ASIAN JOURNAL OF AGRICULTURE
Volume 10, Number 1, June 2026 E-ISSN: 2580-4537
Pages: 11 https://doi.org/10.13057/asianjagric/g100116

Impact of vernalization on flowering, fruiting, and yield of strawberry (*Fragaria* × *ananassa*) cultivars under tropical highland conditions

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Manuscript received: 18 August 2025. Revision accepted: 14 February 2026.

Abstract. *Escomen EO, Jambaro GS. 2026. Impact of vernalization on flowering, fruiting, and yield of strawberry (*Fragaria × ananassa*) cultivars under tropical highland conditions. Asian J Agric 10 (1): g100116. https://doi.org/10.13057/asianjagric/g100116.* Vernalization is a key physiological process influencing flowering, fruiting, and yield in strawberry, yet its effectiveness varies among cultivars, particularly under tropical highland conditions where natural chilling is limited. This study examines the performances of vernalization in terms of phenology, productivity, and fruit characteristics of five strawberry cultivars, namely Albion, Snow White, Summer Princess, Sweet Charlie, and Sweet Honeoye. The experiment was conducted in the tropical highland environment in Marawi City, Philippines, to improve strawberry production in tropical and subtropical areas. A 2x5 split-plot in Randomized Complete Block Design (RCBD) with vernalization (3°C for 10 h before planting) as the main plot and cultivar as the subplot. Vernalization significantly accelerated flowering, increased flower and fruit numbers, and enhanced total yield across cultivars ($p<0.05$). Vernalized plants produced a higher mean yield (10.83 t ha^{-1}) compared with non-vernalized plants (7.38 t ha^{-1}), primarily due to increased reproductive output. Sweet Honeoye and Sweet Charlie produced 13.68 t ha^{-1} and 13.47 t ha^{-1}, respectively. The number of flower formations was greater, as Sweet Honeoye generated up to a mean of 40.25 flowers per plant. The fruit yield was also increased, especially in Sweet Honeoye and Sweet Charlie. The number of runners was reduced due to vernalization, which was most significant with Albion. Snow White experienced an increase in the Total Soluble Solids (TSS) to 15.35°Brix. Each cultivar has a different response to vernalization. Significant interaction effects between vernalization and cultivar were observed for key phenological and yield traits, underscoring genotype-specific responses. These findings demonstrate that short-duration vernalization can substantially improve strawberry productivity in tropical highlands when matched with responsive cultivars, offering a practical strategy for enhancing yield stability under warm-climate conditions.

Keywords: Flowering induction, fruit yield, strawberry cultivars, temperature manipulation, vernalization

INTRODUCTION

Vernalization is an essential physiological treatment in strawberry cultivation, which subjects some plants to low temperatures to induce several biological responses that promote flowering and fruit production. It is a critical process for most strawberry cultivars that transitions them to reproductive growth to ensure optimum production. Strawberries (*Fragaria x ananassa*) are one of the most produced crops in temperate and subtropical areas, where temperature is the key factor in their growth (Ren et al. 2024). Although vernalization is common in most strawberry cultivars, the degrees of vernalization change according to the plant type (Hancock 2020).

Vernalization is dependent on cultivars of strawberries, whereas the modern cultivars with "day-neutral" (day-length-indifferent) flowers require no vernalization in order to flower and fruit (da Costa et al. 2014). For example, Albion is highly intolerant of low temperatures and does not flower or fruit without vernalization (Hancock et al. 2008). In contrast, newer varieties like Sweet Charlie do not need lower temperatures. Nevertheless, the success of vernalization is cultivar-specific; as Sweet Honeoye, a high-yielding variety, significantly increased flower/fruit production with the help of vernalization (Guevara-Matus et al. 2023). These differences also manifested when Albion showed low yields under controlled chilling conditions (Walter et al. 2005). Because of this, growers must select specific cultivars that perform reliably under certain environmental conditions. They can then tune down the vernalization process to take full advantage of the available growing area (Diel et al. 2017).

Vernalization also has an extra effect besides flowering, affecting fruit quality. According to Galletta and Himelrick (1990), when plants have been subjected to vernalization, better-quality fruits are produced. Such desirable traits as sweetness, size, and texture indicate this quality. In strawberry production, this is important because the quality of fruit is a prime determinant of the market. In areas that experience poor chilling temperatures in the tropics, where the variation in temperatures can result in poor vernalization, growers can control the temperature conditions to provide vernalization so that their fruit quality and yield will improve (Thammasophon et al. 2023).

Artificial manipulation through chilling has the strong feature of vernalization, especially in other regions where winters are not experienced. In these regions, natural chilling time may be insufficient to achieve adequate vernalization, so the artificially affected chilling resulted in improved flowering and fruit yield (Krüger et al. 2012).

For example, regions that do not have adequate exposure to low temperatures are assisted through chilling treatments to terminate dormancy, induce flowering and fruiting, and improve overall productivity (Faedi et al. 2002). Temperature and humidity are environmental factors critical for vernalization. This process induced flowering in warm regions, though too much moisture can enhance fungal diseases in plants (Thammasophon et al. 2023).

Different strawberry cultivars had unique characteristics. For example, Albion, a cold-sensitive cultivar, yields high-quality fruits but in lower quantities. Snow White is known for its sweetness and fruit quality. Summer Princess provides a balanced yield and is suitable for intercropping. Sweet Honeoye is ideal for large-scale production and can survive in warmer environmental conditions.

With unpredictable changes in the temperature level, vernalization has been considered as one of the possible methods of counteracting the impact of increasing temperature on strawberry production. Maskey et al. (2018) present the application of machine learning models to predict strawberry crop yields based on weather data, which considers how the vernalization process can be streamlined in coordination with climatic projections to maximize outputs in changing climates. Different strawberry cultivars require vernalization to ensure yield stability, particularly in areas with variable temperatures and chilling hours (Thammasophon et al. 2023).

This research seeks to examine how vernalization influences the flowering, fruiting, and yield of five strawberry cultivars, namely Albion, Snow White, Summer Princess, Sweet Charlie, and Sweet Honeoye, in a particular climatic condition of Marawi City, located in Lanao del Sur, Philippines. This study hypothesized that short-duration vernalization would significantly enhance flowering, fruiting, and total yield of strawberry under tropical highland conditions, and that the magnitude of these responses would vary among cultivars due to genotype-specific sensitivity to low-temperature exposure.

MATERIALS AND METHODS

Location and duration of study

This research was carried out in the Agricultural Experimental Area of the College of Agriculture, Mindanao State University-Main Campus, Marawi, 9700, Lanao del Sur, Philippines (8°00'15"N 124°15'41"E) as indicated in Figure 1. The experiment started in June 2024 by the production of planting materials and terminated in April 2025. The soil in the experimental site is classified as Adtuyon clay loam, Typic Kandiudults, and is typically infertile. The soil needed to be fertilized and limed to maximize plant growth and development. The area also has a Type IV climate according to the Corona classification, characterized by evenly distributed rainfall throughout the year. The average rainfall was 625.05 mm during the crop period, with the relative humidity of 86.07%. The temperature variation was not below 19.96°C, nor above 26.95°C, and averaged 23.46°C.

