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Effect of geospatial conditions and time of panicle emergence on the physiology and sensory attributes of mango var. alphonso

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Abstract

Mango fruit quality is intricately governed by prevailing agro-climatic conditions and the timing of panicle emergence, both of which exert a profound influence on fruit development, ripening behaviour, and consumer-perceived quality. In the present study, a range of geospatial parameters, including altitude, temperature, rainfall, relative humidity, and soil nutrient status, were comprehensively evaluated to elucidate their impact on the physiological performance and sensory characteristics of Alphonso mango. Panicles were tagged on three successive occasions at 10-day intervals across four geographically distinct locations, namely Bengaluru (930 m above mean sea level), Chikkaballapura (865 m MSL), Hogalgeri (836 m MSL), and Ramanagara (747 m MSL), spanning an approximate geographical distance of 228 km. Fruits were harvested at physiological maturity and subsequently assessed for postharvest quality attributes. The results revealed pronounced location-specific variations in fruit physiology and quality. Fruits harvested from Ramanagara exhibited the highest respiration rate (66.01 mg CO₂ kg⁻¹ h⁻¹), which corresponded with the shortest shelf life of 13 days, indicating accelerated metabolic activity and senescence. In contrast, sensory evaluation demonstrated that fruits sourced from Hogalgeri consistently achieved superior ratings for appearance (4.90), colour (4.95), texture (4.62), aroma (4.89), taste (4.68), and overall acceptability (4.64) after nine days of storage, reflecting their exceptional organoleptic quality. Furthermore, fruits derived from early-emerged panicles exhibited enhanced shelf life and superior sensory attributes compared with those originating from late-emerged panicles, highlighting the significance of flowering phenology in determining final fruit quality. Collectively, these findings emphasize the pivotal role of geospatial conditions and panicle emergence timing in shaping the postharvest physiology, sensory excellence, and storage potential of Alphonso mango fruits.

Keywords: Altitude, geospatial, mango quality, sensory attributes, respiration

Introduction

Mango (*Mangifera indica* L.) is one of the most important tropical fruit crops cultivated across diverse agro-climatic regions, with India being the world's largest producer. Among commercial cultivars, Alphonso is highly prized for its superior flavour, aroma, colour, and market value. However, the expression of these quality attributes is strongly influenced by environmental conditions prevailing during flowering, fruit development, and ripening (Singh *et al.*, 2021; Patel *et al.*, 2023) [19, 13]. Fruit quality is determined by the interaction between genetic potential and environmental factors such as temperature, rainfall, relative humidity, altitude, and soil fertility, which regulate physiological processes including photosynthesis, respiration, assimilate partitioning, and synthesis of flavour and colour compounds (Lal *et al.*, 2020; Kumar *et al.*, 2022) [10, 9]. Consequently, mangoes produced in different geographical locations often exhibit considerable variation in physical, biochemical, sensory, and postharvest characteristics (Rajan *et al.*, 2021; Sharma *et al.*, 2024) [14, 18]. Altitude influences temperature regimes, radiation intensity, and soil properties, thereby affecting fruit maturation, respiration, colour development, and storage behaviour (Kumar *et al.*, 2022) [9]. Similarly, temperature, rainfall, and humidity significantly influence fruit growth, ripening, shelf life, and overall quality (Lal *et al.*, 2020; Singh *et al.*, 2021) [10, 19].

In addition to environmental factors, flowering phenology plays a crucial role in determining fruit quality. Mango trees often produce multiple flowering flushes, exposing fruits from different panicle emergence periods to varying climatic conditions during development. As a result, early- and late-emerged panicles may differ significantly in fruit size, dry matter accumulation, sugar content, colour, sensory quality, and shelf life (Jameel *et al.*, 2018; Patel *et al.*, 2023; Rajan *et al.*, 2021; Sharma *et al.*, 2024) [6, 13, 14, 18]. Consumer acceptance of mangoes largely depends on appearance, colour, texture, aroma, taste, and overall eating quality, all of which are influenced by environmental conditions and fruit developmental history (Kumar *et al.*, 2022; Sharma *et al.*, 2024) [9, 18]. Furthermore, location-specific climatic conditions affect respiration rate, ripening behaviour, and storability, making such information valuable for growers, traders, and exporters seeking to maximize fruit quality and market returns (Lal *et al.*, 2020) [10].

