydrates and sugars act as a reserve form of energy in an "on year" and thus, the low availability of carbon source that leads to "off year". Other biochemical components in buds such as protein, chlorophyll, phenols, C:N ratio, etc., that favours vegetative and reproductive bud formation in addition to elements such as nitrogen and phosphorous predict the crop load. The lesser leaf photosynthesis during 'Off' year leads to reduced flow of photo-assimilates into the bud region, leading to increased synthesis of photosynthetic proteins and higher CO_2 assimilation, should considered while studying the flowering behaviour in jamun (Shalom *et al.,* 2012).

In jamun, limited studies have been conducted on the flowering physiology and the results obtained have been unsatisfactory. Still a significant variation in flowering and fruiting behaviour has been observed across different region or in different orchards within a region and among varieties. Hence, there was a need to study the biochemical composition in flowering and vegetative buds to understand the components involved in formation of either vegetative and / or reproductive buds. Climatic conditions prevailing during fruit bud differentiation may also help in understanding their role in promoting precocity in jamun. In view of the above this study was undertaken to understand variations in the biochemical constituents in vegetative and reproductive buds of jamun varieties, and correlating the prevailing climatic conditions during the phenological phases to understand the role in promoting flowering.

Materials and Methods

Experimental site: The study was conducted during 2023-24 at ICAR-IIHR, Bengaluru, India. The experiment was conducted on seven-years-old grafted jamun trees of five varieties Dhupdhal, Selection-45, Selection-58, Savadatti and AJG-85, planted at a spacing of 5 × 5m. From each variety, vegetative and reproductive buds (n=50) were tagged at bud development stage (Fig. 2). The buds were carefully scraped using a sharp blade preserved in liquid nitrogen and brought to the laboratory for analysis. The morphological parameters were measured at shoot maturity stage. Two factors (five varieties and two shoot types) with Factorial Randomized Block Design experiment was set up adding to 10 treatment combinations with three replications.

Climatic conditions: The meteorological data during investigation period was recorded at the meteorological observatory. (Average of 15 days is presented in Fig. 1, August 1 to August 15 = August 23/15). The data comprised maximum and minimum temperature, maximum and minimum relative humidity and average rainfall. Too much variation was observed in rainfall over the fortnight, while not much fluctuation was observed for other parameters.

Morphological parameters: Vegetative parameters, such as shoot diameter at maturity (mm); shoot length (cm), and internodal length (cm) were measured using a measuring scale. The number of flowers per inflorescence, panicle length and width were also recorded.

Biochemical parameters: Anthrone method (Plummer 1990) was employed to analyse carbohydrate content. The chlorophyll content was estimated following procedure of Hiscox and Israelstam (1979). Phenol content was determined using FCR by a spectrophotometric method (Singleton and Rossi, 1965). Total sugar in buds was measured by Nelson-Somogyi method (Somogyi 1952). Total protein was estimated by Broadford method (Broadford, 1976). All the biochemical parameters were analysed in the vegetative buds and reproductive buds at 013 stage (Initiation of vegetative bud elongation) and 511 stage (Initiation of reproductive bud elongation), respectively, of three digit BBCH scale (Fig. 1). Nitrogen content was by the method of Piper (1966); phosphorus was measured by vanadomolybdate reagent method. The C: N ratio was estimated using CHNS Elemental Analyzer based on the dry combustion method (Pribyl, 2010).

Sugar profiling: Sugar was extracted as per the procedure of Steppuhn and Wackers (2004), with minor modifications. A 50 mg bud sample along with 80% warm ethanol was used for extraction and volume was made up to 10 ml. Five millilitre of extract was

