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Research Article

Climate-Induced Variations in Physiological and Quality Parameters of Darjeeling Mandarin in the Upper Hill of Darjeeling, West Bengal

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Abstract: Climatic conditions are vital for the growth, yield, and quality of fruits, directly affecting their commercial viability. A field study was conducted to examine the impact of weather variables on the physiological characteristics and quality of Darjeeling mandarin, which was drip-irrigated from the outset of planting. The results indicated a significant positive relationship between peel percentage, peel thickness, and pulp percentage with minimum temperature and rainfall during the K4 stage. Evaporation was the sole climatic factor positively influencing peel percentage and pulp percentage at this stage. Furthermore, both maximum and minimum temperatures at the K1 and K3 stages, coupled with relative humidity at the K1 stage, significantly contributed to the number of seeds per Darjeeling mandarin fruit. Evaporation also had a favorable impact on seed count during the K2 and K3 stages. Additionally, the stock-to-scion ratio was positively influenced exclusively by evaporation at the K4 stage.

Keywords: Darjeeling mandarin, Climate, Physiological, Quality

1. Introduction

Global climate change refers to shifts in the statistical distribution of weather patterns, leading to profound ecological, agricultural, and economic impacts. Earth's climate has experienced numerous changes throughout history, from ice ages to warm periods, significantly influencing the growth and productivity of various crops. Environmental factors such as high temperatures, heatwaves, droughts, frost, and rising CO2 levels all affect the life cycle of both annual and perennial plants. Climate change poses a significant threat to humanity, necessitating the development of effective strategies to ensure sustainable crop production.

Climate and agriculture are deeply interconnected, with climate having a direct impact on the quality and quantity of crops, including citrus fruits (Kumarand Saha, 2010). Citrus fruits are among the largest fruit crops globally, with Darjeeling mandarin— a hybrid of King Orange (♂) and Willow Leaf (♀) developed by Dr. H.B. Frost in 1915 in California—becoming especially valued by citrus growers in the northwestern regions of India. Citrus crops thrive in diverse climatic zones, including tropical, subtropical, arid, and semi-arid regions. The optimal temperature for citrus growth and fruiting ranges from 12.8 to 37˚C, while temperatures above 44-45˚C can halt growth entirely. Low temperatures limit citrus cultivation, as they can stop metabolic activity, with chilling and frost causing severe damage or even killing the tree. Temperature fluctuations negatively affect growth, reducing yield and fruit quality, especially during the maturation stage. Additionally, heatwaves have adverse effects on citrus production, particularly in seedless varieties like Navel orange, Mandarin, and certain lemon cultivars. Furthermore, regional climate conditions are crucial in determining fruit quality and marketable size (Dolkar et al., 2018).

Chelong and Sdoodee (2013) observed that reduced rainfall and soil moisture in Yala and Pattani regions impacted fruit development, yield, and quality. The quantity of Shogun citrus (Citrus reticulata Blanco) was higher in Pattani compared to Yala, with larger fruit diameters, greater weight, and thicker peel. However, the total soluble solids were lower in Pattani, and the rind color was greener compared to the more mature, yellow rind of fruits in Yala.

On the other hand, rising carbon dioxide levels positively impact citrus seedling growth and tree productivity. Projections of rising global temperatures suggest that the climate in traditional fruit tree cultivation regions will undergo significant changes, potentially altering plant development, growth, and disease incidence. These shifts could lead to negative effects on crop yield, particularly through restricted air exchange and increased humidity (Grange and Hand, 1987). In response to these challenges, a recent study was conducted to assess the impact of weather parameters on the physiological aspects and quality of Darjeeling mandarin during its fruit development stages under the climatic conditions of the Upper Hill of Darjeeling, West Bengal.