Despite the recognized importance of geospatial factors and flowering phenology, information on their combined influence on the physiological and sensory quality of Alphonso mango under the agro-climatic conditions of southern India remains limited. Therefore, the present study was undertaken to evaluate the effects of altitude,

temperature, rainfall, relative humidity, soil nutrient status, and panicle emergence timing on the physiology, sensory attributes, and shelf life of Alphonso mango. The findings will contribute to location-specific production strategies, improved harvest management, enhanced fruit quality, reduced postharvest losses, and greater profitability for mango growers (Bally, 2021; Crane and Balerdi, 2022; Litz, 2020) [1, 3, 12].

Material and Methods

The experiment was conducted across four geographically distinct locations, namely Bengaluru, Chikkaballapura, Hogalgere, and Ramanagara, situated at altitudes of 930, 865, 836, and 747 m above mean sea level, respectively. These locations differed considerably in their geospatial and agro-climatic characteristics. At each location, mango panicles were tagged according to their time of emergence using colour-coded tags: white for early-emerged panicles, yellow for mid-emerged panicles, and pink for late-emerged panicles. Tagging was carried out at intervals of 10-15 days as successive flowering flushes emerged. Fruits from tagged panicles were harvested upon attaining optimum physiological maturity for subsequent evaluation (Table 1).

Table 1: Panicle emergence, tagging and fruit growth and development of mango var. Alphonso at different locations

	Tagging	Harvesting	DAP	DAF	Tagging	Harvesting	DAP	DAF
	Bengaluru				Chikkaballapura			
First tagging	27/12/18	11/05/2019	136	101	20/12/18	07/05/2019	139	104
Second tagging	08/01/19	20/05/2019	132	98	07/01/19	18/05/2019	131	96
Third tagging	20/01/19	31/05/2019	132	98	21/01/19	29/05/2019	129	94
	Hogalgere				Ramanagara			
First tagging	25/12/18	27/05/2019	153	119	08/12/18	16/04/2019	130	95
Second tagging	31/12/18	27/05/2019	148	113	23/12/18	28/04/2019	126	91
Third tagging	06/01/19	27/05/2019	141	106	10/01/19	10/05/2019	120	85

Mature fruits of mango cv. Alphonso were harvested carefully, sorted to remove damaged or defective fruits, and disinfected using 200 ppm sodium hypochlorite solution. The fruits were then pre-cooled, and de-sapping was performed by trimming the fruit stalk to a length of 0.6-1.0 cm, followed by placement in de-sapping trays for approximately four hours at ambient conditions to facilitate complete latex drainage. Ripening was induced using a portable ethylene gas can (Make: Chemtron; Model: Ripelene-6) in a ripening chamber maintained at room temperature (28 °C). The ripened fruits were subsequently utilized for the experimental studies. Data were analysed using a Completely Randomized Design (CRD).

Physiological loss in weight (PLW)

PLW was determined using a high-precision electronic balance with an accuracy of 10 mg (Make: Sartorius, Germany; Model: GE812). Initial fruit weights were recorded prior to storage, and subsequent measurements were taken at three-day intervals throughout the storage period. The cumulative physiological loss in weight was then calculated and expressed as a percentage using the standard formula.

Respiration rate (mg CO₂kg⁻¹h⁻¹)

The fruits of known volume were enclosed in a hermetic container for specified time and head space gas concentration of CO₂ was measured by an auto

oxygen/carbon dioxide analyzer (Make: Quantek, Model: 902D Dual track) and direct reading was noted down from the instrument screen and was calculated using the following formula.

$$\text{Respiration rate (mg kg}^{-1} \text{ h}^{-1}) = \frac{2 \times \% \text{ CO}_2 \times \text{Container volume (ml)} \times 60}{\text{Fruit weight (kg)} \times \text{Enclosing time (min)} \times 100}$$

Sensory qualities

The organoleptic evaluation of mango fruits were conducted on the basis of appearance, colour, texture, aroma, taste and overall acceptability by a semi trained panel using a 5-point rating scale as laid out by Lawless and Heymann (1999) [32]. The score used for assessing the mango fruit is indicated as follows 5-Like; 4- Like slightly; 3- Neither like nor dislike; 2-Dislike slightly; 1-Dislike.