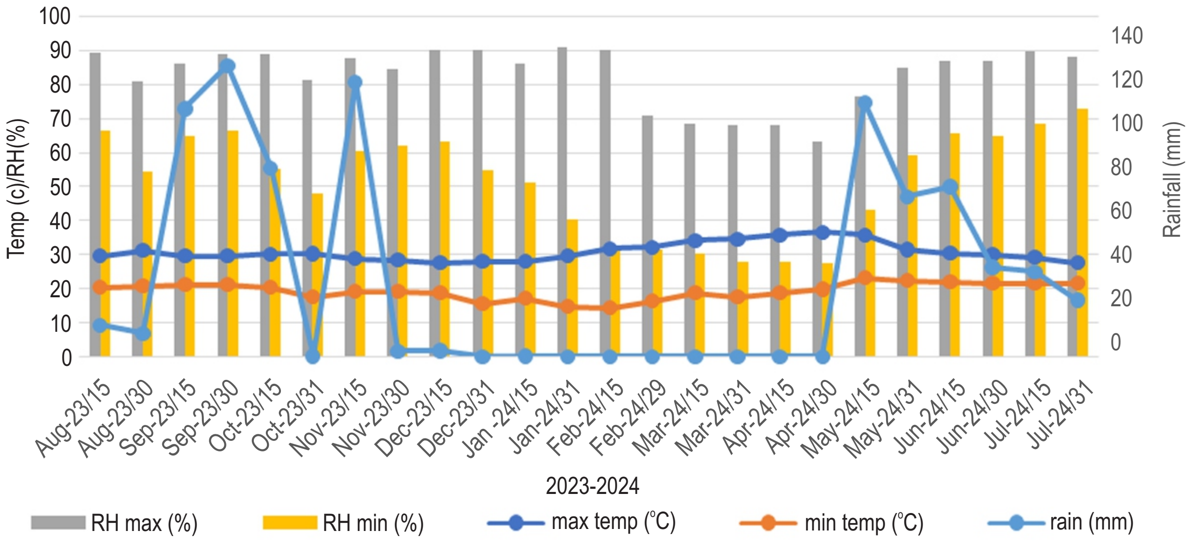

Fig. 1: Meteorology data during investigation period from August 2023 to July 2024.

kept on a water bath and evaporated to obtain the residues, which was dissolved in formic acid. Thereafter, the mixture was sonicated for 10 min and extracted twice with ethyl acetate. Ethyl acetate was removed using water bath at 60-70°C and the volume was made up using a mobile phase containing solvent A and solvent B in 1:1 ratio. The extract was filtered and injected into LCMS/MS (Waters UHPLC class system fitted with TQD MS/MS system) for assessment.

Statistical analyses: The data collected for all parameters were systemized and subjected to ANOVA as per the procedures of Fisher and Yates (1963). Following a significant ANOVA result, Duncan's Multiple Range Test (DMRT) was performed to identify specific differences between treatment means. Simple correlation analysis was also performed using Microsoft Excel 2003 software to understand the relation between different morpho-biochemical parameters.

Results and Discussion

Among climatic conditions, rainfall was highest during September to November which favoured vegetative growth. During December, 2 mm rainfall with minimum temperature of 14°C was recorded. Cool temperature with less rainfall encouraged the formation of reproductive bud, while moderate temperature around 30°C favoured reproductive bud burst (Fig. 1). There was no rainfall from January to April, which resulted in mild stress condition encouraging flower formation.

The correlation study between climatic conditions and phenological phases showed that the maximum temperature was highly favourable for vegetative and reproductive bud burst, except for days taken for full bloom. The minimum temperature was favourable for reproductive bud burst showing strong positive correlation (0.820), the minimum rainfall was also favourable for reproductive bud formation. The vegetative parameters recorded significant differences, wherein the maximum shoot circumference was observed in variety Savadatti. Among flowering and vegetative shoots, the shoot circumference was higher in vegetative shoots (0.58 mm). Vegetative shoots are generally thicker than the reproductive shoots, as vegetative shoots are primarily focused on the development of a tree by adding total biomass (Bajpai *et al.,* 2012) (Table 1). Shoot length among the varieties showed non-significant differences, whereas the shoot length significantly varied between flowering and vegetative shoots. Least shoot length was observed for flowering shoots (18.44 cm) than their counterparts (25.30 cm).

Among flowering and vegetative shoots of different varieties, the maximum internodal length was observed in vegetative shoots of varieties Savadatti (5.20 cm) and AJG-85 (5.46 cm), and least was recorded in flowering shoots of Selection-45 (2.50 cm). A shorter internodal due to shift in the hormonal signals might have induced flowering in those shoots (Hegde *et al.,* 2018). The panicle length, width and number of flowers per inflorescence were high in the selection-45 and selection-58 (Table 2). Phenolic content was higher in flowering buds than in vegetative buds, wherein a higher phenol was observed in Selection-45. Interaction effect showed that the flowering buds of Selection-45 had high phenols (5.05 mg g FW^{-1}) (Table 3), which confirms the increase of phenols in flowering buds. Similar work was reported in mango by Bajpai *et al.* (2021) who reported higher phenols in floral tissues, wherein the variety Amrapali showed the highest phenol content. Dashehari, Chausa and Langra also showed higher phenols in flower buds, while vegetative buds had lower phenolic content. The phenolic content has a positive role in floral morphogenesis, which was discussed

