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A Comprehensive Assessment of the Morphological Development of Inflorescence, Yield Potential, and Growth Attributes of Summer-Grown, Greenhouse Cherry Tomatoes

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Abstract: Understanding how cherry tomatoes respond to variations in greenhouse microclimate is crucial for optimizing tomato production in a controlled environment. The present study delves into the intricate relationship between summer-grown cherry tomatoes (*Cheramy F1*) and greenhouse conditions, exploring the influence of these conditions on growth attributes, inflorescence development, and yield potential. The aim of the study was to characterize the chronology of reproductive events, specifically flowering and fruit stages, in correlation with the prevailing greenhouse climate during the development of the first ten inflorescences on the plant. The performance of each inflorescence has been ranked based on available data, which involve a comparative analysis of both the time duration (number of days) and the frequency of yield-contributing traits, specifically the total number of flowers at the anthesis stage. The duration of each stage required for completion was recorded and presented as a productivity rate factor. Greenhouse conditions exhibited variations during the vegetative and reproductive stages, respectively, as follows: temperature - 25.1 °C and 21.33 °C, CO_2 levels - 484.85 ppm and 458.85 ppm, light intensity - 367.94 W/m^2 and 349.52 W/m^2, and humidity - 73.23% and 89.73%. The collected data conclusively demonstrated a substantial impact of greenhouse microclimate on plant growth, productivity, and inflorescence development. The development of flowers and fruit has been categorized into five stages: the fruit bud stage (FB), the anthesis stage (AS), the fruit setting stage (FS), the fruit maturation stage (FM), and the fruit ripening stage (FR). An irregular productivity and development response was noted across the first (close to roots) to the tenth inflorescence. Inflorescence 5 demonstrated the highest overall performance, followed by inflorescence numbers 4 and 6. The study findings provide valuable insights for enhancing greenhouse operations, emphasizing the improvement of both the yield and growth of cherry tomatoes while promoting environmental sustainability. A statistical analysis of variance was used to rigorously examine the presented results, conducted at a confidence level of $p < 0.05$.

Keywords: greenhouse cultivation; cherry tomatoes; inflorescence development report; growth attributes; productivity

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1. Introduction

The cherry tomato (*Solanum Lycopersicon* var. *cerasiforme*) is considered an ancestor of the cultivated tomato, as evidenced by its widespread occurrence in Central America

and shared traits, including a smaller fruit size and shorter flowering period [1]. The tomato (*Lycopersicon esculentum* L.) is a globally cultivated greenhouse vegetable with widespread uses [2,3]. It holds multifaceted significance, contributing to addressing food scarcity and enhancing food security [4,5]. As a prominent global fruit crop, it serves as a significant nutritional powerhouse, abundant in vitamin C alongside essential minerals like phosphorus, iron, and calcium [6]. With an increasing demand for high-quality produce year-round, the cultivation of cherry tomatoes in controlled environments has become prevalent, with cultivators aiming to optimize productivity and quality irrespective of seasonal variations [7]. Thriving in warmer climates, cherry tomatoes typically exhibit elevated levels of dry matter and soluble solids compared to conventional fresh tomato cultivars. In regions with less favourable environmental conditions, such as more northern or higher latitude areas, greenhouses offer a versatile and sustainable approach to tomato production [8].

The present study aims to investigate the complex dynamics of inflorescence morphology and its relationship to yield potential and growth attributes, with the objective of improving crop management practices and fostering sustainable production in a greenhouse. Greenhouse control minimizes errors, reducing growth variability and facilitating precise assessment of experimental effects on understudied plants [9].

Successful greenhouse cultivation of tomatoes relies on an optimal microclimate and varying light conditions throughout different growth stages. Plants employ various mechanisms to detect and integrate seasonal signals, influencing their key growth changes. The greenhouse microclimate significantly impacts the number of days spent in the five growth stages of tomato plants [8]. The ideal temperature ranges for tomato plants vary depending on their age and variety during each growth stage. The growth and development of inflorescence in cherry tomato plants are highly influenced by greenhouse factors from bud initiation to flower opening and the fruit ripening stage. Cultural practices during the inflorescence development stage play a crucial role in producing high-quality cherry tomato fruit and maximizing fruit yield [10,11].

The transition to flowering is strictly dependent on a critical photoperiod. When the duration of daylight falls below a minimum threshold or surpasses a maximum threshold, plants do not undergo flowering [12]. High temperatures cause early emergence of flowers and increase the number of inflorescences. Different temperature ranges affect the rate of development and the number of flowers produced. Temperatures between 60 °F (15 °C) and 75 °F (24 °C) have been reported to be conducive to flower formation in cherry tomato plants [13]. Some crops and horticultural plants are susceptible to rising temperatures, leading to changes in floral morphology and reduced flower production [14–16]. However, a study indicated that high-temperature treatments (day/night temperatures of 27/14 °C and 30/11 °C) positively affected pollen production and germination at the anthesis stage [17]. The development of flowers and the number at the anthesis stage have also been reported to be susceptible to the combined effects of carbon dioxide and light [18]. A temperature range between 70 °F and 75 °F (21 °C to 24 °C) has been recommended as the optimal temperature range for fruit setting [19].

The interplay of morphology, physiology, and growing conditions influences the productivity and the duration of fruit growth in tomato plants [20]. A study mentioned increased number of flowers, fruits, and yield under the combined effect of elevated CO_2 and temperature treatment (EC_{700} + 2 °C) [21]. Elevated CO_2 concentration can alleviate the adverse impacts of high temperatures on flower quantity and fruit set in tomatoes. Increased levels of carbon dioxide and higher temperatures have the potential to modify both the size and nutritional composition of fruits in horticultural crops [22]. Under high CO_2 concentrations, the length of the flower stem, the quantity of pigments, and the number of flowers increased significantly [3,23]. The number of harvested fruits and plant yield during summer and autumn were significantly and positively linked to solar radiation levels in the days preceding anthesis [24]. Light intensity and day length are two crucial factors that influence the development process of inflorescence. Adequate

lighting conditions favour the early completion of the inflorescence development process. A low light intensity and short photoperiod increase the time taken to open the first flower. Increased temperatures significantly impact the fruit's maturity time [25]. Shading treatments on tomato plants delay fruit maturation and ripening [26].

The growth aspects of tomatoes are also highly susceptible to extreme greenhouse conditions. Various studies have reported significant impacts of greenhouse microclimate on the plant total height, leaf area, and the total number of leaves in response to temperature, light, and CO_2 treatments [21,27,28]. An increased rate of leaf production results in a reduction of the time taken to flower anthesis in tomato plants. Leaf area is an important indicator of plant productivity, with larger leaf area leading to increased fruit production. Taller plants tend to exhibit a greater total number of flower clusters [29]. According to one study, the count of leaves produced before the appearance of the first inflorescence in tomato plants decreases with higher levels of light intensity [30]. At high temperatures, the relative growth rate (RGR) of tomato plants initially increases but rapidly drops over time, while at lower temperatures the growth rate is initially low but declines more gradually [31]. The selection and breeding of cultivars with desirable morphological traits have emerged as promising strategies for improving productivity and resilience in greenhouse conditions [32].

