*AgriEngineering*

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# The Effect of Climatic Parameters on Strawberry Production in a Small Walk-In Greenhouse

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**Abstract:** The purpose of this study was to evaluate the impact of different environmental factors such as temperature, solar radiation, and relative humidity on the quality of strawberries in terms of their shape, size, and sugar accumulation. The experiment was carried out in a small walk-in greenhouse in Matsusaka city, Japan. Harunoka strawberries (*Fragaria* × *ananassa* Duch.) were cultivated from September to May of the following year. Production was evaluated on 20 February 2021 (peak season) and 5 April 2021 (end season). To evaluate the influence of environmental factors on strawberry fruit quality, the weight, shape, and soluble sugar content were recorded and compared to each other. According to the environmental data, the average temperature between day and night at peak harvest was around 12 °C, which was suitable for high-quality strawberry cultivation. However, the average temperature difference between day and night was approximately 4 °C at the end of the season. In addition, there were no significant differences in solar radiation and relative humidity between both seasons. Increasing temperatures led to the decline in the soluble sugar content at the end season. Thus, it can be concluded that the temperature difference between day and night is a major factor affecting strawberry production. The assessment of the impact of environmental conditions on strawberry quality can be used as a guideline not only in temperate climates, but also in other climates, such as in tropical countries.

**Keywords:** environmental factors; strawberry quality; soluble sugar content; strawberry cultivation; temperature difference



**Citation:** Khammayom, N.; Maruyama, N.; Chaichana, C. The Effect of Climatic Parameters on Strawberry Production in a Small Walk-In Greenhouse. *AgriEngineering* **2022**, *4*, 104–121. https://doi.org/10.3390/agriengineering4010007

Academic Editors: Chrysoula Nikita-Martzopoulou and Mohammad Valipour

Received: 27 December 2021
Accepted: 31 January 2022
Published: 3 February 2022



## 1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most popular fruits throughout the world and contains numerous important dietary components, as it is high in minerals as well as vitamins. Strawberry is an important crop worldwide in terms of its commercial value as well. Thus, increases in productivity and strawberry quality are required. Cultivated strawberries are now a commercially important fruit around the world and are also very popular in Japan. Strawberry production has increased over the years [1].

Environmental factors such as temperature, photoperiod, and light intensity have significant effects on growth, yield, and fruit quality [2]. Furthermore, it is known that changes in environmental conditions determine the development of strawberry plants, affecting flowering, fruiting, and the quality of strawberry fruits, among other characteristics [3]. Thus, cultivation in a greenhouse is the solution to overcome climatic diversity. Strawberry production in Japan is performed in a greenhouse, which not only prevents the damage caused by adverse climatic conditions but also provides a suitable environment for strawberry cultivation and protects the crop from insects and pets. The climate of the main production area in Japan is temperate. This means that the temperature remains above freezing during the coldest months and can often reach over 30 °C in the summer. The temperature factor is one key target effect on strawberry growth. Low temperatures (below 7 °C) increase the possibility of damaged fruits as well as changes in fruit size and color [3,4]. On the other hand, high temperatures reduce the plant's photosynthetic rate by up to 44%, reducing crop yield and causing a decrease in sugars at the fruit level and, as a result, decrease sweetness [5]. Higher temperatures affect the photosynthesis process and electron transport chain [6]. Moreover, high temperatures on the fruit surface can hasten ripening, and a high rate of ripening could be argued to be factor that reduces the duration of the crop cycle [7]. A high strawberry growth rate is maintained at day temperatures of 23–28 °C, and the optimum night temperature is between 5–10 °C [8]. A favorable temperature inside the greenhouse results in the strawberry plants having a high growth rate and also improves crop quality (such as flesh firmness, skin resistance, soluble sugar content (SSC), skin color, and organic acids) [9].

The relative humidity in the air is closely related to the temperature, and it conditions the evaporative demand and the transpiration of the plant, both at the leaf and fruit level. As a result, it has a direct impact on the plant's water content, size, and bioactive component concentration. There are currently just a few studies evaluating the effects of this variable on fruit and vegetable quality [10].

In terms of commercial value and economics, the quality of strawberry production is an essential target. Previous studies demonstrated that environmental factors highly affect the quality of strawberries. Thus, environmental factors such as temperature, relative humidity, and solar radiation on strawberry cultivation were investigated. Environmental factors during the three days before harvest were examined. In this present work, a small walk-in greenhouse was designed and constructed for strawberry cultivation in temperate areas in the center of Japan. Generally, the current research focuses on the effect of climatic conditions on the quality of strawberries grown in a small walk-in greenhouse. Thus, in strawberry production in Matsusaka city, Japan, contrasting environmental conditions between the peak and end of the cropping season are differentiated. In the peak season (between December to late February), the photoperiod is shorter, and the solar radiation and ambient temperature are lower than at the end season (March-May). These environmental differences throughout the season may affect strawberry quality. Most fruit qualities are evaluated by SSC. The quality of strawberries in terms of shape and size as well as SSC were evaluated in this work. Then, the influence of these effects on the optimum cultivation conditions was proposed. The optimum ranges of environmental conditions for maintaining strawberry quality can be used as a guideline not only in temperate climates, but also in other climates, such as those found in tropical countries.

## 2. Materials and Methods

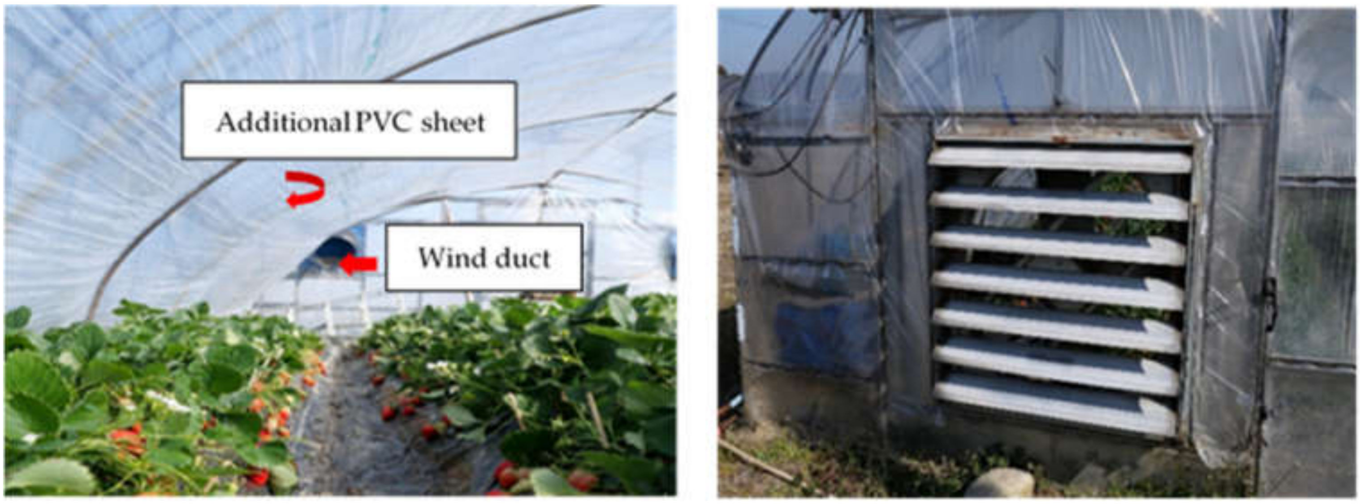
### 2.1. Greenhouse Description

A small walk-in greenhouse was built in Matsusaka city, Japan (latitude 34°34′ N, longitude 136°53′ E). The greenhouse (11.0 m long × 5.2 m wide × 2.5 m high) was constructed with steel frames and was covered with a PVC sheet. The greenhouse was located in a field without shading. The external and internal views, taken in October 2020, are shown in Figure 1a,b, respectively.

