agriculture

Review

The Use of Temperature Based Indices for Estimation of Fruit Production Conditions and Risks in Temperate Climates

Grzegorz P. Łysiak [1] and Iwona Szot [2,*]

[1] Department of Ornamental Plants, Dendrology and Pomology, Faculty of Horticulture and Landscape Architecture, Poznan University of Life Sciences, Dąbrowskiego 159, 60-594 Poznań, Poland
[2] Subdepartment of Pomology, Nursery and Enology, Institute of Horticulture Production, Faculty of Horticulture and Landscape Architecture, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland
* Correspondence: szoti@autograf.pl; Tel.: +48-606464209

Abstract: Temperature is the basic factor that differentiates vegetation around the world. All field experiments require the indication of the range of temperatures occurring in a given growing season. Temperature is an important factor determining fruit plant production, both in the growing season and in the winter dormant period. Various air temperature indicators were developed in a way that allowed the best possible description of adaptations of species, cultivars, and regions of adaptations to cultivation. They are based on experimentally obtained data and calculated optimal temperatures of growth and development of plants in particular development stages. In horticulture, the description of dependencies of the growth and development of plants on weather began to be accompanied with the development of simulation models. The aim of this manuscript was a new review of fruit plant temperature indices to predict abiotic and biotic hazards in fruit production for various selected types of fruit crops in a seasonal temperate climate. This is especially important due to the growing risk of climate change, which significantly alters local growing conditions. Therefore, it is very important to evaluate and present a set of specific indicators for producers, which we have reviewed from the current literature and presented as follows. Climatic conditions characteristic of a given region should be of key importance for the selection of species for commercial cultivation and planning of protection measures.

Keywords: sum of active temperatures (SAT); growing degree days (GDD); latitude temperature index (LTI); phenological model; fruit species; plant development prediction; treatment against pest optimization

Citation: Łysiak, G.P.; Szot, I. The Use of Temperature Based Indices for Estimation of Fruit Production Conditions and Risks in Temperate Climates. *Agriculture* **2023**, *13*, 960. https://doi.org/10.3390/agriculture13050960

Academic Editor: Josef Eitzinger

Received: 22 March 2023
Revised: 23 April 2023
Accepted: 24 April 2023
Published: 26 April 2023

1. Introduction

Temperature is the basic factor that differentiates vegetation around the globe [1,2]. Trees and shrubs with edible fruits are no exception in this regard. Temperature, serving as a measure of the amount of heat, is one of the most important factors affecting the growth and development of plants. For most plants in temperate climates, the temperature optimum for growth is 20–30 °C [3], but the temperature at night is also important (Table 1). Particular species of fruit plants exist in a range from minimum to maximum temperatures (Table 2) for their growth and development. Any excess results first in a decrease in immunity causing disease, and then death [4]. Depending on the cultivar, "safe" temperature for mango (*Mangifera indica* L.) at which no damage occurs to the fruits or leaves varies from 10 to 12 °C [5]. On the other hand, there are plants that survive severe frosts without or with minor damage [6]. Examples include plants growing in temperate climates. According to Proebsting and Mills [7], the flowers of the trees in full bloom survive temperatures below zero degrees Celsius. It is estimated that temperatures between −2.7 °C and −3.1 °C damage only 10% of flowers in full bloom in these species (Table 3). Next to genetic predisposition [8], resistance to low, but also high temperatures depends on many factors, including chemical composition, structure, physiological adaptation, and geographical location [9,10].

Temperature affects the basic processes that occur in plants, such as photosynthesis, transpiration, and respiration. Moreover, it regulates the rate of transition of plants from the vegetative to generative phase [11–13]. The significance of the effect of temperature on yield quality is reported in most studies on fruit plants [14–22].

At temperatures specific for them, plants show characteristic growth and development in particular physiological phases (Tables 1–3). Two temperature ranges are usually designated that affect plant development: low temperatures (chilling) and high temperatures (forcing) [23]. The induction of vegetative growth in a given season occurs after the chilling period, whereas growth and development depend on the range of higher temperatures. The range of low temperatures refers to a prolonged accumulation of chilling at which the plant is able to break winter dormancy. It ensures proper development of particular elements in the flower bud, and then development of fruits when higher temperatures occur. After the dormant period, the accumulation of heat forces their transition through subsequent phenological phases of the plant, and leads to reaching the phase of fruit maturity.

The effect of temperature on the growth and development of plants differs depending on the species (Figure 1). The Cornelian cherry first blossoms and only then leaves appear [24]. In apple trees, leaves develop together with the bursting of flower buds. According to the comparison presented, the Cornelian cherry was prolonged in time, because the bursting of buds occurred already in mid-February and lasted until the end of April, and the bursting of buds of apple trees was observed from mid-April to the first days of May. Sum of actives temperatures until the full bloom of Cornelian cherry was 238 °C, and for apple tree 587 (434 + 153) °C.

Table 1. Optimum temperature ranges for some fruit plants.

Crop	The Range of Optimum Temperature	Literature
Grapes	For optimum photosynthesis activity 25–30 °C; A diurnal min./max temperature for sugar and organic acid content 25–30 °C; Max night temperature for color and flavor 15/25 °C	[25]
Apple	For harvest fruit weight day/night temperatures from 10–40 DAFB cv. ‘Braeburn’ 19/9 °C ‘Golden Delicious’, ‘Fuji’ 22/12 °C; Optimal temperature for growth of leaf and floral initiation 18–21 °C For apple tree growth 21–24 °C	[3] [26] [27]
Peach	26 °C	[28]
Sweet cherry	For shoot growth 12–21 °C; For flowering 12–15 °C	[29]
Strawberry	For leaf and petiole growth 25/12 °C For roots growth 18/12 °C For whole plant growth 25/12 °C	[30]
Raspberry	For production leaves before the terminal flower 15–17 °C; For node production 22 °C; For flowering the day/night temperature 29/24 °C	[31]

Table 2. Minimum and maximum temperature for some fruit plants.

Crop	The Range of Minimum Temperature	The Range of Maximum Temperature
Grapes	−20 °C [32]	35–40 °C [32]
Apple	−15 to −30 °C dependent of rootstocks [33]	30 °C [34]
Pear	−27 °C [35]	32 °C [35]
Peach	−20 to −30 °C [36]	25–30 °C during flowering [37] 34 °C [38]
Sweet cherry	−25 to −30 °C [36]	33 to 37 °C during harvest [39]
Strawberry	−10 to −20 °C at snowless late autumn [40]	30–45 °C [41]
Raspberry	−27 to −30 °C [42]	40–55 °C [43]

Table 3. Critical damage temperature (°C) for some deciduous fruit trees, grapevines, and several small fruits.

Crop	Phenological Stage	10% Kill	100% Kill
Apple [7]	Silver top	−11.9	−17.6
	Full bloom	−2.9	−4.7
	Post bloom	−1.9	−3.0
Apricot [44,45]	Tip silver	−4.3	−14.1
	Full bloom	−2.9	−6.4
	Post bloom	−2.3	−3.3
Sweet cherry [45]	First swell	−11.1	−17.2
	Full bloom	−2.4	−3.9
	Post bloom	−2.2	−3.6
Peach [7]	First swell	−7.4	−17.9
	Full bloom	−2.7	−4.9
	Post bloom	−2.5	−3.9
Pear [7]	Scales separate	−8.6	−17.7
	Full bloom	−2.7	−4.9
	Post bloom	−2.7	−4.0
Plum [7]	First swell	−11.1	−17.2
	Full bloom	−3.1	−6.0
	Post bloom	−2.6	−4.3
	Post bloom	−1.0	−4.0
Grapes [7]	First swell	−10.6	−19.4
	Bud burst	−3.9	−8.9
	First leaf	−2.8	−6.1
	Second leaf	−2.2	−5.6
	Third leaf	−2.2	−3.3
	Four leaf	−2.2	−2.8
Blackberry [46]	Swelled flower buds	n.d	−6.1
	Fully opened buds	n.d	−0.6
Strawberry [47]	Tight bud	n.d	−5.6
	Full bloom	n.d	−0.6
	Immature fruit	n.d	−2.2

[nb]—literature; n.d—no data.