Results and Discussion

Physiological loss in weight (PLW%)

Physiological loss in weight (PLW) during storage was primarily attributed to continuous respiration and transpiration processes (Table 2). Fruits from Ramanagara recorded higher PLW, which may be associated with the relatively higher temperatures prevailing during harvest and storage, along with lower relative humidity (50.38%), resulting in increased moisture loss. In contrast, fruits from Hogalgere exhibited the lowest PLW due to the comparatively lower storage temperature (27 °C), higher

relative humidity (63.27%), and greater dry matter content, which collectively reduced respiratory and transpirational losses. Fruits from the first week of panicle emergence also showed the lowest PLW, indicating better storage performance. These findings corroborate earlier reports by Burdon *et al.* (2004)^[2] and Spadaro *et al.* (2010)^[20], and are

further supported by recent studies demonstrating that lower storage temperatures, higher relative humidity, and greater dry matter accumulation effectively minimize postharvest weight loss and maintain fruit quality during storage (Li *et al.*, 2021; Anand *et al.*, 2023; Rokhani *et al.*, 2024)^[11, 15].

Table 2: Effect of geospatial variations and panicle emergence on physiological loss in weight (%) of mango var. Alphonso during storage

		Day 3	Day 6	Day 9	Day 12	Day 15
Factor I	L ₁	2.48	3.10	6.29	9.95	14.34
	L ₂	2.13	2.46	6.27	10.39	14.11
	L ₃	2.24	2.79	5.02	6.79	8.44
	L ₄	2.26	2.90	9.96	15.66	17.01
	S. Em. (±)	0.12	0.25	0.46	0.60	0.70
	CD (5%)	NS	NS	1.39	1.81	2.12
Factor II	T ₁	2.60	3.03	7.50	11.41	14.49
	T ₂	2.13	2.67	6.33	10.04	13.58
	T ₃	2.35	2.73	6.82	10.65	10.10
	S. Em. (±)	0.18	0.22	0.41	0.53	0.61
	CD (5%)	NS	NS	NS	NS	1.83
Interaction						
	L ₁ T ₁	1.98	3.52	7.09	10.30	14.55
	L ₁ T ₂	1.86	2.28	4.33	7.78	11.25
	L ₁ T ₃	2.18	3.51	7.45	11.80	17.21
	L ₂ T ₁	2.22	2.58	6.86	10.56	13.38
	L ₂ T ₂	2.45	2.45	6.25	10.14	14.77
	L ₂ T ₃	2.66	2.34	5.69	10.45	14.18
	L ₃ T ₁	1.80	3.42	5.78	7.66	7.79
	L ₃ T ₂	1.82	2.65	4.67	6.51	8.35
	L ₃ T ₃	1.85	2.29	4.62	6.21	9.01
	L ₄ T ₁	2.88	2.61	10.28	17.12	22.06
	L ₄ T ₂	2.75	3.28	10.07	15.72	19.95
	L ₄ T ₃	2.80	2.79	9.52	14.15	19.65
	S. Em. (±)	0.42	0.43	0.81	1.05	1.22
	CD (5%)	NS	NS	2.43	3.16	3.67

* Significant at 5% (P_{0.05}), NS: Non significant at 5% (P_{0.05}).

Fruits stored at ambient condition in PHT lab in Bengaluru

- L₁- Bengaluru (Stored during month of May, Avg. temp.: 28.97°C, RH: 54.55%)
- L₂- Chikkaballapura (Stored during month of May, Avg. temp.: 28.97°C, RH: 54.55%)
- L₃- Hogalgera (Stored during month of June, Avg. temp.: 27.73°C, RH: 61.15%)
- L₄- Ramanagara (Stored during month of April, Avg. temp.: 28.31°C, RH: 53.19%)
- T₁- Tagging at first week of panicle emergence
- T₂- Tagging at second week of panicle emergence
- T₃- Tagging at third week of panicle emergence

Respiration rate

Respiration rate differed significantly among fruits harvested from different locations. Respiration encompasses a series of biochemical processes, including ethylene biosynthesis and the degradation of structural polysaccharides, which contribute to fruit softening and ripening (Devanesan *et al.*, 2011)^[4, 5]. Fruits from Hogalgera exhibited the lowest respiration rate (Fig. 1), which may be attributed to the comparatively lower storage temperature and the higher dry matter content of the fruits. Environmental conditions during fruit development also influence respiratory activity; fruits exposed to moderate field stress often exhibit reduced respiration and moisture