To maintain an optimum temperature for strawberry cultivation in the small walk-in greenhouse during the winter season, an additional PVC sheet was introduced inside the greenhouse to reduce night-time heat dissipation from the ground to the outside, as shown in Figure 2a. Due to this structure, supplemental heating was not required during cold weather conditions in this study. However, when the inside air temperature exceeded more than 25 °C, a ventilation fan as well as wind ducts automatically turned on and opened, as shown in Figure 2b. The specifications of the ventilation fan are given in Table 1. The capacity of this fan is for a greenhouse that is 50 m in length. As such, the air change rate was too high for this greenhouse.

(**a**) (**b**)

**Figure 1.** Experimental greenhouse: (**a**) external view; (**b**) inside view.




(**a**) (**b**)

**Figure 2.** Wind ducts and ventilation fan installed in opposite locations: (**a**) wind duct and additional PVC sheets; (**b**) ventilation fan.

**Table 1.** Specification of ventilation fan.

| Designation | Specification |
|---|---|
| Model | HF-80ETG-60 (Mitsubishi Electric Corp.) |
| Size | H 950 mm × V 900 mm |
| Blade diameter | 800 mm |
| Motor | 3 phase 200 V, 60 Hz, 0.4 kW |
| Air flow rate | 290 $m^3$/min |

### *2.2. Greenhouse Environmental Monitoring*

The air temperature, relative humidity as well as solar radiation both inside and outside of the cultivation greenhouse were measured at 5 s intervals during the cultivation period from November 2020 to April 2021. All of these sensors were connected and were recorded by a multi-channel data logger. The dimensions of the small walk-in greenhouse and sensor layouts are shown in Figure 3.

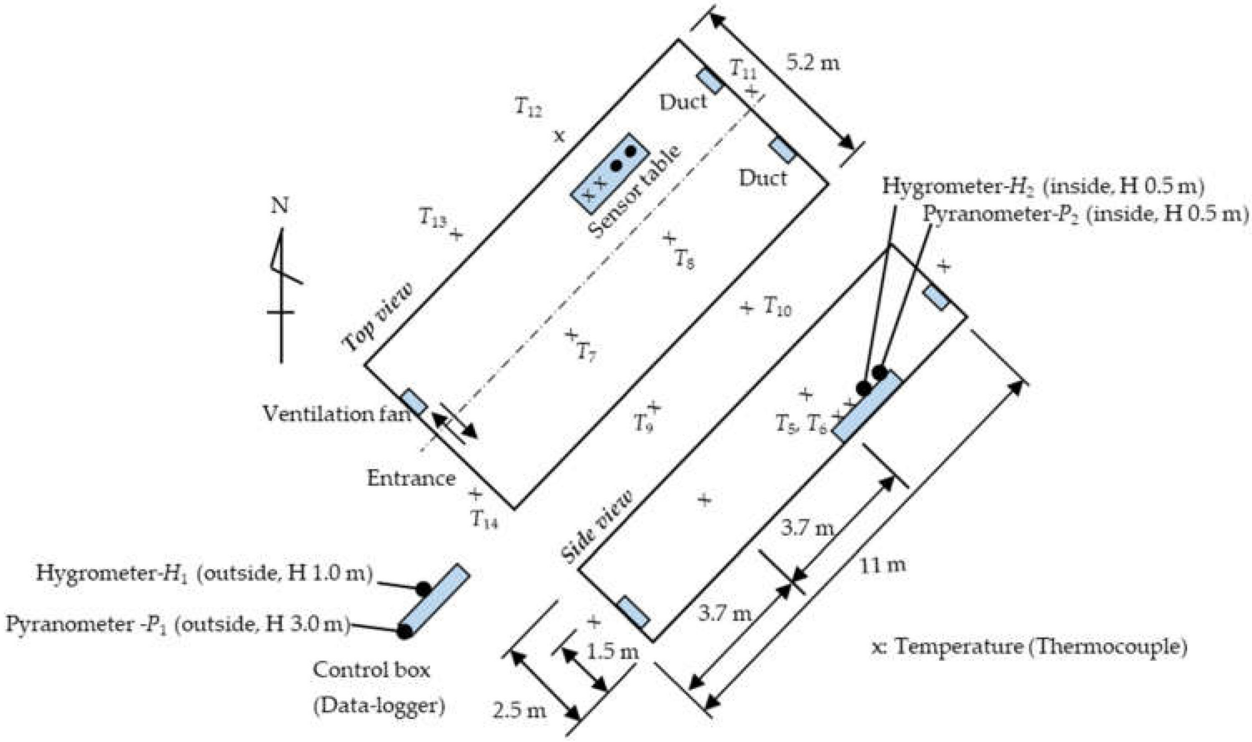



**Figure 3.** Greenhouse layout and measurement location.

There were four thermocouple sensors inside the tunnels: sensors $T_5$ and $T_6$ were all 0.5 m above the ground, while $T_7$ and $T_8$ were hung at 1.0 m from the ceiling to measure the mean inside air temperature. Furthermore, six sensors, $T_9$ to $T_{14}$, were located at a height of 1.5 m on the outside of the small walk-in tunnels to measure the mean outside temperature.

The average inside temperature was obtained by averaging the values from four sensors ($T_5$–$T_8$). Meanwhile, the average outside temperature was calculated by averaging the values from sensors $T_9$–$T_{14}$, as shown in Equations (1) and (2), respectively. During this study, daytime was defined as when the solar radiation was greater than 0 W/m$^2$, while nighttime was defined as taking place when the solar radiation was equal to 0 W/m.

$$\theta_{mean\_in} = \frac{1}{n}\sum_{k=5}^{8} T_k \tag{1}$$

$$\theta_{mean\_out} = \frac{1}{m}\sum_{k=9}^{14} T_k \tag{2}$$

where $\theta_{mean\_in}$ is the average air temperature inside the greenhouse (°C), $\theta_{mean\_out}$ is the average air temperature outside the greenhouse (°C), $T_k$ represents the dataset of values inside the greenhouse,$n$ is the number of thermocouple points inside the greenhouse, and $m$ is the number of thermocouple points outside the greenhouse. The solar radiation in the horizontal plane outside and inside of the greenhouse was measured with a pyranometer at the positions $P_1$ and $P_2$, respectively. Moreover, hygrometers were placed at the positions $H_1$ and $H_2$ to measure the relative humidity outside and inside, respectively. The specification and accuracy of the measurement sensors are shown in Table 2.

**Table 2.** Specifications of sensors and accuracy.

| Parameter | Instrument Name | Model/Type | Measurement Range | Accuracy |
|---|---|---|---|---|
| Temperature | Thermocouple | T-type | −250 to 350 °C | ±1° or ±0.75% (f.s.) (Standard accuracy) |
| Relative humidity | Hygrometer | ES2-THB | 20 to 95% | ±3% |
| Solar radiation | Pyranometer | ML-01 | 0 to 1000 W/m$^2$ | ±1.70% |
| Soluble sugar content | Digital refractometer | PAL-1 | 0 to 53% | ±0.2%Brix |

*2.3. Greenhouse Strawberry Cultivation and Measurement*

Strawberry plants were grown in cultivation beds under the greenhouse from mid-September 2020. The first harvest was in February 2021, and the second harvest was in April 2021. There were five beds in the greenhouse, as shown in Figure 1b. The three beds in the center were 11 m long, 0.95 m wide, and 0.25 m high at the center, while the other beds were 11 m long, 0.68 m wide, and 0.25 m high at the center. All of the beds were covered with a single black plastic sheet to prevent weeds as well as heat dissipation and water evaporation. The distances between the bed centers were 1.2 m for the central beds and 1.0 m for the side beds, respectively. In addition, irrigation and fertilization were the same for all beds in both seasons.

SSC is the collection concentration of sugars, acids, and other substances dissolved in the cell sap. The main soluble sugar components in strawberries are glucose and fructose, which comprise over 80–90% of the total sugar and 40% of the total dry weight [11]. Generally, the SSC of strawberries can vary from 4% to 11%, depending on the cultivar and the environment [12]. It has been found that temperature can affect the SSC [13]. Growing temperatures above 25 °C can reduce the fruit set and decrease fruit SSC.

