

Evaluation of Irwin Mango under Protected Cultivation

Nangsel Tshomo

1. Introduction

Mango (*Mangifera indica* L.) is one of the most important tropical fruit crops globally, highly valued for its nutritional content, economic significance, and wide adaptability to various agroclimatic conditions (Malik et al., 2011). However, mango productivity is highly sensitive to environmental factors such as temperature, humidity, and water availability, particularly during early plant establishment and reproductive development. Adverse environmental conditions can significantly impact not only vegetative growth but also flowering, fruit set, and final fruit quality (Whiley et al., 1988; Medlicott & Thompson, 1985).

In Bhutan, the cultivation of mango has gained attention as part of broader agricultural diversification efforts, especially for improving rural livelihoods and promoting climate-resilient horticulture. Yet, Bhutan's diverse topography and climate present challenges for mango production, particularly in marginal and frost-prone areas where temperature extremes may hinder plant survival and limit productivity. Young mango trees, in particular, are vulnerable to cold injury and growth suppression when exposed to sub-optimal temperatures, highlighting the need for climate-adapted cultivation strategies (Gunjate, 2009; Kumar et al., 2017).

Globally, protected cultivation systems such as greenhouses and net houses have emerged as promising solutions for mitigating abiotic stresses in fruit crops. These systems offer the advantage of modifying the microclimate to optimize temperature, humidity, light, and moisture availability, thereby enhancing overall plant performance and yield (Choudhury et al., 2022; Tripathi et al., 2021). Studies from Japan and India also highlight the potential of protected environments to extend harvest seasons, improve fruit quality, and support the introduction of new cultivars in otherwise unsuitable regions (Yano et al., 2020; Patel & Bhalerao, 2022). Despite this, there remains a lack of region-specific data on mango performance under protected cultivation in Bhutan's agroecological zones.

This Nationally Coordinated Trial aims to address that gap by evaluating the establishment of Irwin mango under protected conditions in two locations of Bhutan, Bajo under Wangdue Phodrang Dzongkhag and Samtenling under Sarphang Dzongkhag. The study also aims to assess how environmental factors such as temperature, humidity, and site conditions influence plant development and to establish a robust foundation for future assessments of flowering, fruiting, and yield potential. The findings are expected to contribute to Bhutan's efforts in expanding sustainable, high-value fruit cultivation. This paper will present the first year's

findings from a multi-year trial, offering initial insights while acknowledging the need for further data collection in upcoming years.

2. Materials and Method

2.1. Experimental site

This NCT trial is conducted in Agriculture Research and Development Centre, Bajo and Agriculture Research and Development Centre, Samtenling.

2.2. Field Preparation and Nutrient Management

Pit digging for 8 mango plants was carried out in February. Planting took place between March and April. Farmyard manure (FYM) was applied in March and again in September. Urea, single super phosphate (SSP), and muriate of potash (MoP) were also applied during March and September.

2.3. Data Collection

The diameter of the tree trunk was measured using a digital calliper at maximum dimensions, and the height was recorded from above the graft union. Temperature (maximum and minimum) and relative humidity (maximum and minimum) were continuously monitored using a data logger (Model RC-4HC) set at one-hour logging intervals, yielding a total of 5,806 recorded data points (**Annexure I**)

3. Methodology

3.1.1. T test

For the analysis of growth differences of Mango (Height and Trunk Diameter) between the two locations (Bajo and Samtenling), independent samples t-tests were performed using the **t.test()** function in R statistical software (version [4.4.3]). The assumption of equal variances between the two groups was specified using the `var.equal = TRUE` argument.

3.1.2. Regression

To investigate the relationship between environmental factors (temperature and humidity) and flowering on the initial growth (height and trunk diameter) of Irwin mango trees, multiple linear regression analyses were conducted using the **lm()** function in R statistical software (version [4.4.3]). Due to observed perfect multicollinearity (**Annexure II**) between temperature and humidity variables, separate regression models were built (Pearson correlation coefficient $r = -0.85$ between temperature and humidity). Statistical significance was set at $p < 0.05$.