Production of planting materials

Due to the limited availability and high cost of planting materials, initial strawberry plants were allowed to produce runners for six months. This process adhered to the standard cultural management practices for strawberry production, as outlined by the Agricultural Training Institute-Cordillera Administrative Region (DA-ATI-CAR, undated). The experiment used the following varieties: Albion (Figure 2.A), Snow White (Figure 2.B), Summer Princess (Figure 2.C), Sweet Charlie (Figure 2.D), and Sweet Honeoye (Figure 2.E).

Soil sampling and soil analysis

Soil samples were collected following the standard procedures set by the Department of Agriculture, Bureau of Soil and Water Management. The farm was divided into sections based on factors such as color, texture, water source, topography, and previous management practices. Soil samples were collected using a soil auger, following the zigzag method of systematic stratified sampling. Each sample was placed in labeled cellophane bags, air-dried, pulverized, and sieved before being sent to the laboratory for analysis. The soil was analyzed for pH, Organic Matter (OM), total nitrogen (N), available phosphorus (P), and extractable potassium (K). Table 1 outlines the laboratory procedures and methods used for each soil test.

Climate data acquisition

Climate data, including rainfall, relative humidity, and mean temperature, were collected from the National Aeronautics and Space Administration (NASA)-Prediction of Worldwide Energy Resources (POWER) project (https://power.larc.nasa.gov/data-access-viewer/) from December 1, 2024 to April 30, 2025.

Figure 1. Overview of the experimental field site at Mindanao State University Main Campus, Marawi City, Lanao del Sur, Philippines

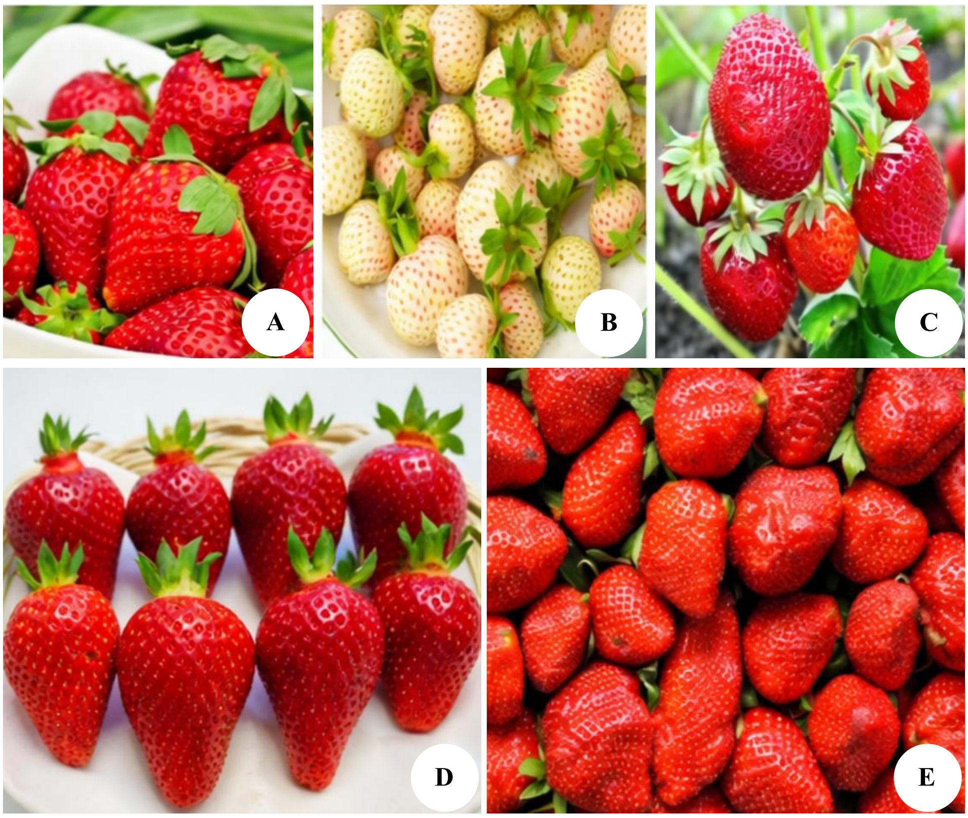


Figure 2. Different strawberry varieties used in the study. A. Albion, B. Snow White, C. Summer Princess, D. Sweet Charlie, E. Sweet Honeoye

Experimental design

The experiment used a 2x5 split-plot in a Randomized Complete Block Design with four replications (Figure 3). The main plot consisted of vernalized (N1) and non-vernalized (N2) treatments. Subplots were different strawberry cultivars, namely Albion (V1), Snow White (V2), Summer Princess (V3), Sweet Charlie (V4), and Sweet Honeoye (V5). Each replicate included 12 plants per plot in a 1×1.80 m plot. The total number of plants in the experiment is 480. The total land area utilized for the study was 456 m^2.

For the vernalization treatment, the plants in the vernalized group were exposed to 3°C for 10 hours in a controlled environment prior to planting. This chilling treatment was applied once and lasted for a continuous 10-hour period. The chosen temperature and duration were based on preliminary trials with the cultivar Sweet Honeoye, which showed that exposure beyond 10 hours did not result in significant improvements in fruit quality or yield. The short-duration chilling was intended to elicit early cold vernalization responses in the strawberry plants. Cold treatment of this type rapidly alters the expression of cold-responsive genes, activating the ICE-CBF signaling pathway and COR transcription factors (Liu et al. 2019). No additional low-temperature exposure was applied beyond this single chilling session. This experimental design enabled a detailed comparison of the effects of vernalization across different strawberry cultivars under controlled conditions.

Cultural management practices

Figure 4 shows the cultural management practices for strawberries. Land preparation entailed plowing, harrowing, and raising beds to improve drainage and prevent plant damage. The use of plastic mulch regulates soil moisture and soil temperature. Plants were spaced at a distance of 30 cm within a double row. The recommended fertilizer rate was 140-140-140 kg N, P_2O_5, K_2O/ha. Nitrogen was applied in three splits: at planting, 4 weeks, and 8 weeks after the initial application. Phosphorus was applied at planting and before flowering, while potassium was applied at planting, pre-flowering, mid-flowering, and during the fruiting phases. Irrigation was done traditionally to sustain the right amount of moisture. Insect pests and diseases were controlled using chemical measures, with application rates and methods following the manufacturer's recommendations. To avoid pest resistance, various active ingredients were used. Common pests observed on the strawberry plants included aphids (*Aphis gossypii*), cutworms (*Spodoptera litura*), tussock moths (*Orgyia* sp.), leaf-feeding beetles (*Monolepta* sp. and *Aulacophora* sp.), adult beetles (*Leucopholis irrorata*), curculionid beetles (*Metapocyrtus* sp.), mealybugs (Pseudococcidae), and ants (*Solenopsis* sp.). Weeding was manually done to ensure no weeds were present around the plants. Healthy, robust, disease-free planting materials with 4-6 healthy leaves were selected. The harvesting of the fruits took place at three-fourths ripeness, which was signified by the redness of the color.

Statistical analysis

Data was analyzed using Analysis of Variance (ANOVA) for RCBD. Significant differences were further analyzed using Tukey's Honest Significant Difference (HSD). The statistical analyses were performed using the STAR 2014 software (International Rice Research Institute 2014), version 2.0.1.