The impact of greenhouse conditions on growth traits and inflorescence development in tomato plants is a complex and multifaceted subject with far-reaching implications for agriculture. Implementation of effective environmental control systems, such as evaporative cooling and shade, can alleviate physiological stresses that might otherwise compromise production quality and overall yield [33]. Changes in plant growth attributes and flower production under environmental stress underscore the susceptibility of cherry tomatoes to climate change and the potential challenges in maintaining crop production. Unlike previous studies that may concentrate on singular aspects like yield potential or growth attributes, this study aims to offer a nuanced understanding of the intricate relationship between greenhouse conditions, the chronological order of inflorescence development, and their impacts on the growth and yield potential of summer-grown greenhouse cherry tomatoes. The hypothesis suggests that variations in greenhouse conditions significantly affect growth and inflorescence development, ultimately leading to low productivity. A comprehensive understanding of these factors and their interactions can guide growers in adopting sustainable cultivation practices to enhance tomato yield, improve fruit quality, and contribute to the sustainability of tomato farming. Moreover, ongoing research in this field holds the promise of unveiling new strategies and technologies for optimizing vegetable production in the face of changing climatic conditions and evolving agricultural demands, particularly in areas with limited agricultural land or regions with adverse weather conditions.

2. Materials and Methods

2.1. Greenhouse Structure and Management

The aim of this study was to investigate the response of the cherry tomato variety *Cheramy 1* to varying environmental conditions within a Venlo Glass greenhouse. The experiments took place over the extended period covering May and June in both 2022 and 2023. Located at the Research Center of Quality Control of Horticultural Products, University of Agronomic Sciences and Veterinary Medicine in Bucharest (coordinates: 44.4710° N, 26.0656° E), the greenhouse features a unique structure with hot-dipped galvanized steel, aluminium system profiles for external cladding, 5.30 m high cultivating gutters, and a glass covering. The foundation and ground exhibit a slope of 10 mm per section, totalling 4000 mm.

The greenhouse structure is further divided into 19 compartments for the cultivation of flowers and various vegetables. The dedicated compartment for tomato growth spans 160.00 m^2, while the total covered area of the greenhouse is 2752.00 m^2. For precise data collection, advanced recording devices, including the Aranet CO_2 sensor (TDSPSPC005),

Aranet temperature and humidity sensors (TDSPT509), and global radiation solarimeter (Aranet PAR sensor), were installed within the tomato-growing compartment. Additionally, the growth compartment is equipped with advanced systems for lighting, cooling, drip irrigation, and ventilation, optimizing the experimental conditions.

2.2. Plant Material and Cultivation Procedure

Seeds of *Cheramy F1* cherry tomatoes (*Solanum Lycopersicon* var. *cerasiforme*) were initially sown on 20 April every year in plastic plug trays (3.5 cm × 3.5 cm), each filled with disinfected coco peat growing media. Subsequently, seedlings emerged and were transplanted into perlite pots after ten days of sowing. The transplantation of 20-day-old seedlings, each with two inflorescences, occurred on May 10th each year within the experimental compartment. In preparation, white cubes containing disinfected hydroponic perlite (2 mm) were utilized as potting material and positioned on coconut slabs. The plants were arranged into 6 rows, each row accommodating 48 plants at a density of 3 plants per metre. A spacing arrangement was diligently upheld, with a 33 cm distance between individual plants and a 120 cm distance between two adjacent slabs carrying immovable benches, as illustrated in Figure 1.

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

Figure 1. (**a**) Tomato plants at vegetative stage and (**b**) tomato plants at reproductive stage within the growing compartment.

2.3. Irrigation and Nutrient Solution

Irrigation, supplemented with various intercultural practices and plant protection measures, was meticulously applied as needed throughout the growth of the tomato plants. The concentration of the supplied nutrient solution was fine-tuned according to distinct growth stages and inflorescence orders: an electrical conductivity (Eco) of 1.5 during the seedling stage, an Eco of 2.3 during the emergence of the first and second inflorescences, and an Eco ranging from 2.8 to 3.0 milli siemens (mS) between the fifth and ninth inflorescences. The pH of the solution was consistently adjusted to 5.5. Throughout the fruiting period, irrigation was conducted in both cubes and slabs 10–12 times per day, with each plant receiving 100–150 mL of the nutrient solution. To prevent over-fertilizing or wastage, the amount of solution at the drain was maintained at 20–25%.

2.4. Experimental Design, Harvest, and Statistical Analysis

Three specific rows (1st, 3rd, and 5th) were deliberately chosen from a total of six as the experimental rows. For data collection, three plants were systematically selected from the front, middle, and end parts of each row, labelled as R1/P1, R1/P2, R1/P3, . . . up to R2 and R3. Continuous harvesting and observations were conducted from 4 July to 5 October each year at consistent one-week intervals. Each observation day involved a thorough and independent study of each plant and cluster. A weekly yield report for each inflorescence was meticulously compiled, considering variations among plants in the number of inflorescences, length of inflorescence, number of fruits per inflorescence, fruit mass per inflorescence, average fruit mass per inflorescence, fruit dry matter per inflorescence, fruit height per inflorescence, and fruit diameter per inflorescence. Graphs were generated using a combination of MS Word Microsoft Word 365 and Jamvoi (version 2.4.0) software. Subsequently, an analysis of variance (ANOVA) was executed, followed by the application of the normality test (Shapiro–Wilk) and the homogeneity of variances test (Levene's) at a confidence level of $p < 0.05$. The statistical assessment of each class limit (day ranges for each stage) was performed with Microsoft Excel Microsoft Word 365 using the following relations:

$$Mean = \frac{\sum (f \cdot m)}{\sum f},$$

where f is the frequency of each interval, m is the midpoint of each interval, and Σ represents the sum over all intervals, and

$$Median = L + \frac{\frac{N}{2} - f}{f}\,\omega,$$

where L is the lower limit of the median interval, N is the total number of observations, F is the cumulative frequency of the interval before the median interval, f is the frequency of the median interval, and w is the width of the interval.

2.5. Data Collection

2.5.1. Inflorescence Development (Phenology)

On every observation day, each plant and cluster underwent independent scrutiny. The developmental process of the inflorescence was categorized into five distinct stages: flower bud stage (FB); anthesis stage, characterized by fully opened yellow petals (AS); fruit setting stage, identified by the petals dropping off a flower when tapped by hand (FS); fruit maturity stage, when the fruit reaches its maximum size (FM); and fruit ripening stage, marked by complete red coloration (FR). Due to the inherent difficulty in precisely estimating the duration of each stage, a minimum day range was forecasted for each developmental phase and compared with prevailing greenhouse conditions, including temperature, light, and CO_2 levels. The frequency of each trait at every stage was quantified by enumerating the total number of flower buds at the initiation stage, total flowers at anthesis (AS), the count of fruit buds, mature and immature fruits, and the number of ripened fruits. The detrimental developmental response (negative performance) of each inflorescence was assessed by comparing the numbers of initial flower buds, buds that failed to reach anthesis, unpollinated flowers (flowers without fruit set), fruits that did not reach maturity, and ripened fruits. The inflorescence development rate was determined by noting the days each stage required to reach maturity, and the number of days between each developmental stage was quantified, presenting the developmental potential day range for each growth stage Additionally, the characterization of the inflorescence was conducted using descriptors specific to tomatoes [34].

2.5.2. Yield and Phenotypic Traits

The comprehensive yield report for each inflorescence was prepared based on the available data discerning differences among the plants, encompassing parameters such

as the number of fruits per inflorescence, total fruit mass per inflorescence, average fruit mass per inflorescence, fruit dry matter per inflorescence, fruit height per inflorescence, and fruit diameter per inflorescence. Upon fruit ripening, the total fresh fruit yield (TFY) per inflorescence was computed by aggregating the harvests from three plants throughout the season, expressed in grams per inflorescence (g Inflorescence^{-1}). The total number of fruits harvested per inflorescence (TNFI) was determined by summing the fruits from each harvest of three plants, regardless of the plant clusters, and expressed as fruits per inflorescence (fruits Inflorescence^{-1}). The average fresh fruit weight per inflorescence (AFW) was derived by dividing the total fresh fruit weight (TFY) by the total number of fruits (TNF), presented in grams per fruit (g per fruit). The count of successful clusters per plant (SCLU) denoted clusters yielding red, harvestable tomatoes and was expressed as successful clusters per inflorescence (CL Inflorescence^{-1}).

