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Effect of the Climatic Conditions in Central Europe on the Growth and Yield of Cornelian Cherry Cultivars

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Abstract: Fruit of Cornelian cherry can be used fresh or processed, and cultivation practices are developing in this direction. Due to the rarity of its cultivation, Cornelian cherry is harvested from natural sites of occurrence. However, the fruit from natural sites is of lower quality than the cultivars, as their seedlings differ in terms of fruit ripening. The objective of this experiment was the evaluation of approximately a dozen cultivars in terms of growth and fruit yield under the conditions of Central Europe. The effect of climatic conditions on the onset date of particular phenological stages was also assessed. All the analysed cultivars are suitable commodity crops, but they should be accurately selected depending on the direction of production. The first phenological stage of Cornelian cherry is the appearance of inflorescences before the development of leaves. The start of particular phenophases depends on the temperature and precipitation. Cornelian cherries cultivated under ecological conditions show satisfactory fruit size and generally a small percentage of stone. Most cultivars have an elongated fruit shape, and the shape factor decreases with their growth and ripening. The fruit grows along a double sigmoid, and its first intensive growth occurs following the extinction of intensive shoot growth.

Keywords: *Cornus mas* L.; vegetative growth; fruit development; double sigmoid; fruit quality; phenological stages; BBCH scale

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1. Introduction

Cornelian cherry (*Cornus mas* L.) belongs to the *Cornaceae* family, which includes approximately 65 species, both edible and inedible fruit, including many with ornamental flowers, leaves, or shoots [1,2]. A characteristic morphological feature helpful in its identification is the opposite leaf arrangement with parallel veins [3].

In its natural state, the Cornelian cherry often grows in rocky areas, slightly shaded or sunny, although proper flower budding and fruit bearing require abundant sun light [4]. Cornelian cherry in its natural state usually forms multi-trunk shrubs, but with appropriate growth guidance, it can grow into a tree. The plants are also suitable for forming hedges. It is a very slow growing but long-lived species [5].

Due to its healthy properties and flavour, the fruit of Carnation cherry is expedient for diversifying the diet. It contains high amounts of vitamin C [6], polyphenols, and irydoids [7], thus showing antioxidant [8], anti-inflammatory [9], antibacterial [10,11], antifungal, and antispasmodic properties. It can be used in prophylaxis as well as in the treatment of diseases such as dyslipidemia, atherosclerosis [12], obesity, diabetes [13], glaucoma [14], and breast, colon, lung, stomach, and central nervous system cancer [15]. The aforementioned effects can be obtained by consuming fresh fruit, as well as by isolating biologically active substances from it [16,17].

High and uniform quality of the fruit can be obtained exclusively through cultivation of cultivars adjusted to given climatic conditions in specialised farms. Cornelian cherry is grown in many European countries, but it does not have many commercial cultivars. It is farmed at a small scale in Ukraine, Italy, France, Poland, the Czech Republic, and Slovakia [1]. Greater supply of the fruit is provided by harvests from natural sites in Iran [18], Azerbaijan, Georgia, and Turkey [19]. In Turkey, annual harvests of approximately 14.8 thousand tons of fruit are processed in the production of jams, marmalades, pestil, paste, sherbet, or dried fruit [20]. The fruit from natural sites, however, is usually smaller, more sour, and less juicy, with a large stone [21]. Yield is also low and variable. In orchards, the average yield may exceed 10–15 t/ha, whereas harvests from natural sites reach 0.5–1 t/ha [22].

Cultivation of new cultivars of Cornelian cherry is conducted in Poland [23], Ukraine [5], Austria [24], Bulgaria, Germany, the Czech Republic [25], Slovakia [3], and Turkey [26,27], as well as in Serbia and Montenegro [25]. Cultivar selection is based on the following criteria: size of fruit, its colour and shape, share of the stone in total mass of the fruit, term and uniformity of ripening and harvest, quantity and quality of yield, resistance to frost, and self-pollination [5].

Fruit of Cornelian cherry is consumed fresh, preserving all their valuable health properties, although in this case, supply is limited to the harvest period. The promotion of a healthy diet emphasises the diversity of the fruit's appearance and flavour. Mature Cornelian cherry fruit has sweet and sour flavour with characteristic aroma [28].

Cornelian cherry fruits are suitable for processing [29]. The large green fruit, before the skin starts changing to red, is suitable for pickling, and the resulting product is similar to Mediterranean olives. This can be achieved with cultivars with uniformly ripening fruits reaching large sizes early in the growing season [30]. Fully coloured, red, shiny stone fruits, before the skin starts matting and the flesh loses firmness, can be candied or dried. The best cultivars for this purpose are those with flesh loosely attached to the stone. The flesh has been found to be more easily separated from the stone in fruit that is not fully ripe [31].

Fruit harvested in the stage of consumption maturity that is already declining is used in the production of juices, soft drinks, purées, jams, and pestils [32]. Such products are best made of fruit with a high share of flesh in total fruit mass. The production of oil, contained in the seed, is the most efficient for fruit with a large stone [33]. Although Cornelian cherry fruits have a different purpose than, for example, apples, they should not be exposed to vibration during transport [34], as this would increase bruising and cause spoilage as a result of rotting fruit. Fully ripe Cornelian cherry fruits are soft, so harvesting and transporting them should be well organised. Cornelian cherry cultivars grown on the commercial scale are planted in a rootstock appropriately selected for the cultivation conditions. The rootstock affects the strength and character of the growth and quality of inflorescences, fruit [35–38], as well as its usefulness for storage [39] and processing. The rootstocks that are used most frequently for Cornelian cherry cultivars are selected seedlings of the species [40]. The harvest yield of the fruit plants and the onset of the fruiting period are also dependent on other factors: the age, genetic characteristics, and climatic conditions in a given vegetative season [41–43]. Like for each fruit plant, the quality and quantity of harvests are improved by additional organic or mineral fertilization [44].

Cornelian cherry is still a weakly known fruit crop. Establishing its plantations is limited by the scarcity of information on the strength and character of the growth and fruiting of particular cultivars. The selection of the appropriate cultivar while establishing a Cornelian cherry plantation is the key element determining the cultivation success. Before planting, the direction of production should be determined, and several cultivars with expected characteristics should be selected. Moreover, little information is available on important phenological stages, namely, blooming, onset of fruiting, and fruit ripening [45]. These processes affect the decisions regarding farming particular cultivars, including conducting maintenance and potential protective measures. The objective of this experiment was to assess the growth and yield of 11 Polish and Ukrainian Cornelian cherry cultivars (with established genotypic features) in the conditions of Central Europe, and determine the term of particular phenological stages, which will facilitate precise recommendations regarding the dates of basic agrotechnical and possibly protective treatments. In addition, we have defined a way of increasing the size of Cornelian cherry fruit and shoots that has not yet been described in the literature available to us. This is essential for planning treatments such as irrigation and others to optimise growth under stress conditions.