Table 1. Methods of analysis and analytical techniques for soil testing

Parameter	Method of analysis	Analytical technique/ Instrumentation	Results
pH	1:1 Soil:water pH method	Potentiometric	4.65 (Strongly Acidic)
Organic Matter (OM)	Walkley and Black method (Walkley and Black 1934)	Titration	1.20% (Critically Low)
Total Nitrogen (N)	Modified Kjeldahl method (Campbell and Hanna 1937)	Distillation and Titration	50 kg/ha (Critically Low)
Available Phosphorus (P)	Bray 1 (FAO-UN 2021)	Visible Spectrophotometer	4.62 kg/ha (Critically Low)
Extractable Potassium (K)	Ammonium acetate method (Chapman 1965)	Flame Photometer	93.00 kg/ha (Critically Low)

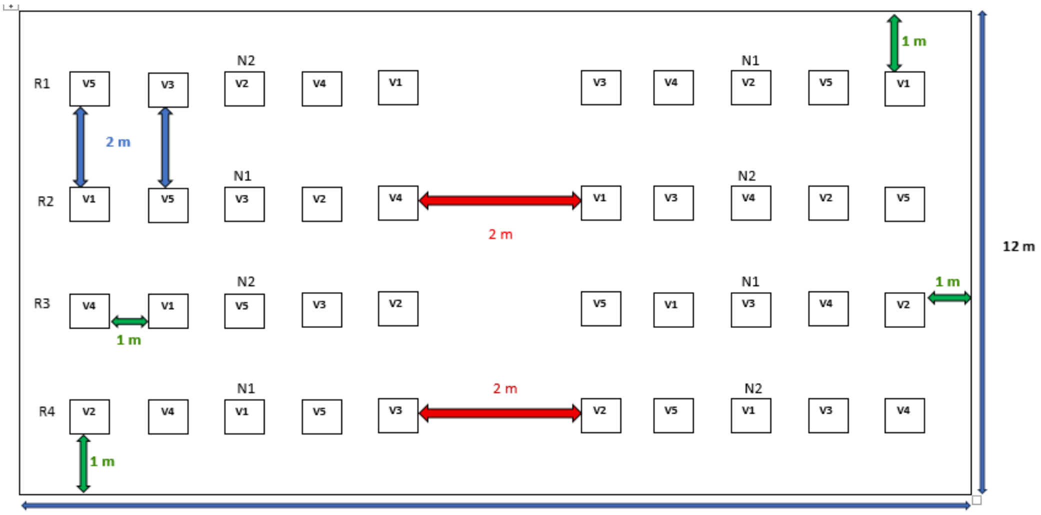


Figure 3. Experimental layout of the area

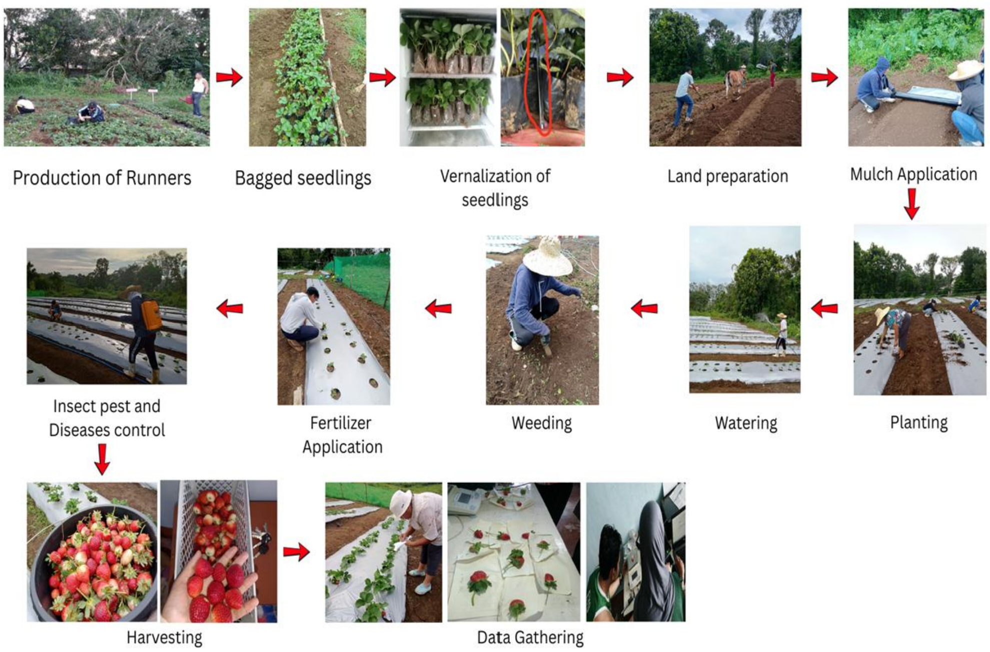


Figure 4. Cultural management practices for strawberries

RESULTS AND DISCUSSION

Climate and soil data

Strawberries have optimum production at temperatures that range between 15 and 24°C. Specific site data records an average temperature of 23.46°C, minimum temperature of 19.96°C, and maximum temperature of 26.95°C, as shown in Figure 5. Temperatures above 30°C may induce heat stress, failing to produce flower and fruit set, thus causing low yields. In Southeast Queensland, Australia, Menzel (2023) reported a 28% reduction in yields compared with 1967 data, which is due partly to rising mean temperature.

Relative humidity is a factor affecting the health of the strawberries due to turgidity maintenance, and photosynthesis is also important. Very high humidity of over 85% creates susceptibility to fungus infections such as powdery mildew and botrytis. The relative humidity of 86.07% in this site demands prior prevention in order to manage/prevent fungal diseases in a humid environment. Kim et al. (2023) also suggest that the combination of pest management advice and environmental information to reduce liability to fungi.

Strawberries are well-drained crops that do not tolerate water deficit, whereby poor drainage may lead to root rot. Appropriate rainfall, more so when there are high levels of rain during the fruit development stage, improves fruit size and quality. The rainfall experienced throughout the cropping season was 625.05 mm, implying that water stress is not likely to be of any threat to soil upkeep and drainage. Maskey et al. (2018) stressed the efficiencies of weather-based models to forecast the production of strawberries, considering different conditions.

Since climate change has been erratic, the latest developments are in the use of climate-indexed yield-prediction models where temperature, precipitation, and humidity are taken into consideration. These models enhance the precise estimation of yield performances of farms with strawberries under varying conditions of nature. Brown et al. (2018) emphasized the opportunities in making climate projections a part of increasing predictability of yields.

Soil analysis revealed a strongly acidic pH of 4.65. Other key indicators were critically low, with organic matter at 1.20%, available nitrogen at 50 kg/ha, available phosphorus at 4.62 kg/ha, and available potassium at 93.00 kg/ha.

Number of days to first flower

The time to first flower was significantly influenced by both cultivar and vernalization treatment, as shown in Figure 6. In the non-vernalized treatment, Albion had the shortest flowering time, with an average of 25-26th days, significantly earlier than the other varieties. Summer Princess flowered at 55-56th days, followed by Sweet Honeoye at 62-63rd days and Sweet Charlie at 63-64th days, the most extended flowering periods among the non-vernalized plants.

In the vernalized treatment, the variation in flowering times was less pronounced. Albion flowered at 43-44th days, followed by Summer Princess at 47-48th days, earlier than Snow White at 62-63rd days, the cultivar with the latest flowering time under vernalization. Sweet Honeoye and Sweet Charlie flowered around the same time at 57.13 days and 57.05 days, respectively, both flowering slightly earlier than Snow White.