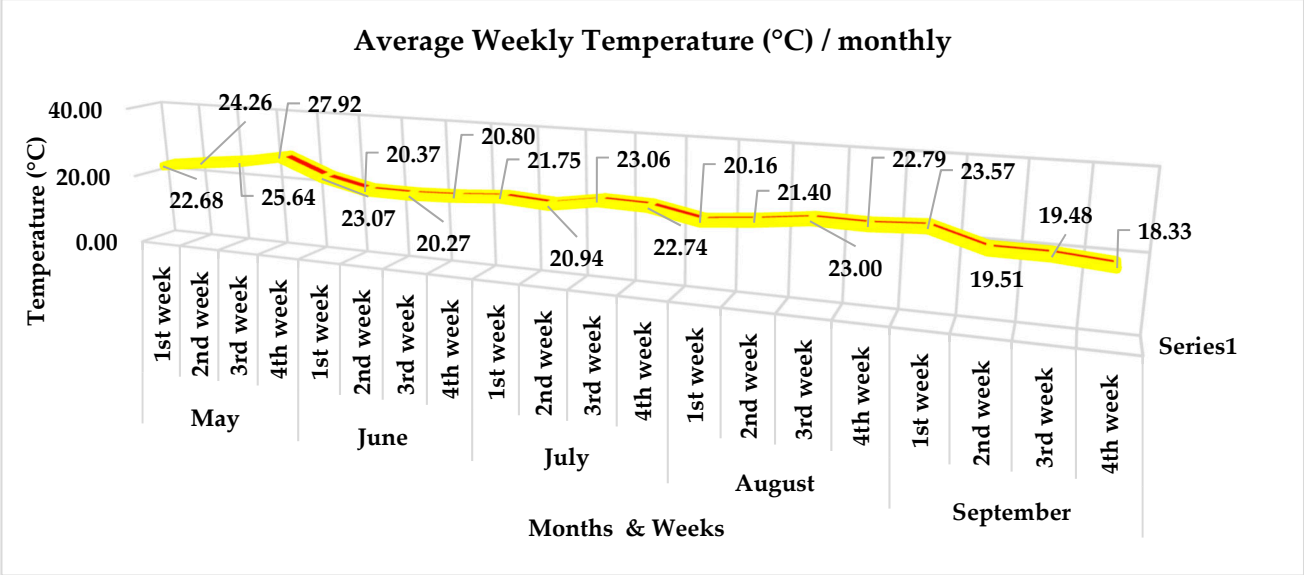
2.5.3. Plant Morphological Traits and Weekly Growth Rate

Three plants from each row are assessed and characterized in utilizing descriptors for tomatoes sourced from IPGRI. Growth-related descriptors included plant growth type, plant size, and stem internodal length.

3. Results

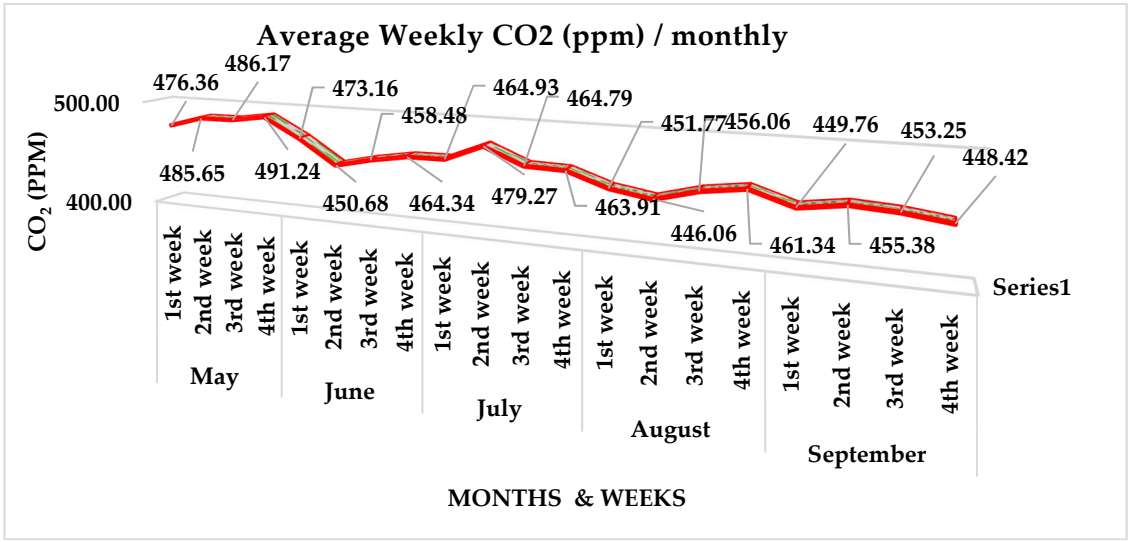
Figure 2 illustrates the mean monthly data pertaining to various greenhouse microclimate parameters, encompassing carbon dioxide levels, sunlight exposure, humidity, and the highest as well as lowest air temperatures. The observed significant fluctuations in greenhouse conditions exerted a considerable impact on the pollination and overall inflorescence development process.

During the initial growth stages of the plants in May and June, the greenhouse recorded highest andlowest air temperatures ranging from 27.92 to 20.27 °C, accompanied by an average carbon dioxide concentration spanning from 491.42 to 450.68 ppm. In the subsequent phases of fruit-bearing and ripening during July and August, the average maximum and minimum temperatures fluctuated within the range of 22.74 to 20.16 °C, while the carbon dioxide levels ranged from 479.27 to 451.77 ppm.



(**a**)

Figure 2. *Cont.*



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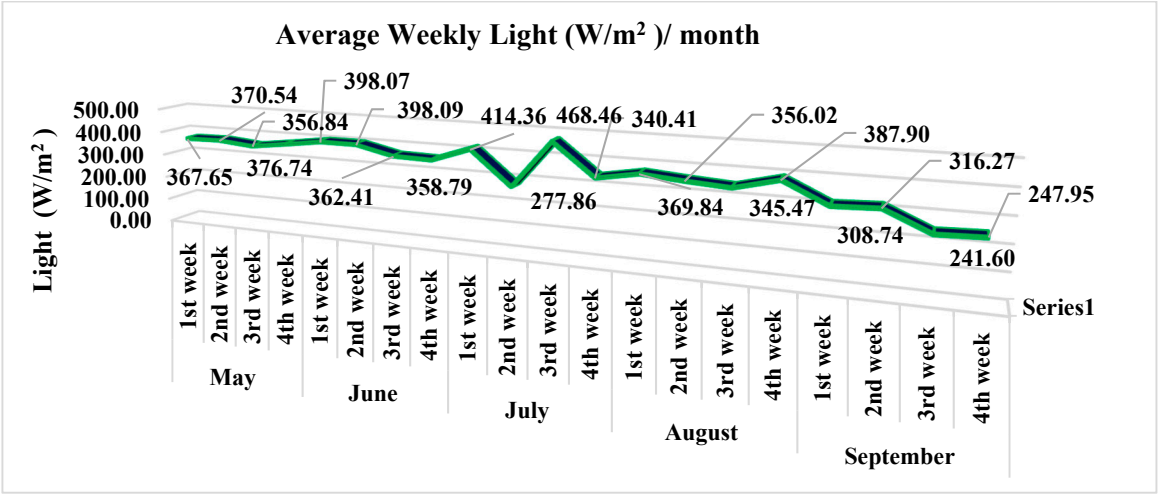

(**c**)

Figure 2. Recorded highest, lowest, and average values of (**a**) temperature °C, (**b**) carbon dioxide (ppm), and (**c**) light intensity (W/m^2) in the greenhouse growing compartment.