Table 1: Shoot circumference, internodal length and shoot length of flowering and vegetative shoots of five jamun cultivars

Shoot circumference (cm)				Length of shoot (cm)				Internodal length (cm)			
Varieties	Flowering shoots	Vegetative shoots	Mean (variety)	Varieties	Flowering shoots	Vegetative shoots	Mean (variety)	Varieties	Flowering shoots	Vegetative shoots	Mean (variety)
V1	0.31^{cd}	0.42^{bc}	0.36^{b}	V1	17.93^{c}	25.66^{a}	21.80^{a}	V1	3.06^{cd}	4.56^{abc}	3.81^{a}
V2	0.44^{bc}	0.53^{ab}	0.48^{a}	V2	17.33^{c}	24.80^{a}	21.06^{a}	V2	2.50^{d}	4.93^{ab}	3.71^{a}
V3	0.28^{d}	0.52^{ab}	0.40^{ab}	V3	19.20^{c}	26.30^{a}	22.75^{a}	V3	3.16^{cd}	4.30^{abc}	3.73^{a}
V4	0.32^{cd}	0.58^{a}	0.45^{ab}	V4	20.23^{bc}	24.26^{ab}	22.25^{a}	V4	4.16^{abc}	5.20^{a}	4.68^{a}
V5	0.41^{bc}	0.51^{ab}	0.36^{b}	V5	17.50^{c}	25.50^{a}	21.50^{a}	V5	3.43^{bcd}	5.46^{a}	4.45^{a}
Mean (shoots)	0.35^{b}	0.51^{a}		Mean (shoots)	18.44^{b}	25.30^{a}		Mean (shoots)	3.26^{b}	4.89^{a}	
	S.Em±	CD@5%			S.Em±	CD@5%			S.Em±	CD@5%	
Variety (V)	0.03	0.09		Variety (V)	1.02	3.05 NS		Variety (V)	0.38	1.15NS	
Shoots (S)	0.02	0.05		Shoots (S)	0.65	1.93		Shoots (S)	0.24	0.73	
Interaction (VXS)	0.04	0.12		Interaction (VXS)	1.45	4.32		Interaction (VXS)	0.55	1.63	

V1: Dhupdal, V2: Selection- 45, V3: Selection -58, V4: Savadatti and V5: AJG-85

Table 2: Panicle length, width and number of flowers per inflorescence in five Jamun varieties

Varieties	Panicle length (cm)	Panicle width (cm)	Number of flowers per inflorescence
Dhupdal	8.42	5.04	22.20
Selection-45	9.00	4.78	32.40
Selectio-58	10.48	5.34	36.00
Savadatti	8.54	4.72	32.00
AJG-85	8.80	5.00	26.20
SEm±	0.209	0.213	2.042
CD at 5%	0.65*	NS	6.35*

*: Significance at P<0.05

in detail by Palanichamy *et al.* (2012) in mango hybrids. Phenols act as critical internal regulator during flower bud differentiation by modulating auxin breakdown, serving as enzyme cofactors and providing structural building blocks for floral organs.

The protein content was relatively high in vegetative buds (5.08 mg g^{-1} f.wt.). Among the interaction effect, vegetative buds of Selection-45 had higher proteins (6.05 mg g^{-1} f.wt.) (Table 3). The proteins in the vegetative buds were also recorded significantly higher in a study by Saxena *et al.* (2013) wherein among four mango cultivars, higher protein (5.54 mg g^{-1}) was found in Langra buds, which might have enhanced protein content in the source which acts as building blocks for the developing sink (flower buds). Similarly, varietal difference in soluble protein content in the bud was noted in mango, with maximum proteins in Bombay (4.88 mg g^{-1}) followed by Zardalu (4.18 mg g^{-1}), and minimum in Dashehari (3.14 mg g^{-1}). Further, buds collected during the on-season contained significantly greater soluble protein (5.73 mg g^{-1} f. wt.) than those from the off-season, representing an increase of approximately 37 percent (Das *et al.*, 2023).