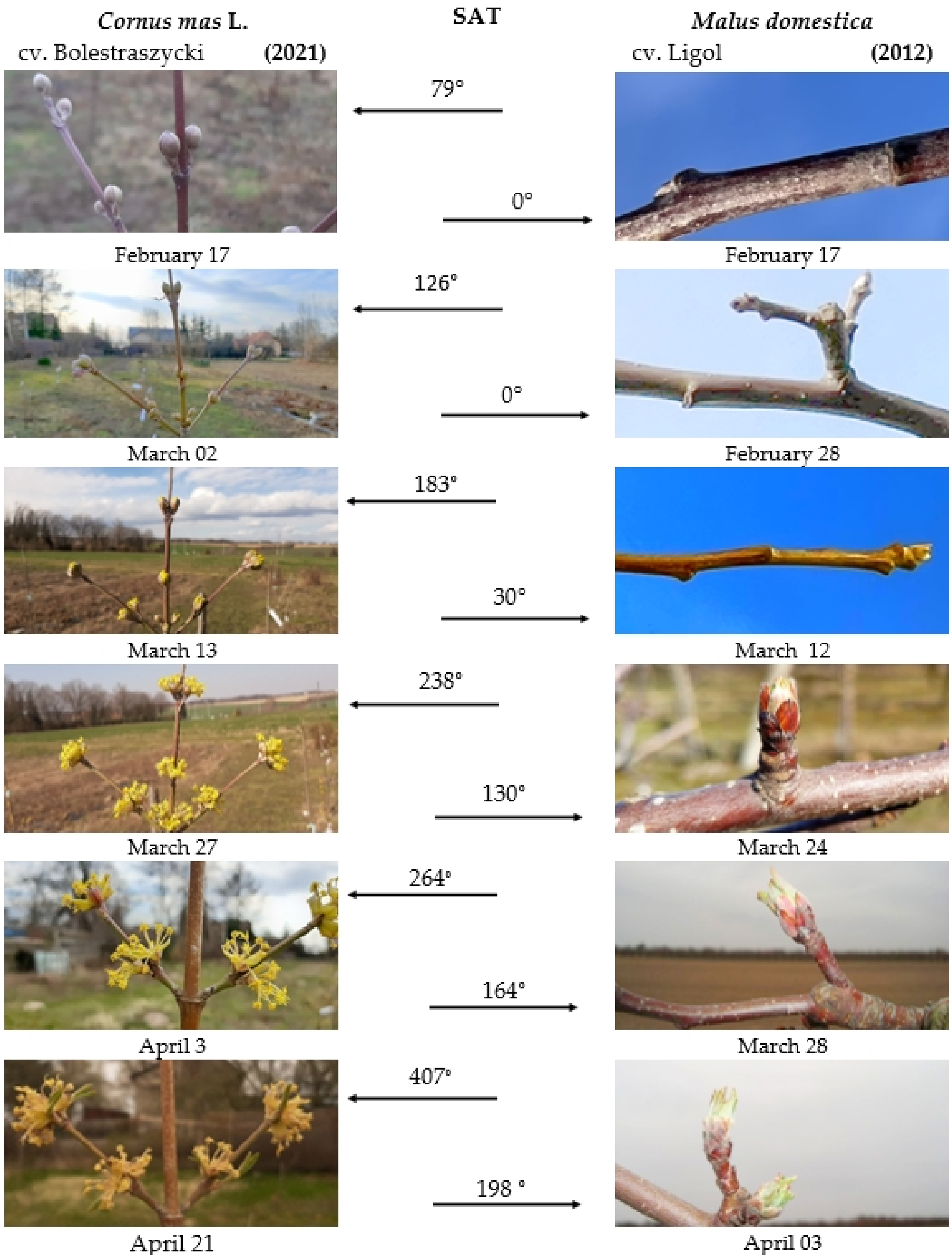

Figure 1. *Cont.*

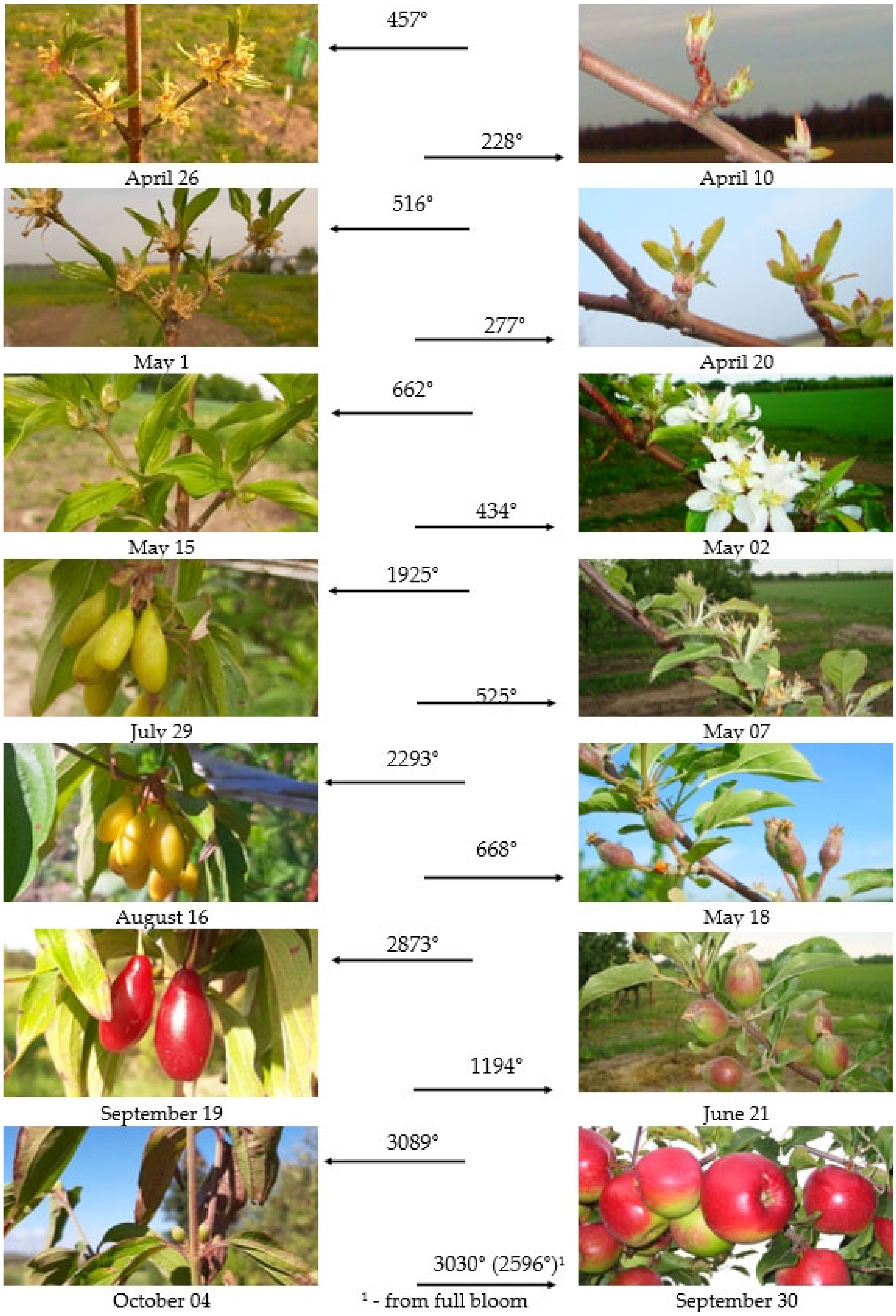

Figure 1. Comparison of the effect of the sum of active temperatures (SAT) measured at a base temperature of 0 °C on reaching particular physiological stages by plants of Cornelian cherry (*Cornus mas* L.) cultivar 'Bolestraszycki' in 2020 and apple tree (*Malus domestica* Borksh.) cultivar 'Ligol' in 2012. Due to the prolonged winter in 2020, measurements commenced approximately 2 weeks later.

Humankind has recognised the importance of temperature for the development of plants since ancient times. Already Pliny the Elder in his book *Natural History* wrote that olive trees planted in cold regions produce scarce fruit, and oil made from them is not tasty. In cultivation of grapevines, he also emphasised the importance of the site, and recommended planting vineyards on southern slopes to ensure higher temperatures

(*Vitis amat colles*—vines love slopes) [48]. In modern times, the first concepts regarding temperatures were described in 1735 by Réaumur. He assumed that in order to transition to subsequent development stages, plants require certain constant temperature—"forcing units". The introduction of the concept of "forcing units" led to its use in agricultural studies in describing development stages of plants and their pathogens (Table 4). It was found that individual development of many plants depends on so-called "physiological time" that determines the total amount of heat that needs to be absorbed by a given organism in order to reach subsequent development stages [49]. Already in 1878, Starchey, describing the growth of agricultural crops, defined formulas for the determination of 'accumulated temperature' above the base temperature of 5.6 °C (42.08 °F) at which plant vegetation begins. Formulas by Starche were adopted by the London and Couties Coke Association in 1933 for the calculation of energy demand for heating buildings, depending on the number of degree days of heating [49].

Table 4. Temperature thresholds for the most dangerous diseases and pests of selected fruit crops.

Crop	The Most Dangerous Diseases	Thermal Threshold	The Most Dangerous Pests	Thermal Threshold
Grapes	Grapevine powdery mildew (*Erysiphe necator*)	For ascosporic infection: 5 °C and 31 °C [50]	Grape phylloxera (*Daktylosphaera vitifoliae*)	For radicole development 6 °C, For hatch of gallicole eggs 8.7 °C, For post embryonic development 7.8 °C [51]
Apple	Apple scab (*Venturia inaequalis*)	0 °C [52]	Codling moth (*Cydia pomonela*)	For preoviposition period 11.4 °C [53]
Pear	Pear rust (*Gymnosporangium sabinae*)	10 °C [54]	Pear sucker (*Cacopsylla pyrisuga*)	For adults acyivity 4.5–5.7 °C [55]
Peach	Peach leaf curl (*Taphrina defgormans*)	5 °C [56]	Green peach aphid (*Myzus persicae*)	6.5–37 °C [57]
Sweet cherry	Spotted wing drosophila (*Drosophila suzukii*)	5–35 °C [58]	Cherry leaf spot (*Blumeriella jaapi*)	8 °C [59]
Strawberry	Gray mold (*Botrytis cinerea*)	For conidium germination 0 °C [60]	Vine weevil (*Otiorhynchus sulcatus*)	For eggs 6.2 °C; For larvae 6.0 °C; For pre-pupae 12 °C [61]

Temperature indices can be useful in predicting the occurrence of dangerous diseases and pests of fruit crops. The most dangerous apple disease is apple scab caused by the fungus *Venturia inaequalis*. Seventy-five percent of pesticides applied to diseases are fungicides, of which seventy percent are sprays against scab [62]. In 1944, after more than 20 years of research, Mills published his table predicting the possibility of occurrence of infection with apple scab [63]. Spores of apple scab need a specific amount of forcing to sprout and grow into the leaf tissue when infecting the plant. The basic criterion applied by the author in his model was the temperature of the air. The duration of the period of wetting the leaf at a given temperature determines the occurrence of infection. After many modifications, the table still finds practical application [64]. Much research has been devoted to predicting the onset and end of primary inoculum emergence, as well as developing models to predict the dynamics of ascospore maturation and emergence based on temperature [65]. One such model was the 'New Hemshire' (NH) model developed by MacHardy and Gadoury [52]. The NH model was built by fitting a linear regression equation to probit-transformed data on the percentage of mature ascospores plotted on a thermal timescale based on degree-day accumulation (base = 0 °C) from the first appearance of ascospores in spring.

The main postharvest pathogens of sweet cherry are *Alternaria* spp. and *Botrytis cinerea*. Larrabee [66] assessed the role of increasing degree days (GDD) in pathogen abundance using linear mixed effects models with multimodel inference and model averaging.

The applicability of total forcing units was also used in research on the biology of insects. It is particularly important to forecast the occurrence of plant pests whose development is closely related to that of the host plant. Temperature values also permit forecasting the occurrence of particular pests. Honěk and Kocourek [67] evidenced that temperature is an important factor that affects the development of juvenile forms of aphids. They determined the base temperature (lower development threshold LDT) below which the development of aphids is terminated. They also calculated the total of effective temperatures, i.e., sum of day degrees above LDT necessary for completing the development stages (Growing Degree Days). They emphasized that LDT and GDD values are typical of particular stages of development, as well as of the species and sex. They showed that an increase in temperature above the lower threshold value determines the faster development of insects. Like plants, most insects also have an upper development threshold above which their rate of development does not increase, but may be inhibited. Such methods are used to calculate the first flight of the first generation of pests such as the plum fruit moth, the cherry fruit fly [68] codling moth [53,69], the apple blossom weevil [70], and spotted wing drosophila (*Drosophila Suzuki*) [71]. It is also possible to estimate the threat of the occurrence of soil pests, particularly pathogenic nematodes [72].

Individual diseases and pests have temperature thresholds that affect their development cycle (Table 4).

We provide a new review of temperature-based indices for fruit growing plants to predict abiotic and biotic risks in fruit production for various selected types of fruit crops in seasonal temperate climate. This is especially important due to the growing risk associated with climate change, which significantly changes local growing conditions. Therefore, it is very important to evaluate and provide a set of specific indicators for producers, which we have reviewed from the latest to the current literature and presented as follows.

2. Temperature Indicators Used in Horticulture

Several indices have been developed based on the heat load (daily accumulated temperatures above a threshold of 10 °C for a fixed period) and temperature requirements of individual fruit plants. These methods were first commonly applied in colder regions of the temperate zone for plants growing in areas with a temperature closer to the lower development threshold (base temperature) [73].

The Sum of Active Temperatures (SAT)—sum of mean daily temperatures above the base temperature (Tbase), during the growing period. Vegetation for a certain plant starts when mean daily temperatures are above its base temperature for at least 6 consecutive days (from the beginning of the year) and it ends when mean daily temperatures are below the base temperature for at least 6 consecutive days (in the second half of the year). The most common period is from 1 April–31 October [74]

The Sum of Active Temperatures is calculated from the following formula:

$$\mathrm{SAT} = \sum_{i-1}^{n} \mathrm{TD}$$

where TD is mean daily air temperature [75].

i = 1,2,3..n—number of days with a mean value above the base temperature for a given plant (Tbase), beginning the growing season (Table 5).

Table 5. Estimated base temperatures (°C) for particular fruit plant species.

Species	Base Temperatures (Tbase)	Literature
Peach	−1.0 to 0.0 0.5 to 4.5 2.2; 6.3 7.0 6.0 to 8.0	[76] [77] [78] [79–82]
Sweet cherry	3.2 to 3.7 −2.0 to 7.0	[83] [84]
Apple	0.0 −2.0 to 5.5 12.0	[85,86] [78,84]
Blackberry	6.0	[75]
Pears	0.0 4.4; 8.2	[87] [88]
Hazel	5.0	[89]
Raspberry	4.0 and 6.0	[90]
Walnut	5.0	[91]
Plum	2.2; 6.2 5.0 to 7.0	[28,78]
Strawberry	0.0; 6.0; 7.0; 10.0 4.0	[92,93]
Grapevine	2.1; 4.3 10.0	[73,78,94–96]
Sour cherry	2.5 4.0 5.5	[97,98] [99]

The comparison of the SAT index requires taking into account factors that could affect its calculation. Differences in the SAT value can result from, for example, different ways of the calculation of mean daily air temperature [94]. Mean daily air temperature values calculated based on meteorological observations and different formulas differ from daily means determined from the automatic procedure covering 24 hourly measurements (Table 6) [100,101].

Table 6. Methods of calculation of mean daily air temperature (based on the guidelines of World Meteorological Organization (WMO 2012).

Average Air Temperature	Calculation Formula	Application
TD1	$TD = \frac{(t_{00}+t_{01}+t_{02}+\ldots t_{23})}{24}$	The average true 24-h temperature in UTC time
TD2	$TD = \frac{T_{max}+T_{min}}{2}$	Average used by the countries of North America and Australia, in Europe in Spain and Great Britain
TD3	$TD = \frac{(t_{00}+t_{03}+t_{06}+t_{09}+t_{12}+t_{15}+t_{18}+t_{21})}{8}$	Average used at IMGW synoptic stations from 1966 until today in UTC time
TD4	$TD = \frac{(t_{00}+t_{06}+t_{12}+t_{18})}{4}$	Average used at IMGW climatic stations in the years 1971–1995 in UTC time
TD5	$TD = \frac{(T_{max}+T_{min}+T_{06}+T_{18})}{4}$	Average used at climatological stations from 1996 until today. Tmax and Tmin are measured from 6.00 p.m. on day "N" to 12.00 p.m. on day 18 "N" = 1, in UTC time

According to Kowalski and Nawalany [94], depending on height above ground level, differences in daily temperature may be significant for SAT. Based on measurements conducted at a height of 1 m in 2011, the SAT for the area of south Poland was 3800 degrees, and 100 degrees more (3900) were recorded in the case of measurements on the ground surface. Due to soil heating, SAT measurement in the same conditions in the surface soil layer provided a value of 4300 °C, and SAT reached 4200 °C in the case of measurement at a depth of 25 cm. The difference between the temperature of soil and air depends on the physical properties of these two different states of matter and can be significant.