Throughout the growth phases of the plants in May and June, the greenhouse encountered peak and trough light intensities measuring between 356.84 and 398.09 W/m^2, along with an overall average humidity spanning from 84.65 to 98.4%. In contrast, during the stages of fruit-bearing and ripening in July and August, the greenhouse witnessed light intensities ranging from 277.86 to 468.46 W/m^2 and the overall average humidity was approximately 89%.

Establishing and sustaining an environment characterized by optimal temperature, light, and carbon dioxide (CO_2) levels is imperative for the robust horticultural development of cherry tomatoes. These conditions support key physiological processes, ensuring efficient photosynthesis, nutrient uptake, and overall plant development [31].

3.1. Inflorescence Development (Phenology)

Figure 3 presents the five distinct developmental stages of inflorescence and infructescence: flower bud stage (FB), anthesis stage (AS), fruit setting stage (FS), fruit maturity stage (FM), and fruit ripening stage (FR). Notable variations in the duration of time within these inflorescence developing stages have been observed. The optimal microclimate conditions for greenhouse tomato cultivation showed variations across the specific growth stages and lighting conditions. Each inflorescence exhibited unique responses, requiring a different maximum and minimum number of days to progress to the next growth stage.

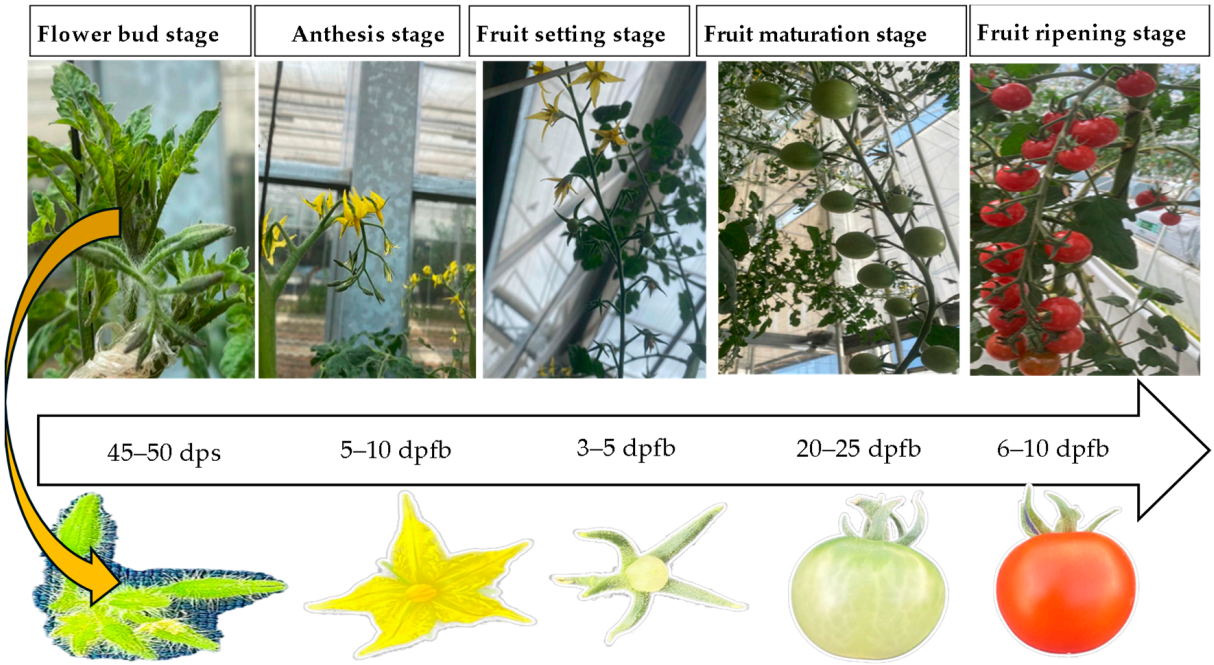

Figure 3. Illustration of the five distinct developmental stages of inflorescence from the flower bud stage to fruit ripening stage. The timeline is measured in days post sowing date (dps) and days post flower bud initiation (dpfb).

The number of days between the sowing date and flower bud initiation (FB) were directly correlated with the order of inflorescence from the base to the top on each plant. Inflorescence number 10 appeared with the maximum number of days, totalling 180, followed by inflorescence numbers 9 and 8 (113 and 108 days, respectively). The first flower bud appeared after 68 days on the first inflorescence, see Table 1. The difference in the number of days between two consecutive inflorescences ranged from 4 to 8 days. (The number of days between the tiny flower bud stage (FB) and the developed flower bud stage, of 3 mm size, exhibited three class limits: 4–8, 6–10, and 6–12 days (adjustments made in the table as well). The corresponding frequency distribution for inflorescence was two, four, and four, respectively (see Table 2). Inflorescence numbers 9 and 10 demonstrated the minimum number of days to reach the developed stage, with inflorescence number 8 (35 days), followed by 6 and 7 (34 and 33 days, respectively), having the highest number of flower buds (productivity rate factor) at the FB stage.

Table 1. Time lags of various developmental stages and days required to reach 50% flowering in the first ten inflorescences of summer-grown tomatoes under available greenhouse conditions.

Number of Inflorescence	Flower Bud Initiation Date	Flower Bud Stage to Developed Stage (4–5 mm)	Developed Stage to Anthesis Stage	Anthesis Stage to Fruit Setting Stage	Fruit Setting Stage to Fruit Maturation Stage	Fruit Maturation Stage to Fruit Ripening Stage	Harvest Date	Days between Sowing Date and Flower Bud Initiation (DSF)	Days between Flower Bud Initiation and Harvest Date (DFH)	Days of 50% of Flowering (DAP)
Inflo. 1	12 May 2023	8–12	4 to 8	3 to 5	20 to 25	5 to 8	10 July 2023	68	55–60	28.5
Inflo. 2	17 May 2023	10–14	5 to 10	3 to 5	18 to 24	7 to 10	16 July 2023	74	55–60	31
Inflo. 3	23 May 2023	8–12	5 to 10	2 to 4	18 to 24	6 to 10	22 July 2023	80	58–60	27
Inflo. 4	29 May 2023	8–12	4 to 8	2 to 4	20 to 25	5 to 8	27 July 2023	87	55–60	26.5
Inflo. 5	4 June 2023	8–12	4 to 8	3 to 5	20 to 25	5 to 8	4 August 2023	89	60–65	27.5
Inflo. 6	8 June 2023	10–14	5 to 10	3 to 5	20 to 25	5 to 8	9 August 2023	99	60–65	30
Inflo. 7	13 June 2023	10–14	6 to 12	3 to 5	20 to 25	5 to 8	16 August 2023	104	63–68	30.5
Inflo. 8	18 June 2023	8 to 12	6 to 12	4 to 6	18 to 24	7 to 10	21 August 2023	108	60–65	28
Inflo. 9	22 June 2023	7 to 10	6 to 12	3 to 5	26 to 30	7 to 10	28 August 2023	113	63–68	32
Inflo. 10	29 June 2023	7–10	6 to 12	4 to 6	26 to 30	7 to 10	4 September 2023	118	63–68	31.5

Table 2. Statistical evaluation of the time duration of inflorescence growth from flower bud stage to fruit ripening stage.