The variations in flowering time of vernalized and non-vernalized treatments were also significantly different, thus supporting the claims of other studies on how vernalization regulates the speeding up of flowering. Albion was the earliest one to flower in non-vernalized treatment, and this was consistent with the evidence of Thammasophon et al. (2023), who documented that some strawberry varieties flower earlier without vernalization. Conversely, Sweet Honeoye, Summer Princess, and Sweet Charlie showed later flowering, indicating that they are more sensitive to environmental factors like temperature and photoperiod, which Kumar et al. (2012) suggest may contribute to delayed flowering in specific cultivars.

In the process of vernalization, Albion and Sweet Honeoye flowered earlier than Snow White, having the most extended flowering period. Madrid (2021) claimed that the vernalization condition usually promotes early flowering by breaking dormancy. When comparing flowering times between Summer Princess and Sweet Charlie under vernalization, this may occur due to the similarity in vernalization response between the two varieties, as concluded by Prohaska et al. (2024), in that some varieties are more strongly affected by vernalization, which results in a consistency in the flowering time parameter irrespective of environmental conditions.

Number of runners

The runner production per plant had been affected by the vernalization treatment and the variety of strawberry. The variations in runners per plant were recorded in the varieties under the non-vernalized treatment. Albion produced fewer runners with an average of 0.53 runners per plant, while Sweet Honeoye produced the most runners at 2.83 per plant, and Sweet Charlie, which had 2.65 runners per plant. Snow White and Summer Princess had 0.60 and 2.68 runners per plant, respectively (Figure 7.A).

When given the vernalized treatment, the production of runners was affected negatively in all the varieties, with Albion being the least affected at 0.1 runners per plant. Sweet Honeoye decreased to 2.50 runners per plant compared to 2.83 runners per plant, while Snow White, Summer Princess, and Sweet Charlie fell to 0.75 to 2.48 and 2.50 runners/plant, respectively. These findings are consistent with the current research and past findings that vernalization alters the assimilation of energy used in vegetative growth to reproduce growth and controls the number of runners originated (Rozbiany and Taha 2023; Intawong et al. 2025). Even though the number of runners is reduced in the vernalized conditions, it does not necessarily mean an overall reduction in productivity because such productivity may be counterbalanced by fruit production (Rozbiany and Taha 2023). Thus, the effects of vernalization on the production of runners are probably genetically and ecologically mediated.

As to varietal differences, more runners were produced in Sweet Honeoye with a mean of 2.66 runners per plant in both treatments, followed by 2.69 and 2.58 runners per plant by Summer Princess and Sweet Charlie, respectively (Figure 7.B). Such results indicate that the behavior of such varieties concerning environmental conditions and vernalization is the same, and yields a similar number of runners. Walter et al. (2005) found that the variety of strawberries is of great importance in maximizing the growth and production of fruits.

In contrast, Albion exhibited the lowest number of runners, averaging 0.31 runners per plant, which is significantly lower than the other varieties. This indicates that Albion could not have good environmental or genetic adaptation to the experimental conditions, especially to vernalization treatment.

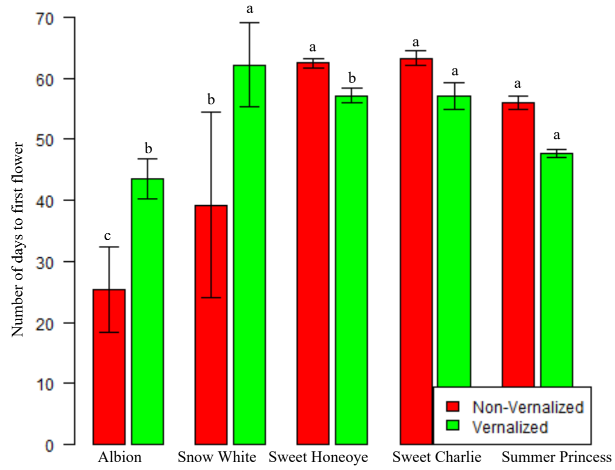


Figure 6. Number of days to first flower as affected by vernalization status and different strawberry varieties. Treatment groups with the same letter do not differ significantly (p=0.0000)

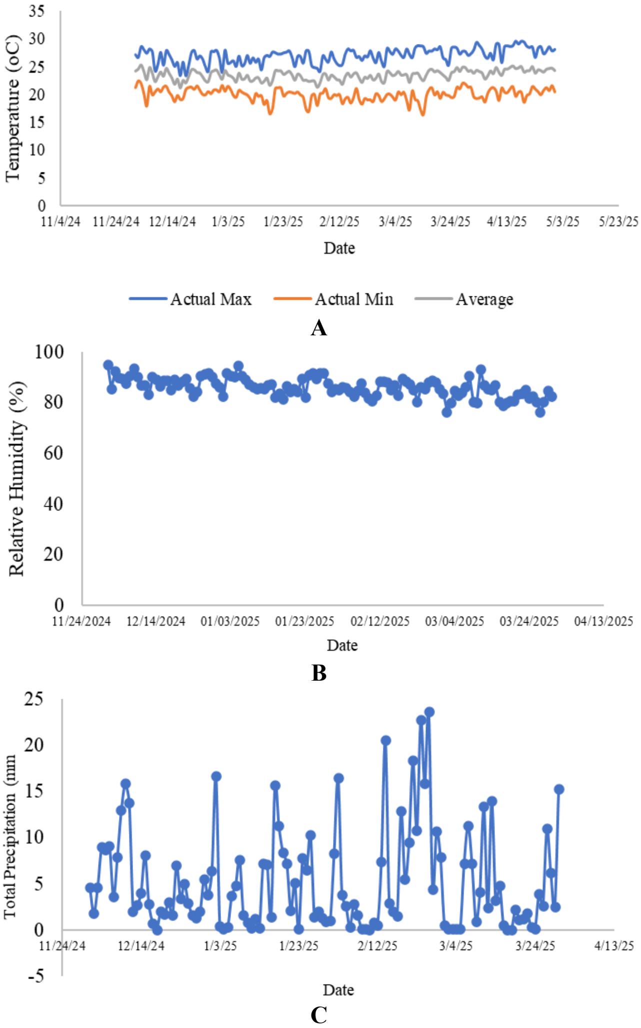


Figure 5. Climate data: A. Temperature, B. Relative humidity, and C. Precipitation for the study site, obtained from NASA-POWER. The average temperature was 23.46°C, with a minimum of 19.96°C and a maximum of 26.95°C. Average relative humidity was 86.07%, and total precipitation was 625.05 mm