The total chlorophyll content was significantly high in vegetative buds of Dhupdal, Selection-45 and AJG-85 (0.851, 0.866 and 0.863 mg g^{-1} f.wt.), respectively. However, in interaction effect, the vegetative buds of AJG-85 had higher chlorophyll content (0.968) (Table 3). The vegetative buds tend to grow into leaves and shoots, and act as a source for the synthesis of photosynthates. In contrast, the reproductive buds tend to produce flowers and fruits, which need chlorophyll for energy synthesis, but at far lesser concentration compared to vegetative buds. Similarly in litchi also, the chlorophyll (a, b and total) contents were higher during flowering stage when compared to flower bud differentiation stage (Singh *et al.*, 2017). Apple floral buds contained lower chlorophyll levels than vegetative buds during the early stages of development. However, chlorophyll concentration increased progressively in floral buds as bud burst approached, indicating enhanced photosynthetic activity associated with the transition to active growth (Botirov, 2025). In contrast, Bajpai *et al.* (2021) though reported higher chlorophyll content in vegetative buds of mango cv. Amrapali, in other irregular varieties, the chlorophyll content was high in reproductive buds.

Table 3: The phenols, protein and chlorophyll content in flowering and vegetative buds of five jamun cultivars

	Phenols (mg g^{-1} f.wt.)				Protein (mg g^{-1} f.wt.)			Chlorophyll (mg g^{-1} f.wt.)		
Varieties	**Flowering** buds	**Vegetative** buds	**Mean** (variety)	**Varieties**	**Flowering** buds	**Vegetative** buds	**Mean** (variety)	**Flowering** buds	**Vegetative** buds	**Mean** (variety)
V1	6.16^{b}	3.80^{f}	4.98^{c}	V1	3.58^{f}	5.89^{a}	4.74^{b}	0.797^{cde}	0.905^{b}	0.851^{a}
V2	5.05^{c}	4.14^{ef}	4.59^{d}	V2	4.16^{e}	6.05^{a}	5.11^{a}	0.813^{cd}	0.920^{ab}	0.866^{a}
V3	7.44^{a}	4.29^{de}	5.87^{a}	V3	4.21^{de}	4.38^{cde}	4.29^{c}	0.741^{f}	0.921^{ab}	0.831^{ab}
V4	5.46^{c}	3.79^{f}	4.63^{d}	V4	3.67^{f}	4.43^{bcd}	4.05^{d}	0.774^{def}	0.833^{c}	0.804^{b}
V5	6.01^{b}	4.61^{d}	5.31^{b}	V5	4.52^{bc}	4.68^{b}	4.60^{b}	0.758^{ef}	0.968^{a}	0.863^{a}
Mean (buds)	6.03^{a}	4.13^{b}		Mean (buds)	4.03^{b}	5.08^{a}		0.777^{b}	0.909^{a}	
	S.Em±	CD@5%			S.Em±	CD@5%		S.Em±	CD@5%	
Variety (V)	0.10	0.31		Variety (V)	0.059	0.17		0.012	0.036	
Buds (B)	0.06	0.19		Buds (B)	0.038	0.11		0.008	0.022	
Interaction (VXB)	0.15	0.44		Interaction (VXB)	0.084	0.25		0.017	0.051	

V1: Dhupdhal, V2: Selection- 45, V3: Selection -58, V4: Savadatti and V5: AJG-85

Table 4: The nitrogen, phosphorous and C: N ratio content in flowering and vegetative buds of five jamun cultivars

	Nitrogen (%)				Phosphorous (%)				C:N ratio		
Varieties	**Flowering shoots**	**Vegetative shoots**	**Mean (variety)**	**Variety**	**Flowering shoots**	**Vegetative shoots**	**Mean (variety)**	**Variety**	**Flowering shoots**	**Vegetative shoots**	**Mean (variety)**
V1	0.295^{c}	0.467^{a}	0.381^{a}	V1	0.085^{b}	0.047^{c}	0.066^{ab}	V1	59.03^{c}	39.95^{h}	49.49^{c}
V2	0.302^{c}	0.452^{ab}	0.377^{a}	V2	0.084^{b}	0.050^{c}	0.0673^{ab}	V2	54.34^{d}	42.05^{g}	48.19^{d}
V3	0.268^{c}	0.460^{ab}	0.364^{a}	V3	0.097^{a}	0.043^{c}	0.0699^{a}	V3	65.75^{a}	47.78^{f}	56.76^{a}
V4	0.287^{c}	0.421^{b}	0.354^{a}	V4	0.087^{b}	0.044^{c}	0.0656^{ab}	V4	59.56^{c}	37.07^{i}	48.31^{d}
V5	0.283^{c}	0.483^{a}	0.383^{a}	V5	0.092^{ab}	0.031^{d}	0.0615^{b}	V5	62.05^{a}	49.43^{e}	55.74^{b}
Mean (shoots)	0.287^{b}	0.456^{a}		Mean (shoots)	0.0891^{a}	0.0431^{b}		Mean (shoots)	60.14^{a}	43.25^{b}	
	S.Em±	CD@5%			S.Em±	CD@5%			S.Em±	CD@5%	
Variety (V)	0.012	NS (0.03)		Variety (V)	0.002	0.006		Variety (V)	0.19	0.57	
Shoots (S)	0.006	0.190		Shoots (S)	0.001	0.004		Shoots (S)	0.12	0.36	
Interaction (VXS)	0.014	0.042		Interaction (VXS)		0.003	0.009	Interaction (VXS)	0.27	0.80	