It was also determined that the SAT index is also not precise in the comparison of conditions occurring at various latitudes [102]. In order to correct the divergencies and provide for comparability of the result, it is supplemented with the so-called "LTI index" (latitude temperature index). LTI was developed in New Zealand at Lincoln University [103]. It indicates the potential for the development of plants taking into account the specifics resulting from the location towards the equator. LTI is a product of mean temperature of the warmest month in a year (expressed in °C) and the latitude degree of the study area [104]. The higher its values, the greater the potential of maturing of grapes in a given area.

LTI is calculated according to the following formula:

$LTI = TC \times (60^{-}\ L)$

TC—mean temperature of the warmest month in a year in °C,

L—latitude degree.

Another, similar unit based on temperature measurement is the sum of degree days (Sum of Effective Temperatures—SET) or growing degree days (GDD). Calculating the growing degree days (GDD) requires values of growth degree hours (GDH), calculated by reducing the mean hourly temperature value by the base temperature value below which the organism ceases to develop. Threshold temperature values are so-called physiological zero temperatures (or thermal threshold) [105]. For cases of lack of availability of hourly data, methods have been developed that permit the determination of degree days (GDD) based on daily maximum and minimum temperature values [106]). The calculation of degree days based on daily min/max values is based on the assumption that the daily temperature distribution profile can be presented in a diagram by means of a sinusoidal curve where a single symmetrical curve is fitted to minimum/maximum daily temperatures. GDD is calculated from the following formula:

$$\boldsymbol{GDD} = \sum_{i=1}^{m} (\mathrm{TD} - \mathrm{Tbase})$$

TD—mean air temperature

Tbase—base temperature,

i = 1,2,3..n—number of days with a mean value above the base temperature for a given plant (Tbase), beginning the growing season.

When base temperature is 0 °C, SAT and GDD values (growing degree days) are the same. The correlations between SATs and GDD (base 10 °C, are between 0.91 and 0.97 over the growing season stages) [74].

3. Use of Temperature Data in Fruit Plant Cultivation

3.1. Phenological Models

In horticulture, with the development of technologies of meteorological data recorders, the description of dependencies of the growth and development of plants on weather began to be accompanied with the development of simulation models [107,108]. The application of simulation intensified in the second half of the last century, with the emergence of the study approach called the Monte Carlo method. It permitted mathematical modelling of actual processes too complex for their results to be predicted by means of analytical solutions. Simulation modelling is a set of model factors that affect the analyzed system. They constitute a model of a simplified version of the system, and then allow for experimenting in it for the purpose of investigating its structure and description of behavior [109].

Growing Degree Days was first used for the development of phenological models in the 1950s [110]. It started to be applied on a larger scale only at the end of the century; however, when the development of computerization accelerated the calculations [111]. Phenological models consider the effect of temperature on obtaining particular phenological stages, e.g., break in dormancy, bursting of flower buds, full bloom, and maturity. Depending on the complexity of the problem, different simulation models are used. If the objective is to describe the effect of temperature, it is usually aimed at the understanding of the functioning of the process resulting from the mutual dependencies of particular phenological phases. Then, systemic-dynamic models are developed for forecasting the term of occurrence of a given phase at a set range of temperatures. Functions describing the process of temperature accumulation can be linear, non-linear, logarithmic, or other. The determination of the phenological phase using forcing units also employs statistical methods of determination of variability such as standard deviation, regression coefficient, and variance coefficient [112]. Through the analysis of the aforementioned variables, the model permits predicting when particular phenological phases will occur, and investigating dependencies between selected variables [47,80,83,87,113–115].

3.2. Models Determining Winter Dormancy Duration

Most fruit plants require a dormancy period. Even in a humid tropical climate, plants do not grow continuously. After a period of active growth, a period of rest occurs during which the stem apex dies or develops a bud. Plants in the warm climate zone are characterized by simultaneous occurrence of stems in the state of intensive growth and at rest [116,117]. Due to the cold and short days in winter, fruit plants from the temperate climate enter winter dormancy. Two types of dormancy are distinguished, namely relative dormancy (ecodormancy), caused by unfavorable environmental conditions, and endodormancy, determined by the effect of external mechanisms in plant organs [114]. Some researchers also distinguish "summer dormancy" [118]. However, Lang et al. [119], taking into account physiology, attempted to formulate a new nomenclature for descriptive communication. Based on one basic term, dormancy, with descriptive, specific, physiological prefixes: endormancy, paradormancy, and ecodormancy. In response to a change in the environmental conditions, plants launch mechanisms permitting their adaptation to new conditions. In dormancy, the molecular activity is inhibited, and can only be renewed after meeting appropriate conditions [120]. A sufficiently long period of low temperature causes hormonal changes in buds, resulting in the termination of deep dormancy. The requirements for low temperature vary from species to species (Table 7) and are defined as the number of hours of chilling necessary to restore the development potential of the buds of perennial plants in spring [121].

Table 7. Average chilling hour requirements for most commercial cultivars of some fruit crops.

Crop	Chilling Hours	Literature
Grapevine	90–800	[122,123]
Apple	400–2900	[124]
Pear	400–900	[125]
Peach	200–900	[126]
Sour cherry	700–1200	[125]
Sweet cherry	900–1500	[127]
Strawberry	200–400	[128]
Raspberry	1200–1700	[129]

In spring, prolonged photoperiod and increased temperature cause the plants' transition from the dormancy state, as manifested in gradually increasing metabolic activity that stimulates the development of buds, followed by the entire plant. The application of mathematical models allowed for calculating the chilling requirement of fruit tree buds necessary for the transition through all stages of the dormant period [130].

The Chilling Hours Model is the oldest method determining the number of units of low temperature necessary for terminating absolute dormancy of plants. The model assumes that effective temperatures are in a range from 0 °C to 7.2 °C, while each hour at temperatures between these thresholds constitutes one chilling hour. This way, chilling hours are accumulated throughout the dormant period [131]. The number of Chilling Hours at time t (CHt; t is measured in hours since the start of the dormancy season) can be calculated as:

$$\mathrm{CHt} = \sum_{i=l}^{t} T7.2$$

where 1 h between 0 °C to 7.2 °C = 1.0 chill unit, else = 0.0 chill unit [132].

In the United States, the Utah model (Chill Units) has been developed. It assesses the chilling efficiency with consideration of the unfavorable effect of excessively high temperature. It assumes that temperatures from 0 °C to 16 °C promote the breaking of rest, whereas temperatures >16 °C negate such effects [121]. The most effective for breaking dormancy is 7 °C. Therefore, 1 h with a temperature of 7 °C is equal to 1 chilling unit, and higher and lower temperatures in a range from 0 °C to 16 °C are less effective. The model therefore assumes the accumulation of cold occurs in a range of temperatures from 2.5 °C to 12.5 °C outside which the accumulation is at a zero or negative level. The algebraic summation of the hourly values gave the daily total [133].

The number of Utah Chill Units at time t (UCUt) can be expressed as:

$$\mathrm{UCU\ t} = \sum_{i=1}^{t} \mathrm{TU}$$

With TU =
1 h below 1.1 °C—0.0 chill units
1 h between 1.6–2.2 °C = 0.5 chill units
1 h between 2.7–8.8 °C = 1.0 chill units
1 h between 9.44–12.2 °C—0.5 chill units
1 h between 12.7–15.6 °C = 0.0 chill units
1 h above 18.3 °C = −1.0 chill units [134].

This model is useful in cold or temperate climate, and it is completely unsuitable in subtropical climate. The duration of the vegetation cycle in the tropics is always shorter than a year and usually lasts 6–8 months [23]. For plants cultivated in the subtropics, the Positive Chilling Units model has been developed, omitting negative values ascribed to high temperatures [134]. A variation in the Utah model was suggested in South Africa by, among others, Linsley Noakes and Allan [135]. They suggest that negation of cold by high temperatures should only be calculated in day mode and refer to "daily positive cold units". This led to a much improved model of their conditions.

A Dynamic Model (Chill Portions) was developed by Fishman et al. in Israel [136]. It calculates chilling in units called "chilling portions" based on hourly temperatures. In this model, the optimum chilling temperature was adopted for 6 °C, and the range of temperatures promoting discontinuation of dormancy is from −2 °C to 14 °C [113]. High temperatures offset previously accumulated chilling, and moderate temperatures can intensify chilling accumulation. It is a model introducing the term of intermediate product, developed under the influence of effective temperatures of winter chill. It can be destroyed after exposure to high temperatures. However, after the accumulation of the threshold chilling amount of such an intermediate product, it is irreversibly accumulated. Summing up 'chilling portions' in the autumn–winter period allows for the accumulation of chill necessary for the stop of winter dormancy. Similarly, temperatures at different times of the season can have very different effects on chill accumulation. This complex model appears more accurate in the conditions of climate warming [123]. This model was successfully applied by Erez et al. [113] to determine the dormancy of the peach bud.

The above models are an example of models with low realism, as they are based on long-term observations in natural conditions, and not on physiological processes occurring in plants. Thus, they fail under certain environmental conditions. The dormancy state is a process that is influenced by various integrated elements and their interaction determines the moment when the dormancy state is released. Therefore, Fuchigami and Wisniewski [114] proposed the Degree Growth Stage (°GA) model as an example of ontogenetic development of temperate woody plants. The numerical system (0–360) used in °GS divides bud development into numerical units, where 0° to 180°GS = paradormancy, 180°–315°GS = endodormancy, 315°–360°GS = ecodormancy. Unlike many phenological models that predict the timing of major point events, the °GS conceptual model lends itself to creating realistic models that relate to physiological processes.

4. Practical Application of Temperature Indices in Horticulture

4.1. Grapevine (Vitis vinifera L.)

Grapevine is sensitive to the occurring air temperature at every stage of development (during flowering, growth, and fruit ripening). The harvest yield, uniform ripening, and consistent wine quality depend on temperature during flowering [137]. The proper course of flowering occurs at minimum mean daily temperatures of 15 °C. Lower temperatures prolong flowering, resulting in evident yielding reduction, and variable pollination terms increase the share of small and slowly ripening fruits [138]. Cultivars originating from *Vitis vinifera* have high thermal requirements, and need high temperatures already before flowering. Moreover, variable temperatures during ripening disturb the accumulation of reserve compounds: sugars and acids, strongly affecting the taste of the grapes through the disturbance of proportions between them [25]. The production of aromatic compounds is also affected, whereas the three aforementioned groups of compounds are key in wine production [139].

According to White et al. [140], calculation the growing season base at 10 °C growing degree day summation is of key importance in grape production. Its variability determines the variability of growth and yielding of plants in particular growing seasons. Grapevine cultivation has long employed the index of forcing accumulation during vegetation, i.e., SAT [74]. The criterion is particularly useful in the selection of the grapevine cultivar for cultivation in a given region. Particular cultivars considerably differ in requirements in terms of the SAT value until reaching full maturity (Table 8). SAT is calculated when daily temperatures means are equal or higher than 10 °C from the period 1 April to 31 October. SAT and GDD values precisely determine the ripening potential of particular grapevine cultivars in a given region (Table 9). GDD in viticulture is call Winkler index, and it is one among many indices that are used to describe temperature conditions adequate for grape-growing [141].

Table 8. Optimal SAT values for particular classified cultivars, depending on the term of their ripening.

SAT	Cultivars
2000–2200 °C	Very early-ripening
2200–2500 °C	Early-ripening
2500–2700 °C	Mid-early ripening
2700–2900 °C	Late-ripening
>2900 °C	Very late-ripening

Table 9. Classifications of suitability of regions for grapevine cultivation based on SAT and GDD.