The fruit weight, width, length, and SSC of the strawberries were measured at room temperature as a reference. "Harunoka" strawberries were selected as samples from which to obtain juice for the SSC measurements. SSC was measured with a digital saccharimeter (see Figure 4a). A strawberry juice sample of approximately 0.3 mL was dropped onto the prism of the digital saccharimeter. Each sample was tested three times. A digital scale was used to measure the weight of the strawberries, providing measurements with 0.1 g of precision (see Figure 4b). Moreover, the strawberry fruit size (width and length) was measured in mm with perpendicular-angle rulers, as shown in Figure 4c. In this work, there were a lot of strawberries in the greenhouse. Additionally, there were many different shapes and sizes of strawberries. As such, it was not necessary to obtain the exact size of each sample. In order to display the typical shape and size only, perpendicular-angle rulers were used to compare them.

(**a**) (**b**) (**c**)

**Figure 4.** Examples of strawberry (**a**) saccharimeter; (**b**) strawberry weight; (**c**) shape.

## 3. Results and Discussion

### *3.1. Climatic Parameters under Double PVC Sheets in Greenhouse*

Temperature, solar radiation, and relative humidity are the main factors that affect the growth of strawberries and fruit quality. Temperature and solar radiation are environmental factors that control strawberry plant growth and development. A high temperature on the fruit surface caused by prolonged exposure to sunlight hastens ripening. Strawberry fruits exposed to higher sunlight levels ripen faster [7]. In this study, "Harunoka" strawberries were grown under double PVC sheets in the greenhouse. To study the climate changes in the small walk-in greenhouse, environmental parameters were monitored and recorded. Generally, the strawberries continued to increase in size during the ripening process. The developmental stages of strawberry ripening are normally divided into four ripeness stages, referred to as the green, white, pink (or turning), and red (or ripe) stages [14]. Strawberries are typically harvested 30–40 days after flowering, depending on the cultivar. The entire ripening process is rapid, generally occurring within a few days following the white stage, depending on air temperature [15]. Thus, in this present study, environmental factors during the three days before harvest were evaluated in each season. Seasons are characterized as the peak and end seasons for fruiting, with the peak season lasting from December to February. After that, the season is referred to as the "end season", which lasts until May.

Figure 5 shows the temperature transition between 17 and 20 February 2021 and between 2 and 5 April 2021. The air temperature was recorded at 5 s intervals and then averaged into 15 min increments.

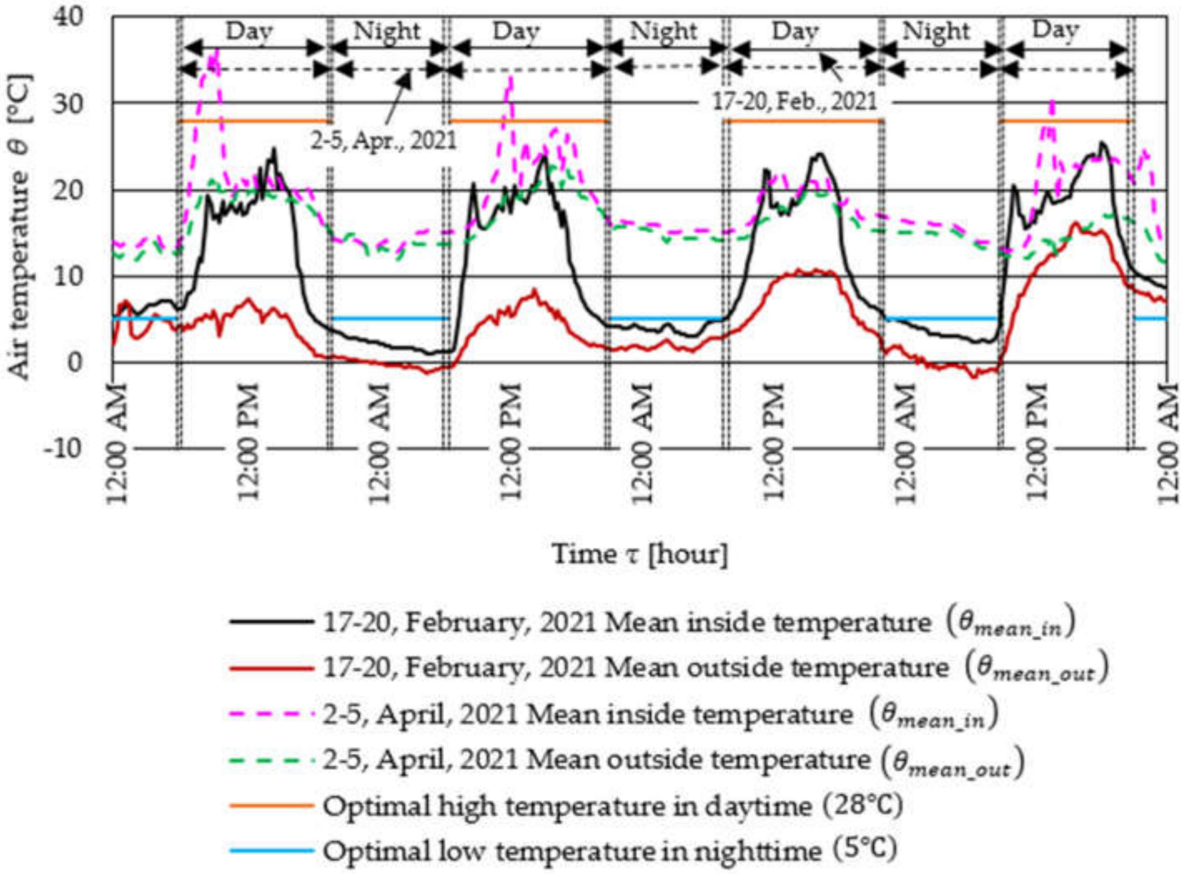



**Figure 5.** The comparison of the temperatures inside and outside the greenhouse at different times.

For 17–20 February 2021, the minimum inside air temperature reached 1.0 °C, and the ambient temperature reached −1.9 °C in the nighttime. The highest daytime ambient temperature was 16.9 °C when the inside air temperature was 27.1 °C. Moreover, it can be seen from Figure 5 that the inside air temperature was more than 30 °C and reached a maximum of 38 °C in the daytime on a sunny day during the period from 2–5 April 2021. Likewise, the differences between the inside and outside air temperatures were small, especially during the nighttime and on cloudy days. The lowest value was found to be 1 °C. Due to the changing of the seasons, the outside air temperature was slightly higher throughout the day. This phenomenon resulted in a higher inside air temperature, which may have had an impact on strawberry quality. Furthermore, the results demonstrate that the inside temperature was always higher than the ambient air temperature in both periods due to the solar radiation trapping phenomenon. The inside air temperature is very stable in the daytime, even when the outside temperature changes, due to the side windows and ventilation fan. It can also observed that the difference between the optimal high and optimal low temperatures can create suitable conditions for strawberry cultivation. According to these results, the temperature between 17 and 20 February 2021 is more suitable for planting than the period of 2–5 April 2021.

Figure 6 presents the variation in the solar radiation inside and outside the greenhouse. The solar radiation increases from the sunrise, reaching its maximum value at noon. The solar radiation is at its highest level from 10:30 to 13:30, and slightly decreases until sunset. It is obvious that the outside solar radiation was greater than the inside solar radiation-the peak value of the solar radiation on clear and sunny days was 770 $W/m^2$ (outside the greenhouse) and 560 $W/m^2$ (inside the greenhouse) during the period of 17–20 February 2021. Approximately 70% of this radiation was transmitted to the inside of the greenhouse. This figure also shows that the outside solar radiation was still higher than the inside solar radiation during the period of 2–5 April 2021, despite the fact that it was mostly cloudy. The maximum value was found to be 900 $W/m^2$ outside the greenhouse, while it was 590 $W/m^2$ inside the greenhouse. On average, 63% of this radiation was transmitted into the inside of the greenhouse, which is similar to what was observed in the peak season. Moreover, solar radiation both inside and outside the greenhouse during the end season fluctuated depending on cloud cover. Likewise, the solar radiation on 4 April 2021 was quite low compared to other days due to it being a rainy day.