Multicollinearity is a statistical phenomenon that occurs when two or more independent variables in a regression model are highly correlated, indicating a strong linear relationship

among the predictor variables. This issue complicates regression analysis by making it difficult to accurately determine the individual effects of each independent variable on the dependent variable.

4. Results

4.1. Descriptive Statistics

Table 1. Means (SD) of Growth and Environmental Variables in Bajo and Samtenling

Place	Height (cm)	Trunk Diameter (cm)	Lowest Temperature (°C)	Highest Temperature (°C)	Highest Humidity (%)	Lowest Humidity (%)
Bajo	62.13(20.80)	1.10(0.28)	2.8	44.5	93.9	19.4
Samtenling	53.37(17.62)	1.5(0.34)	5.6	47.2	54	13.2
<i>P-Value</i>	0.34	0.03				

This descriptive statistics analysis reveals differences in the average initial growth parameters of Irwin mango trees between Bajo and Samtenling in Bhutan. The mean height in Bajo (62.13 cm) was numerically higher than in Samtenling (53.37 cm), although an independent samples t-test indicated that this difference was not statistically significant ($p = 0.34$). In contrast, the average trunk diameter was significantly different between the locations ($p = 0.03$ from an independent samples t-test), with trees in Samtenling exhibiting a larger mean trunk diameter (1.50 cm) compared to those in Bajo (1.10 cm). The environmental conditions also varied between the two sites. Bajo experienced lower average lowest (2.8 °C) and highest (44.5 °C) temperatures but considerably higher average highest humidity (93.9%) and slightly higher average lowest humidity (19.4%) compared to Samtenling, which had higher average lowest (5.6 °C) and highest (47.2 °C) temperatures and lower average highest (54%) and lowest (13.2%) humidity. These findings suggest that while initial height did not significantly differ between the two locations, trunk diameter was significantly greater in Samtenling.

4.2. Independent Sample T test

Independent samples t-tests were conducted to assess the statistical significance of the differences in mean height and trunk diameter between Bajo and Samtenling.

- Height: The t-test revealed no significant difference in mean height between Bajo ($M = 62.13$ cm, $SD = 20.80$) and Samtenling ($M = 53.37$ cm, $SD = 17.62$); $t(14) = 0.98$, $p = 0.34$.

- Trunk Diameter: A significant difference was found in mean trunk diameter between Bajo ($M = 1.10$ cm, $SD = 0.28$) and Samtenling ($M = 1.50$ cm, $SD = 0.34$); $t(14) = -2.41$, $p = 0.03$.

These results indicate that while the average height of the mango trees was similar in both locations, the average trunk diameter was significantly greater in Samtenling.

4.3. Regression

Multiple linear regression analyses were conducted to examine the effects of temperature, humidity, and flowering on plant height and trunk diameter. Due to multicollinearity (singularity) between temperature and humidity, humidity was excluded from the models automatically in both high and low condition regressions. As a result, separate models were run using either the highest or lowest recorded temperature and humidity values. For plant height, none of the predictors were statistically significant, and the overall models were not significant ($F(2,13) = 1.118$, $p = 0.356$). However, for trunk diameter, temperature showed a significant positive effect ($p = 0.0416$), and the overall models were marginally significant ($F(2,13) = 3.077$, $p = 0.081$), suggesting that temperature may influence trunk development more than height.

Table 2 Regression results for plant height and trunk diameter using temperature, humidity, and flowering as predictors. Models use highest and lowest recorded values separately. F(2,13) tests overall model significance.