V1: Dhupdhal, V2: Selection- 45, V3: Selection -58, V4: Savadatti and V5: AJG-85

The carbohydrate was significantly higher in flowering buds (51.34 mg g^{-1} f.wt.) and least in vegetative buds (42.37 mg g^{-1} f.wt.). Highest carbohydrates was found in Savadatti (51.15 mg g^{-1} f.wt.), while in interaction effect, high carbohydrates was recorded in flowering buds of Savadatti (59.53 mg g^{-1} f.wt.) (Fig. 2). Palanichamy *et al.* (2012) reported that the carbohydrate content in mango varieties increased at flower bud differentiation, thereafter, decreased at bud swelling stage and finally increased at flower initiation stage (end of December). Carbohydrates act as a major source during floral bud formation and fruiting. Studies in mango showed significantly higher carbohydrate content observed in the buds of on-season trees indicating greater accumulation of assimilates required to support floral induction and subsequent reproductive development. In contrast, the lower carbohydrate reserves in off-season trees may limit the availability of energy required for floral development .The simultaneous occurrence of higher carbohydrate and comparatively lower nitrogen levels in on-season trees results in a higher carbon-to-nitrogen (C) ratio, is widely considered a favorable physiological condition for flowering in perennial fruit crops (Das *et al.*, 2023), wherein lower C:N ratio and low carbohydrate content leads to vegetative growth. The reproductive bud formation can be increased in grapes when balanced carbohydrate and sugar levels are maintained (Lebon *et al.*, 2004). The total sugar content was highest in flowering buds (25.05 mg g^{-1} f.wt.). Among the varieties, the maximum total sugar content was recorded in Savadatti (20.87 mg g^{-1} f.wt.) and Selection-45 (20.04 mg g^{-1} f.wt.). In interaction effect, the

Fig. 2: vegetative bud (left) and Reproductive bud (right) of jamun.

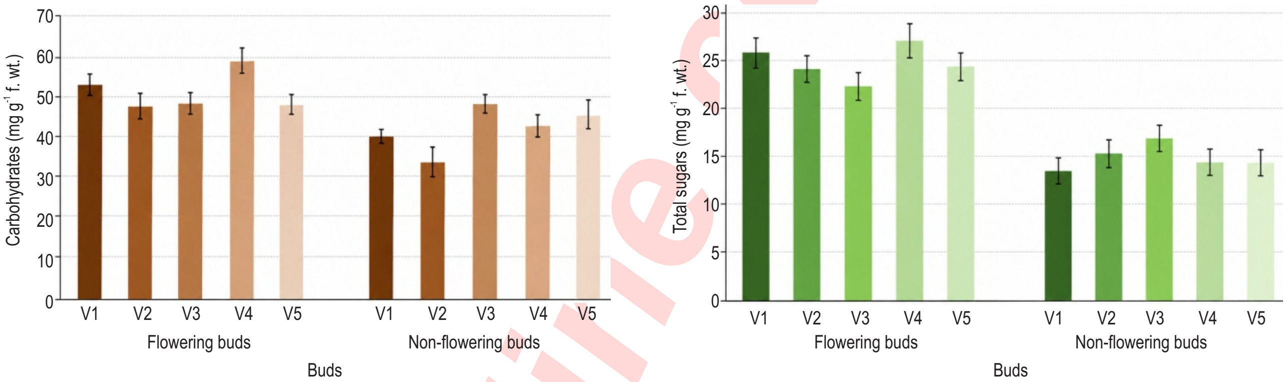

Fig. 3: Carbohydrates and total sugars in flowering and vegetative (non flowering) buds of five Jamun cultivars. *V1: Dhupdhal, V2: Selection- 45, V3: Selection -58, V4: Savadatti and V5: AJG-85. Bars represent mean of three replicate ±SE.

flowering buds of Savadatti (27.22 mg g^{-1} f.wt.) recorded high total sugar content (Fig. 2). Singh and Sharma, (2008) recorded the total sugars in the range 24.10 to 32.41 mg g^{-1} f.wt. in mango cultivars at the flower bud swelling stage.