	Days for Flower Bud to Developed Stage			Days for Developed Stage to Anthesis Stage			Days for Anthesis Stage to Fruit Bud Stage			Days for Fruit Setting to Fruit Maturation Stage			Days for Fruit Maturation to Fruit Ripening Stage		
Number of Days (Class Limits)	I 6–10	II 8–12	III 10–14	I 4–8	II 5–10	III 6–12	I 2–4	II 3–5	III 4–6	I 18–24	II 20–25	III 26–30	I 5–8	II 6–10	III 7–10
Inflorescence Frequency	2	4	4	3	3	4	2	6	2	3	5	2	5	1	4
Percentage Distribution	20%	40%	40%	30%	30%	40%	20	60	20	30%	50%	20%	50%	10%	40%
Mean	10–14			5–10			3–5			20–25			6–10		
Median Class	III			II			II			II			I		
Mode	Shared between I, II			III			II			II			I		
Standard Deviation	±29.85			±20.06			±15.71			±68.82			±24.46		

The duration of all inflorescences from the developed stage to the anthesis stage was categorized into three class limits: 4–8 days, 5–12 days, and 6–12 days (Table 2). The specific days required for each inflorescence varied, with four out of ten inflorescences falling within the range of 6–12 days, three within 4–8 days, and three within 5–12 days.

Inflorescence number 6 exhibited the highest propagation frequency, closely followed by 8 and 7, as it boasted the maximum number of flower buds reaching the anthesis stage. Notably, each inflorescence displayed a distinct range of days required to reach the FS stage from the AS stage. Six inflorescences completed this transition within 3 to 5 days, two within 4–6 days, and two within 2–4 days.

Inflorescence number 6 exhibited the highest conversion of opened yellow flowers to fruit buds at the anthesis stage, with inflorescence numbers 5 and 10 closely following suit. In contrast, inflorescence number 7 displayed a negative response, losing half of its flowers at anthesis and failing to progress to the fruit bud stage.

The estimated time intervals for each inflorescence to reach the FM stage from the FS stage were observed within ranges of 18–24, 20–25, and 26–30 days (Table 2). The majority of inflorescences (five) completed this stage within 20 to 25 days, while three took 18–24 days, and two required 26–30 days. The number of mature fruits was notably high for inflorescence number 6, followed by 5 and 10, displaying a linear pattern of fruit maturation from the proximal to the distal end of each truss.

The estimated time within the final stage from FM to FR was observed as 5–8, 6–10, and 7–10 days, respectively. At the FR stage, the productivity rate factor was highest for inflorescence number 6, followed by inflorescence numbers 5 and 10.

Each inflorescence presented a unique number of days to reach the designated "Days from Flowering to Harvest" (DFH) stage, covering the overall time duration of inflorescence and infructescence development. Inflorescences demonstrating the highest productivity were associated with 60–65 DFH, see Table 1. On the contrary, the deleterious developmental response was most pronounced in inflorescence number 7, followed by 8 and 9 (refer to

Figure 4). The range of DFH for inflorescence number 7 was 63–68, and for inflorescences 9 and 8 it was 60–65 and 63–68, respectively. Additionally, data on the timing of 50 percent flowering over two days varied significantly among the different inflorescences.

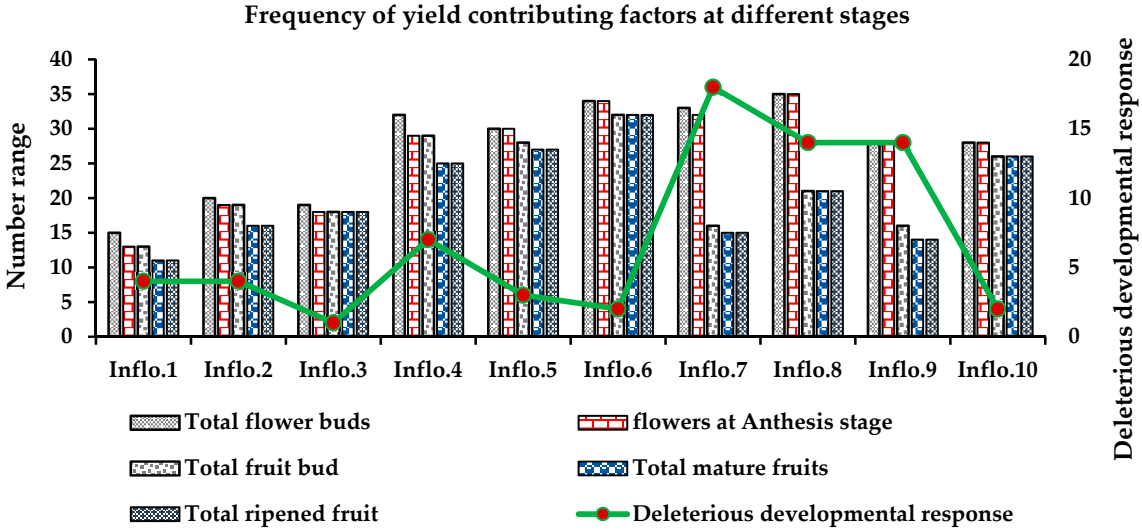

Figure 4. Frequency distribution of yield traits, including total flowers, flowers at anthesis stage, total fruit buds, total mature fruits, total ripened fruits, and negative response, among the first ten inflorescences under available greenhouse conditions.

The maximum number of days to reach 50% of flowering (DAP) was documented for inflorescence number 9 (32 days), followed by number 10 (31.5 days), and number 2 (31 days) (refer to Table 1 and Figure 5). Conversely, the minimum DAP value was recorded for inflorescence number 4 (26.5 days), followed by inflorescence numbers 3 and 5 (27 and 27.5 days, respectively). An interesting relationship emerged between DAP and the productivity performance of each inflorescence, suggesting that inflorescences with fewer DAP days exhibited higher productivity.

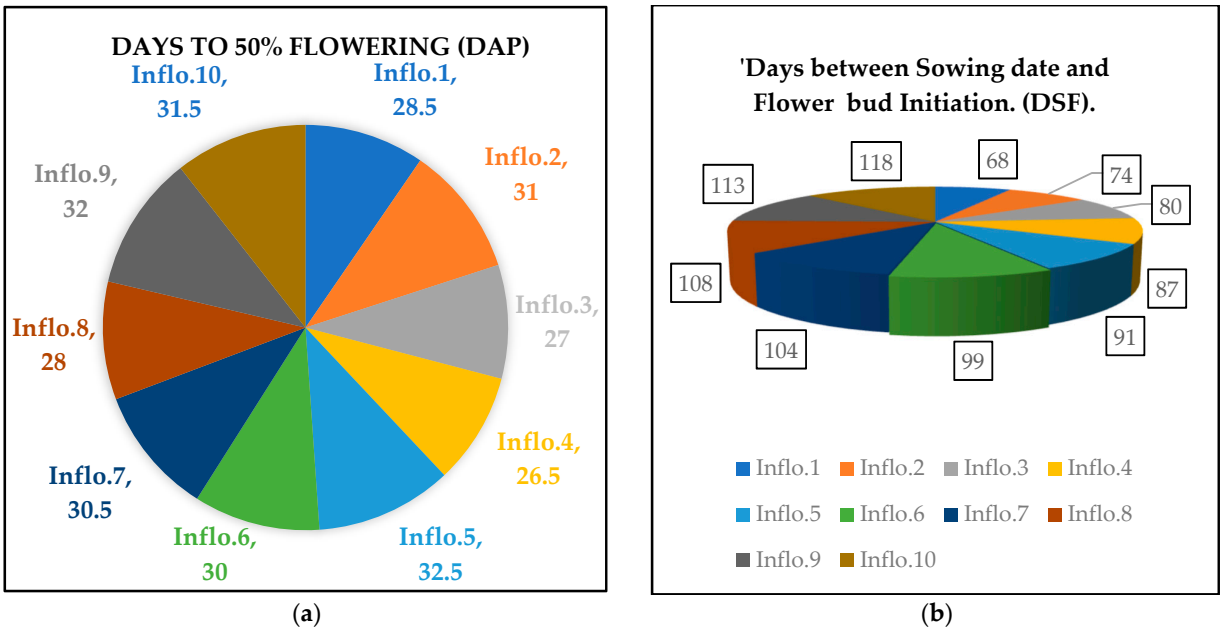

Figure 5. (**a**) Duration of time each inflorescence required for 50% flowering, (**b**) extended period between sowing date and inflorescence initiation.