Figure 7 shows the variation in the relative humidity (RH) inside and outside the greenhouse. During the peak season, the RH inside the greenhouse varied from 30% to 92%, while the RH outside the greenhouse ranged from 43% to 85%. The increase in the relative humidity indicated a decreased air temperature. RH decreased during the daytime to its minimum values and increased in the nighttime to its maximum values. The results demonstrate that the RH inside the greenhouse followed the profile of the RH outside the greenhouse and was slightly less than the RH outside greenhouse during the daytime. Because of the ventilation fan and the side windows, the RH inside the greenhouse fluctuated during the day.

Nevertheless, as the ventilation fan did not turn on and because the side windows were closed in the nighttime, and due to the evapotranspiration of strawberries, the RH inside the greenhouse was higher than the RH outside the greenhouse. Due to the temperature profile during the period of 2–5 April 2021 being rather high and there being small differences between the day and night temperatures, the RH profile did not differ significantly between day and night. The RH inside the greenhouse varied from 30% to 93%, while the RH outside the greenhouse ranged from 43% to 95%. The humidity range at the end season was not different from that of the peak season.

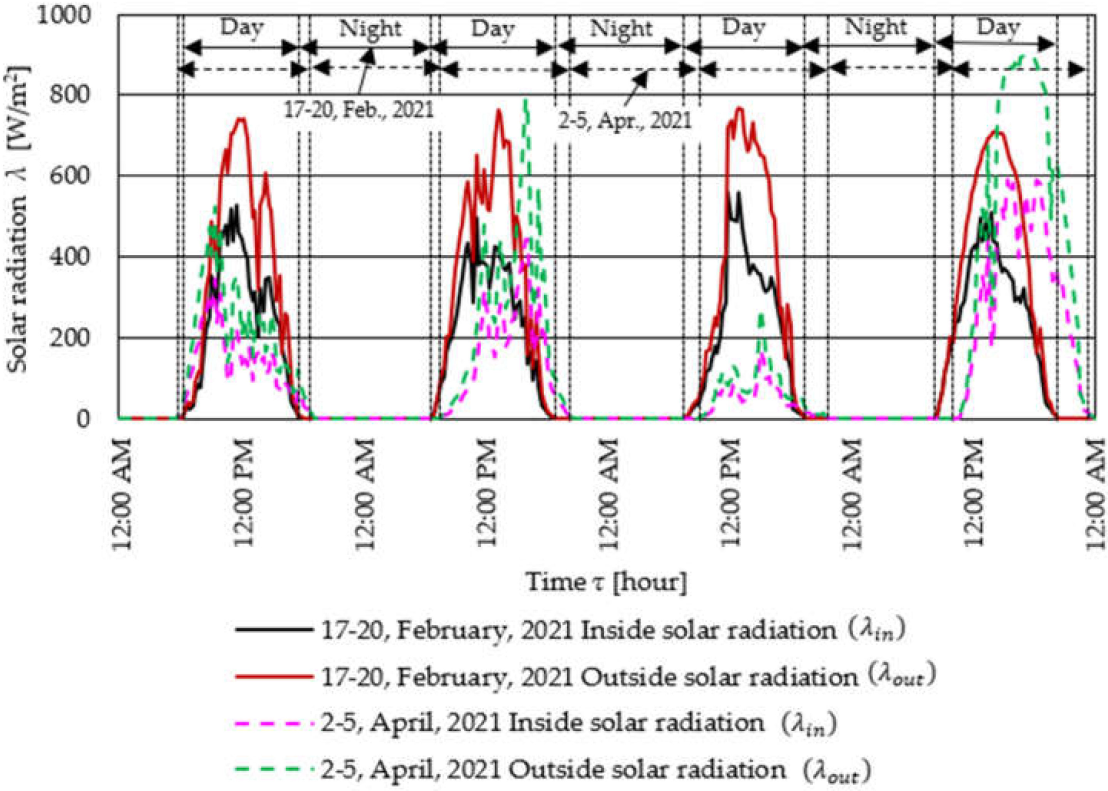



**Figure 6.** The comparison of solar radiation inside and outside the greenhouse at different times.

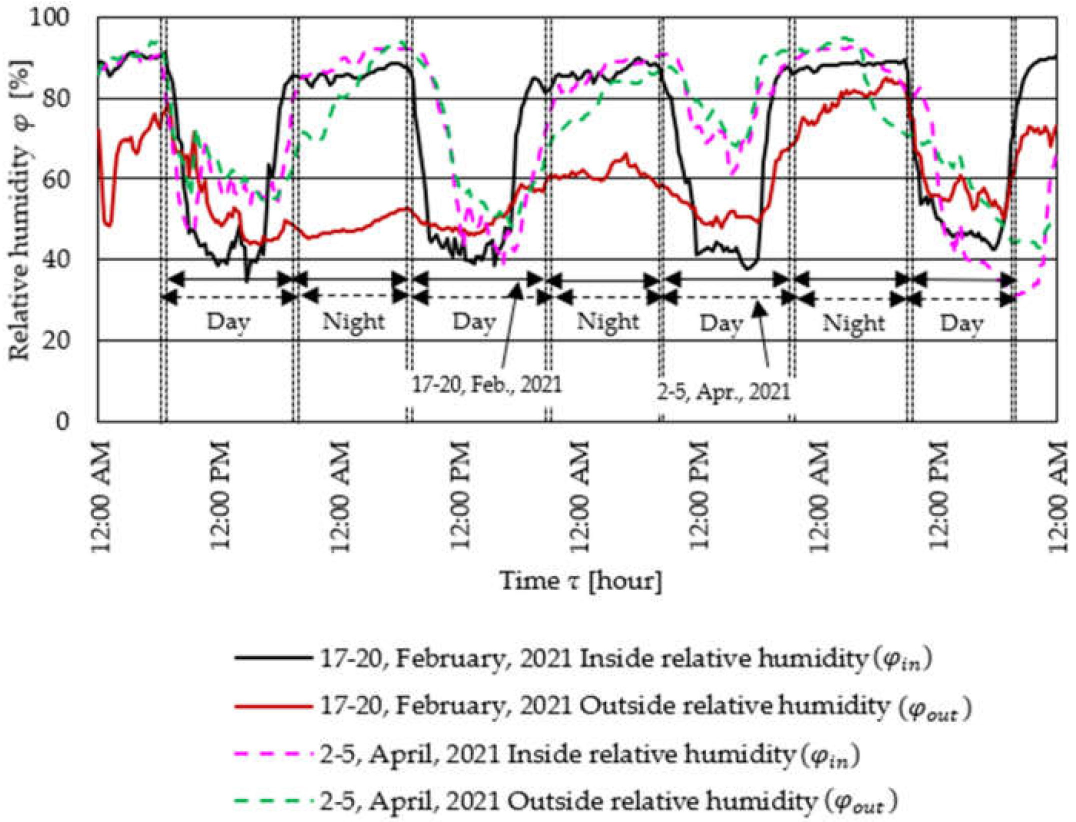



**Figure 7.** The comparison of relative humidity inside and outside the greenhouse at different times.

### *3.2. The Environmental Factors on Pick Up Dates*

#### 3.2.1. Air Temperature

"Harunoka" strawberries have two optimum temperatures for growth, the first being during the day at temperatures varying between 23 and 28 °C, and, most importantly, the nighttime temperature, which varies between 5 and 10 °C. These experiments were conducted on 20 February 2021 and 5 April 2021. Figure 8 shows the variation in the temperature inside and outside the greenhouse on each day. The temperature was recorded at 5-s intervals and then averaged into 15 min increments. On 20 February 2021, it can be seen that the inside temperature was always higher than the outside air temperature due to the solar radiation trapping phenomenon, and the maximum inside air temperature reached 27.1 °C when the outside air temperature was 16.9 °C in the daytime. The average inside air temperatures were approximately 17.8 °C and 5.8 °C during the day and night, respectively. It was seen that the average air temperature inside the greenhouse was unstable and fluctuated because the position of the thermocouples was different, meaning that the average result was highly volatile. It was also noticed that even when the outside temperature was rather low in the nighttime—the minimum reached −1.9 °C—the greenhouse could provide an inside air temperature within the desired range for strawberry cultivation. In addition, the day and night temperatures ($\Delta\theta$) inside the greenhouse differed greatly due to the effect of the outside temperature.