2. Materials and Methods

Experime*ntal site*

The field experiment was conducted over two consecutive years, 2022 and 2023, at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India. The experimental orchard, located in Darjeeling, lies at a latitude of 26°52′ North, a longitude of 88°18′ East, and an altitude of 2128 meters above mean sea level. The region receives an annual rainfall of approximately 446 mm. The mean annual maximum and minimum temperatures are 25.2°C and 6.0°C, respectively. Summers are characterized by warm temperatures ranging from 15.5°C to 23.5°C, with humidity levels between 55.0% and 75.5%. Winters experience mild to severe cold, with average temperatures ranging from 2.5°C to 21.7°C. December is the coldest month, with minimum temperatures dropping to 4°C and occasionally below 0°C. The highest temperature is typically observed in May (25.2°C). Daily maximum and minimum temperatures, along with evaporation rates, begin to rise from February, peak in June, decline from July to September, experience a slight rise in October, and progressively decrease through December.

Experimental design and treatments

The experiment was carried out on 8-year-old, uniformly growing, and fruit-bearing 'Kinnow' mandarin trees, which had been drip-irrigated since planting. The layout followed a randomized block design, with a plant-to-plant spacing of 5 m both within and between rows. Three plants from each replication were randomly selected for the periodic observation of phenological events. Specific stages were identified to mark critical phases essential for the study, based on the external morphological characteristics of Darjeeling mandarin. These stages included: (i) Pre-flowering stage (K1), (ii) Flowering to first fruit set (K2), (iii) First fruit set to maximum fruit set (K3), and (iv) Maximum fruit set to fruit harvest (K4).

Plant sampling and analysis

The experiment involved phenophase-wise correlation studies of growth, yield, and quality parameters across four distinct stages of the crop, following the methodology outlined by Gomez and Gomez (1984). Meteorological factors such as maximum temperature (Tmax), minimum temperature (Tmin), maximum relative humidity (RHmax), minimum relative humidity (RHmin), rainfall (Rf), and evapotranspiration (Ev) were meticulously recorded. Physiological and quality attributes examined included peel thickness, seed count per fruit, and peel percentage. The stock-to-scion girth ratio was also calculated based on measured values.

To assess pulp, fruits were cut into pieces and boiled in hot water for 15 minutes. Seeds were separated using a fine sieve (<20 mm), and the number of seeds per fruit was counted. Juice percentage, pulp percentage, and peel percentage were determined following Romero et al. (2006). Fruit components were manually separated, and the percentages of juice, pulp, and peel were calculated based on their respective weights relative to the total fruit weight. Peel thickness was measured on 10 randomly selected fruits per treatment per replication using a Digital Vernier Caliper, with values expressed in centimeters (cm).

Data analysis

The statistical analysis was done using SPSS 16.0 software. The test of significance was done at p<0.01, 0.05 and 0.005 level.

3. Results and Discussion

The climate of the region where crops are cultivated significantly affects their physiological processes and the quality of the fruits. However, the impact of climate on crops is complex and often intertwined with various other factors, making it challenging to isolate the influence of any single meteorological parameter. Nonetheless, the study prioritized key climatic factors that individually or collectively influenced the growth and quality of Darjeeling mandarins (Fig 2). These factors included maximum and minimum temperatures, maximum and minimum relative humidity, rainfall, and evaporation, observed across both the 2022 and 2023 growing seasons.

Effect of climatic factors on Darjeeling mandarin fruit

The data on the influence of climatic factors on the stock-to-scion ratio of Darjeeling mandarin fruits, presented in Table 1 and Fig 1, revealed several significant correlations. Rainfall at the K3 stage positively impacted the stock-to-scion ratio (r = 0.83**). In contrast, maximum and minimum temperatures at the K1 and K3 stages negatively affected the ratio (r = –0.73*, –0.74* and –0.72*, –0.78**, respectively), as was maximum and minimum relative humidity at the K1 stage (r = –0.74* and –0.74*, respectively), maximum relative humidity at the K4 stage (r = –0.73* and –0.71*), and evapotranspiration during the K1 and K3 stages (r = –0.82** and r= -0.83**).

A tree maintains a balance between water absorption in the root system and transpiration in the shoot system. When water absorption is restricted, it limits shoot growth and production (Singh, and Singh, 2010). During the study, high humidity reduced transpiration, while heavy rainfall created excessive moisture near the root zone, hindering water uptake. These results corroborate the observations of Higuchi et al. (1999), who found that warmer temperatures inhibited shoot growth in Cherimoya trees, whereas cooler temperatures enhanced it.