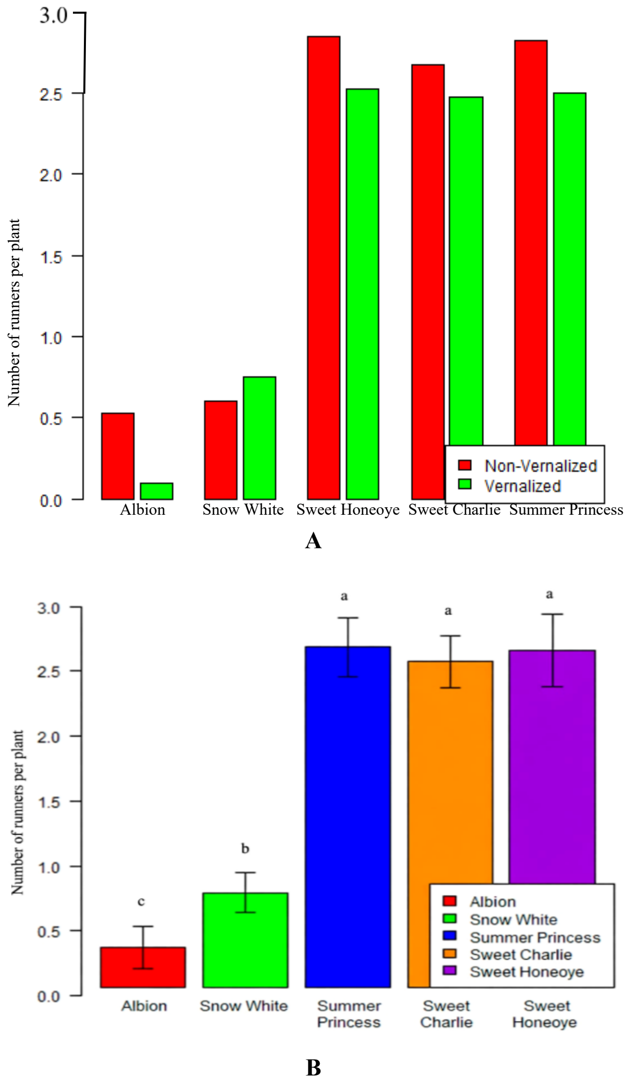


Figure 7. A. Number of runners per plant for different varieties under vernalized and non-vernalized treatments, B. Varietal runner production, showing the average number of runners per plant across both treatments. Treatment groups with the same letter do not differ significantly (p=0.0000)

The same thing was discovered by Hytonen and Elomaa (2011), who point out that the ecological or genetic parameters may restrain vegetative propagation, thereby dwindling the delivery of runners in certain varieties. The 0.68 runners per plant were produced by Snow White, which is a moderate response to the experimental conditions. These findings support that the production of runners depends on the variety of strawberries and that choosing the cultivar is necessary to guarantee the highest vegetative growth and yield (Bisht et al. 2024).

Number of flowers per plant

The number of strawberry flowers per plant was counted within five different varieties of strawberries and in two vernalization treatments, as shown in Figure 8. Under the non-vernalized treatment, a marked intervarietal variation was found. Albion had the fewest flowers, producing an average of 3.50 flowers per plant, and Snow White produced 6.75 flowers per plant on the lowest end of the varieties. Other forms, such as Summer Princess, Sweet Charlie, and Sweet Honeoye, had many more flowers with their mean value of 27.75, and 28.75, and 31.25 per plant, respectively.

In most varieties, the number of flowers was affected positively after application of vernalization treatment. Albion increased to 9.80 flowers/ plant, whereas the increase in Sweet Honeoye reached the highest overall count, increasing to 40.25 flowers/ plant. Snow White and Summer Princess improved totals of 30.50 and 39.00 flowers per plant, respectively, whereas Sweet Charlie improved to a total of 39.25 flowers per plant. These findings indicate that vernalization induced more flowers in most cultivars, yet differences among cultivars.

The impact of vernalization on flower production was different with respect to cultivar. The most significant relative increase was found in Snow White, with the flower count more than quadrupling after vernalization, 30.50 and 6.75 flowers per plant, meaning this cultivar responds strongly to vernalization. Albion, too, produced an unusually high number of flowers relative to its non-vernalized control, 9.75 and 3.50 flowers per plant, and its absolute flower output was low in the absence of vernalization (Bond et al. 2011). Sweet Honeoye and Sweet Charlie also displayed a favorable increase in the number of flowers with 40.25 and 39.25 flowers per plant, respectively, but their relative reaction was not as strong as that of Snow White. Summer Princess showed a slight improvement as flower numbers rose by 11.25 flowers per plant (27.75 to 39.00 flowers), which implies that the flowering phenotype in Summer Princess is less flexible and not easily manipulated by the vernalization process, possibly influenced by other environmental conditions (Massa et al. 2015).

Such results support the significance of cultivar choice that will tolerate temperature variabilities and respond positively to vernalization. Previously identified strategic significance that flower induction holds in warm-climate production systems due to the necessity to develop cultivar-specific management practices toward optimizing flowering (Sønsteby et al. 2013; Oviedo et al. 2020).

Number of fruits per plant

Results of fruit production of strawberry cultivars in the non-vernalized and vernalized treatment are shown in Figure 9. Under non-vernalization conditions, Sweet Charlie and Sweet Honeoye recorded the highest records in fruits per plant with averages of 20.50 and 18.50, respectively. Summer Princess came in second with 20.00 fruits per plant, but the Snow White had a fruiting of fewer than 4.00 fruits, and Albion bearing only 2.00 fruits per plant. Statistical analysis revealed that Sweet Charlie, Sweet Honeoye, and Summer Princess were considerably larger than Albion and Snow White.

Following vernalization, there was an improvement in the fruit yields in all the cultivars. The Sweet Honeoye and Sweet Charlie yielded 28.50 and 24.50 fruits per plant, respectively, followed by Summer Princess (25.00), Sweet Honeoye (25.25), and Sweet Charlie (24.50). Snow White improved significantly, up to 17.50 fruits per plant, and Albion had the lowest improvement, at 5.00 fruits per plant.

These findings align with effects of vernalization, improving the fruit set and yield in warmer environments (Cao 2024). Rivero et al. (2021) also noticed that vernalization is associated with stronger flowering and fruit production, particularly on tropical and subtropical cultivars, supporting the stated findings.

The environmental conditions through which the vernalization process should be considered are essential. In areas with winters having curtailed chilling, the effect of vernalization can be weak, and the fruit yields can also be low, even though it is a variety requiring chilling. Naphrom et al. (2025) established that strawberry plants grown in a subtropical climate could not show as much vernalization assimilation as those grown in temperate climates. Therefore, prerequisites of chilling, which are typical of specific cultivars, are required during vernalization-related procedures, particularly in places where cold is not the norm.

The above observations emphasize the necessity of observing the standards of agricultural cultivation to suit the needs of cultivars. Although vernalization can be used to increase the fruit yield, its use must be incorporated into proper irrigation, fertilization, and pest care to get the best out of vernalization. This kind of integration is the prerequisite for the long-term survival and financial sustainability of strawberry farming.

Total Soluble Solids (TSS)

Total Soluble Solids (TSS), the leading indicator of fruit sweetness, was compared between the different cultivars of strawberries under non-vernalized and vernalized conditions as depicted in Figure 10.A and B, respectively. Generally, Snow White exhibited the most significant TSS values of 14.42 and 15.35ºBrix in the non-vernalized and vernalized groups, respectively. This implies that Snow White generates sweet fruit irrespective of whether vernalization treatment is administered to them.

Sweet Honeoye exhibited relatively high TSS levels. However, it did not show significant changes in sweetness under vernalization, as the level rose by 0.2 to 0.30°Brix.

Compared to Sweet Charlie, the values of TSS were lowest, with 7.93 and 7.73°Brix in the non-vernalized and vernalized treatment, respectively. This indicates that Sweet Charlie might be genetically shaped to reduce the degree of its sweetness relative to the other cultivars.

Although vernalization appears to have enhanced fruit quality even after the treatment, the sweetness of Sweet Honeoye was only slightly enhanced, mainly because of the subsequent sweetness of plants subjected to the treatment. These results highlight the need to pay more attention to the choice of cultivars, not only in terms of yield, but also in terms of such parameters as fruit sweetness, which are gaining more and more popularity in the requirements of contemporary strawberry consumers (Guevara-Matus et al. 2023; Thammasophon et al. 2023).