Sucrose plays a key role in floral induction by serving as both an energy source and a signaling molecule. During the floral transition in blueberries, sucrose and soluble sugar levels increase in leaves and developing buds, promoting the movement of assimilates to the shoot apex. This transient rise in sucrose is associated with the activation of flowering-related genes, such as FT, SOC1 and LFY, thereby facilitating the transition from vegetative to reproductive growth (Wu *et al.*, 2025).

The nitrogen content was highest in vegetative shoots (0.456%) and all varieties had similar nitrogen content, while interaction effect indicates that vegetative shoots of AJG-85 (0.483%) and Dhupdal (0.467%) had significantly higher nitrogen content (Table 4). The nitrogen content is usually mobilized towards vegetative growth once bud break is initiated, which ensures leaves and shoot growth, which further supports the fruit growth and development (Ferreira *et al.,* 2022). Similarly, in an investigation on mango hybrids, decreased nitrogen content was observed from September to December as the bud or shoot tends towards reproductive growth with low nitrogen content (1.89%) at fruit bud differentiation (Palanichamy *et al.,* 2012). Hariprasanth *et al.* (2025) reported that as the reproductive bud development tends to grow in off season mango, the fractions of nitrogen content decreases, while the C:N ratio increases. The phosphorus content was higher in the flowering buds (0.089%). The interaction effect revealed that the flowering shoots of Selection-58 had higher phosphorus content (0.0972%) (Table 4). Phosphorus has a pivotal role in the development of reproductive parts, supporting the formation of flowers and seeds. The optimum phosphorus content in buds lead to early flowering; hence, phosphorus nutrition is essential for induction of flowering in strawberry (Ahmad *et al.,* 2017).

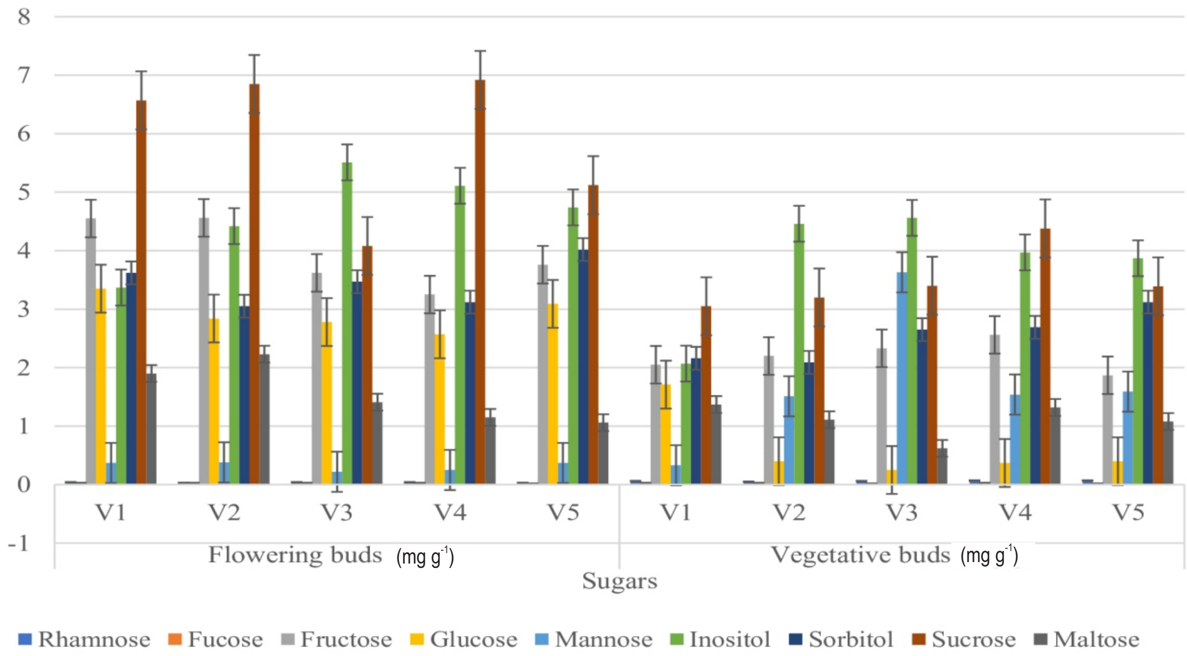

Fig. 4: The sugar profiling in flowering and vegetative buds of five Jamun cultivars. (V1: Dhupdal, V2: Selection- 45, V3: Selection -58, V4: Savadatti and V5: AJG-85).