Juice per cent

The data revealed that maximum and minimum temperatures at the K1 stage (r = 0.75* and 0.77*) and the K3 stage (r = 0.71* and 0.77*) had a positive influence on the juice percentage of Darjeeling mandarins. Conversely, minimum temperature at the K4 stage negatively affected juice content (r = –0.73*). Maximum and minimum relative humidity at the K1 stage (r = 0.76* and 0.77*, respectively) and maximum relative humidity at the K4 stage (r = 0.75*) positively impacted juice percentage. These findings align with observations by Reddy and Venkateswarlu (2015), who reported that fruits cultivated in moist climates tend to have higher juice content compared to those grown in drier conditions. Similarly, evapotranspiration at the K2 and K3 stages (r = 0.84** and 0.82**, respectively) was positively correlated with juice percentage. However, rainfall during the K3 and K4 stages exhibited a negative association with juice content (r = –0.73* and –0.81*, respectively).

Table1:The relationship between climatic factors and the growth and quality of Darjeeling mandarin fruit crops at various stages is analyzed through correlation studies during 2022-23

	St-G: Sc-G	Juice %	No. Seed	Peel %	Pulp %	Peel T
Max RH K1	-0.74*	0.76*	0.67*	-0.73*	-0.72*	-0.75*
Max RH K2	0.26	-0.23	-0.15	0.14	0.21	0.21
Max RH K3	0.16	-0.15	-0.10	0.12	0.12	0.12
Max RH K4	-0.73*	0.75*	0.69*	-0.71*	-0.71*	-0.78*
Min RH K1	-0.71*	0.77*	0.68*	-0.74*	-0.73*	-0.77*
Min RH K2	0.23	-0.19	-0.09	0.16	0.12	0.13
Min RH K3	-0.22	0.09	0.02	-0.12	-0.12	-0.11
Min RH K4	-0.52	0.40	0.33	-0.31	-0.35	-0.44
Epan K1	-0.82**	0.66	0.63	-0.63	-0.31	-0.65
Epan K2	-0.64	0.84**	0.86**	-0.86**	-0.85**	-0.83**
Epan K3	-0.83**	0.82**	0.79*	-0.82**	-0.79*	-0.78*
Epan K4	0.61	-0.67	-0.76*	0.71*	0.73*	0.62
Rain Fall K1	-0.42	0.58	0.49	-0.51	-0.43	-0.59
Rain Fall K2	0.42	-0.36	-0.24	0.21	0.22	0.37
Rain Fall K3	0.83**	-0.73*	-0.79*	0.75*	0.76*	0.70*
Rain Fall K4	0.63	-0.81**	-0.74*	0.81**	0.80*	0.83*

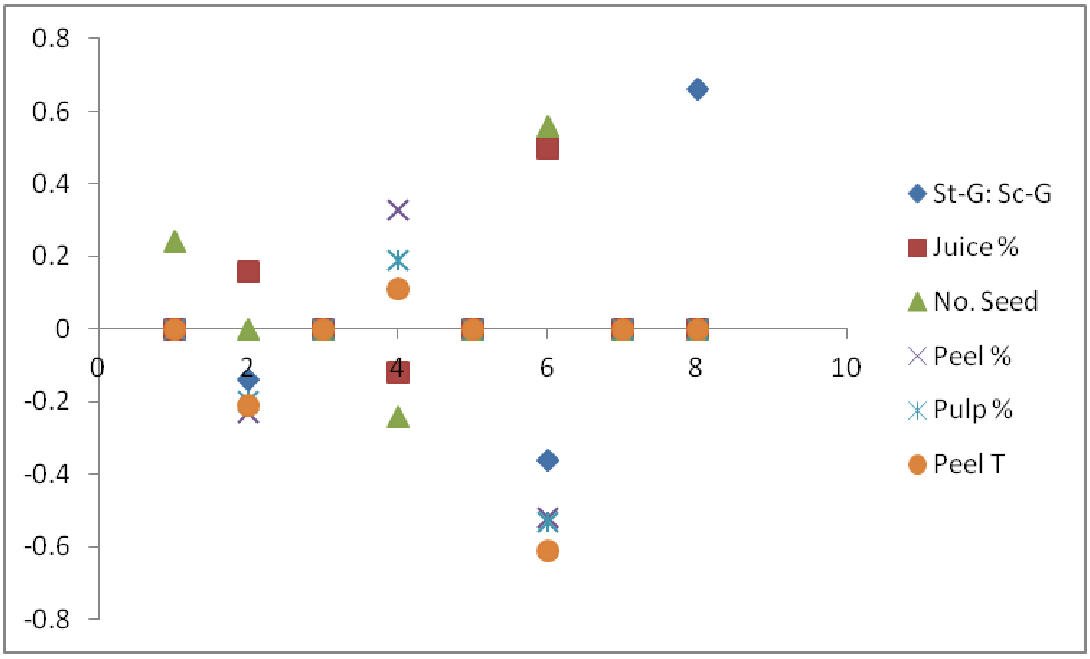
Significant at p< 0.01, 0.05**, 0.005*** level* ;