3.2. Yield and Phenotypic Traits

Table 3 presents the yield traits of all the observed infructescence. A significant relationship ($p < 0.001$) was found between the order of each inflorescence and yield parameters, except for fruit diameter and keeping days. Noteworthy differences ($p < 0.001$) among each inflorescence were observed in terms of their length. Inflorescence number 4 showed the maximum length (51.71 cm), followed by inflorescence number 5 (50.75 cm) and 6 (47.07 cm). Inflorescence productivity also showed significance concerning inflorescence order. Inflorescence number 5 displayed the maximum total mass, followed by inflorescence number 4 and 8. It was evident that inflorescences with greater length produced more fruits and showed a higher total mass. The type of inflorescence also influenced the total mass of fruit, with observations of uni-furcate, bifurcate, and multifurcate trusses.

Table 3. Effects of greenhouse microclimate on yield parameters of the first ten inflorescences: inflorescence length, total mass (g), average fruit mass (g), number of fruits, fruit dry matter contents (%), fruit firmness (N/cm^2), fruit diameter, and fruit keeping days. The plant growth period extended from May to September.

Inflorescence	Inflorescence Length (cm)	Total Mass (TFY) (G)	Average Fruit Mass (AFW)(g)	Number of Fruits (TNFI)	Fruit Dry Matter (%)	Fruit Firmness (N/cm^2)	Fruit Diameter (%)	Fruit Keeping Days
	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD
1	23.40 ± 1.31	175.54 ± 19.09	12.56 ± 0.801	13.00 ± 1.00	10.29 ± 0.23	7.21 ± 0.69	26.93 ± 1.60	6.5 ± 2.08
2	30.07 ± 4.44	211.69 ± 18.94	13.12 ± 0.69	12.66 ± 0.57	9.97 ± 0.38	7.92 ± 0.16	27.50 ± 2.10	6.0 ± 1.73
3	37.18 ± 5.00	220.29 ± 13.49	13.74 ± 0.80	15.33 ± 0.7	9.11 ± 0.39	7.74 ± 0.54	29.98 ± 2.18	7 ± 1.52
4	51.71 ± 2.81	405.06 ± 10.81	13.11 ± 1.49	31.00 ± 6.53	10.82 ± 0.33	6.66 ± 0.53	29.25 ± 2.48	5.7 ± 2.00
5	50.75 ± 4.08	446.65 ± 9.55	14.71 ± 2.74	30.66 ± 4.04	9.38 ± 0.52	6.11 ± 0.81	27.51 ± 4.52	5.66 ± 2.00
6	47.07 ± 5.05	316.27 ± 12.95	12.04 ± 1.14	27.33 ± 4.04	9.02 ± 0.27	5.75 ± 0.51	27.47 ± 0.98	5 ± 2.51
7	43.33 ± 5.53	248.86 ± 14.39	12.88 ± 0.16	18.66 ± 3.78	9.74 ± 0.76	5.49 ± 0.06	24.0 ± 1.89	5.66 ± 1.52
8	35.28 ± 4.60	360.57 ± 22.95	11.53 ± 0.14	31.66 ± 3.21	9.68 ± 0.69	4.91 ± 0.05	26.47 ± 1.68	6 ± 2.51
9	31.48 ± 6.35	138.76 ± 14.39	11.02 ± 1.53	14.33 ± 2.08	10.15 ± 0.58	5.41 ± 0.30	27.0 ± 0.89	5.33 ± 1.52
10	28.21 ± 5.86	195.43 ± 23.95	10.08 ± 1.83	20.66 ± 4.75	10.73 ± 1.01	5.07 ± 0.32	24.41 ± 2.13	6 ± 2.51
Anova	***	***	**	***	**	***	ns	ns

$p < 0.05$…*, 0.01…**, 0.001…*** ns = non-significance level.

Average fruit mass was notably high for inflorescence number 5 (14.71 g), followed by inflorescence number 3 (13.74 g) and 2 (13.12 g). It was observed that the position of fruits on the floral axis directly influenced the average fruit mass, with fruits positioned at the start of floral axis being larger in size than those at the end. The height of the fruit was found to be non-significantly different ($p = 0.29$) among the orders of inflorescence, while fruit circumferences showed significant differences ($p < 0.001$) among the inflorescences.

Fruits were also significant concerning inflorescence order in terms of their firmness, revealing distinct behaviours for each infructescence. Fruit firmness changed as the order of inflorescence progressed from the bottom to the top.

Fruit firmness was notably high in the first three inflorescences, gradually decreasing as the order changed from bottom to top. Specifically, inflorescence number 2 appeared with the highest fruit firmness value, followed by 3 and 1. Each inflorescence also displayed a significant difference in their total dry matter contents ($p = 0.009$). Notably, the dry matter contents (%) of inflorescence number 5 were high, followed by inflorescence number 10 and 1. All the observed phenotypical and morphological traits are detailed in Table 4. Furthermore, a linear delay was identified in the fruit-keeping quality down the inflorescence order from the first to the tenth.

Table 4. Morphological characteristics of *Cheramy F1* cherry tomato based on the IPGRI 1996 Characterization descriptors.

	Plant population density	288 plants/160.00 m^2 or 3 plants/100 cm^2
	General appearance of the population	Good
	Cropping system	Monoculture
Environment and Site		
Country of evaluation	Romania	
Site (research institute)	Research Center for Quality Control of Horticultural Products, University of Agronomic Sciences and Veterinary Medicine of Bucharest, coordinates 44.4710° N, 26.0656° 480 E.	
Plant Descriptors		
Plant characteristics	Plant growth type	Indeterminate
	Plant size	Large
	Stem internode length	Large at the top of stem (7 to 10 cm), intermediate in the middle (5–7 cm), large at the base (6 to 8.5)
	No. of leaves under 1st inflorescence	Many (7 to 8)
	Leaf attitude	Semi-erect
	Leaf type	Standard
	Leaf colour	Green, dark green.
	Stem thickness	Medium at top, strong at base and middle
Inflorescence and Fruit		
Inflorescence	Inflorescence type	Both (partly uniparous, partly multiparous)
	Pedicel length	10 to 56 cm
	Corolla colour	Yellow
	Flower pattern	Basipetal manner
	Days of 50 percent of flowering DAP	26 to 33 days
Fruit	Shape	Round or circular
	Weight	5 g to 22 g
	Fruit size	Small
	Locule	Multilocular
	Fruit size homogeneity	Intermediate
	Exterior colour of mature fruit	Green
	Fruit shoulder shape	Slightly depressed
	Green shoulder size (before ripening)	Medium
	Green shoulder (before ripening)	Present
	Green stripes (before maturity)	Present
	Firmness	Medium

4. Discussion

Various growth stages of tomatoes, coupled with fluctuations in physiological conditions, play a pivotal role in determining the optimal microclimate for greenhouse tomato cultivation. It is essential to recognize that microclimatic conditions exert a significant influence on the developmental processes of plants. Researchers have increasingly focused on investigating the impact of elevated temperatures, light levels, and atmospheric CO_2 concentrations on floral development. In the present study, we have described five growth stages of inflorescence development, spanning from the flower bud stage to fruit ripen-

ing (see Figure 3). Each stage presents a distinct range of days required to complete the development process (refer to Figure 6).