Response Variable	Predictor	Estimate (β)	Std. Error	t value	p-value	Significance
Height (Highest Temp & Humidity)	(Intercept)	249.792	174.111	1.435	0.175	
	Highest Temperature	-4.288	3.812	-1.125	0.281	
	Highest Humidity	NA	NA	NA	NA	
	Flowering	5.806	5.187	1.119	0.283	
	Model Statistics	R² = 0.147	Adj R² = 0.016	F(2,13) = 1.118	p = 0.356	NS
Trunk Diameter (Highest Temp & Humidity)	(Intercept)	-5.244	2.863	-1.832	0.09	.
	Highest Temperature	0.142	0.063	2.26	0.042	*
	Highest Humidity	NA	NA	NA	NA	
	Flowering	0.062	0.085	0.729	0.479	
	Model Statistics	R² = 0.321	Adj R² = 0.217	F(2,13) = 3.077	p = 0.081	~
Height (Lowest Temp & Humidity)	(Intercept)	70.569	16.958	4.161	0.001	**
	Lowest Temperature	-4.135	3.676	-1.125	0.281	
	Lowest Humidity	NA	NA	NA	NA	
	Flowering	5.806	5.187	1.119	0.283	
	Model Statistics	R² = 0.147	Adj R² = 0.016	F(2,13) = 1.118	p = 0.356	NS
Trunk Diameter (Lowest Temp & Humidity)	(Intercept)	0.679	0.279	2.435	0.03	*
	Lowest Temperature	0.137	0.06	2.26	0.042	*
	Lowest Humidity	NA	NA	NA	NA	
	Flowering	0.062	0.085	0.729	0.479	
	Model Statistics	R² = 0.321	Adj R² = 0.217	F(2,13) = 3.077	p = 0.081	~

Note $p < .05$ (*), $p < .1$ (~), NS = Not significant, NA = Predictor excluded due to multicollinearity/singularity.

5. Discussion

This study investigated the first year's vegetative response of Irwin mango under protected cultivation in two agroecologically distinct sites in Bhutan; Bajo and Samtenling, mainly focusing on plant height and trunk diameter as key growth indicators. These traits are especially important in perennial fruit trees, where strong early structural growth often correlates with improved long-term productivity and resilience (Schaffer et al., 2006). Although reproductive traits such as flowering and fruiting were not observed in the first year, several differences in vegetative growth and survival were noted.

The descriptive analysis and t-tests indicated that while height did not differ significantly between sites, trunk diameter was significantly greater in Samtenling, suggesting better early structural development. To further understand this difference, multiple linear regression analyses were conducted. Due to singularity caused by multicollinearity between temperature and humidity, only temperature and flowering were retained in the final models.

Regression results showed that temperature had a significant positive effect on trunk diameter ($p = 0.0416$) but not on height, and the overall model for trunk diameter was marginally significant ($F(2,13) = 3.077$, $p = 0.081$), explaining approximately 32% of the variation ($R^2 = 0.321$). This marginal significance suggests a trend, but the evidence is not strong at the conventional 0.05 threshold. These findings are supported by studies indicating that higher temperatures enhance cambial activity and radial growth in tropical and subtropical tree species (López-López et al., 2010; Malik et al., 2011). Trunk diameter expansion is especially critical in mango, as it supports vascular development and influences the tree's ability to transport water and nutrients efficiently during the reproductive phase (Kumar et al., 2017).

In contrast, flowering did not significantly affect either growth trait, which is not unexpected. In young mango trees, especially during their establishment phase, vegetative and reproductive growth often occur independently (Kobayashi et al., 2013; Lal et al., 2010). The absence of a flowering-growth interaction in this early phase supports the notion that vegetative establishment is prioritized in the first year before substantial reproductive effort is allocated.

A notable finding was the failure of Irwin mango saplings to survive in the open field at Bajo, which led to the cancellation of the open-field comparison component of the study. This failure is likely attributable to cold stress, particularly during nighttime in winter, when temperatures in Bajo can drop to as low as 3°C according to data sourced from the National Center for Hydrology and Meteorology (NCHM), Bhutan. Mango is known to be sensitive to low

temperatures, with injury and dieback commonly observed below 5°C (Whiley et al., 1988; Medlicott & Thompson, 1985). In this context, the frost-prone climate of Bajo, despite its classification within a subtropical to warm temperate zone, clearly presents a physiological challenge that Irwin mango saplings cannot tolerate without protection. Similar observations have been reported in other regions, where frost and sub-optimal winter temperatures were found to significantly reduce mango survival and productivity, particularly in the juvenile stage (Gunjate, 2009). While these findings highlight the potential of protected structures to facilitate mango establishment in marginal climates, it is important to note that reproductive performance and long-term yield stability remain to be evaluated. Ongoing monitoring will determine whether early vegetative advantages translate into superior productivity and fruit quality.