2. Materials and Methods

2.1. Plant Material

The experiment was conducted in the period 2020–2021 on a plantation in Snopków (near Lublin), 51.305653 N, 22.502672 E, in Extra-Alpine Central Europe, on fawn soils from loess deposits. The experimental material were trees of Cornelian cherry (*Cornus mas* L.) obtained through shield budding in 2017 with dormant buds on seedlings of Cornelian cherry. Before planting, the soil contained 1.06–1.15% of humus in the 0–20 cm depth and was characterised as alkaline (pH in 1M KCl 7.3–7.5). Trees of Polish cultivars 'Bolestraszycki', 'Dublany', and 'Szafer' and Ukrainian cultivars 'Pervenets', 'Wydubieckij', 'Władimirskij', 'Radist', 'Ugoliok', 'Semen', 'Prezent', and 'Jubilejnyj' (Figure 1) were planted in autumn 2018, with spacing of 3.0 m × 2.5 m. The cultivars selected for the experiment are available in nurseries. Mechanically weeded fallow soil was maintained in rows of trees, and turf was mowed when needed between rows. The trees were fertilised only organically, with compost and tree ash around trunks. No additional watering was applied, nor protection against pests or diseases.

Figure 1. Fruits and seeds of the studied Cornelian cherry cultivars.

2.2. Phenological Observations

Observations of phenological stages were conducted three times per year on the aforementioned cultivars of Cornelian cherry, from bud burst (start of the growing season) to start of winter dormition (November). The description of particular phases of these phenological stages employed an extended BBCH scale adapted for pome and stone fruits [46] and proposed for Cornelian cherry [45]. The name BBCH comes from the German words Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie. This scale uses the decimal code system by which 10 principal phases (0–9) and minor phases (0–9) are distinguished. The days of the start of a particular phenological stage are as follows:

BBCH 00—Rest period, the leaf and inflorescence buds are closed and covered by bracts; inflorescence buds are round and larger than the leaf buds.

BBCH 55—The inflorescence buds are semi-open; flower buds are clearly visible with closed calyxes.

BBCH 60—First flower is revealed.

BBCH 01—The beginning of swelling of the leaf buds; vegetative buds noticeably elongated and enlarged, scales with a light border.

BBCH 10—Bud scales open wide; green leaf tips 10 mm above the bud scales; first leaves separating.

BBCH 19—the first leaves are fully developed.

BBCH 71—Fruit set; the ovaries increase in size.

BBCH 89—Almost all fruit are ripe for consumption: they have a typical taste and hardness, become dull and fall off.

The average, minimum, and maximum air temperature and precipitation were recorded.

2.3. Quantity and Quality of Yield

2.3.1. Yield Quantity

In the first year of the study, due to weak yield, harvest was performed in three terms, 25.08, 15.09, and 01.10, with the determination of partial yield (g/tree). The sum of such yields constituted the total yield (g/tree). In the second year of the study, fruits of particular cultivars were harvested in the following terms: 10.08, 17.08, 25.08, 31.08, 08.09, 15.09, and 25.09, with determination of partial yield (g/tree). The sum of such yields constituted the total yield (g/tree).

2.3.2. Quality of Fruit

The quality of fruit was analysed based on a representative sample of 30 fruits of each cultivar. The fruit was weighed by means of an electronic scale (with accuracy of 0.01 g), determining the mass of a single fruit (g). Stones from the fruit were soaked for easier separation of residual flesh, cleaned after one week, and weighed by means of an electronic scale (g). The aforementioned parameters provided the basis for the calculation of the mass of stone in the total mass of fruit. The extract content was determined every year for 20 fruits by means of a digital Abbe refractometer (PAL-1 Atago, Tokyo, Japan) at 20 °C.

2.4. Growth of the Shoots and the Diameter of the Fruit

The experiment covered six representative trees of each selected cultivar. On selected branches in the middle of the crown height, the following measurements were performed:

(1) In 2021, the length of the shoots in 20 fruits of that year (cm) was measured (cm) for each cultivar in the following terms: 17 VI, 23 VI, 30 VI, 6 VII 14 VII, and 4 VIII, and the weekly increase rate in this property was determined.
(2) An electric calliper was used to measure (with accuracy of 0.01 mm) the length and diameter (mm) of 20 fruits of each cultivar in the following terms: 15 VI, 22 VI, 30 VI, 6 VII, 14 VII, 21 VII, 28 VII, 4 VIII, 10 VIII, 17 VIII, 25 VIII, and 31 VIII.
(3) The weekly rates of increases in the length and diameter of fruit were determined.
(4) The shape factor of the fruit was also calculated (length/diameter).

2.5. Climatic Conditions

March is the month of the flowering of the Cornelian cherry. In 2020, average temperatures below 0 °C occurred on days 15, 22–24, and 30–31. In 2021, such temperatures occurred on days 6, 8–11, and 18–22.

In 2020, the average temperatures in the first quarter of the year considerably exceeded the multi-annual average (Table 1). Temperatures higher than in the multiannual period (1951–2019) were also recorded from June to December. The warmest month was August. Only May was cooler than an average May in the measurement period. Average air temperature lower by 2 °C was measured at the time. The average air temperatures in 2021 did not deviate from the average multiannual temperature by more than 2 °C. Greater deviations were only recorded in April and July, when average temperatures exceeded multiannual temperatures by 2.3 and 2.9 °C. High differences occurred between precipitation totals in certain months in 2021. In January and February, monthly precipitation exceeded more than 2.5- and 6-fold totals from the multiannual period for these months. In March, April, May, October, and November, monthly precipitation did not reach values recorded in the multiannual period. Then, in August and December, the amount of precipitation again exceeded the multiannual total by approximately three times. In 2020, in July and August, there was a significant period of dryness, but it was mitigated by abundant rainfall in the preceding months (May and June) and in the following months (September) (Figure 2). In 2021, there were favourable conditions for plant growth, because in June and July, there was only a slight period of drought (Figure 3).

Table 1. The air temperature and sums of rainfall during the experimental period in 2020 and 2021.

Month	Mean Temperature (°C)			Precipitation (mm)		
	2020	2021	Many-Year Averages (1951–2019)	2020	2021	Many-Year Sum (1951–2019)
I	0.9 *	−2.0	−3.24	21.3	137.4	49.3
II	2.7	−2.6	−1.9	62.5	190.3	30.5
III	4.2	2.4	2.1	16.5	10.7	31.9
IV	8.4	6.0	8.3	23.6	36.1	61.4
V	10.9	12.1	13.5	97.5	46.5	72.6
VI	18.3	19.1	17.1	142.0	75.2	60.2
VII	18.5	21.6	18.7	34.0	82.5	78.3
VIII	20.0	16.6	18.2	26.7	200.9	59.5
IX	15.0	12.7	13.4	137.9	54.1	51.0
X	10.3	8.6	8.1	103.1	11.9	48.4
XI	4.6	4.6	3.6	24.9	25.4	39.3
XII	1.1	−1.5	−0.5	29.5	92.5	50.3

* The data come from a station based on iMetos Field Climate by Pessl Instruments.