Total yield

According to the total yield performance, it is clear that vernalization is a good factor in enhancing fruit yield, as shown in Figure 11.A and B. Vernalized plants yielded the fruit significantly more than the non-vernalized plants, at a mean of 10.83 and 7.38 t ha^{-1} respectively, as shown in Figures 11. A and B. This increase in fruiting is probably because plants are deliberately exposed to cold temperatures, stimulating physiological mechanisms that encourage growth and reproduction. These results corroborate current scientific knowledge, highlighting the significance of vernalization to the improvement of plant productivity (Staniak et al. 2021; Hüner et al. 2025) and thus reaffirm the potential usefulness of vernalization in agricultural practice in efforts to maximize the yield of crop plants.

Such variations in strawberry yield in diverse cultivars could be explained by several reasons, including the variety of plant genetics, growing environment, and cultural practices. All the cultivars were significantly different in yield, with Sweet Honeoye and Sweet Charlie being the highest yielding cultivars, averaging 13.68 and 13.47 t ha^{-1}, respectively. Those cultivars proved stable between differing growing environments. Conversely, the lowest yield was obtained at Albion (2.35 t ha^{-1}), perhaps because this plant is susceptible to local environmental factors or has specific growth requirements.

Available research also describes how strawberry production is regulated through the vernalization procedure, in which a plant is subjected to low temperatures. Thammasophon et al. (2023) concluded that lower temperatures of vernalization at 2 to 4°C control the spring flowering ability of strawberries by extrapolating the valuable information of the key flowering genes like VRN5, FT, and SOC1. This is particularly useful where the temperature changes are mild in subtropical areas.

Guevara-Matus et al. (2023) added that in comparison with four weeks, a duration of two weeks (336 hours at 0-5°C) leads to such results. This implies that vernalization time has an optimum benefit beyond which demerits can extend. Results of the present research support the importance of selecting appropriate cultivars of strawberry and optimized vernalization to achieve maximum production of fruits. It has been possible to equilibrate the genetic backdrop, the practicing environment, and the local cultures to obtain the optimum performance of strawberry production in different regions of the world.

Overall, this research shows that vernalization considerably increases the strawberries' yields. Sweet Honeoye and Sweet Charlie had the best yields (13.68 t ha^{-1} and 13.47 t ha^{-1}, respectively), whereas Albion produced the lowest yield at 2.35 t ha^{-1}. Intermediate yields were observed in Summer Princess (10.85 t ha^{-1}) and Snow White (5.15 t ha^{-1}). Based on statistical significance, Summer Princess performed notably better than Snow White and Albion, though it did not quite reach the peak yields of the Sweet Honeoye and Sweet Charlie varieties.

These findings underscore the effectiveness of vernalization as far as improving strawberry yields, especially with strains such as Sweet Honeoye and Sweet Charlie; however, they also point out the importance of fine-tuning the practice of vernalization as it pertains to cultivar type and growing conditions (Guevara-Matus et al. 2023; Thammasophon et al. 2023).

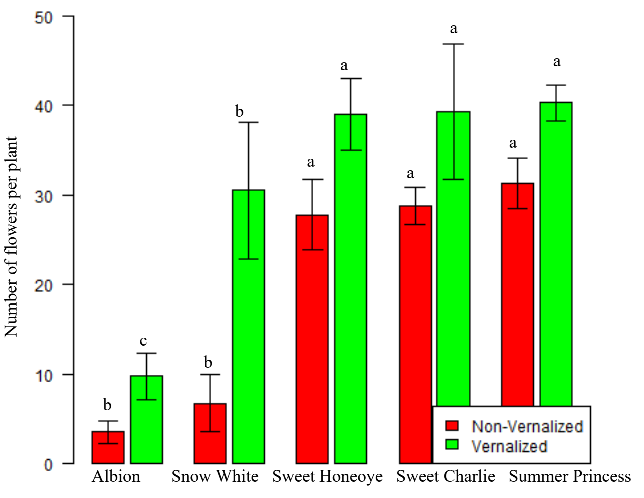


Figure 8. Flower production of different strawberry varieties and vernalization status. Treatment groups with the same letter do not differ significantly (p=0.0000)

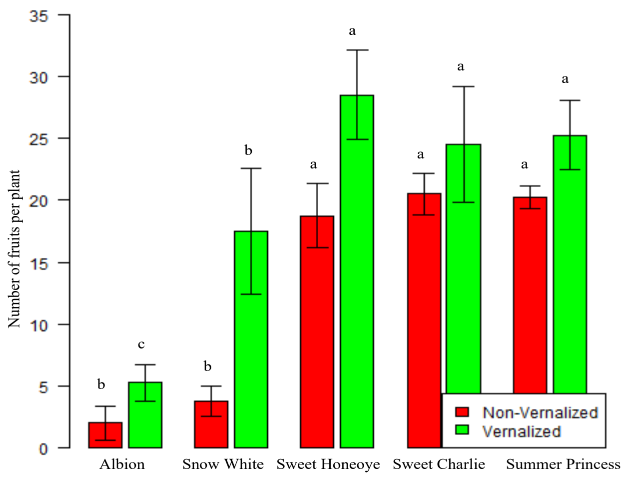
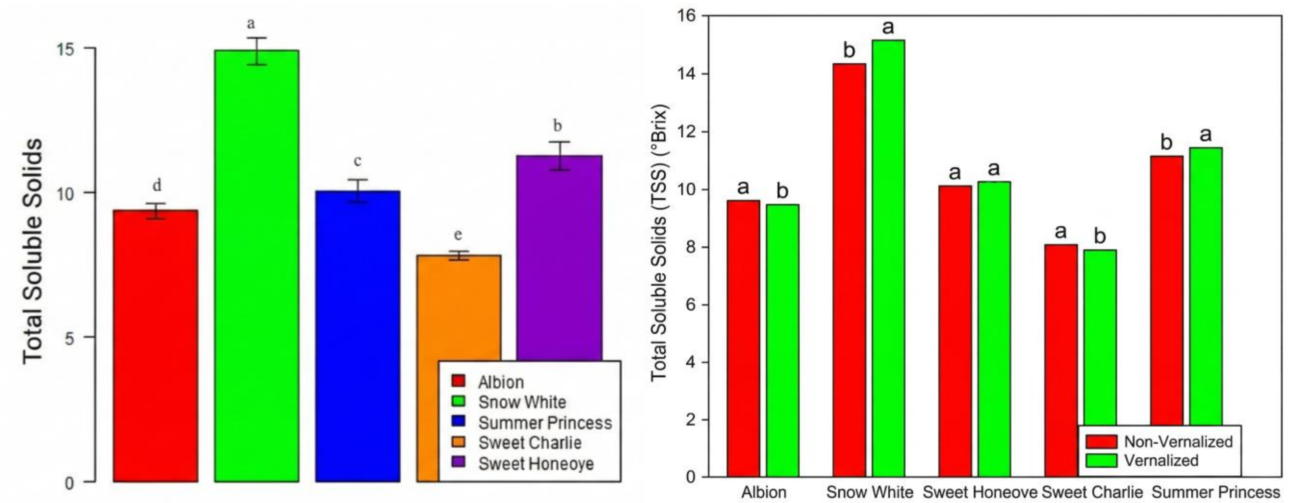
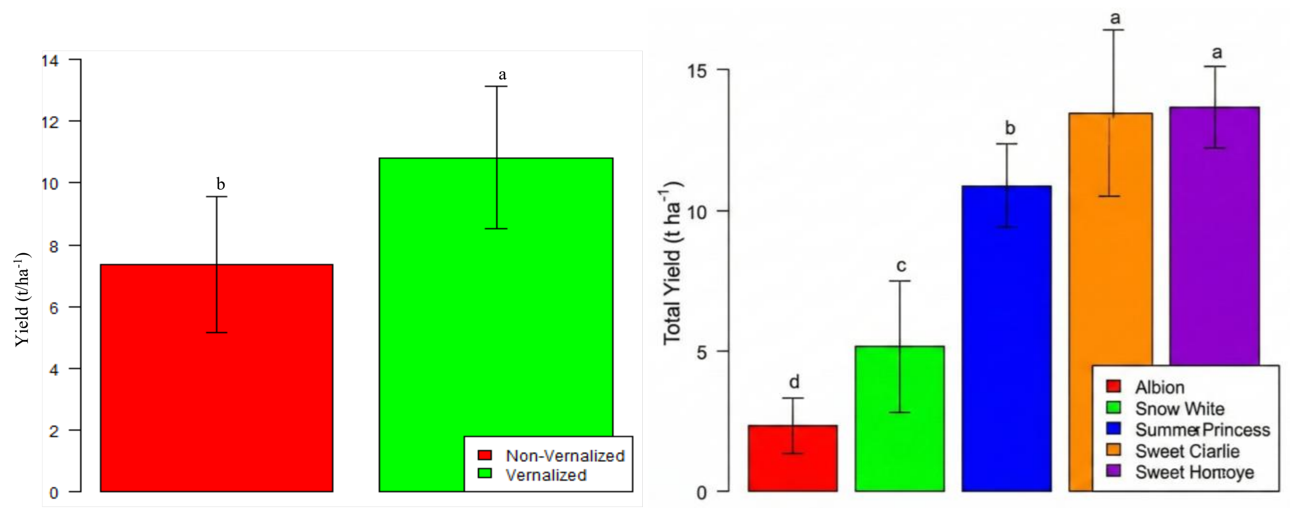