In contrast, Samtenling's subtropical environment, with consistently warm temperatures and minimal risk of frost, provided a more stable climate for mango establishment. This warmer, frost-free environment, characteristic of its subtropical agroecological zone, likely created a favorable microclimate under protected cultivation that promoted trunk thickening, as observed in the significant growth differences. Though high humidity levels can sometimes affect gas exchange and disease susceptibility (Chien et al., 2009), the combination of warm temperatures and protected cultivation likely created a beneficial environment for early trunk development.

Furthermore, the marginal significance of the regression model suggests that additional variables such as light availability within the greenhouse, irrigation consistency, or soil conditions may also contribute to early mango growth. This is consistent with broader horticultural findings, where multi-factorial interactions are often necessary to explain field-level performance (Schaffer & Andersen, 1994). All of these will be taken into consideration next year. The limited sample size may have also constrained the detection of more subtle effects, emphasizing the need for extended monitoring in future seasons.

The findings of this study indicated enhanced early vegetative growth of Irwin mango under protected cultivation in Bhutan. However, establishing protected structures requires substantial initial investment in materials, construction, and potentially climate control systems (Patel & Bhalerao, 2022; Rymbai et al., 2023). This high upfront cost poses a significant barrier, especially for smallholder farmers with limited financial resources. While early growth improvements are promising, further research is needed to quantify their impact on fruit yield, quality, and overall productivity. If protected cultivation results in higher yields of marketable

fruit, an extended productive lifespan of trees, or off-season production that commands premium market prices, the system could prove economically viable. Additionally, reduced losses from adverse weather, pests, and diseases may enhance harvest consistency and reliability (Tripathi et al., 2021).

6. Limitation

This study only presents preliminary findings from the first year of a multi-year trial evaluating Irwin mango under protected conditions. While trunk diameter and height are standard indicators of early growth, they offer a limited view of overall plant development. Future studies could benefit from including a broader range of growth parameters. Environmental variability and sample size limitations should also be considered.

Secondly, although efforts were made to ensure uniformity in management practices, these micro variations within the protected structure could have introduced some level of variability in the observed data. Factors such as subtle differences in air circulation, light intensity distribution, and even minor variations in temperature and humidity across different sections of the protected area could have influenced plant growth which were not monitored vigorously.

Finally, the absence of soil analysis for Samtenling site is a very big limitation. While soil testing was conducted in Bajo, the lack of comparable data from Samtenling makes it challenging to definitively rule out the influence of underlying soil properties on the observed differences in mango establishment between the two locations. It is possible that variations in soil texture, nutrient content (beyond the applied fertilizer), pH, and water-holding capacity could have contributed to the differing growth responses observed.

7. Conclusion

This first-year study on the vegetative performance of Irwin mango under protected cultivation in Bajo and Samtenling demonstrated that environmental conditions, particularly temperature, play a crucial role in early trunk development. While plant height did not significantly vary between the sites, trunk diameter was significantly greater in Samtenling, and regression analysis confirmed a positive relationship between temperature and trunk growth. These findings highlight that Samtenling's warmer, frost-free climate provides more favorable conditions for early structural development of mango trees under greenhouse conditions.

The failure of mango saplings to survive in the open field in Bajo further emphasizes the sensitivity of young mango trees to low temperatures and tells us the importance of protected cultivation in cooler regions. The observed differences suggest that while both sites can support mango growth under controlled environments, Samtenling offers a more suitable climate for successful establishment, especially without the risk of cold stress.

Future research will extend over multiple growing seasons and include additional variables such as light, irrigation, and soil factors (i.e. Soil Testing), LAI (Leaf Area Index to better understand their interactions with plant development. Continued monitoring will be essential to determine whether early vegetative advantages translate into better reproductive performance and yield outcomes over time.