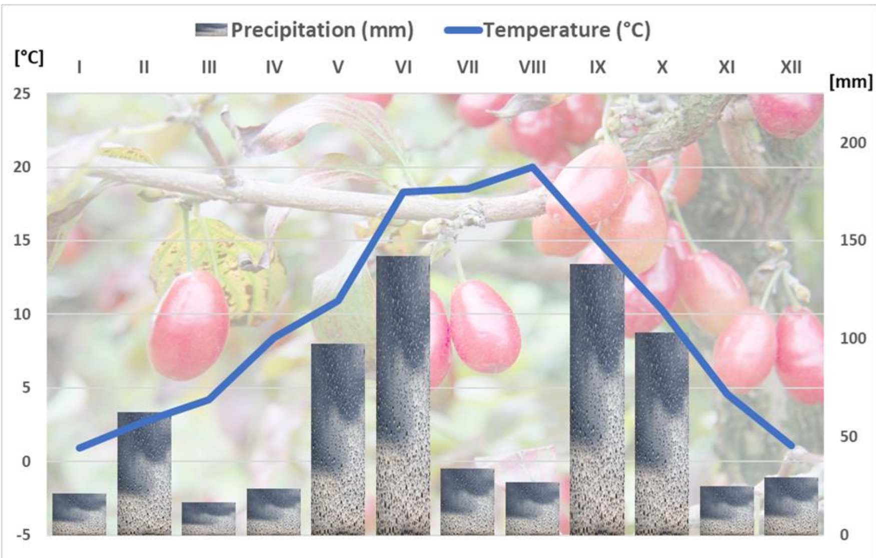

Figure 2. Climate diagram representing climate conditions in 2020.

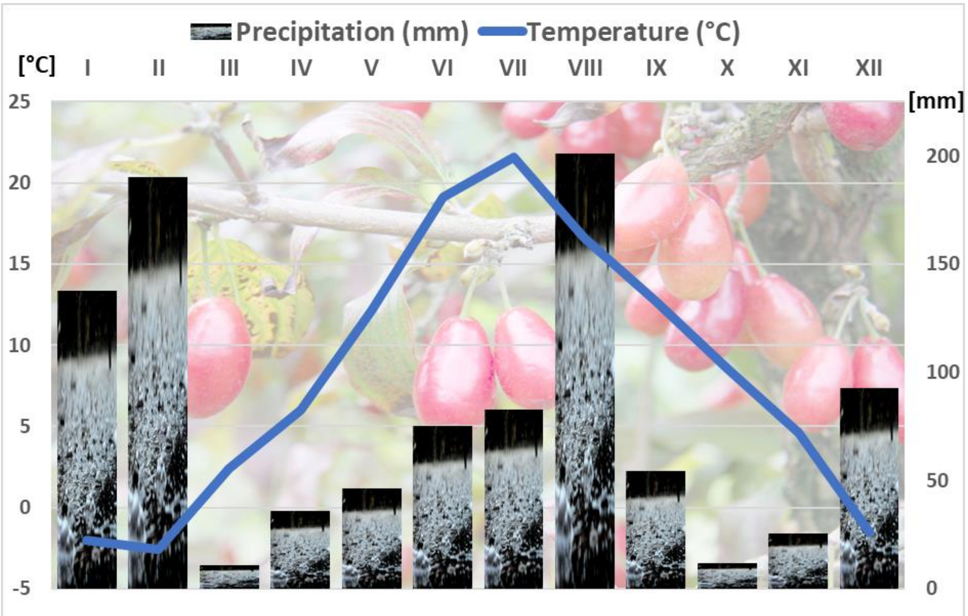

Figure 3. Climate diagram representing climate conditions in 2021.

2.6. Statistical Calculations

All analyses were performed using STATISTICA for Windows 5.5A software, and statistical analyses of significant differences were tested by an HSD Tukey test. Pearson correlations between days of occurrence of selected stages were also determined in accordance with the BBCH code, and the average minimum and maximum air temperature and precipitation. Moreover, correlations between the size of fruit, mass of the stone, and share of the stone in total mass of the fruit were verified.

3. Results and Discussion

3.1. Phenological Stages

The first phenological phase of Cornelian cherry is the emergence of the inflorescence, which may take place in February (BBCH 50–56). Therefore, the Cornelian cherry is the first flowering fruit plant in Polish conditions. However, the onset term of this phase was different in the studied seasons and depended on winter conditions, especially temperature (Table 2, Figures 4 and 5). In 2020, a stronger correlation was found between the day of onset phenophases and the average and maximum temperature than in 2021 (Tables 3 and 4). The rest period (BBCH 00) in 2020 lasted until the 60–65th day of the year, and in the next season, it lasted 14–17 days longer (Table 2). The period between the establishment of the fruit (BBCH 71) and the beginning of ripening in 2020 was 91–123 days, and in 2021, it was 109–139 days. The extension of the fruit growth and ripening period in 2021 compared to the previous year could have been influenced by lower temperatures and more abundant rainfall as compared to the long-average period in August (Table 1). For 2021, a stronger correlation was found between the amount of precipitation and the timing of the onset of phenophases. This resulted in an extended fruit ripening period compared to 2020, despite the fact that the growing season started approximately 15 days earlier (Table 2).

The last phenophase observed in Cornelian cherry was aging and entering winter dormancy (BBCH 91–99). The BBCH 99 phase was characterised by complete leaf shedding. The 2021 season was characterised by a 2-week longer growing season compared to the previous season (Figures 2 and 3). Klymenko et al. [5], comparing several species within the *Cornus* subgenus, observed that *Cornus mas* sheds leaves faster than another, promising due to the health-promoting fruits of the species *C. officinalis*. On *C. officinalis* trees, 1–2 pairs of dried leaves are often left at the top of the shoots until spring.