SAT	GDD	The Suitability of the Region
<2500 °C	<945 °C	Appropriate suitability for cultivation of very early and early ripening cultivars
2500–2900 °C	945–1164 °C	Proper suitability for moderately early and late ripening cultivars
>2900 °C	>1164 °C	Proper suitability for very late ripening cultivars

Several other indicators based on heat load (daily cumulative temperature above the 10 °C threshold for a certain period of time) and the temperature requirements of the vines were also developed [104]. One of them is the Heliothermal index of Huglin (HI). The HI provides information regarding heliothermal and sugar potential. According to Tonietto and Carbonneau [142], is more pertinent to the qualitative factors such as berry sugar potential.

$$\mathrm{HI} = \sum_{IV\ 1st}^{IX\ 30th} \frac{(\mathrm{Tmax} - 10\ ^\circ\mathrm{C}) + (\mathrm{TD} - 10\ ^\circ\mathrm{C})}{2} \mathrm{d}$$

TD—mean air temperature (according to the formula TD2 from Table 3).

d—length of day coefficient ranging from 1.02 to 1.06 between 40° and 50° of latitude. The increase in day length during the growing season increases potentially relative to an increase in latitude [143].

In order to improve the assessment of the quality potential of grapes, especially in relation to secondary metabolites (polyphenols, aromas) in grapes, the cool night index (CI) was introduced [142].

$$\mathrm{CI} = \sum_{IX\ 1st}^{IX\ 30th} \frac{T\ min}{30}$$

Gladstones [144] used Biologically Effective Degree Days (BEDD or E °C) to classify grape varieties according to maturity. BEDD include heat accumulation that is defined by maximum and minimum temperature thresholds (between 10 and 19 °C), and the BEDD formula also modifies heat accumulation for diurnal ranges.

The GDD formula has also been used for the determination of the values of base temperatures of important phenological phases for grapevines, namely bursting of buds and flowering. Oliviera [112] applied several statistical methods based on GDD, and found that the determination of the base temperature of the aforementioned phases is the most precise in the case of application of standard deviation, where GDD is calculated based on mean air temperature. According to the author, the base temperature of bud bursting is 8.7 °C, and flowering 10.7 °C.

According to Jones et al. [139], due to global warming, regions of production of high quality grapes are on their climatic range boundaries. Koźmiński et al. [95], analyzing SAT, found that 60% of the territory of Poland has conditions favorable for intensive grape cultivation. Progress in global warming has resulted in a change in the current limit of intensive grapevine cultivation in the north of Poland (approximately 150 km). The greatest increase in the SAT value has been recorded in the south-west and west of Poland. A considerably lower increase has been observed in the south-east and east, probably due to the fact that it is an area of continental climate, with a boundary that runs through the center of Poland [145]. Kryza et al. [73] observed that in the south-western part of Poland in the period 1971–2010, considerable changes occurred in the values of the SAT and GDD indices that describe the accumulation of forcing necessary for grapevine cultivation. Szyga-Pluta had similar observations when determining GDD, LTI, and SAT in the period 1966–2020. The study period showed an increase in the values of all agroclimatic indices and air temperature during the growing season, suggesting an increase in the thermal resources in the territory of Poland. [146]. As a result of changes in climate, the region is currently suitable for cultivation of more demanding cultivars. Based on historical climatic data and model simulation of future climate conditions, Jones et al. [139] determined that the region of optimal cultivation in the south of Europe will continue to shrink. In some regions, warming may exceed the maximum temperature threshold specific for a given cultivar.

The length of the growing season is very dependent on latitude. This was found to be a better indicator of climate suitability than the GDD system. Jackson [147] found that the LTI is better for comparing the suitability of a region for grape ripening than the use of degree days, especially for areas with cool climates.

4.2. Apple (Malus Domestica Borkh.)

Processes considered in the cultivation of apple trees are extended over time, due to the period from setting flower buds to yielding. The intensity of flowering is determined by the number of produced flower buds, and that process occurs in the preceding year, hence temperature conditions are of importance already at that time. Temperature affects the initiation of flower buds, and in the following year the date and intensity of flowering, pollination, and fruit setting. In addition, it determines the growth of fruits, their ripening, and the quality of the harvest.

Many studies conducted under field conditions [148–150], as well as under controlled temperature [3], point to a strong positive correlation between temperature and the period from flowering to harvest. Stanley et al. [151], conducting research on 'Royal Gala' apple cultivar in New Zealand, evidenced that GDD at a base temperature of 10 °C (GDD 10), determined from the moment of pollination over the following 50 days, was strongly correlated with the weight of apples 50 days after pollination. This confirms the hypothesis that potential maximum size of apples is determined up to 50 days after flowering. It depends on the number of cells, the division of which is affected by temperature and tree nutrition. The authors also evidenced that in the period from 10 to 30 days after full bloom, GDD was strongly correlated with the duration of the period from pollination to harvest.

According to Łysiak [85], the term of harvest of apples of the 'Šampion' and 'Ligol' cultivars can be determined by means of SAT. It only requires precise determination of the term of full bloom and continuous measurement of mean daily temperatures. He proposed 0 °C as the base temperature in the conditions of central-west Poland. For higher base temperatures, the standard deviation increased. SAT necessary for obtaining collective ripening of apples from the 'Ligol' cultivar was 2600 °C, and for 'Šampion' 2550 °C. This method, however, may not be as effective in another location, because the phenophases of particular cultivars may respond differently to environmental conditions [152].

Viškelis et al. [153], analyzing SAT, found the index to be strongly correlated with the ability to accumulate polyphenols in apples. The analysis of the content of polyphenolic compounds in fruit from the 'Auksis' and 'Ligol' cultivars showed that an increase in the content of these substances is inversely proportional to SAT. The index gradually decreased with a reduction in the growing period duration. According to research, greater accumulation of polyphenolic compounds occurs in stress conditions such as drought, diseases, and pest infestations, or lack of nutrients [145,154,155]. Estonia has less favorable conditions for apple tree cultivation than Poland, located approximately 400 km to the south. Due to the more difficult growth conditions, fruit of the 'Auksis' and 'Ligol' cultivars in Estonia accumulated 139% and 77% more phenolic compounds, respectively, than those grown in Poland [153]. This confirms the effect of temperature on changes in the patterns of accumulation of bioactive compounds.

Another important feature related to temperature is the duration of the dormant period in apple trees (Figure 1). Dormancy of trees in temperate climate ends in spring, after the tree was subjected to appropriately long chilling during winter. It is determined by the minimum sum of chilling hours required to break the dormancy of vegetative buds of the apple tree [156]. The optimal chilling temperature depends on the cultivar, the location, and the intensity of dormancy [86,157]. Putti et al. [158] also report differences in base temperatures between apple tree cultivars. According to the authors, apple cultivars differ in the duration of the necessary low temperature period that initiates breaking dormancy.

They identified cultivars with low requirements regarding chilling, where the range of low effective temperatures was from 3 to 12 °C, and cultivars with high chilling requirements, with a range of low effective temperatures from 3 to 6 °C.

4.3. Pear (Pyrus communis L., Pyrus Pyrifolia Nakai)

Pear trees grow and yield well in temperate climate. Pear cultivation at a larger scale has developed in regions where temperature in winter does not fall below −27 °C, and in summer does not exceed 32 °C. Despite the thermophilic character of the species, proper development and fruiting of popular pear cultivars (originating from *P. communis*) requires approximately 400–800 chilling hours (temperature below 7 °C). Some cultivars, however, require more than 1050 chilling hours, e.g., 'Bartlett' [35], whereas others (originating from *P. pyrifolia*), e.g., 'Patharnakh' and 'Punjab Beauty' only need 150–200 h [159].

According to Łysiak [87], SAT can be useful for the determination of the term of pear harvest. The author evidenced that measurements are the most precise at a base temperature of 0 °C. The duration of the harvest window is minimum 5 days. Twelve years of research showed that pear of the 'Conference' cultivar in the conditions of west Poland was ready for harvest when the SAT value in the period from full bloom to harvest was 2469 °C, and the standard deviation was only 20°.

Drapper et al. [160] defined the period of winter dormancy as chilling (in autumn), full dormancy (in winter) and forcing (in spring). In the study, they used the selected and dynamic + growing degree hour (GDH) phenological models and their sensitivity to parameter optimization. They noted that the acceleration of flowering under the influence of higher temperatures during winter dormancy was greater for pear cv. 'Conference' than for apple trees cv. 'Jonagold'.

4.4. Peach (Prunus persica L.)

Despite its sensitivity to frost damage in winter, peach grows well in temperate climate, and the differences in thermal requirements between cultivars are substantial. Peach cultivars that require a short chilling period (50–300 h) at a temperature below 7.2 °C prefer low temperature in winter and high temperature (30 °C) in summer to obtain appropriately ripe fruit [38]. Cultivars with moderate chilling requirements need from 300 to 525 chilling hours, and those with high requirements from 525 to 1390 h [116,161]. In comparison to other stone fruits, peach is tolerant of higher temperatures in summer, and its fruit ripening requires temperatures of more than 24 °C. Climate changes involving an increase in temperatures in winter may result in shrinking of regions suitable for peach cultivation. In the south-eastern part of the USA, in the state of Georgia in 2017, drastic twice-lower yielding of peach was recorded in comparison to the preceding year due to the shortening of the chilling period necessary for appropriate development of the fruit by 200 h.

Peaches respond with weaker resistance of buds to frost in winter, if in the period from 15 October to 31 December the maximum air temperature exceeds 18 °C. It also results in disturbances in entering the dormancy period. The resistance of cells to frost is directly determined by the accumulation of reserve substances in the vacuoles. Their high concentration decreases the freezing point of plant tissues [9]. A properly prepared peach tree for winter dormancy can survive temperature declines in winter of up to −25 °C. A warm winter caused early development of buds, making them more susceptible to spring damage. The assessment of the risk of excessively early development employed the GDD formula. It was determined that if from 15 February to the last day with a critical temperature of −1.7 °C the GDD value exceeds 335, the risk of damage of excessively developed buds or flowers is very high [82].

In the Czech Republic, Litschmann et al. [80] observed that the term of start of particular phenological phases in peaches is strongly dependent on temperature above 7 °C, measured from 1 January. This dependency was even observed in years with exceptionally high temperatures. The dependency between SAT 7 and bursting of flower buds (start of phenophase 01 according to BBCH) permits planning and scheduled spraying against peach leaf curl, even in seasons with different weather conditions. The authors emphasized a close correlation between the value of SAT 7 counted for 2 months from the onset of flowering, and the number of days from flowering to fruit harvest. This allows for precise determination of the term of peach harvest.

4.5. Sour (Prunus cerasus L.) and Sweet Cherry (Prunus avium L.)

Like other fruit trees in temperate climate, sour and sweet cherries require an appropriate amount of "chilling units" in autumn and winter to break winter dormancy. After meeting the chilling condition, the trees enter the period of relative dormancy during which dormancy is only determined by unfavorable environmental conditions (temperature, duration of the day, etc.). In that period, higher temperatures break winter dormancy and promote the development and growth of trees [115]. Guak and Neilsen [84] analyzed the effect of temperature in controlled and natural conditions on the end of the dormancy period in sweet cherry of the 'Sweetheart' cultivar. Shoots for the experiment were collected before the dormancy period, and subjected to a constant effect of 7 temperatures in a range from −2 to 16.8 °C. The study showed that the optimum chilling temperature for the analyzed sweet cherry cultivar is within the range from −2 to 7 °C, and temperature above 13 °C has no chilling effect. For all processes required for the dormancy period to occur in the plant, the value of chilling units needs to reach 740.

Zavalloni et al. [97] developed a simulation model based only on temperature data that can be useful for producers in increasing the accuracy of decision making regarding pest control, fertilization, or irrigation. They developed formulas based on GDD values at a base temperature of 4 °C, permitting the determination of terms of particular stages of development of flower buds and fruits of sour cherry of the 'Montmorency' cultivar. The differences between the predicted and observed dates varied in a maximum of 4 days.

Persely et al. [98] developed a similar simulation model for three Hungarian sour cherry cultivars, namely 'Debreceni Bőtermő', 'Újfehértói Fürtös', and 'Kántorjánosi 3′. They employed the GDD formula at a base temperature of 2.5 or 5 °C. The analyzed cultivars in the study years did not differ in GDD values determined for bursting of flower buds, but significant differences occurred between years. In one of the seasons, bursting of flower buds occurred at GDD equal to 17.5 °C, and in another at 39.7 °C. Responses to a given temperature were determined to depend on the physiological stage of the tissues and previously occurring environmental conditions [162,163].

