Brief Report

Prediction of the Flowering and Ripening Time of Strawberry (Fragaria × ananassa) Cultivars in Estonia by Using the K-Means Clustering Method

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Prediction of the Flowering and Ripening Time of Strawberry (*Fragaria* × *ananassa*) Cultivars in Estonia by Using the K-Means Clustering Method

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Abstract: Finding the ideal statistical method for grouping phenological data is always an important step for breeders to draw correct conclusions from it possibly. In this paper, K-cluster analysis is presented as a perfect tool for grouping phenological data. The present research was performed based on the phenological data of 61 strawberries *(Fragaria × ananassa)* cultivars of different geographical origins grown in Estonian conditions. Groups of strawberry cultivars were determined according to flowering and ripening time: early, middle and late, based on the sum of effective temperatures above +5°C. The result of the K-cluster analysis carried out in this way makes it possible to precisely plan the ripening time of berries of different strawberry cultivars. Using such analysis data, it is possible to combine with different early, mid or late strawberry cultivars to extend the picking period. Also, this technique can be used to study the effect of climatic changes occurring over the years on the phenology of strawberry cultivars grown in the region.

Keywords: strawberry cultivars; a sum of effective temperatures; K-means clustering; phenological growth stages

1. Introduction

Strawberries (*Fragaria* × *ananassa*) are one of the most well-liked berries worldwide [1]. There were more than 380,000 ha and 8,8 million tons of strawberries produced worldwide in 2020 [2,3]. In 2021, approximately 1500 tons of strawberries were grown in Estonia on a total of 737 ha [4]. As the phenological rhythms of plants run under certain temperature conditions to which they have adapted during evolution, the strawberry is a seasonal crop for growing in open ground. Temperature conditions of different regions of the Earth are not identical and change over the course of the year, so the heat demand of plants is determined by the location area and phases of their vegetation [5]. The strawberry growing season on outdoor depends primarily on the right selection of cultivars suitable for the growing area's climatic conditions. The species *Fragaria x ananassa* has a moderate temperature requirement, 10 °C to 27 °C are needed for the growth of flowers and fruits[6–8]. Strawberries need different temperature conditions in different phases of the growing season. During the phase of active growth in spring, a moderate daytime temperature is needed, which gradually rises to 15-20 °C. In the berry ripening phase, the optimal daily temperature for different cultivars is 18 - 25 °C [9–12]. In the post-harvest phase, plants need gradually decrease plus temperatures up to 5 °C, at which vegetative propagation of plants, winter preparation and laying of fruit buds take place. The suitable sum of active (>5 °C) temperatures is considered for strawberry flowering to be an average value 300 °C and 500 °C for berry ripening [13].

In spring and early summer, plants may be damaged by air temperatures of about zero, which often occurs in the Estonian climate. In the same period, the daily average air temperature can reach over 10 °C. Night frost is a temperature drop under 0 °C in the immediate surroundings of the air, ground or vegetation during the crop vegetation period. The air measured on the ground and at the

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height of plant growth is often 2–4 °C colder than the air measured at a height of 2 meters. In some years, night frosts lead to damage or death of wild plants as well as field and garden crops [14].

For strawberries is a particularly dangerous night frost in May–June time when strawberry plants start flowering [15]. Determining the time of flowering and fruit ripening of strawberry cultivars, taking into account the sum of the effective temperatures corresponding to Estonian conditions, is very important in order to gain more knowledge about the real course of phenological rhythm[16]. Good knowledge and analysis of the phenological rhythm of different strawberry cultivars make it possible to predict the need for frost protection, harvesting dates, and to combine growing with different early, middle or late strawberry cultivars to extend the harvest period. The study of the phenological rhythm of plants is of great practical importance, which determines the selection of cultivars and forms most adapted to specific climatic conditions.

Finding a good method for processing phenological data is a great challenge for researchers. The K-means clustering method has been used in the analysis of similar data sets, which has, for example, given good results in the evaluation of the target characteristics of strawberry cultivars (yield, fruit weight, TSS content of soluble solids, optimal titratable acidity TA content and °Brix/acidity ratio) [17]. The point of K-mean clustering is to divide the set of data points into a number of groups so that the data points within per group are more comparable to one another and different from the data points within the other groups. It is practically a grouping of something based on how similar and different they are to one another[18,19]. The standard algorithm of K-mean clustering was first proposed in 1957, but it was not published as a journal article until 1982 [20]. The K-means cluster analysis could be well suited for processing a large amount of phenological data.