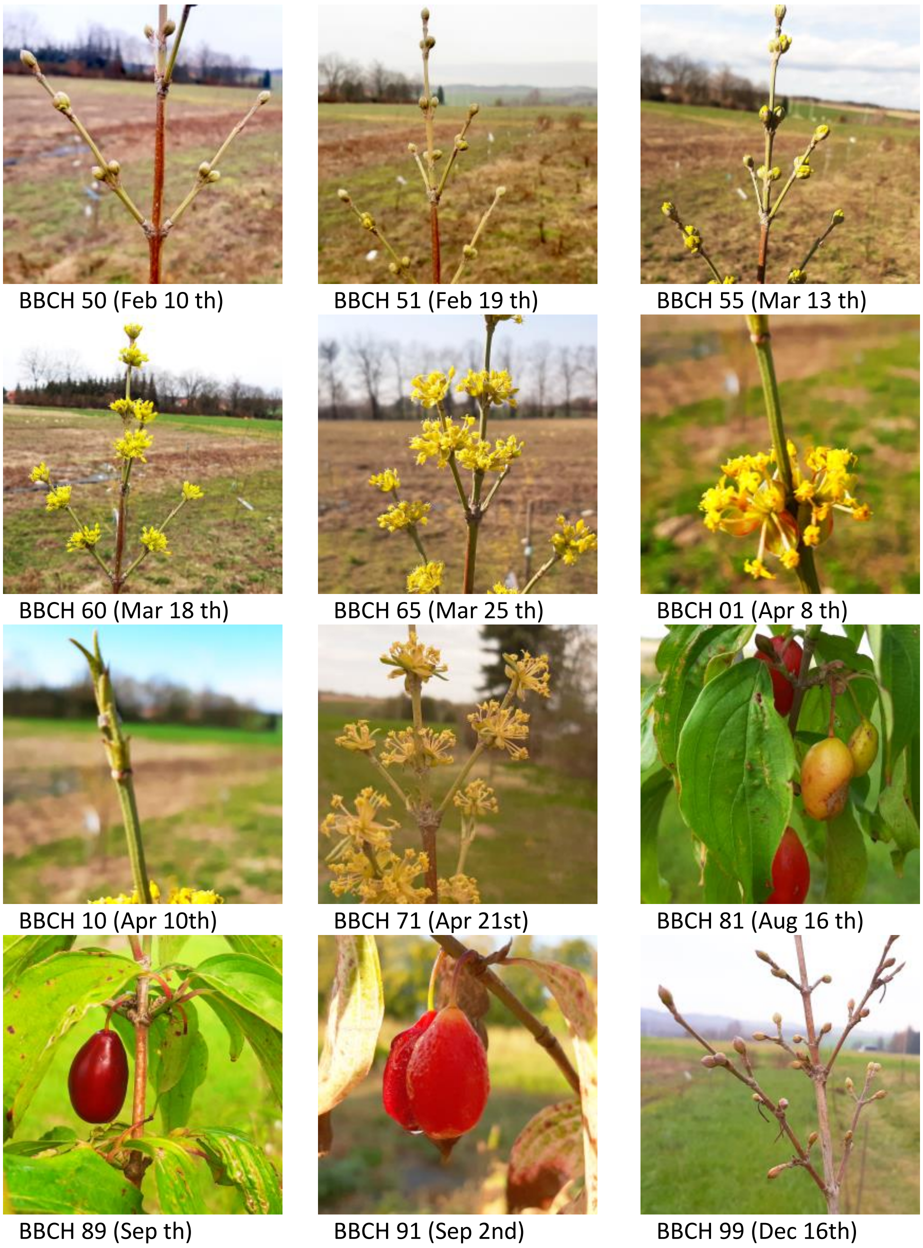

Figure 4. Phenological growth stages of Cornelian cherry cv. 'Bolestraszycki' trees, according to the BBCH in 2020.

Table 2. Comparison of the onset of selected phenophases (BBCH) in the 2020 season and in 2021 among the cultivars of Cornelian cherry.

Cultivar/BBCH Scale	Year	00	55	60	01	10	19	71	81	89
		Day of Year								
Bolestraszycki	2020	60	88	93	102	114	137	128	229	251
	2021	43	72	78	99	101	136	112	229	252
Dublany	2020	65	89	90	103	114	139	114	217	237
	2021	48	73	78	97	99	134	101	229	243
Jubilejnyj	2020	65	89	91	100	114	140	114	237	251
	2021	48	71	73	90	100	134	101	240	259
Pervenets	2020	63	89	92	100	112	141	127	222	251
	2021	48	76	80	97	93	136	111	229	259
Prezent	2020	65	88	91	100	127	140	125	222	229
	2021	48	67	71	97	99	134	109	223	243

Table 2. *Cont.*

Cultivar/BBCH Scale	Year	00	55	60	01	10	19	71	81	89
		Day of Year								
Radist	2020	65	89	90	100	114	139	127	222	237
	2021	48	71	73	99	101	136	111	223	247
Semen	2020	65	91	97	100	115	140	127	229	243
	2021	48	76	80	90	94	136	111	229	247
Szafer	2020	65	89	92	100	115	141	127	232	243
	2021	48	76	80	97	89	136	111	231	254
Ugoliok	2020	62	84	87	100	114	140	125	216	222
	2021	48	73	78	90	92	132	109	218	238
Władimirskij	2020	65	90	91	101	115	142	114	222	229
	2021	48	75	78	99	101	134	101	229	252
Wydubieckij	2020	65	89	91	101	115	142	114	222	229
	2021	48	75	78	99	101	134	101	229	252

Figure 5. Phenological growth stages of Cornelian cherry cv. 'Bolestraszycki' trees, according to the BBCH in 2021.

Table 3. Correlation coefficients between the day number of the beginning of the phenological stage and climatic conditions in 2020.

Traits	Day of the Year	Mean Temperature °C	Minimum Temperature °C	Maximum Temperature °C	Precipitation (mm)
Day of the year	1	0.78 *	0.78 *	0.77 *	0.11 *
Mean temperature °C		1	0.92 *	0.94 *	0.08 *
Minimum temperature °C			1	0.85 *	0.15 *
Maximum temperature °C				1	0.01 *
Precipitation (mm)					1

* Significantly different at 95%.

Table 4. Correlation coefficients between the day number of the beginning of the phenological stage and climatic conditions in 2021.

Traits	Day of the Year	Mean Temperature °C	Minimum Temperature °C	Maximum Temperature °C	Precipitation (mm)
Day of the year	1	0.67 *	0.78 *	0.64 *	0.41 *
Mean temperature °C		1	0.89 *	0.9 *	0.18 *
Minimum temperature °C			1	0.89 *	0.28 *
Maximum temperature °C				1	0.14 *
Precipitation (mm)					1

* Significantly different at 95%.

3.2. The Size of the Fruit

The fruit from the plantation where the cultivars are grown is larger than the fruit from seedlings. In the work of Szot et al. [6], where the fruit size of several dogwood seedlings was compared, the fruit weight ranged from 1.61 to 2.34 g, their diameter from 11.9 to 13. 6 mm, and length from 15.0 to 16.7 mm. In our work, the fruits of each of the cultivars grew longer than the aforementioned length and diameter (Tables 5 and 6). All cultivars, except for 'Ugoliok' and 'Prezent', were also heavier (Table 7). The size of the fruit is a genetic trait, but also depends on the yield on trees. So far, no research on thinning has been conducted, but probably, as in the case of other stone trees, the reaction will be similar [47]. Fruit weight was strongly positively correlated with stone weight, and inversely proportional to the share of the stone in the total fruit weight. The share of the stone in the weight of the fruit was proportional to the weight of the stone (Figures 6–8).

The size of the fruit and its colour and shape are the features that determine the possibility of their use. Fruits of several cultivars intended for direct consumption should be as large as possible and should be diversified in terms of shape and colour. Ukrainian cultivars significantly exceed the size of cultivars bred in other countries. The average fruit weight is 5.0–8.0 g, and the stone weight is 7.5–11.0% of the fruit weight [5]. In Slovak studies, the average fruit weight of local genotypes was 1.41 g, and the stone was 17% of the fruit weight [3]. The fruit weight of the Serbian genotypes was greater, ranging from 2.25 to 6.61 g, and the stone share was 18–20% of the fruit weight [25]. In the experiment, the cv. 'Ugoliok' had the lowest mean fruit weight, and the cv. 'Jubilejnyj' had the highest (Table 7). Comparing the cultivars 'Władimirskij' and 'Wydubieckij' in Ukrainian conditions, it was found that the fruits of the cv. 'Władimirskij' were larger than those of the cv. 'Wydubieckij' [5]. In our experiment, the fruits of both cultivars, throughout the entire measurement period, grew similarly in length and width. However, the values of these features were lower than in Klymenko's experiment [5]. In the study by Kucharska et al. [23], the cultivars 'Kresowiak' and 'Bolestraszycki' had the highest share (15.87% and 15.7%). In our research, we found that the cv. 'Bolestraszycki' had the largest share of the stone in the weight of the fruit, and 'Semen' had the smallest. The fruits of Polish cultivars ('Szafer', 'Dublany', and 'Bolestraszycki') had a lower average fruit weight than in studies conducted in southeastern Poland [23]. This may be due to the fact that in our experience, the plants were grown organically and without irrigation.