4.6. Strawberry (Fragaria x Ananassa Duchesne)

The yielding potential of particular strawberry cultivars strongly depends on the mutual effect of day duration and temperature. Strawberry cultivars show high genetic variability, and therefore different responses to the shortening of day duration and course of temperature. Temperature has a strong and variable effect of the generative processes in strawberries. At low temperatures (below 10 °C), the short day genotypes and those neutral towards day duration show no response to the photoperiod, and at higher temperatures, a reduction in day duration below 14 h induces the onset of flowering. Everbearing cultivars induce flowering in the conditions of a long day, i.e., throughout summer. In the conditions of a short day, at an increase in temperature to 24 °C, strawberries respond with intensified production of flower buds. The range of the inducing temperatures is from 12 to 22 °C. Below and above that range, the effectiveness of the inducive effect of a short day on the production of inflorescences in strawberries decreases. In the case of everbearing cultivars, inflorescences are initiated irrespective of day duration in a range of temperatures from 10 to 28 °C [164].

According to Tanino and Wang [165], flowering term is correlated with the accumulation of chilling hours, and fruit yield is correlated with cumulative chilling units. The authors concluded that strawberry may be affected by more complex environmental factors than its flowering. The effect of temperature during the chilling period on yielding is indirect, because it depends on the term of flowering, nutrition of the plants, and growth rate of the vegetative parts [166]. Moreover, different optimum chilling temperatures apply to the vegetative development, yielding, and fruit quality [47].

The subject of the study was also the determination of the dependencies of vegetative growth of strawberry on temperature. Description of the development of strawberry leaves applies the terms phyllochron and plastochron. According to Bonhomme [111], phyllochron is duration of time (usually in days) between the appearance of two subsequent leaves. Plastochron stands for the time duration between the initiation of two subsequent leaves. Mendonça at al. [164], using a model of linear regression between GDD at a base temperature of 7 °C and number of leaves in the crown of the strawberry, introduced the term phyllotherm expressed in $^{\circ}\text{day}^{-1}$ (degree day). The studied cultivars varied in terms of the phyllotherm values from $60.38^{\circ}\text{day}^{-1}$ (cv. 'Ventana') to $199.96^{\circ}\text{day}^{-1}$ (cv. 'Albion'). Based on GDD, Bethere et al. [93] developed a phenological model for strawberries. They then used it to predict the timing of phenological processes in strawberries in the period 1951–2099. The results of their research show that an acceleration of physiological processes can be expected in the future, contributing to a change in regionalization of strawberry cultivation.

4.7. Raspberry (Rubus idaeus L.) and Blackberry (Rubus fruticosus L.)

Raspberry and blackberry show an active response to temperature in adjusting the term of flowering and fruit ripening. American research has shown that the northern range of cultivation of primocane fruiting raspberries was closely correlated with the accumulation of forcing units at a base temperature of 5 °C [167]. Privé et al. [168] analyzed the effect of climatic conditions on the development and growth of the vegetative and generative parts of primocane-fruiting raspberries. The effect of climatic factors, such as insolation, duration of the day, availability of water, GDD, and soil and air temperature, were estimated based on the analysis of multiple regression coefficients. The effect of air temperature and insolation was the strongest during initiation of flower development, i.e., in June and July, and day duration was the most significant from June to October. Climatic conditions to the greatest degree determined parameters such as the number of fruits, their weight, and harvest yield, whereas the total number of nodes on a stem and term of harvest proved the least dependent. Particular raspberry cultivars showed different responses to climatic conditions. The 'Autumn Bliss' cultivar proved less sensitive than 'Heritage' or 'Redwing'.

The blackberry growing in the zone of temperate climate enters the dormant phase due to the shortening of the day and the low temperatures in autumn, and the phase ends after the completion of the necessary winter chilling [169]. Bursting of buds of floricane-fruiting blackberries occurs at the turn of March and April. Fruiting shoots grow out of the auxiliary buds on two-year shoots and lateral shoots. Over the following 4–5 weeks, the inflorescences develop on the fruiting lateral shoots, and flower buds on the inflorescence open from mid-May to mid-June. Jennings [75] compared the terms of flowering and fruit ripening of several genetically variable blackberries. The accumulated forcing units (temperature above 6 °C) proved strongly correlated with the term of fruit ripening.

Based on phenological observations, Black et al. [90] tested linear and curve prediction models with the application of the range of cardinal temperatures. They determined that the flowering term under field conditions is best predicted by a linear model with a base and an optimal temperature [89] of 6 and 25 °C, and curve model with a base and an optimal temperature of 4 and 27 °C. Based on the linear increase in degree days (GDH), the authors determined that from the moment of flowering, the 'Chicksaw' cultivar needs 9200 GDH, and 'Merton Thornless 18,900 GDH.

4.8. Other Species

Temperature indices can be useful in the introduction of new species and cultivars to cultivation. Ishchuk et al. [91] used GDD and SAT to describe the biorhythm of six species from genus *Juglans*, namely *J. nigra*, *J. cinerea*, *J. rupestris*, *J. major*, *J. californica*, and *J. hindsii*. Based on GDD, they compared the terms of flower bud swelling and bursting. SAT was applied in the comparison of term of onset and end of flowering, fruit setting, and fruit ripening. In combination with observations of resistance to frosts depending on the degree of winter dormancy, they determined the usefulness of the aforementioned species for plantings in the Ukrainian Right-bank Forest-Steppe. Based on SAT above 5 °C, Mirotadze et al. [89] divided cultivars of hazel (*Corylus avellana*) cultivated in Georgia into early ripening—SAT from 1800 to 2200 °C, medium early ripening—SAT from 2200 to 2600 °C, and late ripening—SAT from 2600 to 3000 °C.

5. Conclusions

Temperature is an important factor determining fruit plant production, both in the growing season and in the winter dormant period. Dependencies on temperature are observed in pathogens and pests of fruit plants. This factor determines the time of occurrence of fungi and insects that poses a potential threat to the health condition of the quality of the cultivated plants and the obtained fruits.

The close correlation of this parameter with processes occurring in living organisms permitted the development of methods used for the description and prediction of the occurrence of particular phenological phases of fruit plants. Various air temperature indicators were developed in a way that allowed the best possible description of adaptations of species, cultivars, and region of cultivation adaptations. Among the indicators described, Growing Degree Days is the most frequently used in research. They are based on experimentally obtained data and calculated optimum temperatures of growth and development of plants at particular development stages. Proper interpretation of the effect of temperature on the development of the analyzed plants requires detailed determination of all elements used for the calculation of the index. The limitation of the use of temperature indicators is also the fact that particular fruit species, and even cultivars, show different responses to the occurring range of temperatures by entering particular phenological phases.

Temperature conditions of a given region should be of key importance for the selection of species for commercial cultivation and planning of protection measures. Climate change is clearly observed in many parts of the world. The developed models can be used to simulate conditions in the context of the progressing climate warming. Changes in the distribution of temperatures also translate into increased expansion of many diseases and pests, as well as invasive species. Therefore, the presented review, evaluating and providing a set of specific indicators, is important for producers.

Author Contributions: Conceptualization, G.P.Ł. and I.S.; investigation, G.P.Ł. and I.S.; resources, G.P.Ł. and I.S.; data curation, G.P.Ł. and I.S.; writing—original draft preparation, G.P.Ł. and I.S.; writing—review and editing, G.P.Ł. and I.S.; visualization, G.P.Ł. and I.S.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Data available on request.

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

References

1. Fang, J.-Y.; Ohsawa, M.; Kira, T. Vertical Vegetation Zones along 30° N Latitude in Humid East Asia. *Vegetatio* **1996**, *126*, 135–149. [CrossRef]
2. Smale, M.C.; Wiser, S.K.; Bergin, M.J.; Fitzgerald, N.B. A Classification of the Geothermal Vegetation of the Taupō Volcanic Zone, New Zealand. *J. R. Soc. N. Z.* **2018**, *48*, 21–38. [CrossRef]
3. Warrington, I.J.; Fulton, T.A.; Halligan, E.A.; de Silva, H.N. Apple Fruit Growth and Maturity Are Affected by Early Season Temperatures. *J. Am. Soc. Hortic. Sci.* **1999**, *124*, 468–477. [CrossRef]
4. Kozlowski, T.T.; Pallardy, S.G. Acclimation and Adaptive Responses of Woody Plants to Environmental Stresses. *Bot. Rev.* **2002**, *68*, 270–334. [CrossRef]

5. Núñez-Elisea, R.; Davenport, T.L. Flowering of Mango Trees in Containers as Influenced by Seasonal Temperature and Water Stress. *Sci. Hortic.* **1994**, *58*, 57–66. [CrossRef]
6. Rodrigo, J. Spring Frosts in Deciduous Fruit Trees—Morphological Damage and Flower Hardiness. *Sci. Hortic.* **2000**, *85*, 155–173. [CrossRef]
7. Proebsting, E.L.; Mills, H.H. Low Temperature Resistance of Developing Flower Buds of Six Deciduous Fruit Species1. *J. Am. Soc. Hortic. Sci.* **1978**, *103*, 192–198. [CrossRef]
8. Chitu, E.; Paltineanu, C. Phenological and Climatic Simulation of the Late Frost Damage in Cherry and Sour Cherry in Romania. *Acta Hortic.* **2006**, *707*, 109–117. [CrossRef]
9. Łysiak, G.; Kurlus, R.; Michalska-Ciechanowska, A. Increasing the Frost Resistance of 'Golden Delicious', 'Gala' and 'Šampion' Apple Cultivars. *Folia Hortic.* **2016**, *28*, 125–135. [CrossRef]
10. Palonen, P.; Buszard, D. Current State of Cold Hardiness Research on Fruit Crops. *Can. J. Plant Sci.* **1997**, *77*, 399–420. [CrossRef]
11. Dziedzic, E.; Błaszczyk, J. Evaluation of Sweet Cherry Fruit Quality after Short-Term Storage in Relation to the Rootstock. *Hortic. Environ. Biotechnol.* **2019**, *60*, 925–934. [CrossRef]
12. Kowalczyk, B.A.; Bieniasz, M.; Kostecka-Gugała, A. Flowering Biology of Selected Hybrid Grape Cultivars under Temperate Climate Conditions. *Agriculture* **2022**, *12*, 655. [CrossRef]
13. Faust, M.; Erez, A.; Rowland, L.J.; Weng, S.Y.; Norman, H.A. Bud Dormancy in Perennial Fruit Trees: Physiological Basis for Dormancy Induction, Maintenance, and Release. *HortScience* **1997**, *32*, 623–627. [CrossRef]
14. Bieniasz, M.; Konieczny, A.; Błaszczyk, J.; Nawrocki, J.; Kopeć, M.; Mierzwa-Hersztek, M.; Gondek, K.; Zaleski, T.; Knaga, J.; Pniak, M. Titanium Organic Complex Improves Pollination and Fruit Development of Remontant Strawberry Cultivars under High-Temperature Conditions. *Agriculture* **2022**, *12*, 1795. [CrossRef]
15. Błaszczyk, J.; Bieniasz, M.; Nawrocki, J.; Kopeć, M.; Mierzwa-Hersztek, M.; Gondek, K.; Zaleski, T.; Knaga, J.; Bogdał, S. The Effect of Harvest Date and Storage Conditions on the Quality of Remontant Strawberry Cultivars Grown in a Gutter System under Covers. *Agriculture* **2022**, *12*, 1193. [CrossRef]
16. Bieniek, A.; Draganska, E.; Pranckietis, V. Assesment of Climatic Conditions for Actinidia Arguta Cultivation in North-Eastern Poland. *Zemdirb.-Agric.* **2016**, *103*, 311–318. [CrossRef]
17. Kowalczyk, W.; Wrona, D. Growth and Bearing of Apple Cultivar "Elise" on Eighteen Vegetative Rootstocks in 'V' Planting System. *Acta Sci. Pol. Hortorum Cultus* **2011**, *10*, 125–135.
18. Rutkowski, K.; Łysiak, G.P. Thinning Methods to Regulate Sweet Cherry Crops—A Review. *Appl. Sci.* **2022**, *12*, 1280. [CrossRef]
19. Sitarek, M. Evaluation of Selected Apricot Cultivars Based on Many Years of Research in the Collection of RIH in Skierniewice, Poland. *Acta Hortic.* **2020**, *1290*, 155–158. [CrossRef]
20. Sosna, I.; Kortylewska, D. Evaluation of Several Less Known Pear (*Pyrus communis* L.) Cultivars in the Climatic Conditions of Lower Silesia. *Acta Agrobot.* **2012**, *65*, 157–162. [CrossRef]
21. Stefaniak, J.; Sawicka, M.; Krupa, T.; Latocha, P.; Łata, B. Effect of Kiwiberry Pre-Storage Treatments on the Fruit Quality during Cold Storage. *Zemdirb. Agric.* **2017**, *104*, 235–242. [CrossRef]
22. Tomala, K. Orchard Factors Affecting Nutrient Content and Fruit Quality. *Acta Hortic.* **1997**, *448*, 257–264. [CrossRef]
23. Erez, A. Bud Dormancy; Phenomenon, Problems and Solutions in the Tropics and Subtropics. In *Temperate Fruit Crops in Warm Climates*; Erez, A., Ed.; Springer: Dordrecht, The Netherlands, 2000; pp. 17–48. ISBN 978-90-481-4017-6.
24. Szot, I.; Łysiak, G.P. Effect of the Climatic Conditions in Central Europe on the Growth and Yield of Cornelian Cherry Cultivars. *Agriculture* **2022**, *12*, 1295. [CrossRef]
25. Hunter, J.J.; Bonnardot, V. Suitability of Some Climatic Parameters for Grapevine Cultivation in South Africa, with Focus on Key Physiological Processes. *S. Afr. J. Enol. Vitic.* **2016**, *32*, 137–154. [CrossRef]
26. Heide, O.M.; Rivero, R.; Sønsteby, A. Temperature Control of Shoot Growth and Floral Initiation in Apple (Malus × Domestica Borkh.). *CABI Agric. Biosci.* **2020**, *1*, 8. [CrossRef]
27. Luedeling, E.; Guo, L.; Dai, J.; Leslie, C.; Blanke, M.M. Differential Responses of Trees to Temperature Variation during the Chilling and Forcing Phases. *Agric. For. Meteorol.* **2013**, *181*, 33–42. [CrossRef]
28. Marra, F.P.; Inglese, P.; DeJong, T.M.; Johnson, R.S. Thermal Time Requirement and Harvest Time Forecast for Peach Cultivars with Different Fruit Development Periods. *Acta Hortic.* **2002**, *592*, 523–529. [CrossRef]
29. Sønsteby, A.; Heide, O.M. Temperature Effects on Growth and Floral Initiation in Sweet Cherry (*Prunus avium* L.). *Sci. Hortic.* **2019**, *257*, 108762. [CrossRef]
30. Wang, S.Y.; Camp, M.J. Temperatures after Bloom Affect Plant Growth and Fruit Quality of Strawberry. *Sci. Hortic.* **2000**, *85*, 183–199. [CrossRef]
31. Sønsteby, A.; Heide, O.M. Effects of Photoperiod and Temperature on Growth and Flowering in the Annual (Primocane) Fruiting Raspberry (*Rubus idaeus* L.) Cultivar 'Polka'. *J. Hortic. Sci. Biotechnol.* **2009**, *84*, 439–446. [CrossRef]
32. Bucur, G.M.; Babes, A.C. Research on Trends in Extreme Weather Events and Their Effects on Grapevine in Romanian Viticulture. *Bull. Univ. Agric. Sci. Vet. Med. Cluj-Napoca Hortic.* **2016**, *73*, 126. [CrossRef]
33. Galasheva, A.; Krasova, N. Study of Frost Resistance and Drought Resistance of Apple Tree Varieties of VNIISPK Breeding on Clonal Rootstock 54–118. *E3S Web Conf.* **2021**, *254*, 01005. [CrossRef]
34. Dalhaus, T.; Schlenker, W.; Blanke, M.M.; Bravin, E.; Finger, R. The Effects of Extreme Weather on Apple Quality. *Sci. Rep.* **2020**, *10*, 7919. [CrossRef] [PubMed]