2. Materials and Methods

2.1. Plant Material

The research work was carried out in 2021–2022 at the Polli Horticultural Research Centre of the Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences (58°7′26″ N, 25°32′43″ E). The object of the research was 61 cultivars of strawberries: one Belgian (‘Lovril’), seven Canadian (‘AAC Lila’, ‘Annapolis’, ‘Bounty’, ‘Kent’, ‘Nisga’a’, ‘Redcoat’, ‘Vantage’), one German (‘Senga Sengana’), two Estonian (‘Helean’, ‘Regatt 80’), three Finnish (‘Hiku’, ‘Suvetar’, ‘Valotar’), three French (‘Darselect’, ‘Matis’, ‘Surprise des Halles’), seven British (‘Alice‘ , ‘Elegance’, ‘Fenella’, ‘Judibell‘, ‘Pandora‘, ‘Pegasus’, ‘Red Gauntlet’), two Italian (‘Alba’, ‘Asia’), two Latvian (‘Junija Smaids’, ‘Saulene’), four Lithuanian (‘Dange’, ‘Nida’, ‘Suitene’,‘Venta’), twelve Dutch (‘Allegro’, ‘Induka’, ‘Jive’, ‘Korona’, ‘Lambada’, ‘Polka’, ‘Rumba’, ‘Salsa’, ‘Sonata’, ‘Sonsation’, ‘Susette’, ‘Vivaldi’), four Norwegian (‘Frida’, ‘Gudlief’, ‘Jonsok’, ‘Nobel’), five Polish (‘Dukat’, ‘Filon’, ‘Filut’, ‘Marduk’, ‘Panon’), three Russian (‘Festivalnaja’, ‘Klubnitšnaja’, ‘Lord’), one Scottish (‘Rhapsody’), one Swedish (‘Annelie’), and three United States (‘Black Swan’, ‘Earliglow’, ‘Honeoye’).

2.2. Experiment Scheme

The cultivar plantation was based in May 2020 by using bare-root plants. To the soddy-podzolic clay loamed strawberry bed, covered by black plastic mulch, were planted of each cultivar ten plant at distances 0.3 m from each other. The ground was without an irrigation system. There were no used plant protection treatments throughout the cultivation period. The fertilization of soil was made before planting with NPK mineral fertiliser Cropcare 8-11-21 (Yara International, Oslo, Finland) (600 kg/ha). In the spring of the year after planting, was applied 5 mL of Cropcare 8-11-21 fertiliser per plant by hand. The area between the strawberry beds were maintained by mechanical mowing. Weeds were removed by hand from around the plants during the month following harvest.

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2.3. Meteorological Conditions

From April to May 2021, the average monthly air temperature was 1.1 and 0.8 °C below the long-term average, respectively. The average monthly temperatures were noted by 3.7°C in June and by 3.1°C in July higher than the long-term average in Figure 1. Rainfall deficit was observed in the third decade of June and in July.

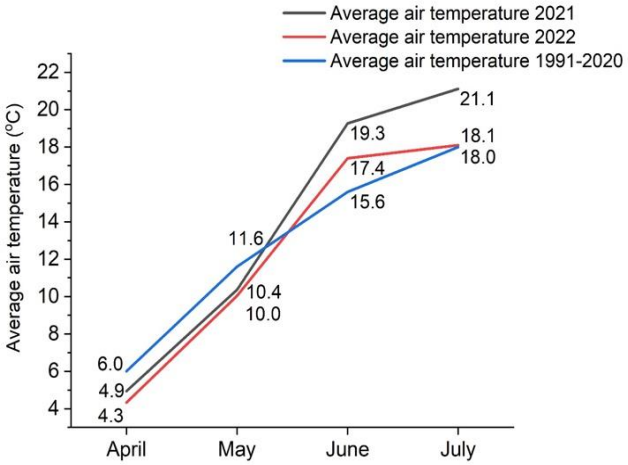

Figure 1. Average monthly temperatures (°C) during April, May, June and July in test years (2021–2022) in Polli.

From April to May 2022, the average monthly air temperature was 1.7 and 1.6 °C below the long-term average, respectively. The average monthly temperatures were noted by 1.8 °C in June higher than the long-term average. In July, the average monthly air temperature was within the long-term average in Figure 1. Rainfall deficit was noted in the third decade of June and the first decade of July.