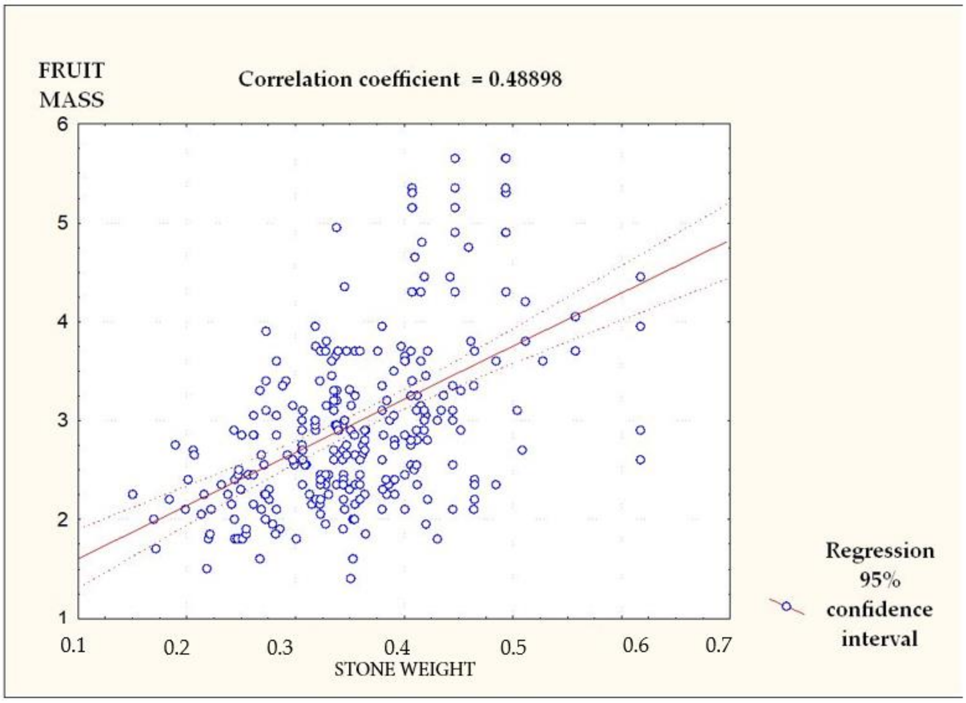

Figure 6. Correlation coefficient for stone weight and fruit mass of Cornelian cherry fruit.

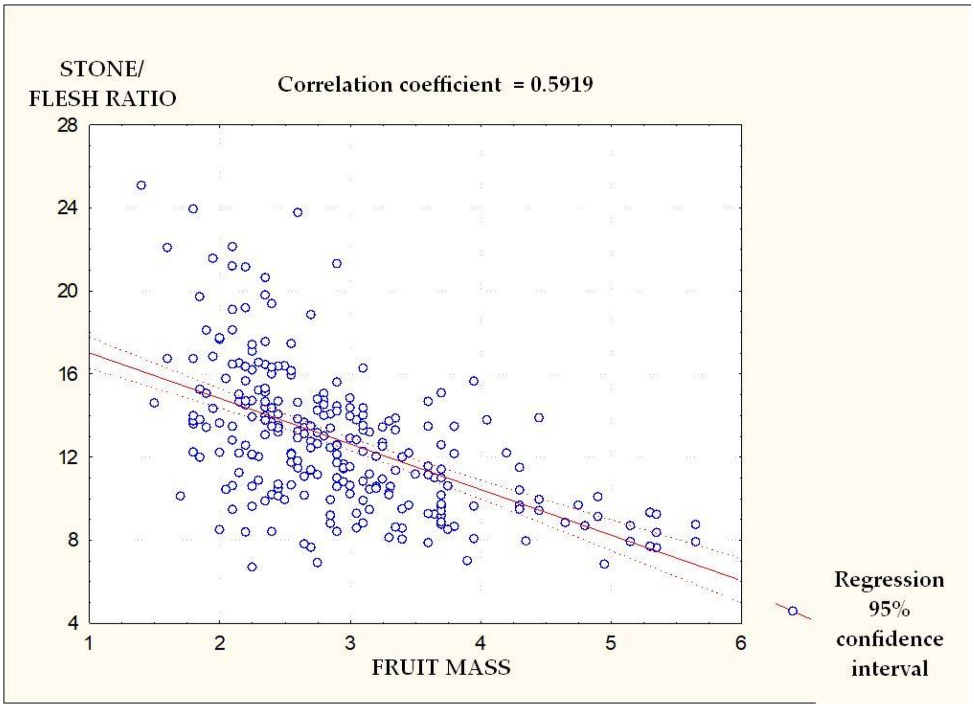

Figure 7. Correlation coefficient for fruit mass and stone/flesh ratio of Cornelian cherry fruit.

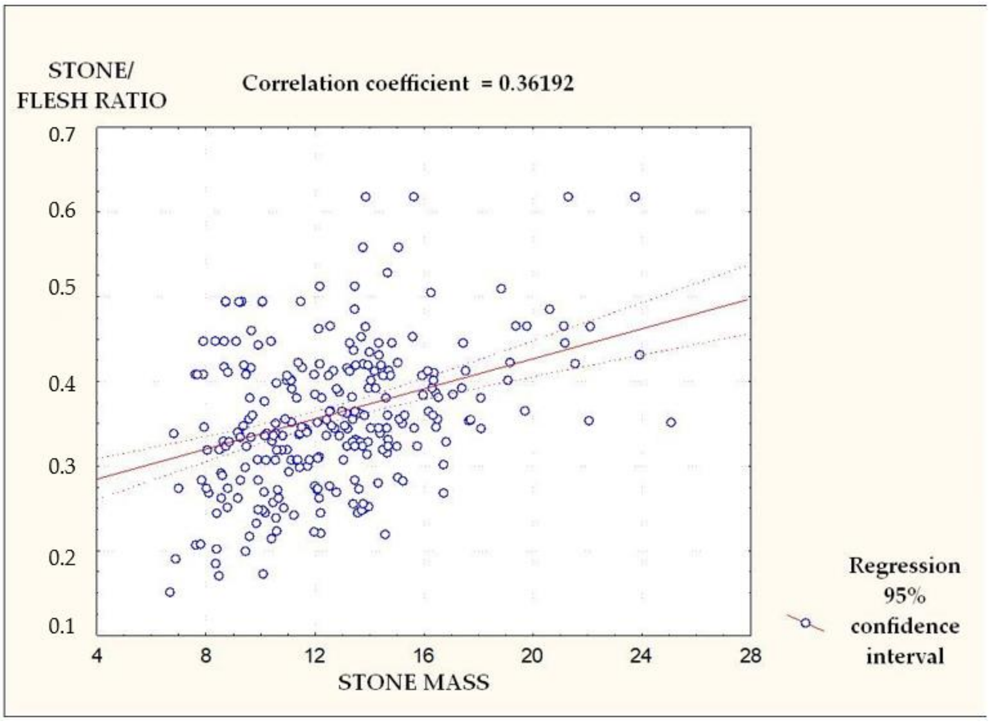

Figure 8. Correlation coefficient for stone weight and stone/flash ratio of Cornelian cherry fruit.

Red fruit is intended for processing, with the smallest share of stone in the fruit weight (on average 9–10%). Jaćimović and Božović [32], examining a dozen or so genotypes in Montenegro, found that the share of the stone in the fruit ranged from 10.1% to 20.2%. Among the Polish cultivars studied by Kucharska et al. [23], the smallest seeds are found in 'Podolski', 10.14%. In our research, this cultivar was not found, while the Ukrainian cv. was not. 'Jubilejnyj' stood out with the smallest stone (9.13%).

