International Journal of Environment and Climate Change

Volume 14, Issue 12, Page 757-765, 2024; Article no.IJECC.126546
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Yield Variability in Response to Planting Dates and Weather Conditions for Strawberry (*Fragaria x ananassa* Duch.) at Kerala's High Ranges (Wayanad), India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i124660

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/126546

Original Research Article

Received: 01/09/2024
Accepted: 02/11/2024
Published: 30/12/2024

ABSTRACT

The modern cultivated strawberry (*Fragaria x ananassa* Duch.) is a highly valuable crop, known for its quick return on investment and adaptability to varying climates. This study examines how different planting dates and weather conditions effect the yield of the Winter Dawn cultivar in high-altitude regions of Kerala, India. The field experiment was conducted at the Regional Agricultural Research Station in Wayanad, located in Kerala's high range zone. A randomized block design was

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Cite as: *V. C., Ajaykumar., Shajeesh Jan P., B. Ajithkumar, Chitra M. T., and Zahida P. M. 2024. "Yield Variability in Response to Planting Dates and Weather Conditions for Strawberry (Fragaria X Ananassa Duch.) at Kerala's High Ranges (Wayanad), India". International Journal of Environment and Climate Change 14 (12):757-65. https://doi.org/10.9734/ijecc/2024/v14i124660.*

used, featuring five distinct planting dates. The crop yield was analyzed to weather conditions during each phenophase using Pearson's correlation coefficient. The results showed significant variations in strawberry yield related to fluctuations in temperature and photoperiod. Specifically, higher maximum and minimum temperatures during later growth stages had a negative impact on yield. Additionally, there were negative correlations between minimum temperature and rainfall with fruit yield during critical phenophases. Other factors, such as humidity, bright sunshine hours, and wind speed, exhibited varying relationships with yield. The study concluded that planting on September 30th resulted in the highest yield, with favorable weather conditions enhancing both vegetative growth and fruit development. Gaining insights into the relationship between weather parameters and strawberry phenophases can significantly improve strawberry cultivation practices in Kerala's climate.

Keywords: Strawberry; yield; weather; dates of planting.

1. INTRODUCTION

The modern cultivated strawberry (*Fragaria x ananassa* Duch.), belonging to the Rosaceae family, is a monoecious octoploid hybrid crop, derived from the crossing of two dioecious octoploid species: *Fragaria chiloensis* and *Fragaria virginiana* (2n=8x=56) (Darrow, 1966). It offers one of the fastest returns on investment among fruits, making it highly appealing to growers. Additionally, strawberries are well-suited to adapting to shifting climate conditions, offering resilience in the face of increasing climate unpredictability.

Strawberries are perennial, herbaceous plants that grow close to the ground. They reproduce vegetatively by producing runners or stolons above ground stems that trail and root at their nodes, giving rise to clonal daughter plants. In 2022, global strawberry production reached 9.6 million metric tons (MT), China led with 3.3 MT, accounting for 35% of total production, followed by the United States (1.26 MT), Turkey (0.73 MT), and Egypt (0.64 MT) (Food and Agricultural Organization of the United Nations, 2022). In India, strawberries are mainly grown in states like Haryana, Maharashtra, Jammu & Kashmir, Mizoram, and Meghalaya. Kerala contributes 0.30% to India's strawberry production (Agricultural and Processed Food Products Export Development Authority, 2022). Changes in temperature, daylight duration, nutritional availability and their interplay can impact vegetative growth, as well as the onset of flowering and the development of stolons in plants. Depending on the variety and location strawberries can be planted at different times of the year. For the successful production of quality fruits, planting time and variety are considered an influencing parameter (Kanchan et al., 2017). Since weather significantly influences the entire cultivation process, effectively utilizing optimal weather conditions at each stage of crop growth can lead to improved results. Providing crops with the ideal growing environment, such as appropriate temperature, humidity and light, allows them to realize their genetic potential fully. Sowing at the optimal time ensures that plants are exposed to the necessary conditions, including adequate Growing Degree Days (GDD) and effective use of rainfall and humidity. Today, strawberries are cultivated in high-altitude areas of Kerala, such as Munnar and Wayanad, due to the development of tropical varieties (Amrutha and Vijayaraghavan, 2020). Keeping in view the facts mentioned above, the present study aims to investigate the changes in yield of strawberries under different planting dates and weather conditions in Wayanad, the high-range zone of Kerala.