2.4. Experimental Methods

Observations were carried out on separate phenological phases: the beginning of flowering, the end of flowering, the beginning of ripening of berries and the end of ripening. The beginning of flowering is considered the opening of the first flowers on the most developed stems, the flowering is noted by the date the first blooming flowers when 5-10% of the flowers are bloomed on. The end of flowering is marked by the date when about 90% of the flowers have faded in the plot (in 75% of the flowers the petals fell off, the rest withered and turned brown). The beginning of ripening is when the first berries have ripened. The end of ripening is marked by the date of the last harvest of ripe berries.

The formation of groups of cultivars according to the timing of flowering and ripening was carried out taking into account the accumulation of the sum of effective (>5 °C) temperatures at the beginning of the phase [21].

Statistical processing of the study results was carried out by multivariate analysis using K-means cluster analysis using the OriginPro 2020b program.

3. Results

3.1. Clustering of strawberry cultivars into three groups

In the spring, the transition of the average daily air temperature through 5 ºC determines the beginning of the growing season for strawberries. The beginning of the strawberry vegetation time in the research-making region, according to long-term average data, could be in 15. April. During the years of research, the beginning of vegetation was observed in period 12. April - 18. April, and it occurred almost simultaneously in the studied cultivars of different periods of flowering and

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ripening. In the strawberry cultivars we studied, the time of the beginning of the flowering phase changed over the years depending on the temperature regime of the spring period. According to the results of the K-mean cluster analysis of data for each cultivar on the accumulation of effective temperatures necessary for the onset of the phases of the beginning of flowering and ripening, strawberry cultivars are divided into three groups – early (Cluster 1), middle (Cluster 2) and late (Cluster 3) in Figure 2.

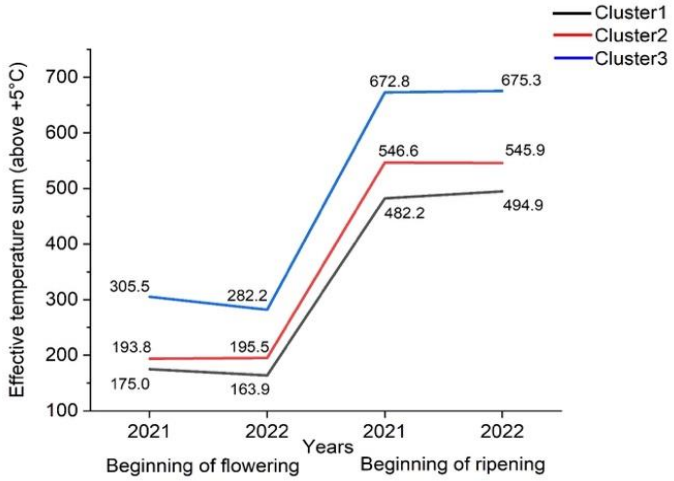

Figure 2. Sums of effective temperatures above 5°C required for the beginning of flowering and the beginning of the ripening phases of the 2021 and 2022 strawberry cultivars grouped in clusters 1-3 according to K-means.

Early cultivars - Cluster 1 (34): 'Aac Lila', 'Alba', 'Allegro', 'Annapolis', 'AnneLie', 'Asia', 'Dukat', 'Earliglow', 'Filon', 'Frida', 'Gudleif', 'Helean', 'Honeoye', 'Induka', 'Jonsok', 'Junija smaids', 'Kent', 'Korona', 'Lambada', 'Marduk', 'Nobel', 'Polka', 'Redcoat', ' Regatt 80', 'Rhapsody', 'Rumba', 'Saulene', 'Sonata', 'Surprise des Halles', 'Suvetar', 'Valotar', 'Vantage', 'Venta', 'Vivald'.

Middle cultivars - Cluster 2 (24): 'Alice', 'Black Swan', 'Bounty', 'Dange', 'Darselect', 'Elegance', 'Fenella', 'Festivalnaja', 'Filut', 'Hiku', 'Jieve', 'Klubnitšnaja', 'Lord', 'Lovril', 'Matis', 'Nida', 'Nisga'a', 'Panon', 'Pegasus', 'Redgauntlet', 'Salsa', 'Senga Sengana', 'Sonsation', 'Suitene'.

Late cultivars - Cluster 3 (3): 'Judibell', 'Pandora', 'Susette'.