K1: Pre-flowering stage, K2: Flowering to first fruit set , K3: First fruit set to maximum fruit set, K4: Maximum fruit set to fruit harvest; Max: maximum, Min: Minimum, Temp=Temperature, RH=Relative humidity, RF=Rainfall;

Number of seeds

Both maximum and minimum temperatures, along with maximum relative humidity at the K2 stage (r = 0.64* and r= 0.61* respectively), positively influenced the number of seeds per Darjeeling mandarin fruit. Additionally, maximum and minimum temperatures at the K3 stage (r = 0.77* and 0.776*, respectively), maximum and minimum relative humidity at the K4 and K1 stages (r = 0.69* and 0.68*, respectively), and evapotranspiration at the K2 and K3 stages (r = 0.86** and 0.79*, respectively) also exhibited positive correlations.

In contrast, the number of seeds per fruit at the K4 stage was negatively affected by minimum temperature and evapotranspiration (r = –0.82** and –0.76*, respectively), as well as by rainfall during the K3 and K4 stages (r = –0.79* and –0.74*, respectively). Higuchi et al. (1998) reported that warmer temperatures resulted in asymmetrical and smaller Cherimoya fruits with fewer seeds, primarily due to reduced pollen viability. Meanwhile, maximum temperature at the K4 stage, evapotranspiration at the K1 stage, and rainfall at the K4 stage showed no significant correlation with seed count. An



inverse relationship between cell size and water potential, likely due to the direct impact of turgor pressure on cell expansion under low water availability, was previously observed by Gucci et al. (2009).

Fig 1: The relationship between climatic factors viz: temperature on the growth and quality of Darjeeling mandarin fruit crops during 2022-23

Peel per cent

Table 1 and Fig 1 presents the influence of various climatic factors on the peel percentage of Darjeeling mandarins. Among these, minimum temperature at the K4 stage showed a positive correlation with peel percentage (r = 0.77*), whereas both maximum and minimum temperatures at the K1 and K3 stages exhibited negative correlations (r = –0.71*, –0.73* and –0.71*, –0.77*, respectively). Similarly, maximum and minimum relative humidity were negatively correlated with peel percentage at the K1 stage (r = –0.73* and –0.74*, respectively), as was maximum relative humidity at the K4 stage (r = –0.71*).

In contrast, rainfall during the K3 and K4 stages positively influenced peel percentage (r = 0.75* and 0.81**, respectively). Evapotranspiration also had a positive correlation at the K4 stage (r = 0.71*), while it negatively impacted peel percentage at the K2 and K3 stages (r = –0.86** and –0.82**, respectively). These findings are consistent with those of Chelong and Sdoodee (2013), who reported that reduced rainfall and soil moisture in Yala and Pattani regions significantly affected the peel, juice, and peel thickness of Shogun mandarins (*Citrus reticulata* Blanco).