35. Kretzschmar, A.A.; Brighenti, L.M.; Rufato, L.; Pelizza, T.R.; Silveira, F.N.; Miquelutti, D.J.; Faoro, I.D. Chilling Requirement for Dormancy Bud Break in European Pear. *Acta Hortic.* **2011**, *909*, 85–88. [CrossRef]
36. Szewczuk, A.; Gudarowska, E.; Dere, D. The Estimation of Frost Damage of Some Peach and Sweet Cherry Cultivars After Winter 2005–2006. *J. Fruit Ornam. Plant Res.* **2007**, *15*, 55–63.
37. Carpenedo, S.; Raseira, M.C.B.; Byrne, D.H.; Franzon, R.C. The Effect of Heat Stress on the Reproductive Structures of Peach. *J. Am. Pomol. Soc.* **2017**, *71*, 112–118.
38. Souza, A.P.D.; Leonel, S.; Silva, A.C.d. Basal Temperature and Thermal Sum in Phenological Phases of Nectarine and Peach Cultivars. *Pesqui. Agropecuária Bras.* **2011**, *46*, 1588–1596. [CrossRef]
39. Caprio, J.M.; Quamme, H.A. Influence of Weather on Apricot, Peach and Sweet Cherry Production in the Okanagan Valley of British Columbia. *Can. J. Plant Sci.* **2006**, *86*, 259–267. [CrossRef]
40. Ozherelieva, Z.; Prudnikov, P.; Zubkova, M. Estimation of the Frost Resistance of the Strawberry. *Biol. Commun.* **2020**, *65*, 288–296. [CrossRef]
41. Kesici, M.; Gulen, H.; Ergin, S.; Turhan, E.; Ipek, A.; Koksal, N. Heat-Stress Tolerance of Some Strawberry (Fragaria × Ananassa) Cultivars. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2013**, *41*, 244. [CrossRef]
42. Rachenko, M.A.; Kiseleva, E.N.; Rachenko, A.M.; Kuznetsov, A.A. Winter Hardiness of Remontant Raspberry under Field and Controlled Conditions. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1112*, 012100. [CrossRef]
43. Islamov, S.; Zuftarov, E. Study of Heat Resistance of Raspberry Varieties. *Eur. J. Agric. Rural Educ.* **2022**, *3*, 1–3.
44. Dumanoglu, H.; Erdogan, V.; Kesik, A.; Dost, S.E.; Delialioglu, R.A.; Kocabas, Z.; Ernim, C.; Macit, T.; Bakir, M. Spring Late Frost Resistance of Selected Wild Apricot Genotypes (*Prunus armeniaca* L.) from Cappadocia Region, Turkey. *Sci. Hortic.* **2019**, *246*, 347–353. [CrossRef]
45. Kaya, O.; Kose, C.; Esitken, A.; Gecim, T.; Donderalp, V.; Taskin, S.; Turan, M. Frost Tolerance in Apricot (*Prunus armeniaca* L.) Receptacle and Pistil Organs: How Is the Relationship among Amino Acids, Minerals, and Cell Death Points? *Int. J. Biometeorol.* **2021**, *65*, 2157–2170. [CrossRef]
46. Takeda, F.; Glenn, D.M. United States Department of Agriculture, Agricultural Research Service, Appalachian Fruit Research Station, Kearneysville, USA Susceptibility of Blackberry Flowers to Freezing Temperatures. *Eur. J. Hortic. Sci.* **2016**, *81*, 115–121. [CrossRef]
47. Lieten, P. Chilling Unit Model for Greenhouse Production of Strawberry cv. 'Elsanta'. *Acta Hortic.* **2006**, *1*, 381–388. [CrossRef]
48. Pliny the Elder. *Natural History*; Harvard University Press: Cambridge, MA, USA, 1938; Volume 1.
49. Snyder, R.L.; Spano, D.; Duce, P.; Cesaraccio, C. Temperature Data for Phenological Models. *Int. J. Biometeorol.* **2001**, *45*, 178–183. [CrossRef]
50. Jailloux, F.; Thind, T.; Clerjeau, M. Release, Germination, and Pathogenicity of Ascospores of *Uncinula Necator* under Controlled Conditions. *Can. J. Bot.* **1998**, *76*, 777–781. [CrossRef]
51. Turley, M.; Granett, J.; Omer, A.D.; De Benedictis, J.A. Grape Phylloxera (Homoptera: Phylloxeridae) Temperature Threshold for Establishment of Feeding Sites and Degree-Day Calculations. *Environ. Entomol.* **1996**, *25*, 842–847. [CrossRef]
52. MacHardy, W.E.; Gadoury, D.M. A Model to Estimate the Maturity of Ascospores of Venturia Inaequalis. *Phytopathology* **1982**, *72*, 901–904.
53. Blomefield, T.L.; Giliomee, J.H. Effect of Temperature on the Oviposition, Longevity and Mating of Codling Moth, *Cydia pomonella* (L.) (*Lepidoptera*: *Tortricidae*). *Afr. Entomol.* **2011**, *19*, 42–60. [CrossRef]
54. Lāce, B.; Kārkliņa, K.; Deņisova, I. *Gymnosporangium Sabinae* Development Cycle—Peculiarities and Influencing Factors. *J. Phytopathol.* **2022**, *170*, 675–682. [CrossRef]
55. Simionca Mărcășan, L.I.; Hulujan, I.B.; Florian, T.; Alpar, S.P.; Militaru, M.; Sestras, A.F.; Oltean, I.; Sestras, R.E. The Importance of Assessing the Population Structure and Biology of Psylla Species for Pest Monitoring and Management in Pear Orchards. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2022**, *50*, 13022. [CrossRef]
56. Rossi, V.; Bolognesi, M.; Languasco, L.; Giosuè, S. Influence of Environmental Conditions on Infection of Peach Shoots by *Taphrina deformans*. *Phytopathology* **2006**, *96*, 155–163. [CrossRef] [PubMed]
57. Davis, J.A.; Radcliffe, E.B.; Ragsdale, D.W. Effects of High and Fluctuating Temperatures on Myzus Persicae (Hemiptera: Aphididae). *Environ. Entomol.* **2006**, *35*, 1461–1468. [CrossRef]
58. Ryan, G.D.; Emiljanowicz, L.; Wilkinson, F.; Kornya, M.; Newman, J.A. Thermal Tolerances of the Spotted-Wing Drosophila *Drosophila Suzukii* (Diptera: Drosophilidae). *J. Econ. Entomol.* **2016**, *109*, 746–752. [CrossRef]
59. Holb, I.J. Some Biological Features of Cherry Leaf Spot (*Blumeriella jaapii*) with Special Reference to Cultivar Susceptibility. *Int. J. Hortic. Sci.* **2009**, *15*, 91–93. [CrossRef]
60. Li, T.; Zhou, J.; Li, J. Combined Effects of Temperature and Humidity on the Interaction between Tomato and *Botrytis Cinerea* Revealed by Integration of Histological Characteristics and Transcriptome Sequencing. *Hortic. Res.* **2023**, *10*, uhac257. [CrossRef]
61. Stenseth, C. Effects of Temperature on Development of Otiorrhynchus Sulcatus (Coleoptera: Curculionidae). *Ann. Appl. Biol.* **1979**, *91*, 179–185. [CrossRef]
62. Carisse, O.; Meloche, C.; Boivin, G.; Jobin, T. Action Thresholds for Summer Fungicide Sprays and Sequential Classification of Apple Scab Incidence. *Plant Dis.* **2009**, *93*, 490–498. [CrossRef]
63. MacHardy, W.E.; Gadoury, D.M. A Revision of Mill's Criteria for Predicting Apple Scab Infection Periods. *Phytopathology* **1989**, *79*, 304–310. [CrossRef]