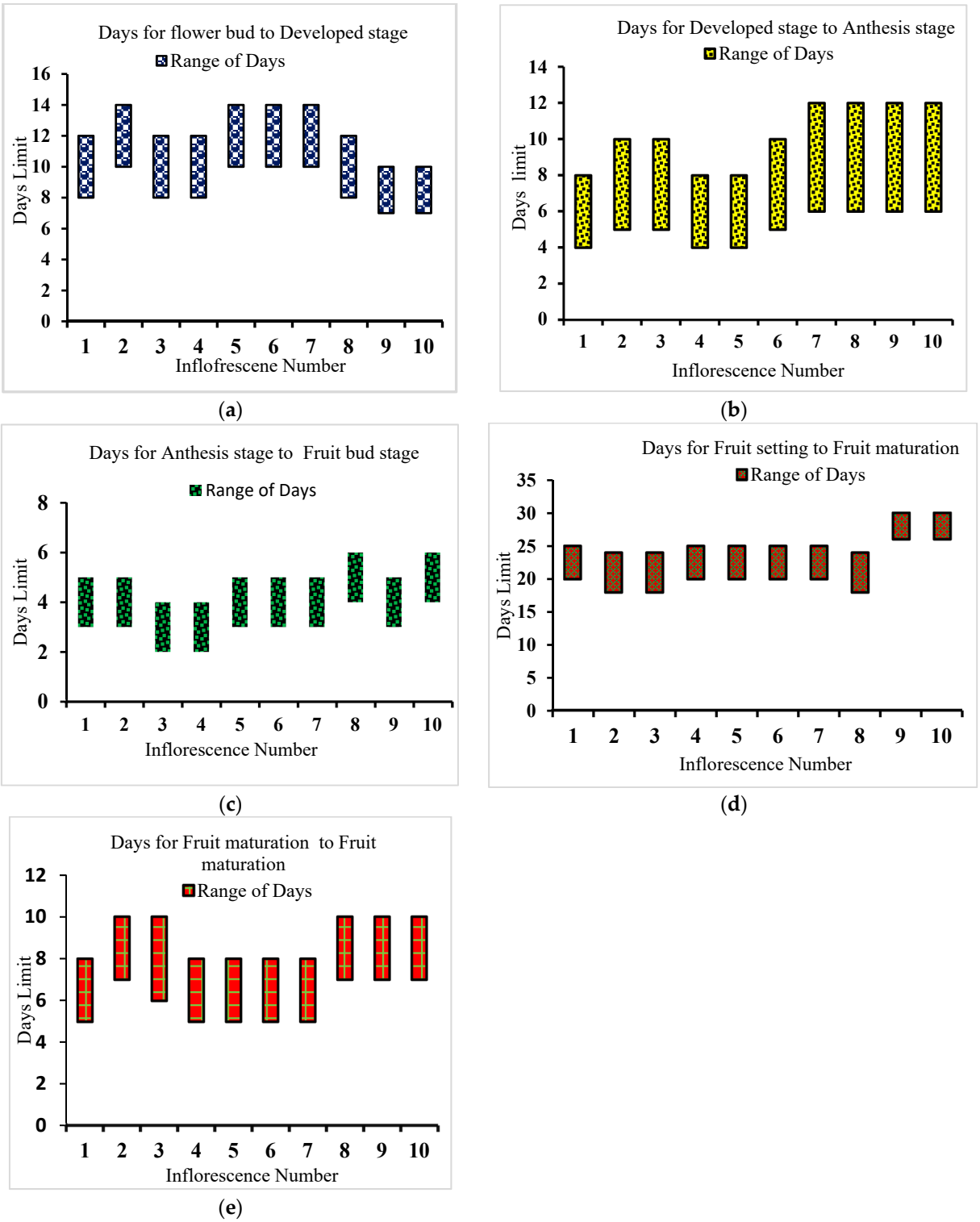

Figure 6. Range of days (maximum-minimum). Each stage extends during inflorescence development: (**a**) flower bud stage (FB), (**b**) anthesis stage (AS), (**c**) fruit setting stage (FS) (**d**) fruit maturity stage (FM), and (**e**) fruit ripening stage (FR).

Greenhouse conditions and the positioning of plants within the greenhouse structure have been identified as two important factors influencing the duration of each stage. Consistent with our findings, existing research supports a direct correlationp between the duration of each stage and the prevailing environmental conditions [8]. The early vegetative period of growth is characterized by high metabolic activity as plants focus on foliage growth and robust root system establishment. In our current study, the vegetative growth period persisted until the emergence of 7–8 leaves. According to the collected data, this was observed to take 25 to 35 days under the specific environmental conditions (average temperature of 23.46 °C, light intensity of 377.7 W/m^2, humidity of 72.99%, and CO_2 concentration of 474.53 ppm) between sowing and the initiation of the first flower bud (see Figure 2). Similar durations have been reported in prior studies [8,35], ranging from 20 to 30 days for early plant growth.

Inflorescence growth commenced when the vegetative meristem transitioned to the inflorescence meristem [36]. Previous studies have underscored the positive impact of optimal growing conditions—extended daily light duration and intensity (2.34 kWh m^{-2} day^{-1}), temperature (22 °C), humidity (0.35 to 1.0 kPa), and CO_2 levels (400 to 700 ppm)—on vegetative growth and development [37,38]. As plants transition from the vegetative phase to the reproductive phase, they initiate flower and, eventually, fruit production.

The FB stage commenced towards the end of May and the beginning of June, characterized by an average temperature of 25.49 °C, humidity at 93.98%, CO_2 concentration of 482.20 ppm, and light intensity measuring 387.41 W/m^2. Environmental conditions play a crucial role in regulating flower interaction, with tiny flower buds progressing through three stages—tiny, medium, and large—to transition from the FB to the mature bud stage. On average, this transformation takes 6–10 days. A previous study divided this time duration from the emergence of sepals primordia to corolla emergence from the calyx (buds of 5–6 mm in length) in 13 different stages [39]. Environmental variations, especially insufficient light, can significantly extend this timeframe by impeding starch and sugar export, leading to inadequate carbohydrate accumulation in bud source organs. This delay, in turn, hampers floral initiation and reduces the flower bud count [30].

The initiation of flowering represents a critical transition from vegetative development to reproductive phases, marking a pivotal stage in establishing plant yield [12]. Increased light intensity and lower temperatures can influence the development time of the first inflorescence in plants, given their impact on total assimilate production [31]. As the flower bud reaches the developed stage, sepals start separating from each other, and upon the corolla limb formation and its complete expansion (10 mm), the flower progresses to the anthesis stage (AS).

The present study documented a duration of 5–10 days for flowers to progress to the anthesis stage, with observations of flowers reaching the AS stage in mid-June. Ensuring an ideal daily air temperature is essential at this stage for proper pollen development and the maintenance of a healthy anther. Exposure to low temperatures has been correlated with reduced auxin synthesis, impeding the growth of floral structures, and resulting in increased flower shedding [40]. Adequate assimilation presence is crucial for pollen viability and the development of sexual organs.