Pulp per cent

The pulp percentage of Darjeeling mandarins was positively influenced by minimum temperature at the K4 stage (r = 0.79*). Conversely, both maximum and minimum temperatures at the K1 and K3 stages exhibited negative correlations with pulp percentage (r = –0.70*, –0.72* and –0.68*, –0.74*, respectively). Maximum and minimum relative humidity at the K1 stage (r = –0.72* and –0.73*, respectively) and maximum relative humidity at the K4 stage (r = –0.71*) also showed negative correlations.

In contrast, rainfall during the K3 and K4 stages positively affected pulp percentage (r = 0.76* and 0.80*, respectively), as did evapotranspiration at the K4 stage (r = 0.73*). However, evapotranspiration at the K2 and K3 stages had a negative impact on pulp percentage (r = –0.85** and –0.79*, respectively).

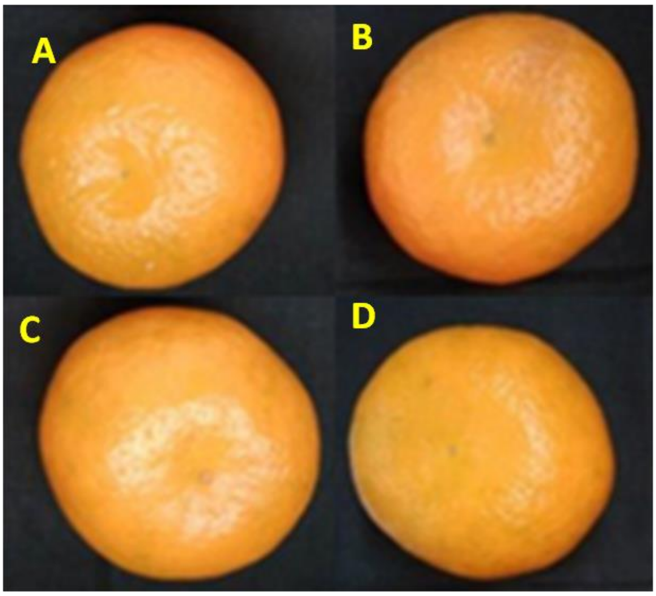


Fig 2: Climatic factors effects of Darjeeling mandarin fruit crops at various altitude A: Higher altitude B: Middle altitude C: Lower altitude D: Tarai Regions

Peel Thickness

The data presented in Table 1 and Fig 1 indicates that peel thickness percentage in Darjeeling mandarin fruit was positively influenced by minimum temperature at the K4 stage (r = 0.67* and 0.94***, respectively) and rainfall at the K3 and K4 stages (r = 0.70* and 0.83*, respectively). Conversely, peel thickness was negatively affected by both maximum and minimum temperatures at the K1 and K3 stages (r = –0.74*, –0.76* and –0.68*, –0.74*, respectively). Additionally, maximum and minimum relative humidity at the K1 stage (r = –0.75* and –0.77*, respectively) and maximum relative humidity at the K4 stage (r = –0.78* and –0.76*, respectively) showed negative correlations with peel thickness percentage.

Furthermore, evapotranspiration had a negative impact on peel thickness percentage at the K2 and K3 stages (r = –0.83** and –0.78*, respectively). These findings are consistent with those of Reddy and Venkateswarlu (2015), who observed that fruits grown in moist climates tend to have thinner peels compared to those grown in drier climates.

5. Conclusions

In conclusion, the study on the influence of climatic factors on the growth, yield, and quality of Darjeeling mandarin revealed several significant correlations. Temperature, relative humidity, rainfall, and evapotranspiration at various phenophases (K1, K2, K3, and K4 stages) played a crucial role in determining the physiological and quality parameters of the fruit. Specifically, factors such as maximum and minimum temperatures, relative humidity, and rainfall had varying degrees of positive and negative effects on peel thickness, juice percentage, pulp percentage, and seed count per fruit.

The findings suggest that optimal climatic conditions, such as moderate temperature and appropriate humidity levels, enhance the fruit quality, particularly in terms of juice content and pulp percentage. However, extreme conditions, including high temperatures or excessive rainfall, were found to negatively affect the growth and quality of Darjeeling mandarins. These results align with previous studies and highlight the importance of understanding the complex interactions between climatic variables in managing and optimizing fruit production.

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