Variation in the temperature inside and outside the greenhouse on 5 April 2021 was also observed; the green dashed line in Figure 8 shows that the outside air temperature was very stable throughout the day and night. The average daily outside air temperature was about 13 °C, causing the inside air temperature to reach a maximum of 32 °C for a short time. The average day and night temperatures were 21.2 and 12.7 °C, respectively.

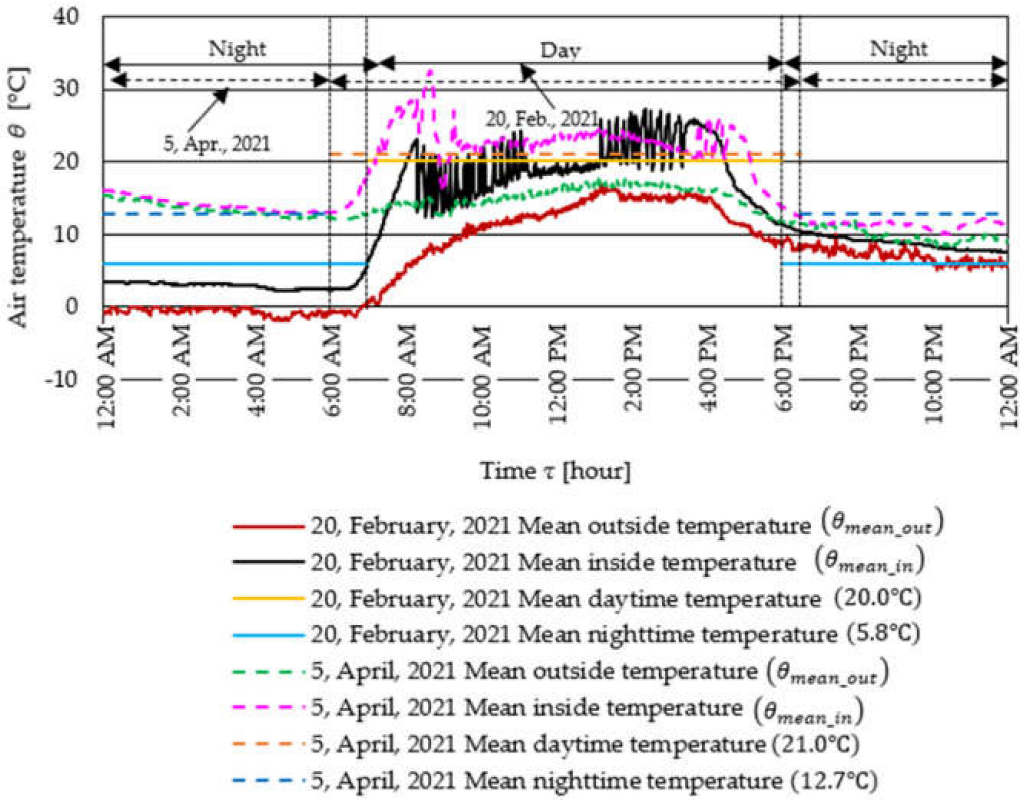



**Figure 8.** Variation in temperature inside and outside the greenhouse on each day.

Figure 9 shows the air temperature difference between the inside and the outside on each day ($\Delta\theta$). The difference in the air temperature can be calculated by Equation (3).

$$\Delta\theta = \theta_{in} - \theta_{out} \quad (3)$$

where $\Delta\theta$ is the air temperature difference (°C), $\theta_{out}$ is the air temperature outside the greenhouse (°C), and $\theta_{in}$ is the air temperature inside the greenhouse (°C).

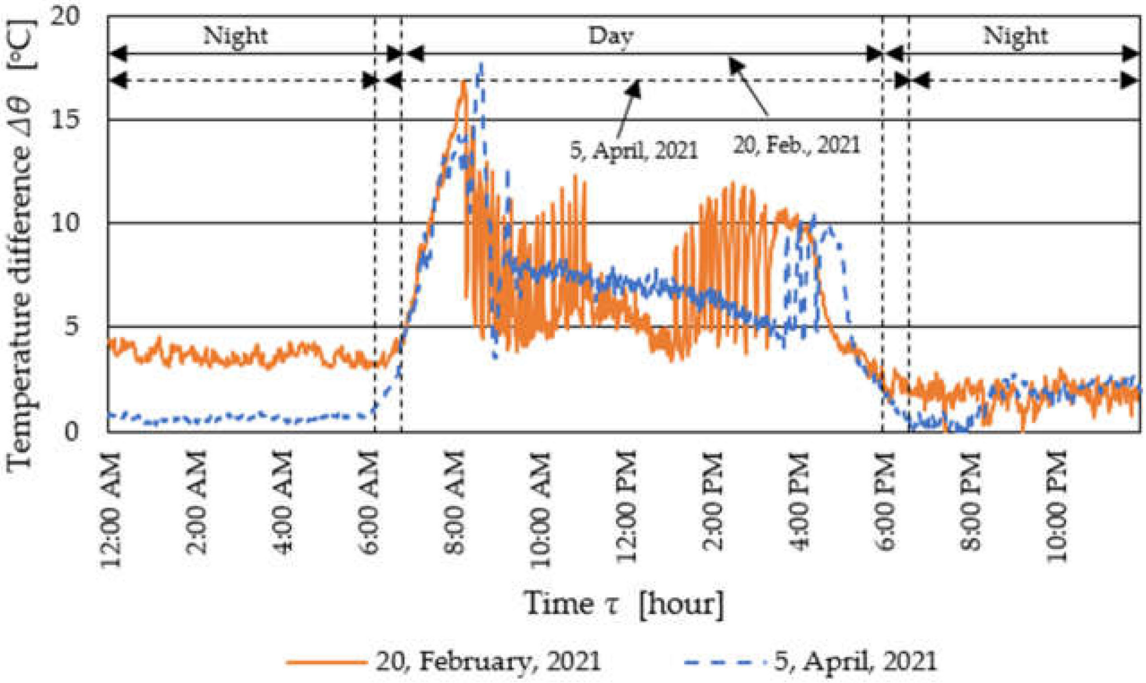



**Figure 9.** The air temperature difference between the inside and outside on each day.

The results demonstrate that the difference between the inside and outside air temperatures on 5 April 2021 was less compared to the data for 20 February 2021 due to the average outside temperature being quite stable all day and night. Moreover, the average inside temperature on 5 April 2021 was similar to the average outside temperature during the nighttime, and it was a little higher than the optimum night temperature. As mentioned in the previous Section 2.3, strawberry cultivation requires optimum temperatures (23–28 °C day/5–10 °C night). Therefore, a small difference between the inside and outside air temperature will not be able to provide suitable temperatures for strawberry cultivation and may affect the size of strawberries, their quality, among other things.