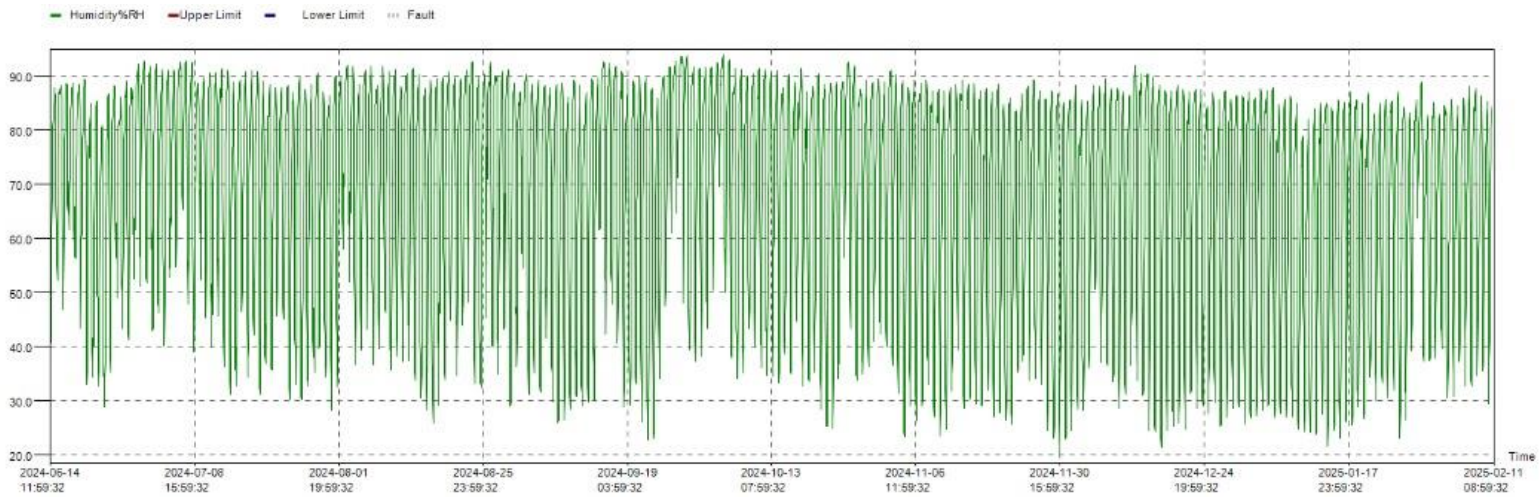
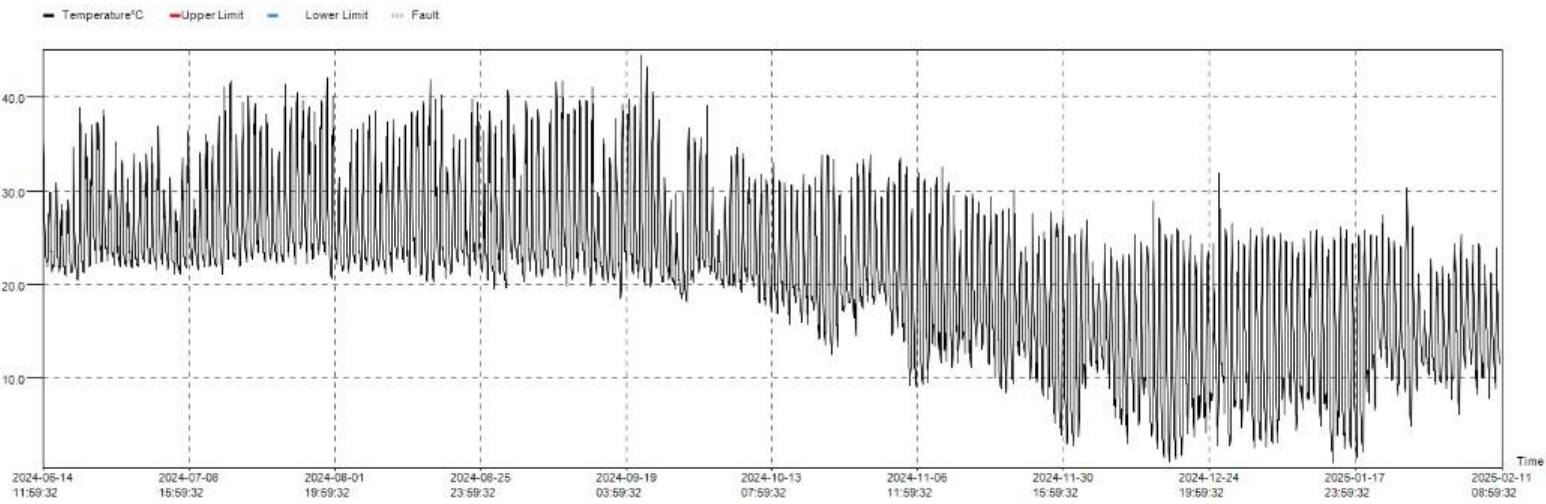
Reference