The cultivars with large stones are used to produce oil, which is rich in unsaturated fatty acids. Cornelian cherry oil mainly contains linoleic acid (70–75%), oleic acid (15.0–16.7%), and palmitic acid (2.0–4.6), and stearic acid (1.0–6.2%) and linolenic acid (1.1–2.1%). The oil is consumed as a dietary supplement and is used in the production of cosmetics [48,49]. Roasted and raw Cornelian cherry seeds are an excellent substitute for coffee. Klymenko [50] reports that the yield of seeds per hectare can range from 20 to 25 tons. The content of the extract is the basic characteristic determined to estimate the quality of fruit intended for direct consumption and processing. It is closely correlated with the perception of sweetness and richness of taste [6]. The content of soluble solids in Cornelian cherry fruits in the literature ranges from 12.5% to 21.2% [19,26,51], and our results are in accordance with these values (Table 7).

Most Cornelian cherry cultivars have elongated fruit, and the fruit length-to-diameter ratio is 1.55 on average (Table 8). An increase in this proportion shows that the fruit is more elongated. In our study, the fruit length to width ratio ranged from 1.24 ('Prezent') to 1.86 ('Semen'), and it did not differ from the results reported by other authors [1,23,52]. The variety of the shape of the fruit can be used when selling the fruit in small, packaged containers. The variety of shapes and colours positively influences the decision to buy them [53]. When fully ripe for consumption, Cornelian cherry fruits are soft, and like other stone fruits, e.g., cherries [54], blueberries, and strawberries [55], are suitable only for short storage. The shelf life of Cornelian cherry fruits can be extended to about 35 days by packing them in a polymer film and storing them at 1 °C and 90–95% humidity [56]. It is expected that the storage stability will last longer under the modified atmosphere.

Table 5. Changes in fruit length (mm) of some cultivars of Cornelian cherry.

Cultivar	Date of Measurement											
	15 VI	**22VI**	**30VI**	**6VII**	**14VII**	**21VII**	**28 VII**	**4 VIII**	**10 VIII**	**17 VIII**	**25 VIII**	**31 VIII**
Bolestraszycki	17.9 b [1]	18.3 de	18.8 cd	19.8 f	19.9 f	20.4 e	21.0 ef	21.0 c–e	22.2 cd	23.3 bc	24.0 b	25.9 bd
Dublany	18.0 b	18.1 de	18.3 cd	18.7 de	18.7 de	18.7 de	20.0 de	22.8 ef	23.7 c–f	23.8 bc	23.9 b	25.1 b
Jubilejnyj	17.9 b	19.8 ef	20.0 d	20.1 f	20.2 fg	20.5 e	21.6 e–f	22.3 ef	23.2c–e	25.5 cd	27.8 d	28.3 e
Pervenets	16.8 a	17.1 c	17.3 c	17.7 cd	18.0 de	18.0 cd	18.4 cd	19.1 bc	21.5 c	22.8 b	23.1 b	24.7 b
Prezent	13.0 a	13.3 a	13.4 a	13.4 a	13.5 a	13.6 a	13.7 a	14.0 a	15.5 a	16.3 a	17.3 a	17.3 a
Radist	18.0 b	18.3 de	18.6 cd	18.8 ef	18.9 de	19.5 de	20.9 e	21.7 ef	23.4 c–f	23.5 bc	24.2 b	24.3 b
Semen	20.3 c	20.6 f	20.6 de	22.0 g	22.6 gh	22.6 ef	22.8 f–h	24.0 fg	25.1 e–g	26.9 d	27.5 cd	28.6 e
Szafer	18.1 b	18.2 de	18.3 cd	19.2 ef	19.7 f	19.9 de	20.7 ef	21.4 de	22.1 cd	24.3 bc	24.9 bc	25.6 bc
Ugoliok	13.8 a	14.0 a	14. 1 ab	14.2 ab	14.3 ab	14.9 a	15.2 ab	16.1 ab	17.0 ab	17.7 a	18.0 a	18.5 a
Władimirskij	20.6 c	21.2 f	21.9 e	22.6 h	23.2 h	23.2 g	23.8 gh	24.9 fg	26.4 g	27.0 d	27.0 cd	28.4 e
Wydubieckij	21.0 c	21.1 f	22.1 e	22.1 gh	22.3 gh	22.7 ef	24.3 h	25.2 g	26.0 fg	26.7 d	27.6 d	27.8 c–e
Average	17.8	18.2	18.5	19.0	19.2	19.5	20.2	21.1	22.4	23.4	24.1	25.0

[1] One-way analyses of variance; data in the same column marked with the same letter are not significantly different at $\alpha = 0.05$ (Tukey's test).

Table 6. Changes in fruit diameter (mm) of some cultivars of Cornelian cherry.

Cultivar	Date of Measurement											
	15 VI	**22VI**	**30VI**	**6VII**	**14VII**	**21VII**	**28 VII**	**4 VIII**	**10 VIII**	**17 VIII**	**25 VIII**	**31 VIII**
Bolestraszycki	7.72 b–e [1]	8.47 c–e	8.47 a–c	9.28 d–f	9.51 b–d	9.60 a–d	9.96 a–c	11.90 bc	13.45 c–f	14.13 b–e	15.14 b–d	15.14 a–d
Dublany	7.32 b–e	8.02 a–d	8.03 a–c	8.06 ab	8.94 a–c	9.00 ab	10.94 b–d	13.08 cd	14.25 ef	14.30 b–e	14.38 b–d	14.90 a–d
Jubilejnyj	8.20 ef	9.04 e	9.65 d	9.70 ef	10.40 d	10.40 d	11.76 de	13.06 cd	15.07 f	16.67 f	18.25 e	18.95 e
Pervenets	9.02 f	9.03 e	9.06 cd	9.61 ef	9.65 cd	10.32 d	11.20 c–e	13.58 d	14.40 ef	15.16 ef	15.92 d	15.98 d
Prezent	7.01 a–d	7.50 ab	7.54 a	7.67 a	8.41 ab	8.46 a	8.66 a	10.01 a	11.72 a	12.59 ab	13.48a–d	13.98 ab
Radist	7.97 de	8.67 de	9.06 cd	9.74 f	9.98 cd	10.56 d	11.84 de	13.89 d	14.85 f	14.91 e	15.68 d	15.81 cd
Semen	7.89 c–e	8.37 b–e	8.71 b–d	8.97 c–e	9.60 cd	9.74 b–d	11.25 c–e	12.69 cd	13.76 d–f	14.53 c–e	15.40 b–d	15.41 b–d
Szafer	7.28 b–e	7.94 a–d	7.97 ab	8.32 a–c	8.77 a–c	8.79 ab	9.63 ab	10.49 ab	12.10 a–d	13.88 a–e	15.05 b–d	15.68 cd
Ugoliok	6.84 a	7.43 a	7.57 a	8.02 ab	8.03 a	8.72 ab	9.67 ab	10.64 ab	11.89 ab	12.11 a	12.27 a	13.60 a
Władimirskij	7.53 b–e	8.72 de	8.88 b–d	9.46 ef	9.65 b–d	10.32 d	11.20 c–e	12.78 cd	14.41 ef	14.80 de	15.66 cd	15.74 cd
Wydubieckij	8.01 e	8.21 b–e	8.84 b–d	9.07 c–e	9.57 b–d	10.37 d	12.52 e	13.77 d	14.59 f	14.89 c–e	15.52 b–d	15.82 d
Average	7.71	8.31	8.53	8.90	9.32	9.66	10.78	12.35	13.68	14.36	15.16	15.55

[1] One-way analyses of variance; data in the same column marked with the same letter are not significantly different at $\alpha = 0.05$ (Tukey's test).