### 3.2.2. Solar Radiation

The outside solar radiation started increasing from 6:30 a.m. in sunny weather and reached a maximum of around 715 W/m$^2$ at noon on 20 February 2021, as shown in Figure 10. The inside solar radiation reached 540 W/m$^2$ at 11:30 under the double vinyl sheet. It can be seen that the outside solar radiation was always higher than it was inside, and the average transmittance of solar radiation from the outside to the inside was approximately 72%. Due to the difference in the sun's altitude and azimuth, the pyranometer was shaded, so its solar radiation measurements probably fluctuated. This graph also shows the solar radiation on 5 April 2021, which increased from the sunrise until its maximum at noon. The solar radiation reached its highest level at 10:30 to 13:30 and then decreased slightly until sunset. Moreover, both inside and outside the greenhouse, the solar radiation rapidly decreased at 9:00 because the clouds shaded the solar radiation sensors. It is obvious that the outside solar radiation was greater than the inside solar radiation—the peak value of solar radiation was high outside, at 905 W/m$^2$, and it was 628 W/m$^2$ inside the greenhouse.

On average, approximately 62% of this radiation was transmitted into the inside of the greenhouse. In addition, the results show that the solar radiation both inside and outside on 5 April 2021 was higher than the solar radiation data for 20 February 2021 due to seasonal changes (winter to spring). According to this graph, it can be seen that outside solar radiation fits to a bell curve on both days. However, the inside solar radiation fluctuated due to the effect of the double vinyl sheets and cloud cover. Furthermore, even though the seasons were different, the inside solar radiation for both days was not significantly different. It can be concluded that the polyvinyl chloride sheet and the additional sheet can filter out high solar radiation. In addition, in this study, the effect of solar radiation on strawberry quality was not observed due to the inside solar radiation values being similar.

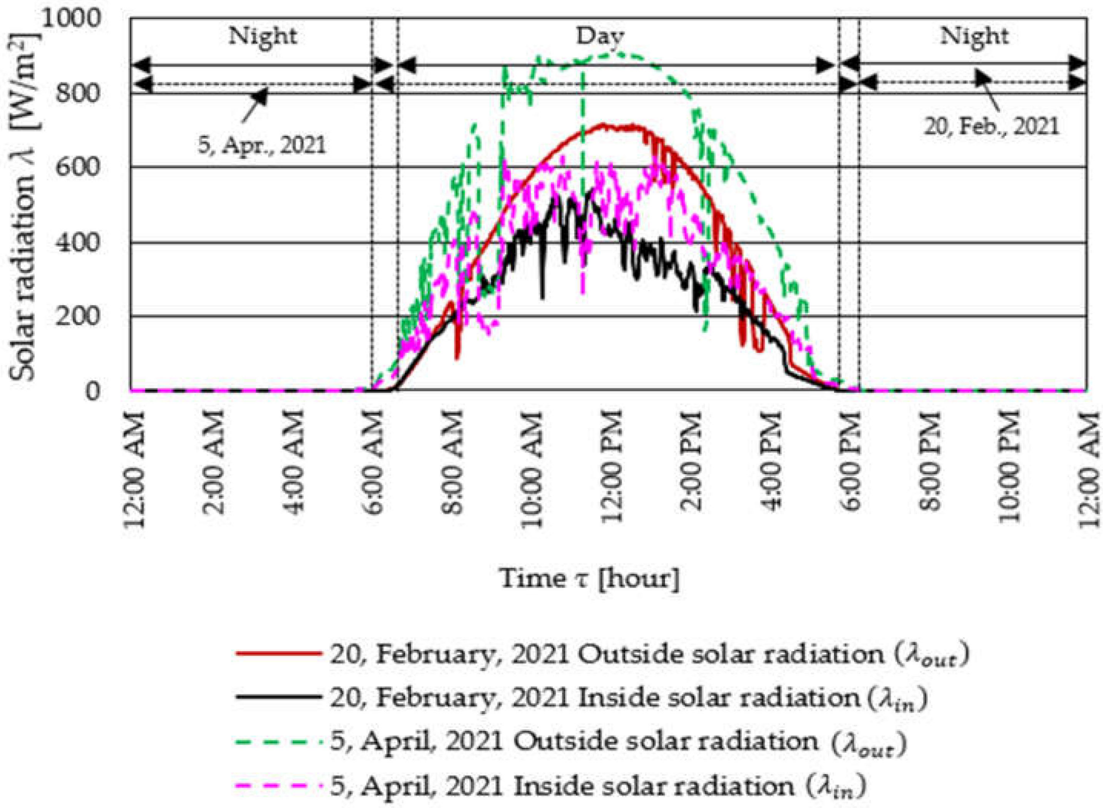



**Figure 10.** Variation in solar radiation inside and outside the greenhouse on each day.

3.2.3. Relative Humidity

Figure 11 shows the hourly air relative humidity evolution inside and outside the greenhouse. According to the figure, the relative humidity both inside and outside follows the same trend as the one found for the variations in the air temperature. Moreover, the relative humidity decreased to its minimum values during the day and increased to its maximum values at night.

On 20 February 2021, relative humidity values that were recorded ranged between 39% and 91% and 49% and 85% for inside and outside, respectively. This graph also shows that the relative humidity inside the greenhouse varied from 30% to 92%, while the RH outside the greenhouse ranged from 42% to 92% on 5 April 2021. It can be noted that the outside relative humidity was rather unstable at night compared to the data from 20 February 2021, and it continued to decline with time, hitting a minimum at 4 p.m. When the inside air temperature exceeded 25 °C, the ventilation fan was operated, which reduced excess moisture and improved air flow. As a result, the inside relative humidity was low during the day. In these cases, the relative humidity in the nighttime was rather high compared to the optimal values of relative humidity, at approximately 70%.

When the relative humidity is too high, it increases the rate at which fungal diseases develop [16]. Morning aeration can reduce the air humidity and thus removes the water droplets that form on the side windows. Maintaining the proper relative humidity is critical for growing strawberries. Thus, to avoid an *RH* that is too high in a greenhouse, dehumidification techniques should be used. There are various techniques, i.e., ventilation dehumidification, which is a very simple technique but will cause heat loss during the heating period [17]. The moisture can also be removed by condensation on the interior wall of the covering materials, but water droplets may drop onto plants and increase the fungal threat [18]. Both mechanical refrigeration dehumidifiers and hygroscopic dehumidifiers can provide internal dehumidification without air exchange and heat loss to the outside, but this method is expensive [19]. None of the current techniques are technically and economically feasible; therefore, ventilation combined with a hygroscopic or mechanical dehumidifier, etc., is desirable for greenhouses. Choosing dehumidification systems requires knowing the loads as they are affected by the season, crop, and local climate conditions [20].