Figure 9. Number of fruits per plant as affected by vernalization and non-vernalization treatments for different strawberry varieties. Treatment groups with the same letter do not differ significantly (p=0.0108)



A **B**

Figure 10. A. Total Soluble Solids (°Brix) of different strawberry varieties, B. Total Soluble Solids (°Brix) of different strawberry varieties, showing the effects of vernalization. Treatment groups with the same letter do not differ significantly (p=0.0000)



A **B**

Figure 11. A. Total yield of strawberry plants as affected by vernalization status. Treatment groups with the same letter do not differ significantly (p=0.0077). B. Total yield of different strawberry varieties. Treatment groups with the same letter do not differ significantly (p=0.0000)

In conclusion, this study demonstrated that short-duration vernalization (3°C for 10 h prior to planting) significantly enhanced flowering, fruiting, and yield of strawberry under tropical highland conditions. Across cultivars, vernalized plants produced a higher mean yield (10.83 t ha^{-1}) than non-vernalized plants (7.38 t ha^{-1}), representing an overall yield increase of approximately 46.7%. Yield improvement was primarily associated with increased reproductive output rather than vegetative growth, as vernalization reduced runner production in all cultivars. Cultivar responses were markedly different. Sweet Honeoye and Sweet Charlie showed the strongest positive responses, achieving mean yields of 13.68 and 13.47 t ha^{-1}, respectively, and producing up to 40.25 flowers and 28.50 fruits per plant. Summer Princess exhibited moderate yield gains, while Snow White expressed limited yield improvement but consistently produced the sweetest fruits, reaching a maximum total soluble solids value of 15.35°Brix. In contrast, Albion showed the weakest response to vernalization, with yield remaining low (approximately 2.35 t ha^{-1}) despite increased flowering, indicating poor adaptation to the local climatic conditions. The significant interaction between vernalization treatment and cultivar confirms that vernalization effectiveness is genotype-dependent. These results highlight the importance of matching appropriate cultivars with targeted temperature manipulation to optimize strawberry production in warm-climate environments.

Therefore, the study was conducted over a single cropping cycle and used only one vernalization temperature and duration, which may limit broader generalization. Future research should evaluate multiple chilling durations and temperature regimes, assess multi-season yield stability, and integrate economic analyses to determine cost–benefit feasibility. Further investigation into physiological and molecular responses to vernalization would also strengthen cultivar selection strategies for tropical and subtropical strawberry production systems.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the Ministry of Science and Technology-Bangsamoro Autonomous Region in Muslim Mindanao (MOST-BARMM), Philippines, for their financial support of this project. This manuscript is part of the project titled “Development of Integrated Crop Management for Strawberry (*Fragaria* × *ananassa* Duch) and Establishment of Strawberry Farms in the Province of Lanao del Sur in Philippines.”

We also extend special thanks to Ma'am Elien, Ma'am Aminah, and Ma'am Jade from the Office of the Vice Chancellor for Research, Extension, and Development and the Mamitua Saber Institute of Research and Creation, Philippines, led by Dr. Fema M. Abamo and Dr. Mahid M. Mangontarun, respectively. Lastly, we are grateful to the late President Atty. Basari D. Mapupuno, former President of the Mindanao State University System, for his unwavering support and encouragement.

REFERENCES

Bisht N, Pant P, Kumar A, Biswas SS. 2024. Seasonal variation of factors influencing reproductive and vegetative growth in strawberry: A review. J Agric Technol 11 (1-2): 165-178.

Bond DM, Dennis ES, Finnegan EJ. 2011. The low-temperature response pathways for cold acclimation and vernalization are independent. Plant Cell Environ 34 (10): 1737-1748. https://doi.org/10.1111/j.1365-3040.2011.02370.x.

Brown JN, Hochman Z, Holzworth D, Horan H. 2018. Seasonal climate forecasts provide more definitive and accurate crop yieldpredictions. Agric. For Meteorol 260: 247-254. https://doi.org/10.1016/j.agrformet.2018.06.001.

Campbell WR, Hanna MI. 1937. The determination of nitrogen by modified Kjeldahl methods. J Biol Chem 119 (1): 1-7. https://doi.org/10.1016/s0021-9258%2818%2974426-8.

Cao D. 2024. Vernalization or devernalization? A question about *VRT2*. Plant Physiol 196 (4): 2266-2268. https://doi.org/10.1093/plphys/kiae440.

Chapman HD. 1965. Total exchangeable bases. In: Norman AG (eds). Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. Agronomy Monograph No. 9. American Society of Agronomy, Madison, WI, USA. https://doi.org/10.2134/agronmonogr9.2.c7.

da Costa RC, Calvete EO, Mendonça HFC, De Costa LA. 2014. Phenology and leaf accumulation in vernalized and non-vernalized strawberry seedlings in neutral-days. Acta Sci Agron 36 (1): 57-62. https://doi.org/10.4025/actasciagron.v36i1.17285.

DA-ATI-CAR. (n.d.). Standard Cultural Management Practices for Strawberry Production. Agricultural Training Institute, Cordillera Administrative Region. [UNDATE]

Diel MI, Pinheiro MVM, Cocco C, Thiesen LA, Altíssimo BS, Fontana DC, Caron BO, Testa V, Schmidt D. 2017. Artificial vernalization in strawberry plants: Phyllochron, production, and quality. Aust J Crop Sci 11 (10): 1315-1319. https://doi.org/10.21475/ajcs.17.11.10.pne603.