- Chien, C. C., Wang, Y. H., & Hsu, M. Y. (2009). *High humidity effect on physiological responses of mango (Mangifera indica) during floral induction*. Scientia Horticulturae, 122(1), 72–76.
- Choudhury, B. I., et al. (2022). *Protected cultivation of mango: A strategy for climate-resilient horticulture*. Journal of Tropical Agriculture, 60(2), 134–140.
- Gunjate, R. T. (2009). *Mango cultivation in subtropical conditions: challenges and strategies*. Acta Horticulturae, 820, 31–38.
- Kobayashi, M., Yamamoto, M., & Goto, Y. (2013). *Interaction between flowering and vegetative growth in fruit trees*. Japan Agricultural Research Quarterly, 47(1), 1–7.
- Kumar, R., Pandey, V., & Verma, R. (2017). *Physiological and biochemical indicators for assessing trunk health in mango*. Journal of Applied and Natural Science, 9(1), 592–596.
- Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2005). *Applied Linear Statistical Models* (5th ed.). McGraw-Hill Education.
- Lal, D., Patel, R. K., & Singh, A. (2010). *Effect of reproductive load on vegetative growth and return bloom in mango*. Indian Journal of Horticulture, 67(Special Issue), 225–228.
- López-López, P., Pérez-Zamora, O., & Ayala-Sánchez, M. (2010). *Effect of temperature on trunk diameter growth in mango trees*. Revista Chapingo Serie Horticultura, 16(3), 191–198.
- Malik, A. U., Singh, Z., & Khan, A. S. (2011). *Mango tree physiology and orchard management: implications for productivity*. Acta Horticulturae, 890, 85–94.
- Medlicott, A. P., & Thompson, A. K. (1985). *Analysis of the effects of humidity on mango fruit ripening*. Journal of Horticultural Science, 60(3), 403–408.
- Patel, M. R., & Bhalerao, M. M. (2022). *Climate-smart protected cultivation for fruit crops in subtropical zones*. Acta Horticulturae, 1355, 225–232.
- Patel, M. R., & Bhalerao, M. M. (2022). *Climate-smart protected cultivation for fruit crops in subtropical zones*. Acta Horticulturae, 1355, 225–232.
- Rymbai, D., et al. (2023). *Advances in greenhouse fruit production: A review*. Indian Horticulture Journal, 7(2), 78–85.

- Rymbai, D., et al. (2023). Advances in greenhouse fruit production: A review. *Indian Horticulture Journal*, 7(2), 78–85.
- Schaffer, B., Whiley, A. W., & Wolstenholme, B. N. (2006). *The Avocado: Botany, Production and Uses*. CABI.
- Tripathi, S., et al. (2021). *Effect of protected structures on growth and yield of fruit crops in India*. *International Journal of Agricultural Sciences*, 13(1), 33–39.
- Tripathi, S., et al. (2021). Effect of protected structures on growth and yield of fruit crops in India. *International Journal of Agricultural Sciences*, 13(1), 33–39.
- Whiley, A. W., Rasmussen, T. S., & Searle, C. (1988). *The effect of low temperatures on growth and physiology of mango*. Proceedings of the Australian Society of Horticultural Science, 25, 58–62.
- Yano, K., et al. (2020). *Mango cultivation under greenhouse conditions in Japan: Variety selection and challenges*. *Japan Agricultural Research Quarterly*, 54(1), 42–50.

ANNEXTURE I

Data logger Graph of Temperature and Humidity



ANNEXTURE II

Correlation Matix

	Lowest Temperature	Highest Temperature	Highest Humidity	Lowest Humidity
Lowest Temperature	1	1	-1	-1
Highest Temperature	1	1	-1	-1
Highest Humidity	-1	-1	1	1
Lowest Humidity	-1	-1	1	1

ANNEXTURE III

Pictures