2. MATERIALS AND METHODS

2.1 Experimental Location

The experiment was conducted at Regional Agricultural Research Station, Ambalavayal, Wayanad which is a high-range zone located at 76.12º E latitude, 11.37º N longitude and at an altitude of 974 m above the mean sea level. The experimental site experiences a mild tropical to sub-tropical climate. The field experiment was conducted during the period of 2023 - 2024.

Table 1. Treatments used for the experiment

Treatments	Planting time
T1	1st September
T2	15th September
T3	30th September
T4	15th October
T5	30th October

Table 2. Correlation between yield per plant and weather parameters for different phenophases of strawberry

YIELD	TMAX	TMIN	RH1	RH2	RF	WS	BSS	EV
P1	.812**	-0.314	0.116	-.809**	-.498*	0.403	.734**	.497*
P2	-.468*	-0.419	0.397	.590**	-0.231	0.15	-0.007	.494*
P3	-.510*	-0.363	-0.315	.544*	-0.209	0.048	0.032	0.329
P4	0.005	-0.361	0.206	-0.126	-0.377	.520*	-0.003	0.314
P5	-0.2	-0.374	0.366	.573**	-.624**	-0.038	0.047	0.381
P6	-0.367	-.668**	0.339	.573**	0.183	-0.061	-0.35	-0.352

2.2 Field Preparation and Rising of Strawberry

The performance of the strawberry cultivar under varying weather conditions was evaluated by planting on different dates at fortnightly intervals.

The cultivar selected for the experiment was Winter Dawn, a hand-pollinated cross between FL 93-103 and FL 95-316. The crop was planted on five specific dates: 1st September, 15th September, 30th September, 15th October, and 30th October, as outlined in Table 1. The experiment was conducted using a randomized block design with four replications. One-week-old tissue-cultured strawberry runners were planted on raised beds measuring 2.1 m x 1.6 m, with a spacing of 30 cm x 40 cm between plants. The beds were covered with polythene mulch to suppress weed growth. Fertilizer application and intercultural operations were carried out as required. Fruits were harvested at the ripening stage.

2.3 Data Collection and Analysis

Weather data were collected from the Principal Agromet Observatory at RARS Ambalavayal. The daily weather variables were converted to weekly variables. Simple correlation coefficients were computed between weather parameters and strawberry yield. of the strawberry plant were identified based on the BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale (Bleiholder et al., 2001) which provides a standardized classification of growth phases across various plant species. The six phenophases considered were: planting to inflorescence emergence (P1), inflorescence emergence to first flower opening (P2), first flower opening to fruit set (P3), fruit set to full flowering (P4), full flowering to fruit development (P5), and fruit development to fruit ripening (P6). Weather data and yield per plant (g plant^{-1}) were collected for the experiment. weather data and yield per plant (g plant^{-1}) were collected. Weather variables included maximum temperature (Tmax) and minimum temperature (Tmin) in °C, forenoon relative humidity (RH1) and afternoon relative humidity (RH2) in percentage, rainfall (RF) in mm, bright sunshine hours (BSS) in hours, and evaporation (EV) in mm. Yield data were based on the average of three randomly selected plants from each replication across the five treatments.

The correlations between yield data and weather parameters were analysed using the Pearson correlation coefficient. The collected data were subjected to statistical analysis through analysis of variance (ANOVA) for the Randomized Block Design.

3. RESULTS AND DISCUSSION

3.1 Effect of Weather on Yield of Strawberry

The strawberry variety Winter Dawn showed significant variations in yield per plant across different planting dates. Weather conditions had a notable impact on each phenophase of the strawberry plant. Table 2 presents the correlation between yield and weather parameters during each phenophase. Temperature and photoperiod were identified as the key weather factors influencing strawberry yield (Heide, 1977).

Maximum temperature demonstrated a significant positive correlation with yield per plant from planting to inflorescence emergence (Fig. 1a.) but showed a significant negative correlation during the stages from inflorescence emergence to first flower opening (Fig. 1b.) and from flower opening to fruit set (Fig. 1c.). Minimum temperature displayed a significant negative correlation during fruit development to fruit ripening (Fig. 2).