64. Wrzesień, M.; Treder, W.; Klamkowski, K.; Rudnicki, W.R. Prediction of the Apple Scab Using Machine Learning and Simple Weather Stations. *Comput. Electron. Agric.* **2019**, *161*, 252–259. [CrossRef]
65. Holb, I.J. Timing of First and Final Sprays against Apple Scab Combined with Leaf Removal and Pruning in Organic Apple Production. *Crop Prot.* **2008**, *27*, 814–822. [CrossRef]
66. Larrabee, M.M.A. *Environmental Effects on the Presence and Quality of Postharvest Fungal Pathogens on Sweet Cherry in the Okagan Valley. Master of Science in the College of Graduate Studies*; The University of British Columbia: Vancouver, BC, Canada, 2019.
67. Honěk, A.; Kocourek, F. Temperature and Development Time Insects: A General Relationship between Thermal Constans. *Zool. Jb. Syst.* **1990**, *117*, 401–439.
68. Baker, C.R.B.; Miller, G.W. The Effect of Temperature on the Post-Diapause Development of Four Geographical Populations of the European Cherry Fruit Fly (*Rhagoletis Cerasi*). *Entomol. Exp. Appl.* **1978**, *23*, 1–13. [CrossRef]
69. Jones, V.P.; Hilton, R.; Brunner, J.F.; Bentley, W.J.; Alston, D.G.; Barrett, B.; Van Steenwyk, R.A.; Hull, L.A.; Walgenbach, J.F.; Coates, W.W.; et al. Predicting the Emergence of the Codling Moth, *Cydia Pomonella* (Lepidoptera: Tortricidae), on a Degree-Day Scale in North America: Codling Moth Emergence in North America. *Pest Manag. Sci.* **2013**, *69*, 1393–1398. [CrossRef]
70. Samietz, J.; Graf, B.; Höhn, H.; Schaub, L.; Höpli, H.U. Phenology Modelling of Major Insect Pests in Fruit Orchards from Biological Basics to Decision Support: The Forecasting Tool SOPRA. *EPPO Bull.* **2007**, *37*, 255–260. [CrossRef]
71. Kamiyama, M.T.; Bradford, B.Z.; Groves, R.L.; Guédot, C. Degree Day Models to Forecast the Seasonal Phenology of Drosophila Suzukii in Tart Cherry Orchards in the Midwest U.S. *PLoS ONE* **2020**, *15*, e0227726. [CrossRef]
72. Rutkowski, K.; Łysiak, G.P.; Zydlik, Z. Effect of Nitrogen Fertilization in the Sour Cherry Orchard on Soil Enzymatic Activities, Microbial Population, and Fruit Quality. *Agriculture* **2022**, *12*, 2069. [CrossRef]
73. Kryza, M.; Szymanowski, M.; Błaś, M.; Migała, K.; Werner, M.; Sobik, M. Observed Changes in SAT and GDD and the Climatological Suitability of the Poland-Germany-Czech Republic Transboundary Region for Wine Grapes Cultivation. *Theor. Appl. Climatol.* **2015**, *122*, 207–218. [CrossRef]
74. Jones, G.V.; Davis, R.E. Climate Influences on Grapevine Phenology, Grape Composition, and Wine Production and Quality for Bordeaux, France. *Am. J. Enol. Vitic.* **2000**, *51*, 249–261. [CrossRef]
75. Jennings, D.L. Genotype-Environment Relationships for Repening Time in Blackberries and Prospects for Breeding an Early Ripening Cultivar for Scotland. *Euphytica* **1979**, *28*, 747–750. [CrossRef]
76. Chandler, W.H.; Tufts, W.P. Influence of the Rest Period on Opening of the Buds of Fruit Trees in Spring and on Development of Flower Buds of Peach Trees. *Proc. Amer. Soc. Hort. Sci.* **1933**, *10*, 180–186.
77. Chandler, W.H.; Brown, D.S.; Kimball, M.H.; Philip, G.L.; Tufts, W.P.; Weldon, G.P. Chilling Requirements for Opening of Buds on Deciduous Orchard Trees and Some Other Plants in California. *Calif. Agric. Exp. Stat. Bull* **1937**, *611*, 1–66.
78. Rafael, A.; Biasi, L.A. Base Temperature as a Function of Genotype: A Foundation for Modeling Phenology of Temperate Fruit Species. *Semina Ciênc. Agrár.* **2016**, *37*, 1811. [CrossRef]
79. Erez, A.; Lavee, S. The Effect of Climatic Conditions on Dormancy Development of Peach Buds. I. Temperature1. *J. Am. Soc. Hortic. Sci.* **1971**, *96*, 711–714. [CrossRef]
80. Litschmann, T.; Oukropec, I.; Křižan, B. Predicting Individual Phenological Phases in Peaches Using Meteorological Data. *Hortic. Sci.* **2008**, *35*, 65–71. [CrossRef]
81. Pérez-Pastor, A.; Ruiz-Sánchez, M.C.; Domingo, R.; Torrecillas, A. Growth and Phenological Stages of Búlida Apricot Trees in South-East Spain. *Agronomie* **2004**, *24*, 93–100. [CrossRef]
82. Winkler, J.A.; Burnett, A.W.; Skipper, B.J.; Moore, J.B.; Mulugeta, G.; Olson, J.M. Agroclimatic Resource Assessment: An Example for Peach Cultivation in the Lower Peninsula of Michigan. *Phys. Geogr.* **1990**, *11*, 49–65. [CrossRef]
83. Mahmood, K.; Carew, J.G.; Hadley, P.; Battey, N.H. Chill Unit Models for the Sweet Cherry Cvs Stella, Sunburst and Summit. *J. Hortic. Sci. Biotechnol.* **2000**, *75*, 602–606. [CrossRef]
84. Guak, S.; Neilsen, D. Chill Unit Models for Predicting Dormancy Completion of Floral Buds in Apple and Sweet Cherry. *Hortic. Environ. Biotechnol.* **2013**, *54*, 29–36. [CrossRef]
85. Łysiak, G. The Sum of Active Temperatures as a Method of Determining the Optimum Harvest Date of "Šampion" and "Ligol" Apple Cultivars. *Acta Sci. Pol.Hortorum Cultus* **2012**, *11*, 3–13.
86. Naor, A.; Flaishman, M.; Stern, R.; Moshe, A.; Erez, A. Temperature Effects on Dormancy Completion of Vegetative Buds in Apple. *J. Am. Soc. Hortic. Sci.* **2003**, *128*, 636–641. [CrossRef]
87. Łysiak, G.P. Degree Days as a Method to Estimate the Optimal Harvest Date of 'Conference' Pears. *Agriculture* **2022**, *12*, 1803. [CrossRef]
88. Spiegel-Roy, P.; Alston, F.H. Chilling and Post-Dormant Heat Requirement as Selection Criteria for Late-Flowering Pears. *J. Hortic. Sci.* **1979**, *54*, 115–120. [CrossRef]
89. Mirotadze, N.; Gogitidze, V.; Mikadze, N.; Goginava, L.; Mirotadze, M. Agro-Ecological Zones of Hazelnut in Georgia. *Acta Hortic.* **2009**, *845*, 291–294. [CrossRef]
90. Black, B.; Frisby, J.; Lewers, K.; Takeda, F.; Finn, C. Heat Unit Model for Predicting Bloom Dates in Rubus. *HortScience* **2008**, *43*, 2000–2004. [CrossRef]
91. Ishchuk, H.; Shlapak, V.; Ishchuk, L.; Bayura, O.; Kurka, S. Alien North American Species of the Walnut Genus (*Juglans* L.) in the Right-bank Forest-steppe of Ukraine and Their Use. *Trak. Univ. J. Nat. Sci.* **2021**, *22*, 77–92. [CrossRef]

92. García-Tejero, I.F.; López-Borrallo, D.; Miranda, L.; Medina, J.J.; Arriaga, J.; Muriel-Fernández, J.L.; Martínez-Ferri, E. Estimating Strawberry Crop Coefficients under Plastic Tunnels in Southern Spain by Using Drainage Lysimeters. *Sci. Hortic.* **2018**, *231*, 233–240. [CrossRef]
93. Bethere, L.; Sīle, T.; Seņņikovs, J.; Bethers, U. Impact of Climate Change on the Timing of Strawberry Phenological Processes in the Baltic States. *Est. J. Earth Sci.* **2016**, *65*, 48. [CrossRef]
94. Kowalski, W.; Nawalany, G. New Approach to Determine the Sum of the Active Temperatures (SAT) Exemplified by Weather Conditions of Western Malopolska. In *Infrastructure and Environment*; Krakowiak-Bal, A., Vaverkova, M., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 203–216. ISBN 978-3-030-16541-3.
95. Koźmiński, C.; Mąkosza, A.; Michalska, B.; Nidzgorska-Lencewicz, J. Thermal Conditions for Viticulture in Poland. *Sustainability* **2020**, *12*, 5665. [CrossRef]
96. Nagata, R.K.; Scarpare Filho, J.A.; Kluge, R.A. Temperatura Base e Soma Térmica (Graus-Dia) Para Videiras 'Brasil' e 'Benitaka'. *Rev. Bras. Frutic.* **2000**, *22*, 329–333.
97. Zavalloni, C.; Andresen, J.A.; Flore, J.A. Phenological Models of Flower Bud Stages and Fruit Growth of 'Montmorency' Sour Cherry Based on Growing Degree-Day Accumulation. *J. Am. Soc. Hortic. Sci.* **2006**, *131*, 601–607. [CrossRef]
98. Persely, S.; Szabó, T.; Ladányi, M. Budbreak Date of Cherry and Temperature Sums: A Model Approach. *Acta Hortic.* **2014**, *1020*, 247–256. [CrossRef]
99. Anderson, J.L.; Richardson, E.A.; Kesner, C.D. Validation Of Chill Unit And Flower Bud Phenology Models For "Montmorency" Sour Cherry. *Acta Hortic.* **1986**, *184*, 71–78. [CrossRef]
100. Kuśmierek-Tomaszewska, R.; Żarski, J.; Dudek, S. Comparison of Average Daily Air Temperature Calculated Based on Different Measurement Procedures. *Infrastruct. Ecol. Rural areas* **2013**, *1*, 109–121.
101. WMO. *Guide to Agricultural Meteorological Practices*; WMO: Geneva, Switzerland, 2012.
102. Prescott, A.J. The Climatology of the Vine (*Vitis Vinifera* l) 3. A Comparison of France and Australia on the Basis of the Warmest Month. *Trans. R. Soc. S. Aust.* **1969**, *93*, 7–19.
103. Sluys, S.L. Climatic Influences on the Grapevine: A Study of Viticulture in the Waipara Basin. Degree of Master of Science in Geography, University of Cantebury. 2006. Available online: https://library.wmo.int/index.php?lvl=notice_display&id=12113#.ZEibLc5Bw2w (accessed on 20 February 2023).
104. Badr, G.; Hoogenboom, G.; Abouali, M.; Moyer, M.; Keller, M. Analysis of Several Bioclimatic Indices for Viticultural Zoning in the Pacific Northwest. *Clim. Res.* **2018**, *76*, 203–223. [CrossRef]
105. Cesaraccio, C.; Spano, D.; Duce, P.; Snyder, R.L. An Improved Model for Determining Degree-Day Values from Daily Temperature Data. *Int. J. Biometeorol.* **2001**, *45*, 161–169. [CrossRef]
106. Roltsch, W.J.; Zalom, F.G.; Strawn, A.J.; Strand, J.F.; Pitcairn, M.J. Evaluation of Several Degree-Day Estimation Methods in California Climates. *Int. J. Biometeorol.* **1999**, *42*, 169–176. [CrossRef]
107. Tijskens, L.M.M.; Verdenius, F. Summing up Dynamics: Modelling Biological Processes in Variable Temperature Scenarios. *Agric. Syst.* **2000**, *66*, 1–15. [CrossRef]
108. Sarker, R.A.; Newton, C.S. *Optimization Modelling: A Practical Approach*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2007.
109. Łatuszyńska, M. Modelowanie i Symulacja w Zarządzaniu Produkcją. *Przegląd Organ.* **2015**, *12*, 51–57. [CrossRef]
110. Baggiolini, M. Les Stades Repères Dans Le Développement Annuel de La Vigne et Leur Utilisation Pratique. *Rev. Romande Agric. Vitic. Arbor.* **1952**, *8*, 4–6.
111. Bonhomme, R. Bases and Limits to Using 'Degree.Day' Units. *Eur. J. Agron.* **2000**, *13*, 1–10. [CrossRef]
112. Oliveira, M. Calculation of Budbreak and Flowering Base Temperatures for *Vitis Vinifera* Cv. Touriga Francesa in the Douro Region of Portugal. *Am. J. Enol. Vitic.* **1998**, *49*, 74–78. [CrossRef]
113. Erez, A.; Fishman, S.; Linsley-Noakes, G.C.; Allan, P. The Dynamic Model for Rest Completion in Peach Buds. *Acta Hortic.* **1990**, 165–174. [CrossRef]
114. Fuchigami, L.H.; Wisniewski, M. Quantifying Bud Dormancy: Physiological Approaches. *HortScience* **1997**, *32*, 618–623. [CrossRef]
115. Matzneller, P.; Blümel, K.; Chmielewski, F.-M. Models for the Beginning of Sour Cherry Blossom. *Int. J. Biometeorol.* **2014**, *58*, 703–715. [CrossRef]
116. Fadón, E.; Herrera, S.; Guerrero, B.; Guerra, M.; Rodrigo, J. Chilling and Heat Requirements of Temperate Stone Fruit Trees (*Prunus* Sp.). *Agronomy* **2020**, *10*, 409. [CrossRef]
117. Campoy, J.A.; Ruiz, D.; Egea, J. Dormancy in Temperate Fruit Trees in a Global Warming Context: A Review. *Sci. Hortic.* **2011**, *130*, 357–372. [CrossRef]
118. Saure, M.C. Dormancy Release in Deciduous Fruit Trees. In *Horticultural Reviews*; Janick, J., Ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2011; pp. 239–300. ISBN 978-1-118-06073-5.
119. Lang, G.A.; Early, J.D.; Martin, G.C.; Darnell, R.L. Endo-, Para-, and Ecodormancy: Physiological Terminology and Classification for Dormancy Research. *HortScience* **1987**, *22*, 371–377. [CrossRef]
120. Zhang, H.; Zhou, C. Signal Transduction in Leaf Senescence. *Plant Mol. Biol.* **2013**, *82*, 539–545. [CrossRef] [PubMed]
121. Richardson, E.; Seeley, S.D.; Walker, D.R. A Model for Estimating the Completion of Rest for 'Redhaven' and 'Elberta' Peach Trees1. *HortScience* **1974**, *9*, 331–332. [CrossRef]
122. Reginato, G.H.; Callejas, R.H.; Sapiaín, R.A.; García-de-Cortázar, V. Rest Completion and Growth of "Thompson Seedless" Grapes as a Function of Temperatures. *Acta Hortic.* **2010**, *872*, 427–430. [CrossRef]