3.2. Flowering

The Effective temperatures sum (above +5 °C) average at the beginning of flowering in 2021 and 2022 is presented in Table 1. The early cultivars were characterized by the beginning of the flowering phase in the second and third decade of May during the research years. The average of the sum of effective temperatures for the beginning of flowering of early strawberry cultivars was 175 °C in 2021 and 164 °C in 2022.

The middle cultivars were characterized by the beginning of the flowering phase in the third decade of May and the first decade of June during the research years. The average of the sum of effective temperatures for the beginning of flowering of middle strawberry cultivars was 194 °C in 2021 and 196 °C in 2022. The late cultivars were characterized by the beginning of the flowering phase in the first decade of June during the research years. The average of the sum of effective temperatures for the beginning of flowering of late strawberry cultivars was 175 °C in 2021 and 164 °C in 2022.

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Table 1. Effective temperatures sum (above +5 °C) average, at the beginning of flowering in 2021 and 2022.

	Effective temperatures sum (above +5°C) average		
Period	**Cluster 1**	**Cluster 2**	**Cluster 3**
Beginning of flowering 2021	175±22	194±17	306±42
Beginning of flowering 2022	164±19	196±24	282±76

3.3. Ripening

The time of the ripening period and its duration in the cultivars of strawberries studied by us changed over the years depending on the temperature regime of the summer period. The Effective temperatures sum (above +5 °C) average at the beginning of ripening in 2021 and 2022 is presented in Table 2. The early cultivars were characterized by the beginning of the ripening phase in the second and third decade of June during the research years. The average of the sum of effective temperatures for the beginning of ripening of early strawberry cultivars was 482 °C in 2021 and 495 °C in 2022.

The middle cultivars were characterized by the beginning of the ripening phase in the third decade of June during the research years. The average of the sum of effective temperatures for the beginning of ripening of middle strawberry cultivars was 547 °C in 2021 and 546 °C in 2022. The late cultivars were characterized by the beginning of the ripening phase in the first decade of July during the research years. The average of the sum of effective temperatures for the beginning of ripening of late strawberry cultivars was 673 °C in 2021 and 675 °C in 2022.

Table 2. Effective temperatures sum (above +5 °C) average, at the beginning of ripening in 2021 and 2022.

	Effective temperatures sum (above +5°C) average		
Period	**Cluster 1**	**Cluster 2**	**Cluster 3**
Beginning of ripening 2021	482±29	547±25	673±36
Beginning of ripening 2022	495±25	546±29	675±36

4. Discussion

The yield depends on the intensity of flowering, which is one of the main stages in the formation of the strawberry crop, as well as on the conditions in which it occurs.

In order to predict the flowering and ripening time of strawberry cultivars, it is important to know the sum of effective temperatures exceeding the lower limit necessary for the beginning of the flowering or ripening phase.

The data of two-year average on the sums of effective temperatures for the passage of the main phenological phases of strawberries, based on cluster analysis, are presented in Table 3. The sum of the average effective temperatures of the two years at the beginning of flowering and the beginning of fruit ripening differs not much from the sums of the corresponding effective temperatures of different years (Tables 1 and 2). This shows good suitability using of the sum of the effective temperatures for the prediction of the flowering and ripening time of strawberries.

Table 3. Effective temperatures sum (above +5 °C) average, at the beginning of flowering and ripening years' average.

	Effective temperatures sum (above +5°C) years' average		
Period	**Cluster 1**	**Cluster 2**	**Cluster 3**
Beginning of flowering 2021 and 2022	169±21	195±20	294±56
Beginning of ripening 2021 and 2022	489±28	546±26	674±32

The phenorhythms of strawberry cultivars introduced in Estonia may not always correspond to the data provided by the countries of origin. For example, the early cultivar 'Darselect' in France flowered simultaneously with the medium cultivars in Estonia[22]. This situation is entirely acceptable because the duration of the interphase period from the beginning of plant emergence from dormancy to flowering depends on the genotypic characteristics of the cultivar, which are related to a certain amount of heat.

5. Conclusions

The study of the phenorhythms of the modern strawberry assortment based on the sum of effective temperatures above +5°C can be used in the future to forecast the timing of flowering and ripening of garden strawberry cultivars. Predicting the timing of flowering and ripening of garden strawberry cultivars is important for protecting the crop from frost, setting the timing of harvesting, as well as carrying out chemical protective measures against diseases and pests. The study of the phenological rhythm of plants in different world regions bay be giving also possible to study the changes that happening in climatic conditions.

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