Table 7. Comparison of selected quality features of Cornelian cherry fruit between cultivars.

Cultivar	Fruit Weight (g)	Stone Weight (g)	Share of the Stone in the Total Weight of the Fruit (%)	Total Soluble Solids (%)
Bolestraszycki	3.08 cd [1]	0.36 b	11.7 b–d	15.9 bc
Dublany	2.98 cd	0.37 b	12.4 b–e	17.1 cd
Jubilejnyj	4.93 f	0.45 c	9.1 a	14.0 ab
Pervenets	2.85 b–d	0.35 b	12.3 b–e	13.7 a
Prezent	2.24 a	0.27 a	12.1 bc	13.4 a
Radist	2.58 a–c	0.36 b	14.0 c–e	16.0 bc
Semen	3.09 cd	0.45 c	14.6 e	18.1 cd
Szafer	2.80 b–d	0.34 b	12.1 b–e	17.8 cd
Ugoliok	2.19 a	0.23 a	10.5 ab	16.3 cd
Władimirskij	3.31 de	0.37 b	11.2 a–c	14.0 ab
Wydubieckij	3.71 e	0.44 c	11.9 b–e	18.3 d

[1] One-way analyses of variance; data in the same column marked with the same letter are not significantly different at α = 0.05 (Tukey's test).

Table 8. Changes in shape ratio (length/diameter) of some cultivars of Cornelian cherry fruit.

Cultivar	Date of Measurement											
	15 VI	22VI	30VI	6VII	14VII	21VII	28 VII	4 VIII	10 VIII	17 VIII	25 VIII	31 VIII
Bolestraszycki	2.32c–e [1]	2.17 b–d	2.22 c–f	2.13 c–e	2.09 c–f	2.13 cd	2.10 ef	1.76 d–e	1.65 c–e	1.65 f–g	1.58 cd	1.71 e–g
Dublany	2.45 d–f	2.25 d–f	2.28 d–f	2.32 d–f	2.09 c–f	2.08 bc	1.82 c–f	1.75 de	1.67 c–e	1.66 f–g	1.66 d–f	1.69 d–f
Jubilejnyj	2.18 bc	2.19 b–e	2.07 b–e	2.13 c–e	1,94 b–e	1.97 bc	1.84 c–f	1.70 cd	1.54 a–d	1.53 d–f	1.52 bc	1.49 bc
Pervenets	1.86 a	1.89 a–c	1.91 a–c	1.84 a–c	1.86 a–c	1.75 ab	1.64 a–d	1.40 ab	1.50 a–d	1.50 c–e	1.45 ab	1.54 cd
Prezent	1.85 a	1.77 a	1.77 a	1.75 a	1.61 a	1.61 a	1.58 a	1.56 a	1.32 a	1.30 a	1.28 a	1.24 a
Radist	2.26 b–d	2.22 c–e	2.05 b–d	1.93 a–c	1.89 a–c	1.84 ab	1.76 b–e	1.89 e–f	1.57 b–e	1.57 d–f	1.54 bc	1.54 cd
Semen	2.58 fg	2.46 ef	2.36 f–h	2.45 h	2.35 ef	2.32 c	2.03 ef	2.03 e–f	1.83 e	1.85 h	1.78 g	1.86 g
Szafer	2.48 d–f	2.30 d–f	2.30 e–g	2.31e–g	2.25 d–f	2.26 bc	2.15 f	2.04 f	1.83 e	1.75 gh	1.65 d–f	1.63 c–e
Ugoliok	2.13 ab	1.88 ab	1.87 ab	1.78 ab	1.78 ab	1.71 a	1.57 a–c	1.51 a–c	1.43 a–c	1.46 b–d	1.47 ab	1.37 ab
Władimirskij	2.74 g	2.43 d–f	2.46 gh	2.39 f–h	2.41 f	2.25 bc	2.13 f	1.95 e–f	1.83 e	1.82 h	1.72 fg	1.81 fg
Wydubieckij	2.62 fg	2.57 f	2.50 h	2.44 gh	2.33 ef	2.19 bc	1.83 c–f	1.83 e–f	1.78 de	1.80 h	1.78 g	1.76 e–g
Average	2.25	2.13	2.10	2.07	2.00	1.94	1.78	1.70	1.59	1.57	1.54	1.55

[1] One-way analyses of variance; data in the same column marked with the same letter are not significantly different at α = 0.05 (Tukey's test).

3.3. Increase in Fruit Size and Shoot Length

From the moment of setting, the fruit grows and matures, reaching the size typical for a cultivar. Fruit grows through cell division and an expansion in cell volume. The daily weight gain of, for example, apples is high in the period preceding harvest, so leaving the fruit on the tree allows for a higher yield [57]. Fruit growth can be determined by increasing its diameter, length, or weight. Individual species differ in the course of fruit growth and their final size. In the case of fruit plants, fruit growth follows a sigmoid curve (apples, pears, bananas, pineapple, avocado, orange, mango) or a double sigmoid curve (strawberries [58], coffee [59], plums, cherries, cherries, currants, raspberries [60]). Cornelian cherry fruits were characterised by an increase according to a double sigmoid curve, with the first period of growth being more intense, which may testify to increased cell division during this period [59] and a period of thickening of the cell walls that build endocarp and their lignification [61] (Figure 9). The first intense increase in fruit diameter and length occurred after the end of intensive growth (after July 14) (Figures 9 and 10). Particular cultivars differed in the length of this year's shoots. The shortest shoots were characteristic of 'Semen', and the longest were characteristic of 'Ugoliok' (Table 9. Jacyna et al. [62] reported that the features characterizing the shoot growth can be used to predict the yield of young cherry trees. The strength of this year's shoot growth affects the plant volume. Czech studies also showed differences in the vegetative growth of individual cultivars based on the measurement of the plant volume [24], but it did not affect the yield efficiency.

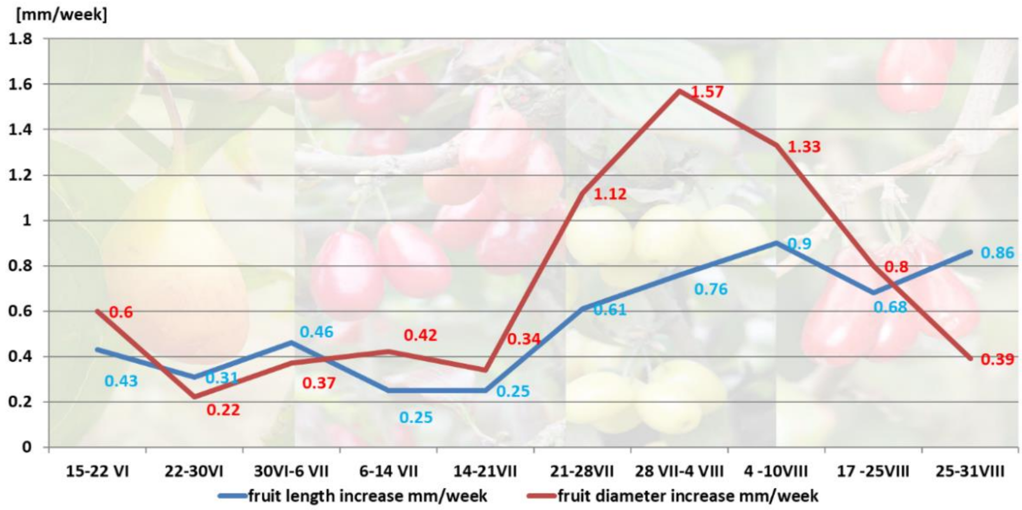

Figure 9. Average increase in length and diameter of Cornelian cherry fruit—average for all cultivars.