The C: N ratio in the flowering shoots was higher in all the varieties with highest recorded in Selection-58 (56.76), while interaction effect also showed a higher C: N ratio in flowering shoots of Selection-58 (65.75) and AJG-85 (62.05) (Table 4). Carbohydrates reserves are essential inducing flowering, wherein high C: N ratio and accumulation of carbohydrates are necessary build-ups for flowering (Leite *et al.,* 2021). These research findings are in agreement with the findings of Humayun and Babu (2002), who revealed that with fruit bud differentiation progression from August to December, the C: N ratio in Baneshan variety increased from 32.46 to 55. Prior to bud break, the concentration of C: N ratio increased in all three mango hybrids and three varieties studied.

Higher sugar content was identified in flowering buds (21.15 to 24.40 mg g^{-1} f.wt.) than vegetative buds (12.83 to 17.53 mg g^{-1}) (Fig 3). Sugars like sucrose play a substantial role in regulating and differentiation of flowering buds. They act as signalling molecules influencing gene expression and process of flower bud differentiation. In blue berries, sucrose and Trehalose – 6- Phosphate play a crucial role in promoting fruit bud differentiation. In loquat, sorbitol was found to promote early fruit bud differentiation (Awasthi *et al.,* 2024). In many fruit crops, the growth rate of flowering buds was complimented with fructose, glucose and sorbitol. In grapes (Campbell and Strother, 1996) sucrose, glucose and fructose were the major sugars to feed inflorescence, which was found in both xylem and phloem sap. As Flowering Locus T (FT) homologs expression is increased by sucrose, sugars may act as a complimentary element for FT expression (Cho *et al.,* 2018). Sugars, especially fructose, sucrose, inositol and sorbitol were found higher in the reproductive buds of jamun in this study.

In this study, the carbohydrate level was positive by correlated (Table 5) with sugars (0.652), higher accumulation of carbohydrates leads to high sugar metabolism, which is important for bud development (Ito *et al.,* 2002). The carbohydrates showed a complementary correlation with phosphorus (0.693). Though the phosphorus content does not directly influence the carbohydrate reserve or transportation, low phosphorus content can reduce the synthesis of carbohydrates. In a study on phosphorus levels, carbohydrate reserves on flower quality of olives reported that high leaf phosphorus content had a positive correlation with increased levels of phosphorus and carbohydrates in olive flowers (Erel *et al.,* 2016; Tromp *et al.,* 2005). Carbohydrates showed a positive correlation with C: N ratio (0.832) (Table 5). Carbohydrates and C: N ratio tends to increase at the same rate as the progress of flower bud differentiation. In fruit trees, distinct flower bud differentiation was explained by the C/N-ratio theory. It is hypothesized that lowering is inhibited by excessive nitrogen fertilization, while flower development is favoured by high C/N ratios. C: N ratio has a strong correlation with carbohydrates and total sugars (Reyes *et al.,* 2016). The phenols and carbohydrates recorded a positive correlation (0.643) (Table 5), indicating higher availability of carbon, which causes the plants to divert their synthesis towards

Table 5: Correlation matrix among vegetative parameters and physio-biochemical parameters of flowering shoots

	Carbo	Phenols	Protein	Sugars	Nitrogen	Phosp	Chl	SC	SL	IL	C:N
Carbo	1.000										
Phenols	0.643*	1.000									
Protein	-0.660**	-0.830**	1.000								
Sugars	0.652**	0.499	-0.438	1.000							
Nitrogen	-0.660**	-0.589*	0.560*	-0.559*	1.000						
Phosp	0.693**	0.554*	-0.655**	0.532*	-0.343	1.000					
Chl	-0.774**	-0.720**	0.796**	-0.539*	0.658**	-0.778**	1.000				
SC	-0.251	-0.628*	0.358	-0.120	0.497	-0.078	0.222	1.000			
SL	-0.002	-0.407	-0.397	0.343	-0.019	0.326	-0.298	0.125	1.000		
IL	-0.159	0.039	-0.061	-0.082	0.180	0.048	0.058	0.158	-0.009	1.000	
C:N	0.832**	0.761**	-0.786**	0.542*	-0.650**	0.775**	-0.842**	-0.521*	0.186	-0.112	1.000