The study highlights a critical timeframe for 50% flowering, ranging from 26 to 32 days (refer to Figure 5), a critical marker for plant development. Additionally, it establishes a direct correlation between this timeframe and the availability of assimilates, underscoring their essential role in regulating the flowering process. Previous research indicates that low light intensity and temperature can adversely impact assimilate availability [41,42].

Following pollination, the flowers progress to the fruit-setting stage once the sepals attain their maximum length. A previous research report suggests that pollination typically spans two to three days, requiring both biotic and abiotic agents. Additionally, extreme temperature (>29 °C or <10 °C), insufficient light exposure, wind pressure, and humidity levels (>40% or <70%) are identified as primary factors leading to blossom drop due to

an unsuccessful fertilization and pollination processes [43]. Misting greenhouse blossoms twice on hot days can boost flower development. A study found a direct link between pollen count and fruit set percentage. Optimal temperatures ranged from 26 °C to 22 °C; extremes (32/26 °C) hindered pollen production and delayed fertilization [40].

Following fertilization, the inflorescence transitions into infructescence, marking the onset of the FS stage. Fruit set, characterized by the moment when all petals shed upon gentle tapping, varies for each flower. Physiological factors contribute to temporal delays in fruit set, initiating post-pollination. The term "fruit set" denotes the developmental phase occurring between the flowering stage and the attainment of anthesis, during which a certain percentage of flowers successfully progress to the production of fruits, typically exceeding 37 mm in size [44].

Exploring the detrimental impacts of elevated CO_2 levels (500 to 700 ppm) and temperature variations (16 to 19 °C), the study noted delayed flowering (from proximal to distal positions) and a decline in fruit set of 10% to 60% [45]. The same source also highlighted a direct relationship between increased CO_2 levels and temperature, resulting in a gradual decrease in tomato leaf retention and reduced fruiting efficiency across the initial seven inflorescences, from the first to the seventh.

After the formation of fruit buds, fruit maturation commenced, lasting an average of 20 to 25 days. During this period, the greenhouse experienced an average temperature of 21.86 °C, a light intensity of 371.98 W/m^2, humidity levels of 78.88%, and a CO_2 concentration of 467.45 ppm.

The processes of cell proliferation and expansion play pivotal roles in the development of tomato fruit following successful pollination and fertilization [2]. The duration for fruits to transition from the FS to the FM stage, as well as the subsequent growth in size and weight, are primarily influenced by the available carbon dioxide (CO_2) in the greenhouse. Research indicates that the division of cells in the fruit's outer layer (pericarp) takes place over a period of 5 to 10 days following the FS stage. Similarly, sources describe cell expansion, occurring after cell division, as the main driving force behind the increase in fruit size. The process of fruit size and maturity is highly influenced by the available concentration of CO_2 [46].

The maturation of tomato fruit is contingent upon a consistent provision of carbohydrates originating from source leaves. Elevated CO_2 levels impact the regulation of the source-to-sink ratio in tomato plants, leading to increased concentrations of fruit flesh [47,48].

In our study, we observed that it took approximately 55 to 60 days to achieve the initial harvest under conditions wherein the average temperature was 23.13 °C. These results align with previous research [21], which reported a similar time frame of 55 to 60 days from planting to the attainment of marketable maturity for early tomato varieties. As the fruit reaches its maximum size, it enters the FR stage, lasting 6–10 days. Elevated levels of CO_2 in greenhouses possess the capacity to enhance both ethylene production and carotenoid contents in tomatoes during the fruit ripening process [49].

Regarding the productivity and biochemical composition of each inflorescence, we observed the highest fruit in the initial inflorescence. Notably, the process of fruit maturation progressed along the floral axis, advancing from the proximal to the distal end. The arrangement of fruits on a truss has been found to influence the fruit ripening process. The timeframe of fruit setting, genetic makeup, environment conditions, and the agricultural methods employed significantly determine the fruit size and biochemical composition of tomatoes [50]. The size of the fruit is an important factor in determining yield at harvest and, even under controlled conditions, variations in fruit production can be substantial based on their position on trusses. Fruit at the beginning of each truss exhibited rapid and substantial development, consistent with findings reported under 15 °C temperature treatments [51].

A study established a direct correlation between the number of flowers and yield under greenhouse conditions, emphasizing the pronounced impact of cumulative solar

radiation (CSR) on the number of flowers [52]. Additionally, a study established that high humidity levels (0.31 to 1.0 kPa) reduce fruit weight and quality, with a mention of higher early yield in response to elevated humidity [53]. Pre-harvest cultural practices and the influence of available greenhouse conditions have been identified as important factors determining the quality of tomatoes [46,54].

Higher temperatures and stress in the parral-type greenhouse were found to decrease lycopene and essential elements while increasing phytonutrients and antioxidants in cherry tomatoes [55]. Elevated carbon dioxide (EC) was noted to enhance nutritional components like glucose, fructose, antioxidants, and calcium in vegetables but decrease flavonoids and phenols in tomatoes at 500 and 700 ppm. Elevated temperature (ET) adversely affected tomato yield, fruit quality, and mineral content, resulting in reduced lycopene levels and negative impacts on fruit number and development [56,57]. To address the question of why, on certain inflorescences, various blooming flowers failed to mature: the cause could be an excess of nitrogen or a failure in the pollination process. If the pollination process proceeded but only resulted in a tiny bud, it suggests that late pollination was influenced by extreme greenhouse conditions, negatively impacting the fruit maturation process. A study identified significant differences in the expression of male and female structures under the combined influence of temperature and carbon dioxide [58]. Regarding the bifurcate truss formation, another study reported a significant relationship between low-temperature treatments and an increase in flower number [43].

The study focuses solely on the *(Cheramy F1)* variety of cherry tomatoes. Different varieties may respond differently to greenhouse conditions, so the findings may not be applicable to other cherry tomato varieties. The study only explores variations in greenhouse microclimate conditions such as temperature, CO_2 levels, light intensity, and humidity. Other factors that could affect cherry tomato growth and yield, such as nutrient levels, soil composition, and air circulation, are not considered. There may also be a genetic effect and pests or diseases could disrupt the cultivation of tomatoes in greenhouses. The study also only examines the development of the first ten inflorescences on the plant. Cherry tomato plants may continue to produce inflorescences beyond this timeframe, and their response to greenhouse conditions over a longer period may differ. The study investigates the ideal greenhouse conditions, including temperature, CO_2 levels, and light intensity, to optimize inflorescence development and the overall growth of cherry tomatoes. It offers recommendations for enhancing environmental sustainability in greenhouse operations beyond improving productivity and yield.

5. Conclusions

The study uncovered a significant correlation between greenhouse conditions and the sequential progression of inflorescence development, as well as between the attributes of yield and growth. Optimal conditions identified for inflorescence development and high yield included a temperature range of 18 °C to 22 °C, a light intensity between 360.87 and 384.45 W/m^2, and a carbon dioxide level ranging from 450.85 to 480.74 ppm. The impact of microclimate conditions on the duration of each stage varied significantly among the inflorescences.

The duration of each stage and with the frequency of a key yield-contributing factor—specifically, the number of fruits at the fruit-setting stage—emerged as crucial indicators of productivity. It was concluded that light exposure significantly influences plant growth, with plants positioned in the middle of greenhouses (receiving maximum daylight) exhibiting greater height and productivity compared to others.

These findings underscore the importance of considering greenhouse cultivation practices in future research on tomatoes. The insights from this study can guide decision-making regarding the regulation of greenhouse environments, particularly in determining practical ranges for CO_2, light, and temperature. This information proves valuable for both strategic planning and day-to-day operational choices.

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