123. Luedeling, E. Climate Change Impacts on Winter Chill for Temperate Fruit and Nut Production: A Review. *Sci. Hortic.* **2012**, *144*, 218–229. [CrossRef]
124. Hauagge, R. "IPR JULIETA", A New Early Low Chill Requirement Apple Cultivar. *Acta Hortic.* **2010**, *872*, 193–196. [CrossRef]
125. Ferlito, F.; Di Guardo, M.; Allegra, M.; Nicolosi, E.; Continella, A.; La Malfa, S.; Gentile, A.; Distefano, G. Assessment of Chilling Requirement and Threshold Temperature of a Low Chill Pear (*Pyrus communis* L.) Germplasm in the Mediterranean Area. *Horticulturae* **2021**, *7*, 45. [CrossRef]
126. Razavi, F.; Hajilou, J.; Tabatabaei, S.J.; Dadpaur, M.R. Comparison of Chilling and Heat Requirement in Some Peach and Apricot Cultivars. *Res. Plant Biol.* **2011**, *1*, 40–47.
127. Seif, S.; Gruppe, W. Chilling Requirements of Sweet Cherries (*Prunus avium*) and Interspecific Cherry Hybrids (*Prunus* X *Ssp*.). *Acta Hortic.* **1985**, *169*, 289–294. [CrossRef]
128. Al-Madhagi, I.A.H.; Al-Munibary, M.; Al-Doubibi, M. Effect of Chilling and Accumulative Photo-Thermal Units on Flowering of Strawberry (*Fragaria* × *Ananassa* Duch.). *J. Hortic. Res.* **2018**, *26*, 25–35. [CrossRef]
129. Mazzitelli, L.; Hancock, R.D.; Haupt, S.; Walker, P.G.; Pont, S.D.A.; McNicol, J.; Cardle, L.; Morris, J.; Viola, R.; Brennan, R.; et al. Co-Ordinated Gene Expression during Phases of Dormancy Release in Raspberry (*Rubus idaeus* L.) Buds. *J. Exp. Bot.* **2007**, *58*, 1035–1045. [CrossRef]
130. Dennis, F.G. Dormancy—What We Know (and Don't Know). *HortScience* **1994**, *29*, 1249–1255. [CrossRef]
131. Weinberger, J.H. Chilling Requirements of Peach Varieties. *Proc. Am. Soc. Hortic. Sci.* **1950**, *56*, 122–128.
132. Luedeling, E.; Brown, P.H. A Global Analysis of the Comparability of Winter Chill Models for Fruit and Nut Trees. *Int. J. Biometeorol.* **2011**, *55*, 411–421. [CrossRef]
133. Dennis, F.G. Problems in Standardizing Methods for Evaluating the Chilling Requirements for the Breaking of Dormancy in Buds of Woody Plants. *HortScience* **2003**, *38*, 347–350. [CrossRef]
134. Chhetri, A.; Ramjan, M.; Dolley, N. Various Models to Calculate Chill Units in Fruit Crops. *Indian Farmer* **2018**, *5*, 439–442.
135. Linsley-Noakes, G.C.; Allan, P. Comparison of Two Models for the Prediction of Rest Completion in Peaches. *Sci. Hortic.* **1994**, *59*, 107–113. [CrossRef]
136. Fishman, S.; Erez, A.; Couvillon, G.A. The Temperature Dependence of Dormancy Breaking in Plants: Computer Simulation of Processes Studied under Controlled Temperatures. *J. Theor. Biol.* **1987**, *126*, 309–321. [CrossRef]
137. Mira de Orduña, R. Climate Change Associated Effects on Grape and Wine Quality and Production. *Food Res. Int.* **2010**, *43*, 1844–1855. [CrossRef]
138. Santos, J.; Malheiro, A.; Pinto, J.; Jones, G. Macroclimate and Viticultural Zoning in Europe: Observed Trends and Atmospheric Forcing. *Clim. Res.* **2012**, *51*, 89–103. [CrossRef]
139. Jones, G.V.; White, M.A.; Cooper, O.R.; Storchmann, K. Climate Change and Global Wine Quality. *Clim. Change* **2005**, *73*, 319–343. [CrossRef]
140. White, M.A.; Diffenbaugh, N.S.; Jones, G.V.; Pal, J.S.; Giorgi, F. Extreme Heat Reduces and Shifts United States Premium Wine Production in the 21st Century. *Proc. Natl. Acad. Sci. USA* **2006**, *103*, 11217–11222. [CrossRef] [PubMed]
141. Amerine, M.A.; Winkler, A.J. Composition and Quality of Musts and Wines of California Grapes. *Hilgardia* **1944**, *15*, 493–675. [CrossRef]
142. Tonietto, J.; Carbonneau, A. A Multicriteria Climatic Classification System for Grape-Growing Regions Worldwide. *Agric. For. Meteorol.* **2004**, *124*, 81–97. [CrossRef]
143. Blanco-Ward, D.; Monteiro, A.; Lopes, M.; Borrego, C.; Silveira, C.; Viceto, C.; Rocha, A.; Ribeiro, A.; Andrade, J.; Feliciano, M.; et al. Analysis of Climate Change Indices in Relation to Wine Production: A Case Study in the Douro Region (Portugal). *BIO Web Conf.* **2017**, *9*, 01011. [CrossRef]
144. Gladstones, J. *Viniculture and Environment*; Winetitles: Adelaide, Australia, 1992.
145. Łysiak, G.P.; Michalska-Ciechanowska, A.; Wojdyło, A. Postharvest Changes in Phenolic Compounds and Antioxidant Capacity of Apples Cv. Jonagold Growing in Different Locations in Europe. *Food Chem.* **2020**, *310*, 125912. [CrossRef]
146. Szyga-Pluta, K. Assessment of Changing Agroclimatic Conditions in Poland Based on Selected Indicators. *Atmosphere* **2022**, *13*, 1232. [CrossRef]
147. Jackson, D. *Monographs in Cool Climate Viticulture—2: Climate*; Daphne Brasell Associates Ltd.: Wellington, New Zealand, 2001.
148. Beattie, B.B.; Folley, R.R.W. Production Variability in Apple Crops. II. The Long-Term Behaviour of the English Crop. *Sci. Hortic.* **1978**, *8*, 325–332. [CrossRef]
149. Blanpied, G.D.; O'Kennedy, N.D. A Study of the Relationship Between Climate and Apple Fruit Growth. *HortScience* **1967**, *2*, 155–156. [CrossRef]
150. Lakso, A.N.; Corelli Grappadelli, L.; Barnard, J.; Goffinet, M.C. An Expolinear Model of the Growth Pattern of the Apple Fruit. *J. Hortic. Sci.* **1995**, *70*, 389–394. [CrossRef]
151. Stanley, C.J.; Tustin, D.S.; Lupton, G.B.; Mcartney, S.; Cashmore, W.M.; Silva, H.N.D. Towards Understanding the Role of Temperature in Apple Fruit Growth Responses in Three Geographical Regions within New Zealand. *J. Hortic. Sci. Biotechnol.* **2000**, *75*, 413–422. [CrossRef]
152. Defila, C.; Clot, B. Phytophenological Trends in the Swiss Alps, 19512002. *Meteorol. Z.* **2005**, *14*, 191–196. [CrossRef]
153. Viškelis, J.; Uselis, N.; Liaudanskas, M.; Lanauskas, J.; Bielicki, P.; Univer, T.; Lepsis, J.; Kviklys, D. Location Effects across Northeastern Europe on Bioactive Compounds in Apple Fruit. *Agric. Food Sci.* **2019**, *28*, 93–100. [CrossRef]

154. Juozas, L.; Darius, K.; Mindaugas, L.; Valdimaras, J.; Nobertas, U.; Jonas, V.; Pranas, V. Lower Nitrogen Nutrition Determines Higher Phenolic Content of Organic Apples. *Hortic. Sci.* **2018**, *44*, 113–119. [CrossRef]
155. Treutter, D. Managing Phenol Contents in Crop Plants by Phytochemical Farming and Breeding—Visions and Constraints. *Int. J. Mol. Sci.* **2010**, *11*, 807–857. [CrossRef]
156. Delgado, A.; Dapena, E.; Fernandez, E.; Luedeling, E. Climatic Requirements during Dormancy in Apple Trees from Northwestern Spain–Global Warming May Threaten the Cultivation of High-Chill Cultivars. *Eur. J. Agron.* **2021**, *130*, 126374. [CrossRef]
157. Thompson, W.; Jones, D.; Nichols, D. Effects of Dormancy Factors on the Growth of Vegetative Buds of Young Apple Trees. *Aust. J. Agric. Res.* **1975**, *26*, 989. [CrossRef]
158. Putti, G.L.; Petri, J.L.; Mendez, M.E. Temperaturas efetivas para a dormência da macieira(Malus domestica Borkh). *Rev. Bras. Frutic.* **2003**, *25*, 210–212. [CrossRef]
159. Sawant, S.S.; Choi, E.D.; Song, J.; Seo, H.-J. Pear Production Trends and Characteristics of Important Pests in India. *J. Korean Soc. Int. Agric.* **2021**, *33*, 265–269. [CrossRef]
160. Drepper, B.; Gobin, A.; Remy, S.; Van Orshoven, J. Comparing Apple and Pear Phenology and Model Performance: What Seven Decades of Observations Reveal. *Agronomy* **2020**, *10*, 73. [CrossRef]
161. Singh, A.; Babu, D.K.; Patel, R.; De, L.C. Low Chilling Peaches. *Underutil. Underexploit. Hortic. Crops* **2007**, *2*, 89–103.
162. Kobayashi, K.D.; Fuchigami, L.H. Modeling Bud Development during the Quiescent Phase in Red-Osier Dogwood (*Cornus sericea* L.). *Agric. Meteorol.* **1983**, *28*, 75–84. [CrossRef]
163. Walser, R.H.; Walker, D.R.; Seeley, S.D. Effect of Temperature, Fall Defoliation, and Gibberellic Acid on the Rest Period of Peach Leaf Buds1. *J. Am. Soc. Hortic. Sci.* **1981**, *106*, 91–94. [CrossRef]
164. Mendonça, H.F.C.; Müller, A.L.; Tazzo, I.F.; Calvete, E.O. Accumulated Leaf Number in Strawberry Cultivars Grown in a Greenhouse. *Acta Hortic.* **2012**, *926*, 295–300. [CrossRef]
165. Tanino, K.K.; Wang, R. Modeling Chilling Requirement and Diurnal Temperature Differences on Flowering and Yield Performance in Strawberry Crown Production. *HortScience* **2008**, *43*, 2060–2065. [CrossRef]
166. Taylor, D.R. The Physiology of Flowering in Strawberry. *Acta Hortic.* **2002**, *567*, 245–251. [CrossRef]
167. Hoover, E.; Luby, J.; Bedford, D.; Pritts, M.; Hanson, E.; Dale, A.; Daubeny, H. Temperature Influence on Harvest Date and Cane Development of Primocane-Fruiting Red Raspberries. *Acta Hortic.* **1989**, *262*, 297–304. [CrossRef]
168. Privé, J.-P.; Sullivan, J.A.; Proctor, J.T.A.; Allen, O.B. Climate Influences Vegetative and Reproductive Components of Primocane-Fruiting Red Raspberry Cultivars. *J. Am. Soc. Hortic. Sci.* **1993**, *118*, 393–399. [CrossRef]
169. Warmund, M.R.; Krumme, J. A Chilling Model to Estimate Rest Completion of Erect Blackberries. *Acta Hortic.* **2008**, *40*, 275–281. [CrossRef]