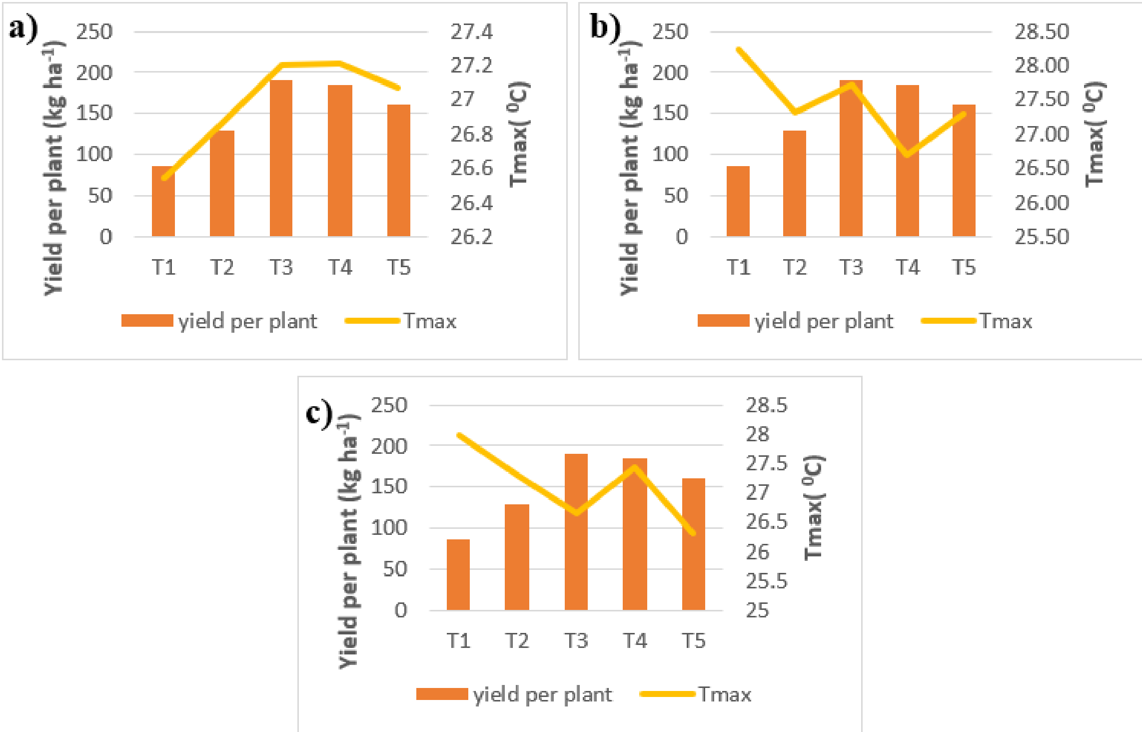

Fig. 1. Effect of maximum temperature (Tmax) on yield of strawberry during a) planting to inflorescence emergence. b) Inflorescence emergence to first flower opening. c) first flower opening to fruit set

Fig. 2. Effect of minimum temperature (Tmin) on yield of strawberry during Fruit development to ripening

Increased Tmax (Fig. 1a.) in the initial phenophase of strawberry associated with the T3 planting date, might have contributed to the increase in yield.

Increased temperatures during floral primordia differentiation following short-day floral induction enhance flowering in strawberries (Krüger et al., 2022).

The variety Winter Dawn is a short day cultivar that requires long nights and optimal temperatures for floral initiation. While most strawberry cultivars and species have an average growth temperature of 15°C, they perform best within a range of 20°C to 26°C (Bhamini et al., 2017). However, temperatures above 28°C reduce flowering in short-day strawberry cultivars (Okimura and Igarashi 1996). During inflorescence emergence to the first flower opening Tmax above 28ºC associated with September 1st planting showed a decrease in yield (Fig. 1b.).

The low temperature during later stages associated with September 30th planting may be one of the reasons for increased yield. Ariza et al., (2020) reported a significant negative correlation between temperature and strawberry fruit weight, with maximum temperatures (r = -0.51 to -0.75) and minimum temperatures (r = -0.63 to -0.76). Compared to earlier stages of flower development, fruit size and yield are more strongly influenced by temperature during later developmental stages (Chen, 2013; Ledesma et al., 2008).

Cultivars grown under short-day conditions with low to intermediate temperatures produced more flowers compared to those raised under long-day and high-temperature conditions (Sønsteby and Heide, 2017). At higher temperatures, plants allocate more energy towards vegetative growth, which reduces flower production (Samad et al., 2021). Additionally, high temperatures in strawberries reduce photosynthetic activity (Kadir et al., 2006).

Temperature during the fruit development phase plays a crucial role in the yield of strawberries grown in warmer seasons (Kagaya et al., 1991). There is a strong correlation between the duration of floral development and the weight of the resulting fruit. The fresh weight of strawberries increases as the time between anthesis and fruit harvest lengthens, a process influenced by both day and night temperatures. Lower temperatures extend this period, resulting in heavier fruit and higher yields (Kumakura and Shishido, 1995). Elevated temperatures also disrupt the photosynthetic process by altering enzyme activity and the electron transport chain (Sage and Kubien, Kubien).