Pearson correlation**Significant at p≤ 0.01, *Significant at p≤ 0.05; Carbo: Carbohydrates, Phosp: Phosphorus, Chl: Chlorophyll, SC: Shoot circumference, SL: Shoot length, IL: Internodal length, C:N : C:N ratio

phenols (Amin *et al.,* 2010). The protein with carbohydrates showed a (-0.660) negative correlation, the low nitrogen and high carbohydrates content reduce protein synthesis and higher accumulation of carbohydrates in leaves. Nitrogen deficiency reduces invertase activity and sugar utilization, leading to carbohydrate accumulation in the source tissue. (Ruan *et al.,* 2010). Phenols with C: N ratio showed a positive correlation (0.761). Since the C: N ratio was relatively high, the availability of nitrogen was very less, which caused stress conditions, thus enhancing the carbon-based secondary metabolites such as antioxidants, phenols and flavonoids. The higher carbon content in trees and low nitrogen availability are a triggering point for phenol synthesis. In grapes, the low nitrogen and high C: N ratio enhanced phenolic content (Deluc *et al.,* 2007).

The correlation between protein and phenol (-0.830) (Table 5) showed strong negative correlation. Higher phenols bind to proteins and form biologically inactive complexes. The high hydroxyl groups, thus forming hydrogen bonds with amine groups in the protein may produce inactive forms showing a negative interaction of phenols and protein, which decreases the availability of protein as reported by Butler *et al.* (1992). Nitrogen and phenols showed a negative correlation (-0.589), wherein when nitrogen content is limited, the protein synthesis is suppressed and the synthesis of phenols is enhanced. Nitrogen at higher levels tends to promote more growth, thus reducing the accumulation of phenols in grapes (Lattanzio *et al.*, 2006).

Protein content was positively correlated (0.796) with chlorophyll content. The protein was severely affected in flowering buds, with the lower rates of proteins at early stages of reproductive bud development, which is known to eventually enhance at inflorescence stage. Similarly, chlorophyll content decreased during the early phases of the flower bud development in apple (Fuleki and Daun, 1967). C: N ratio had a negative correlation with protein (-0.786), wherein low nitrogen content had an impact on protein synthesis. Since in this study, C: N ratio was high, the availability of nitrogen content was less and thus protein synthesis might have affected (Leite *et al.*, 2021).

Phosphorus and C:N ratio were positively correlated (0.775) (Table 5), wherein higher accumulation of carbohydrates and sugars had higher carbon content in the reproductive buds. Availability of nutrients like phosphorus can directly impact the provision of essential 'building blocks' viz., carbohydrates and energy required for flower bud differentiation. In addition, it can modulate the hormonal status of tree, and indirectly control the reproductive processes (Ye *et al.*, 2019). The C: N ratio showed a negative correlation (Table 5) with chlorophyll content (-0.842). The higher carbon content and low nitrogen content affects chlorophyll content. In the current study, when C: N ratio was high, the availability of nitrogen was relatively less, which might have resulted in lesser chlorophyll thus showing an inverse relationship. Similarly, confirmed that nitrogen supply enhances the chlorophyll biosynthesis in forest tree species, thus significantly lowering the C: N ratio. The shoot circumference showed a negative correlation with C: N ratio (-0.521). The shoot circumference was relatively less for reproductive shoots as the high C: N ratio might have restricted the shoot growth and thus encouraging the flowering in such shoots. The lower nitrogen in the reproductive shoots must have reduced the shoot circumference by reducing the cell division and cell elongation. High C: N ration has linked to stunted growth and reduced organ size under nutrient limitation situations as reported by Sardans *et al.* (2012).

Morphological and biochemical traits, influenced by climate, determine whether buds become vegetative or reproductive. These traits serve as markers to breed fruits with higher yields and regular bearing. Among climatic conditions, high temperature and rainfall triggered reproductive bud formation. Biochemically, accumulation of higher phenols, phosphorus, total sugars and C: N ration can modify the vegetative buds into fruit buds.

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