loss during storage (Karabacak and Karabacak, 2019)^[7, 8]. Furthermore, fruits from later-emerged panicles showed higher respiration rates than those from early-emerged panicles, owing to enhanced metabolic activity involving the breakdown of starch, sugars, and organic acids into simpler compounds such as carbon dioxide and water. Since respiration rate is inversely related to storage life, fruits with higher respiration rates generally exhibit shorter shelf-life. A typical climacteric respiratory pattern was observed across all locations and harvest periods. Respiration initially declined to a pre-climacteric minimum, followed by a rapid increase to the climacteric peak and a subsequent decline during senescence (Sen *et al.*, 2012)^[16, 17]. As respiration is regulated by enzyme-mediated metabolic reactions that are highly temperature-dependent, variations in storage temperature likely contributed to the observed differences in respiratory behaviour. Similar observations have been reported in earlier studies (Devanesan *et al.*, 2011; Karabacak and Karabacak, 2019; Sen *et al.*, 2012)^[4, 5, 7, 8, 16, 17] and are supported by recent findings indicating that lower storage temperatures and reduced metabolic activity effectively suppress respiration and prolong postharvest life in mango and other climacteric fruits (Li *et al.*, 2021; Wang *et al.*, 2022; Rokhani *et al.*, 2024)^[11, 21, 15].

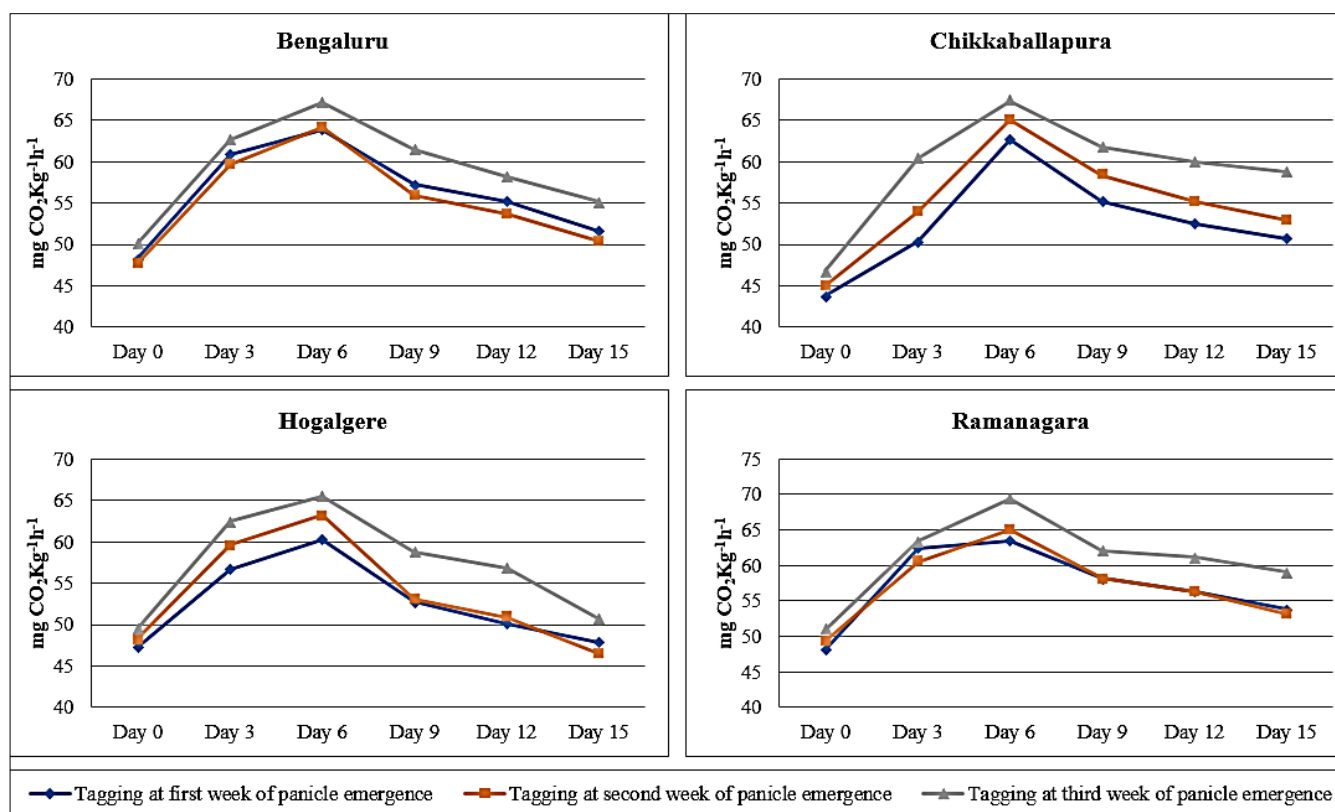


Fig 1: Effect of geospatial variations and panicle emergence on respiration rate (mg CO₂ Kg⁻¹ h⁻¹) of mango var. Alphonso during storage