Faedi W, Mourgues F, Rosati C. 2002. Strawberry breeding and varieties: Situation and perspectives. Acta Hortic 567: 51-59. https://doi.org/10.17660/ActaHortic.2002.567.1.

Food and Agriculture Organization of the United Nations (FAO-UN). 2021. Standard Operating Procedure for Soil Available Phosphorus: Bray I and Bray II Method (SPS-1234). FAO, Rome. https://openknowledge.fao.org/bitstream/1234/5678/1/SPS-1234.pdf.

Galletta GJ, Himelrick DG (eds). 1990. Small Fruit Crop Management. Prentice Hall PTR, Englewood Cliffs, New Jersey, USA.

Guevara-Matus K, Loría-Quirós CL, Granados-Montero M. 2023. Effect of vernalization on strawberry stolon production. Rev Mex Cienc Agric 14 (1): 129-137. https://doi.org/10.29312/remexca.v14i1.3187.

Hancock JF, Sjulin TM, Lobos GA. 2008. Strawberries. In: Hancock JF (eds). Temperate Fruit Crop Breeding: Germplasm to Genomics. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-1-4020-6907-9_13.

Hancock JF. 2020. Breeding and genetics. In: Hancock JF (eds). Strawberries. 2nd ed. CABI, Wallingford, UK. https://doi.org/10.1079/9781789242270.0210.

Hüner NPA, Ivanov AG, Szyszka-Mroz B, Bravo LA, Savitch LV, Krol M. 2025. Vernalization of winter crops increases photosynthetic energy conversion efficiency and seed yield. Plants 14 (15): 2357. https://doi.org/10.3390/plants14152357.

Hytonen T, Elomaa P. 2011. Genetic and environmental regulation of flowering and runnering in strawberry. Gene Genom Genomic 5 (S1): 56-64.

Intawong R, Panchai W, Naphrom D. 2025. Effects of cold water on plant growth and development of strawberry under a hydroponic system. Eur J Hortic Sci 90: 1-9. https://doi.org/10.1079/ejhs.2025.0010.

International Rice Research Institute. 2014. STAR (Statistical Tool for Agricultural Research) for Windows, version 2.0.1. International Rice Research Institute, Los Baños, Philippines.

Kim, S., Jo, J. S., Luk, V., Kim, S. K., & Kim, D. S. (2023). Estimating the impact of environmental management on strawberry yield using publicly available agricultural data in South Korea. *PeerJ*, *11*, Article e15390. https://doi.org/10.7717/peerj.15390

Krüger E, Josuttis M, Toldam-Andersen TB, Carlen C, Mezzetti B. 2012. Influence of growing conditions at different latitudes of Europe on strawberry growth performance, yield, and quality. J Berry Res 2: 143-157. https://doi.org/10.3233/JBR-2012-036.

Kumar A, Mishra P, Kumari K, Panigrahi KCS. 2012. Environmental stress influences plant development and flowering. Front Biosci 4: 1315-1324. https://doi.org/10.2741/s333.

Liu Y, Dang P, Liu L, He C. 2019. Cold acclimation by the CBF-COR pathway in a changing climate: Lessons from *Arabidopsis thaliana*. Plant Cell Rep 38: 511-519. https://doi.org/10.1007/s00299-019-02376-3.

Madrid E, Chandler JW, Coupland G. 2021. Gene regulatory networks controlled by FLOWERING LOCUS C that confer variation in seasonal flowering and life history. J Exp Bot 72 (1): 4-14. https://doi.org/10.1093/jxb/eraa216.

Maskey ML, Pathak TB, Dara SK. 2018. Weather-based strawberry yield forecasts at the field scale using statistical and machine learning models. Atmosphere 10 (7): 378. https://doi.org/10.3390/atmos10070378.

Massa GD, Chase E, Santini JB, Mitchell CA. 2015. Temperature affects long-term productivity and quality attributes of day-neutral strawberry for a space life-support system. Life Sci Space Res 5: 39-46. https://doi.org/10.1016/j.lssr.2015.04.003.

Menzel CM. 2023. Fruit set is moderately dependent on insect pollinators in strawberry and is limited by the availability of pollen under natural open conditions. J Hortic Sci Biotechnol 98 (6): 1-31. https://doi.org/10.1080/14620316.2023.221260.

Naphrom D, Santasup C, Panchai W, Boonraeng S, Promwungkwa A. 2025. Effect of root zone cooling on the growth and development of strawberry (*Fragaria* × *ananassa*) in a tropical climate. Intl J Plant Biol 16 (2): 54. https://doi.org/10.3390/ijpb16020054.

Oviedo VRS, Enciso-Garay CR, Figueredo EIG. 2020. Vernalizing pre-transplants improved the agronomic characteristics of strawberry genotypes under tropical conditions. Rev Caatinga 33: 653-659. https://doi.org/10.1590/1983-21252020v33n308rc.

Prohaska A, Petit A, Lesemann S, Rey-Serra P, Mazzoni L, Masny A, Sánchez-Sevilla JF, Potier A, Gaston A, Klamkowski K, Rothan C, Mezzetti B, Amaya I, Olbricht K, Denoyes B. 2024. Strawberry phenotypic plasticity in flowering time is driven by the interaction between genetic loci and temperature. J Exp Bot 75 (18): 5923-5939. https://doi.org/10.1093/jxb/erae279.

Ren C, Jiang L, Chen W, Wang Z. 2024. Effect of different post-flowering photoperiods on main agronomic traits of strawberry (*Fragaria* × *ananassa* Duch. cv. Akihime). Agronomy 14 (9): 2039. https://doi.org/10.3390/agronomy14092039.

Rivero R, Remberg SF, Heide OM, Sønsteby A. 2021. Environmental regulation of dormancy, flowering and runnering in two genetically distant everbearing strawberry cultivars. Sci Hortic 290: 110515. https://doi.org/10.1016/j.scienta.2021.110515.

Rozbiany PMK, Taha SM. 2023. Response of strawberry (*Fragaria* × *ananassa* Duch.) flowering and yield to photoperiod. In: Kafkas NE (eds). Recent Studies on Strawberries. IntechOpen, London, UK. https://doi.org/10.5772/intechopen.105442.

Sønsteby A, Opstad N, Heide OM. 2013. Environmental manipulation for establishing high yield potential of strawberry forcing plants. Sci Hortic 157: 65-73. https://doi.org/10.1016/j.scienta.2013.04.014.

Staniak M, Czopek K, Stępień-Warda A, Kocira A, Przybyś M. 2021. Cold stress during flowering alters plant structure, yield, and seed quality of different soybean genotypes. Agronomy 11 (10): 2059. https://doi.org/10.3390/agronomy11102059.

Thammasophon T, Pusadee T, Bundithya W, Naphrom D. 2023. Effects of vernalization on off-season flowering and gene expression in sub-tropical strawberry cv. Pharachatan 80. Horticulturae 9 (1): 87. https://doi.org/10.3390/horticulturae9010087.

Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37: 29-38. https://doi.org/10.1097/00010694-193401000-00003.

Walter M, Snelling C, Boyd-Wilson KSH, Williams G, Langford GI. 2005. Evaluation of organic strawberry runner production. Hort Technol 15 (4): 787-791. https://doi.org/10.21273/HORTTECH.15.4.0787.