These findings can be explained as the reason for the negative relationship between yield and temperature. In addition to air temperature, bright sunshine hours (BSS) also exhibited a significant correlation with yield, showing a positive relationship during the P1 stage.

In this study, afternoon relative humidity showed a significant positive correlation with yield in later stages (Fig. 3. b, c, d). Bradfield and Guttridge (1984) attributed increased fruit weight to the movement of water into the fruits, driven by root pressure, which is enhanced by higher night time humidity. Higher relative humidity tends to increase fruit weight and is also associated with enhanced leaf expansion and photosynthesis, which may explain the positive relationship with strawberry yields (Bradfield and Guttridge 1979). However, during the P1 stage (Fig. 3a.), elevated afternoon relative humidity was found to reduce fruit yield. For optimal growth and productivity, a relative humidity level of 65% to 75% throughout the day is considered ideal for strawberries (Lieten, 2000). Excessive humidity can cause tip burn in strawberry plants, negatively affecting yield (Guttridge et al., 1981). In general, high relative humidity can promote the occurrence of diseases that lead to fruit malformation, ultimately reducing overall crop yield.

High temperatures and humidity can negatively impact pollen viability in strawberries (Leech et al., 2000). Condori et al., (2017) found that relative humidity had a significant negative effect on strawberry plant yield.

Cumulative rainfall demonstrated a significant negative correlation with strawberry yield during the P1 (Fig. 4a.) and P5 (Fig. 4b.) phenophases. Hortyński et al., (1994) noted that during the early growth stages, rainfall had a negative correlation with strawberry yield.

In the first phenophase, the higher rainfall associated with the September 30th planting (T3) may have mitigated the adverse effects of temperature, leading to increased yield. In contrast, the high rainfall linked to the September 1st planting (T1) may have severely reduced strawberry yield.

Stress is well-known to diminish agricultural output and accelerate fruit ripening (Henson, 2008). Due to the relationship between yield and temperature, an increase in temperature can lead to earlier fruit production but ultimately results in a decrease in total yield (Palencia et al., 2009).

3.2 Effect of Date of Planting on the Yield of Strawberry

The analysis of variance for the yield of strawberry plants for different planting dates is given in Table 3. The study found that among the five planting dates, strawberries planted on September 30th (T3) achieved the highest yield per plant, which was comparable to the yields from the 30th of October (T5) and 15th of September (T2). Conversely, the lowest yield per plant was recorded for the September 1st planting (T1).

Palencia et al., (2009) reported similar findings, noting that the strawberry cultivar 'Sweet Charlie' planted on October 1st produced the maximum number of fruits and the highest weight compared to those planted on September 1st, November 1st, and December 1st, as the October 1st plantings benefitted from conditions conducive to vegetative growth. For the September 30th and October 15th planting dates, the plants had more time and favorable temperatures for growth prior to blooming.

This additional time allowed them to develop more vegetative growth, which served as a source of increased photosynthates, ultimately leading to higher yields per plant. High temperatures and reduced light exposure during the development phase disrupted the carbon balance, resulting in smaller fruit sizes and lower yields (Rahman et al., 2016). Additionally, a study by Bhamini et al., (2017) found that the strawberry variety 'Winter Dawn' produced maximum yields when planted on October 15th, compared to planting dates of November 1st, 15th, and December 1st.