Sensory attributes

Sensory evaluation clearly demonstrated that both geospatial conditions and panicle emergence timing significantly influenced the sensory quality of Alphonso mango fruits during storage (Fig. 2). At the edible ripe stage (3 days of storage), fruits from Chikkaballapura recorded the highest scores for appearance (4.97), colour (4.98), and texture (5.00), while fruits from Hogalgere exhibited superior aroma (4.98), taste (5.00), and overall acceptability (5.00). Across all sensory attributes, fruits originating from the first week of panicle emergence consistently recorded the highest scores, with appearance (4.79), colour (4.79), texture (4.95), aroma (4.96), taste (4.95), and overall acceptability (4.97). As storage progressed, fruits from Hogalgere maintained

superior sensory quality and exhibited the highest retention of appearance (4.28), colour (4.22), texture (3.70), aroma (3.51), taste (3.45), and overall acceptability (3.96) even after 15 days of storage. In contrast, comparatively lower scores were observed in fruits from Chikkaballapura, Bengaluru, and Ramanagara for specific sensory attributes. Similarly, fruits derived from early-emerged panicles consistently retained better appearance, colour, texture, aroma, taste, and overall acceptability throughout storage compared with fruits from mid- and late-emerged panicles (Fig. 3). These findings indicate that favourable geospatial conditions and early panicle emergence contribute significantly to enhanced sensory quality and improved storage performance of Alphonso mango fruits.

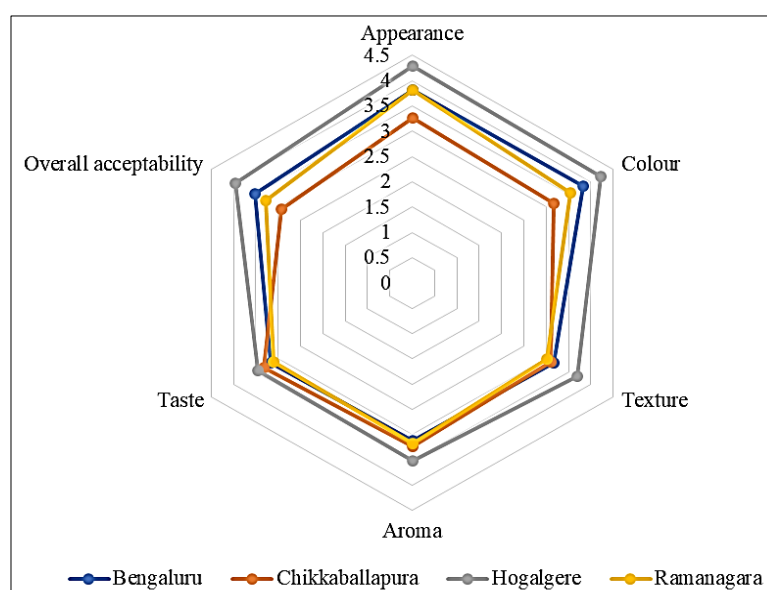


Fig 2: Effect of geospatial variations on sensory attributes of mango var. Alphonso after 15 days of storage