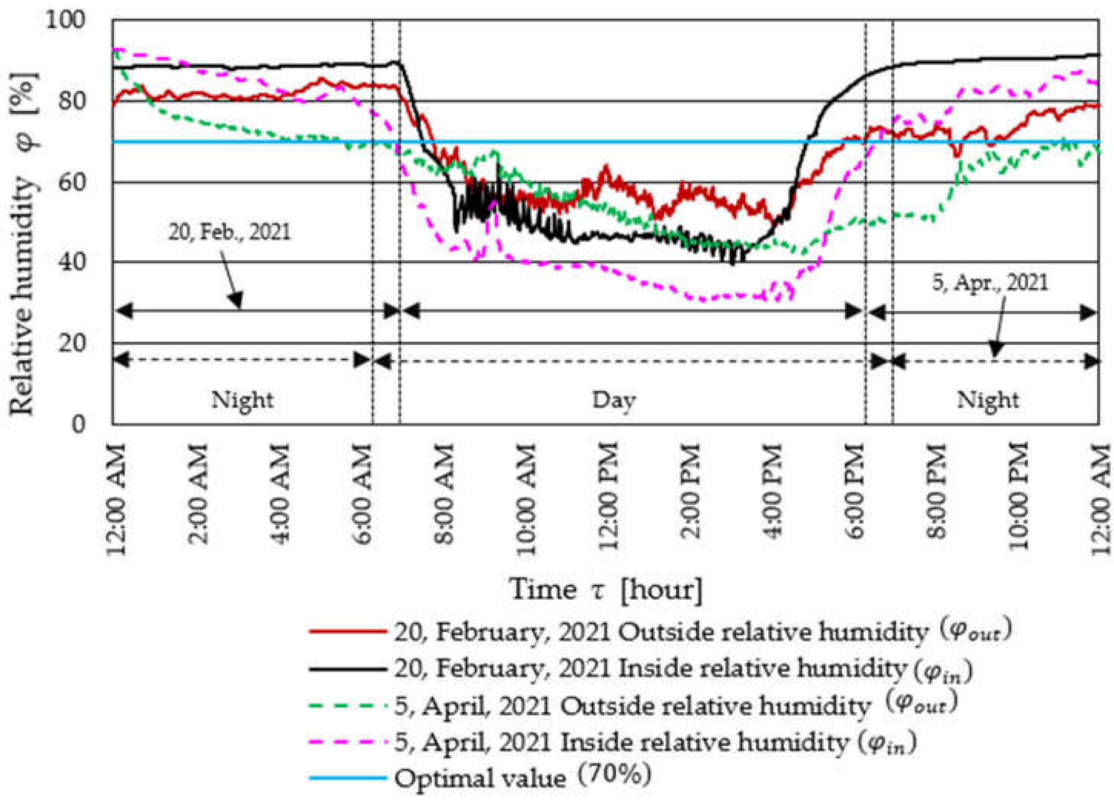



**Figure 11.** Variation in relative humidity inside and outside the greenhouse on each day.

In this study, the values from the two days of data were not significantly different. Thus, it cannot be concluded that relative humidity affects strawberry quality. However, reducing relative humidity during the nighttime should be implemented in future work to avoid the development of fungal diseases and damage to the strawberries.

### *3.3. Effect of Environmental Factors on Strawberries Production*

To evaluate the influence of environmental factors on strawberry quality, eight strawberry samples were randomly selected in each period. Additionally, pictures of the samples were taken using a digital camera inside the greenhouse. However, the weather on each day was different. It was sunny and clear on 20 February 2021, while it was cloudy and occasionally drizzly on 5 April 2021. Therefore, the light and shadow levels in the figures was out of our control.

### 3.3.1. Harvest on 20 February 2021

On the day of harvesting (20 February 2021), the weight, shape, and soluble sugar content (SSC) of the strawberries were recorded. The SSC was measured three times, and we also determined an average SSC value. Table 3 shows a summary of the measured parameters. The results demonstrate that the SSC ranged from 8.8% to 12.8%. The SSC range was of satisfactory quality. The SSC values for the "Harunoka" cultivar range from 8% to 12%, indicating good quality. The strawberries were very sweet in taste, and the fruit firmness was very favorable. The heaviest strawberry was 49.6 g. As shown in Figure 12, the fruits from the strawberry plants grown under small walk-in greenhouse conditions were rather large (a short-wedge) and had a consistent red color. Furthermore, it is noticed that strawberry shape had no effect on the sweetness, even if the strawberry did not have a good shape.

**Table 3.** Strawberry quality parameters on 20 February 2021.

| Sample No. | Width (mm) | Hight (mm) | Weight (g) | Mean $\beta$ (%) |
|---|---|---|---|---|
| 1 | 40 | 48 | 24.0 | 12.8 |
| 2 | 46 | 51 | 31.9 | 9.90 |
| 3 | 50 | 62 | 38.5 | 10.6 |
| 4 | 53 | 36 | 19.3 | 11.6 |
| 5 | 60 | 55 | 49.6 | 12.3 |
| 6 | 50 | 51 | 33.3 | 9.90 |
| 7 | 54 | 50 | 37.4 | 11.2 |
| 8 | 50 | 55 | 34.6 | 8.80 |

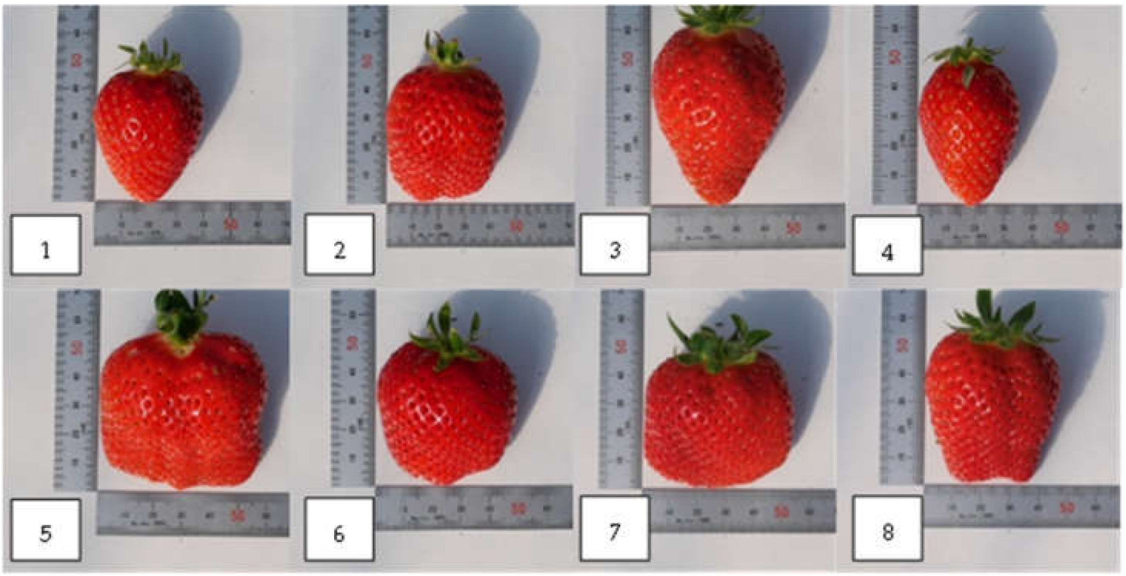



**Figure 12.** Strawberry fruits harvested on 20 February 2021.

### 3.3.2. Harvest on 5 April 2021

Table 4 shows a summary of the measured parameters on 5 April 2021. The results show that the soluble solid contents ranged from 7.4% to 8.9%. The SSC range was less than that in the data for 20 February 2021 (see Table 3). The strawberries were sweet but also tasted slightly sour. The heaviest strawberry was approximately 41 g. Moreover, according to Figure 13, the shape of strawberries was a beautiful long conical shape [21], and they a had ruddy red color. However, the firmness was quite sensitive.

**Table 4.** Strawberry quality parameters on 5 April 2021.

| Sample No. | Width (mm) | Hight (mm) | Weight (g) | Mean $\beta$ (%) |
|---|---|---|---|---|
| 1 | 45 | 51 | 31.0 | 8.6 |
| 2 | 42 | 57 | 36.0 | 7.9 |
| 3 | 41 | 55 | 27.0 | 8.3 |
| 4 | 39 | 54 | 27.0 | 8.7 |
| 5 | 54 | 61 | 40.5 | 8.9 |
| 6 | 37 | 58 | 17.5 | 7.7 |
| 7 | 45 | 57 | 34.0 | 8.6 |
| 8 | 45 | 52 | 30.0 | 7.4 |