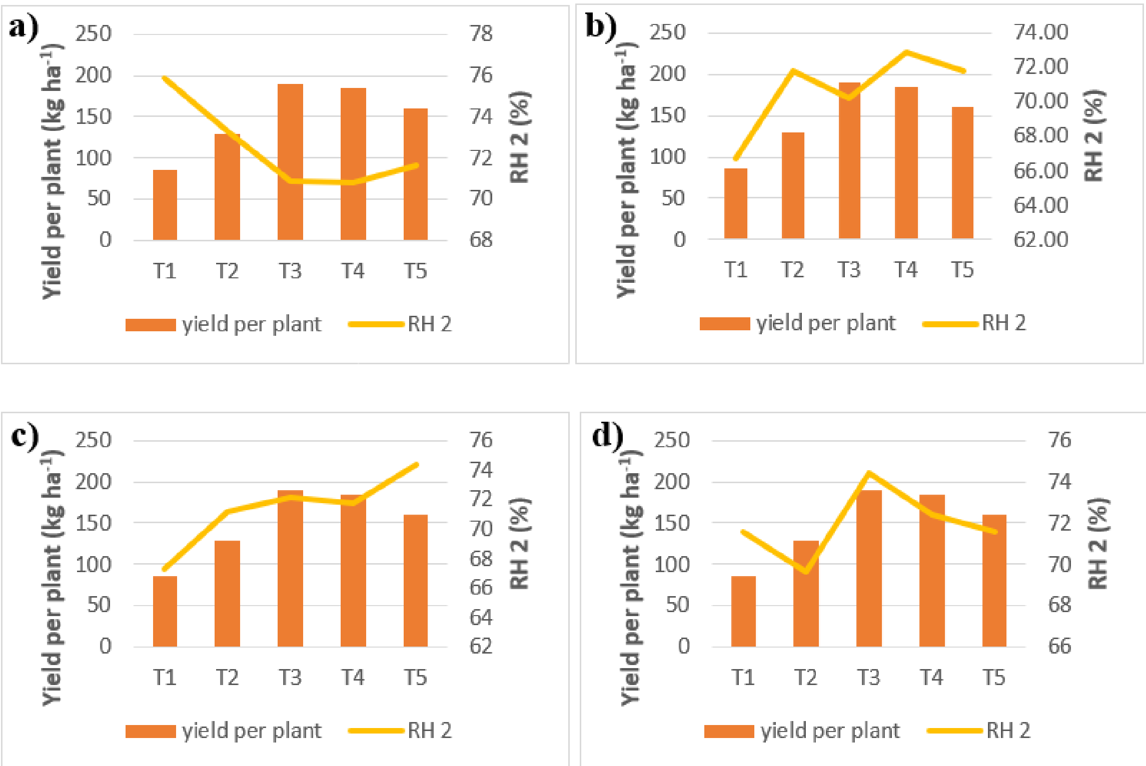

Fig. 3. Effect of afternoon relative humidity (RH 2) on yield of strawberry during a) planting to inflorescence emergence b) inflorescence emergence to flower opening. c) flower opening to fruit set d)

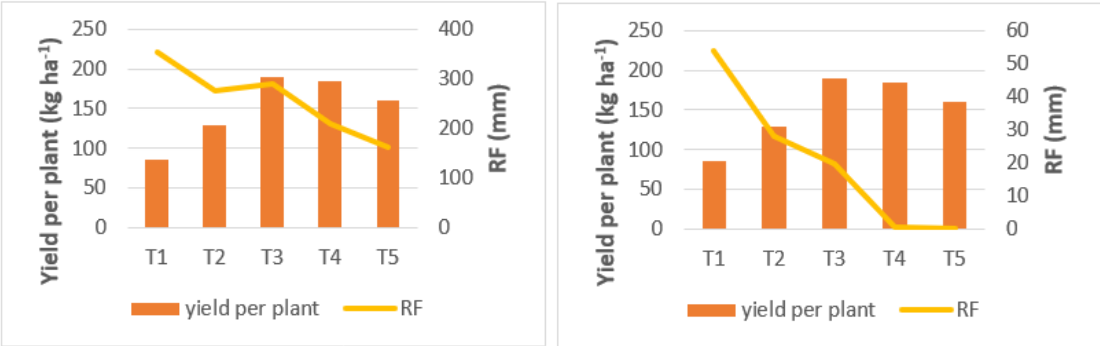

Fig. 4. Effect of Rainfall (RF) on yield of strawberry during a) planting to inflorescence emergence, b) full flowering to fruit development

Table 3. ANOVA for yield per plant at different dates of planting

Treatments	Mean yield
T1	85.64[c]
T2	129.72[bc]
T3	190.60[a]
T4	184.39[a]
T5	160.42[ab]
CD	**49.413**

4. CONCLUSION

This study examined the effect of different planting dates on the yield of strawberry (*Fragaria x ananassa* Duch., cv. Winter Dawn) in the high-range zone of Wayanad, Kerala. The results demonstrated that weather conditions significantly influenced strawberry yield at various phenophases. Among the five planting dates, September 30th produced the highest yield followed by the October 15th planting. These favorable results were attributed to the optimal weather conditions which enhanced vegetative growth and fruit development.

The study highlights the importance of selecting optimal planting dates in regions like Wayanad, where weather variability can directly affect strawberry yield. Planting dates closer to the end of September and mid-October provided more favorable conditions for the development of higher yield. These findings offer valuable insights for strawberry growers in Kerala, helping them optimize planting schedules to maximize yields and improve fruit quality.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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