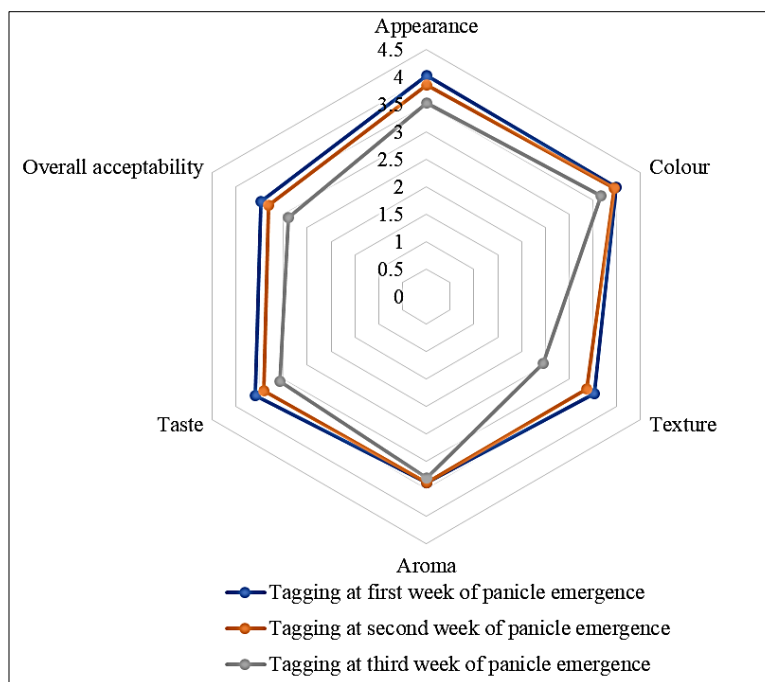


Fig 3: Effect of time of panicle emergence on sensory attributes of mango var. Alphonso after 15 days of storage

Correlation

The correlation analysis revealed significant relationships between geospatial factors and the postharvest physiological characteristics of Alphonso mango (Table 3). Physiological loss in weight (PLW) showed significant positive correlations with relative humidity ($r=0.84$), maximum temperature ($r=0.72$), and respiration rate ($r=0.99$), indicating enhanced moisture loss under conditions promoting higher metabolic activity. Respiration rate was positively correlated with relative humidity ($r=0.74$) and maximum temperature ($r=0.64$), suggesting increased fruit metabolism under warmer and more humid conditions. Shelf

life exhibited a significant positive correlation with relative humidity ($r=0.86$) and altitude ($r=0.53$), whereas it was negatively correlated with maximum temperature ($r=-0.68$), physiological loss in weight ($r=-0.98$), and respiration rate ($r=-0.94$). These results indicate that elevated respiration and moisture loss accelerated fruit senescence and reduced storage life. Overall, the study demonstrates that geospatial conditions substantially influence postharvest physiology, with favourable environmental conditions contributing to reduced metabolic activity, lower weight loss, and extended shelf life of Alphonso mango fruits.

Table 3: Correlation of geospatial conditions with physical and physiological parameters of mango var. Alphonso

Variables	DAF	Altitude (m MSL)	Rainfall	RH	Temp (Max)	Temp (Min)	Physiological loss in weight	Respiration rate	Shelf life
DAF	1								
Altitude (m MSL)	0.33	1							
Rainfall	-0.11	0.64*	1						
RH	-0.73**	-0.89**	-0.41	1					
Temp (Max)	-0.54	-0.92**	-0.30	0.93**	1				
Temp (Min)	0.20	0.15	-0.62*	-0.20	-0.48	1			
Physiological loss in weight	-0.97**	-0.51	0.08	0.84**	0.72**	-0.36	1		
Respiration rate	-0.97**	-0.37	0.25	0.74**	0.64*	-0.44	0.99**	1	
Shelf life	0.98**	0.53	0.08	-0.86**	-0.68*	0.16	-0.98**	-0.94**	1

- DAF: Days after flowering
- MSL: Mean sea level
- RH: Relative humidity
- *: significant correlation at 5 per cent level ($P_{0.05}$)
- **: highly significant correlation at 5 per cent level ($P_{0.05}$)

Conclusion

This study conclusively establishes that geospatial heterogeneity and panicle emergence phenology exert a profound influence on the postharvest physiology, sensory excellence, and storage potential of Alphonso mango. Distinct location-specific variations in respiration rate, physiological loss in weight, shelf life, and organoleptic

attributes underscore the pivotal role of altitude and prevailing agro-climatic conditions in modulating fruit quality. Fruits harvested from Hogalgere consistently exhibited superior sensory attributes, lower metabolic activity, and enhanced storability, whereas those from Ramanagara displayed accelerated respiration and reduced shelf life. Furthermore, fruits originating from earlyemerged panicles demonstrated markedly superior sensory quality and storage performance compared with those from later flowering flushes.

The strong correlations observed between geospatial variables and postharvest traits reaffirm that environmental conditions prevailing during fruit development govern

subsequent ripening behaviour and quality retention. Collectively, these findings provide compelling evidence that the interplay between production environment and flowering phenology is a decisive determinant of Alphonso mango quality. The study offers valuable insights for precision orchard management, optimized harvest scheduling, and quality-oriented production strategies aimed at enhancing marketability, reducing postharvest losses, and sustaining premium fruit quality across diverse growing environments.

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