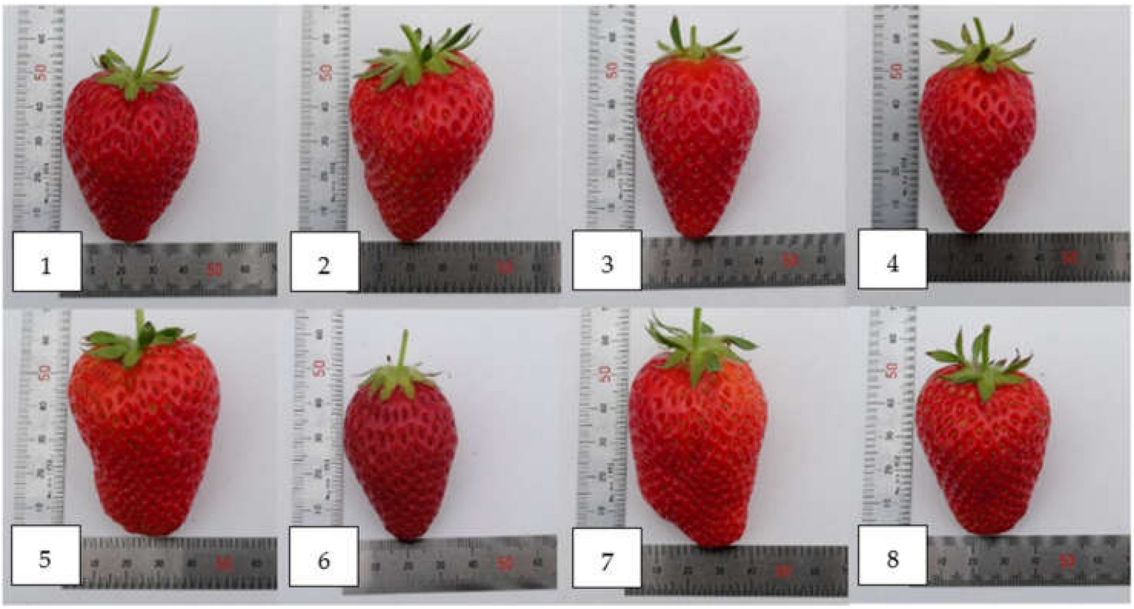



**Figure 13.** Strawberry fruits harvested on 5 April 2021.

In these experiments, eight sample strawberries were harvested in each period to show their typical shape, size, and color, and they were then compared. It can be seen that during the peak season, the typical strawberry shape was a short wedge. The width was significantly greater than the height among these strawberries. During the second harvest, the strawberries were a beautiful long conical shape. In addition, it was noticed that the sizes were similar, but the SSC, firmness, and the color of the strawberries from the two seasons were different. The average SSCs of the fruit grown in the greenhouse covered with double vinyl sheets on 20 February 2021 and 5 April 2021 were 10.9% ± 1.3% and 8.3% ± 0.5%, respectively, as shown in Table 5. This result indicates that the SSC during the peak season was significantly higher than that at the second harvest. It can be inferred that growing strawberries in a greenhouse provided a better microclimate, i.e., a more appropriate temperature during the cold period. In addition, strawberry cultivation requires different day (23–28 °C) and night (5–10 °C) air temperatures. The difference between the day and night air temperatures may cause an increase in fruit SSC. The average difference between the day and night air temperatures during the peak season (~12 °C) was greater than during the end season (~8 °C). Table 6 indicates the comparison of the climatic parameters on different harvest days. In the peak season, the greenhouse can provide suitable temperatures for strawberry growth. At the end of the season, the air temperature during the nighttime was rather high, with the maximum air temperature at night being above the favorable temperature range. In both seasons, it was observed that temperature did not affect strawberry weight. In previous studies on strawberries and other berries, the variations observed in the fruit quality parameters throughout the season were associated with an increasing photoperiod and/or temperature towards the end of the season [22–25]. Other studies reported that high temperatures may affect flower and fruit quality as well as quantity [26–30]. Increasing temperatures lead to a decline in the soluble sugar content at the end of the season [31]. Based on these results, we can conclude that temperature is the major factor that is responsible for the end-season decline in the SSC, firmness, and color of strawberry fruits in a temperate production system. According to the results, in the peak season, the average relative humidity inside the greenhouse was about 73%, while it was 63% during the end season. The relative humidity between the two seasons was not significantly different. In addition, it can be seen that the solar radiation was slightly higher during the end season than the solar radiation in the peak season. A previous study stated that even through fruit SSC is positively corelated with the effect of solar radiation in other fruits [32], fluctuations in solar radiation are not likely to have a major impact on strawberry SSC.

**Table 5.** Mean and standard deviation of strawberry samples ($s$ = 8) on different days of harvest.

| Traits | 20 February 2021 | | 5 April 2021 | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| $\beta$ | 10.9 (%) | 1.3 | 8.3 (%) | 0.5 |

**Table 6.** Comparison of climatic parameters on different days.

| Characteristics | 20 February 2021 | 5 April 2021 |
|---|---|---|
| Average inside air temperature at night, $\theta_{in\_night}$ (°C) | 5.8 | 12.7 |
| Average inside air temperature during the day, $\theta_{in\_day}$ (°C) | 17.8 | 21.2 |
| Average difference between day and night temperatures, $\Delta\theta$ (°C) | 12.0 | 8.5 |
| Average inside solar radiation during the day $\lambda_{in}$ (W/m$^2$) | 255 | 307 |
| Average inside relative humidity $\varphi_{in}$ (%) | 73 | 63 |

## 4. Conclusions

In this study, strawberry cultivation in a greenhouse covered with double vinyl sheets was studied to investigate the effect of experimental factors on strawberry production. Environmental factors, including solar radiation, air temperature, and relative humidity, were monitored and recorded during the experiment. Additionally, the harvest times were different: (1) the first harvest was on 20 February 2021, during the peak season, and (2) the second harvest was on 5 April 2021, at the end of the season. Eight strawberry samples were harvested during each period, and their size, weight, and SSC were measured and compared to each other. The difference between day and night air temperatures may cause an increase in fruit SSC. According to the results, the average difference between the day and night air temperatures ($\Delta\theta$) in the peak season (approximately 12.0 °C) was greater than it was during the end season (approximately 8.5 °C). Based on these results, we conclude differences in the temperature are one of the major factors responsible for the end-season decline in the SSC, firmness, and color of strawberry fruits in a temperate production system. In both seasons, it was observed that temperature did not affect strawberry weight. Increasing temperatures led to a decline in the SSC at the end of the season. The relative humidity was not significantly different between the two seasons, and it was around 30–92%. In addition, it can be seen that the solar radiation was slightly higher at the end of the season than the solar radiation during the peak season. Furthermore, it can be stated that even through fruit SSC was positively correlated with the effect of solar radiation in other fruits, fluctuations in solar radiation are not likely to have a major effect on fruit SSC. In addition, other factors such as the age of the plants and the predominant order of the harvested fruit could affect the fruit SSC independently. Thus, it can be concluded that temperature differences are a major factor that is responsible for strawberry quality.

In future work, some characteristics related to the leaf area index, light interception, and biomass of cultivated strawberries should be measured. Additionally, comparisons of the results with long-term climate change for more than one location should be studied. The requirements of future cultivation systems for strawberries need to discussed further to minimize the negative impact on the environment and the risk of damage related to climate change.

**Author Contributions:** Conceptualization, N.K. and N.M.; Data curation, N.K. and N.M.; Formal analysis, N.K.; Methodology, N.K.; Project administration, N.M.; Supervision, N.M.; Writing—original draft, N.K.; Writing—review & editing, N.M. and C.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Thailand Science Research and Innovation (TSRI) in Thailand.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** This research project is supported by Thailand Science Research and Innovation (TSRI) in Thailand. The authors also wish to thank Graduate School of Engineering, Mie University, Japan, for providing support during experiment.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Nomenclature

| | |
|---|---|
| $m$ | number of thermocouple points outside the greenhouse |
| $n$ | number of thermocouple points inside the greenhouse |
| Greek symbols | |
| $\beta$ | soluble sugar contents (%) |
| $\theta$ | temperature (°C) |
| $\lambda$ | solar radiation (W/m$^2$) |
| $\tau$ | time (hour) |
| $\varphi$ | relative humidity (%) |
| Subscript | |
| *day* | daytime |
| *high* | optimal high |
| *in* | inside greenhouse |
| *low* | optimal low |
| *mean* | mean value |
| *night* | nighttime |
| *out* | outside greenhouse |
| Abbreviations | |
| PVC | polyvinyl chloride |
| RH | relative humidity |
| SD | standard deviation |
| SSC | soluble sugar content |

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