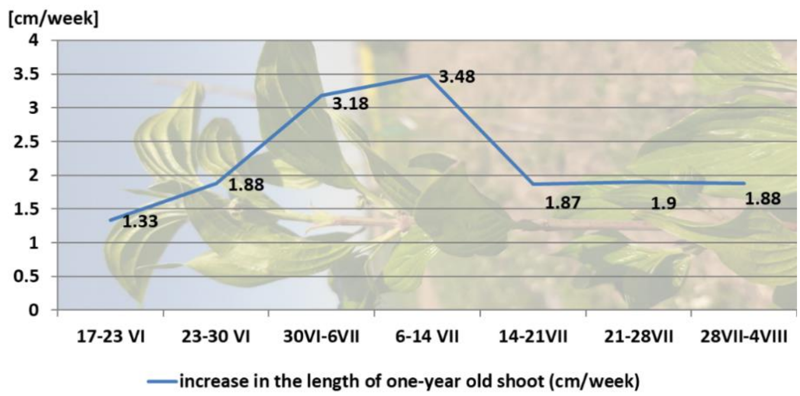

Figure 10. Weekly growth of one-year old shoots, average for all cultivars (cm/period).

Table 9. Weekly growth of one-year old shoots (cm) of some Cornelian cherry cultivars.

Cultivar	Date of Measurement							
	17 VI	23 VI	30 VI	6 VII	14 VII	21VII	28VII	4 VIII
Bolestraszycki	15.6 b–d [1]	15.9 a–c	17.0 a–c	18.2 ab	19.9 ab	20.7 ab	21.5 ab	22.3 ab
Dublany	19.9 cd	23.3 bc	23.7 bc	25.3 bc	35.4 cd	36.2 a–c	37.0 a–c	37.8 a–c
Jubilejnyj	13.1 a–c	14.4 ab	14.5ab	15.7 ab	17.2ab	17.5 a	17.8 a	18.1 ab
Pervenets	14.6 a–c	15.1 a–c	21.3 a–c	23.7 ab	25.2 a–c	29.6 a–c	34.0 a–c	38.4 a–c
Prezent	16.8 b–d	17.8 a–c	22.3 bc	23.1 ab	23.4 a–c	23.4 ab	23.5 ab	23.5 ab
Radist	21.2 cd	21. 8 bc	22.3 bc	23.3 ab	32.9 b–d	36.6 bc	40.1 bc	43.7 bc
Semen	6.5 a	8.0 a	8.7 a	9.4 a	11.4 a	11.7 a	11.9 a	12.2 a
Szafer	16.9 b–d	17.3 a–c	17..4 a–c	25.8 bc	27.9 a–c	32.8 bc	37.9 bc	42.9 bc
Ugoliok	22.3 d	25.8 c	28.7 c	39.8 c	42.7 d	47.2 c	51.9 c	56.5 c
Władimirskij	14.4 a–c	16.0 a–c	16.2 ab	21.5 ab	25.3 a–c	25.8 ab	26.3 ab	26.8 ab
Wydubieckij	11.4 ab	13.1 ab	16.5 ab	17.7 ab	20.6 a–c	20.9 ab	21.3 ab	21.6 ab

[1] One-way analyses of variance; data in the same column marked with the same letter are not significantly different at α = 0.05 (Tukey's test).

3.4. Yield and Maturation Date

The length of the juvenile period for Cornelian cherry depends, among other things, on the method of reproduction. Plants obtained by budding begin to bloom and bear fruit in the second year after planting, while those from cuttings bloom 4–5 years after planting, and from seedlings, only in the eighth year after planting. The time of fruit ripening and harvesting depends on the weather conditions (temperature, rainfall) and the cultivar [63]. In our experiment, Cornelian cherry reproduced by budding with a sleeping eye on Cornelian cherry seedlings yielded already in the second year after planting, but the yield was very poor, which was affected by the unfavourable weather conditions during flowering. The size of the Cornelian cherry yield depends on the cultivar, rootstock, age, reproduction method, and climatic conditions. After entering the fruiting period, Cornelian cherry yields annually and more abundantly each year. Klymenko [50] stated that 8–25 kg can be harvested from 5–10-year-old Cornelian cherries, 40–60 kg from 15–20-year-old fruits, and 80–100 kg from 25–40-year-old fruits. In our experience, the highest yields in both seasons were obtained from the Polish cultivar 'Dublany' (Figure 11).

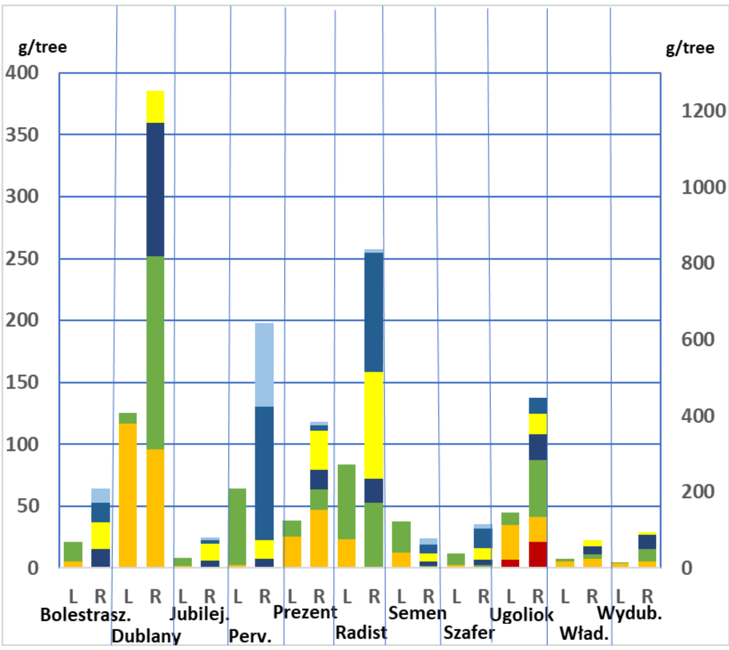

Figure 11. Individual crops of cornelian cherry cultivars in 2020 and 2021.

Within the cultivars, the first bar shows the yield in 2020, and the second one in 2021. The main axis (left—L) concerns the yield in 2020, and the secondary axis (right—R) concerns that in 2021.

1st harvest (in 2020—25.08; in 2021—10.08)
2nd harvest (in 2020—15.09; in 2021—17.08)
3rd harvest (in 2020—20.09; in 2021—25.08)
4th harvest (in 2021—31.08)
5th harvest (in 2021—08.09)
6th harvest (in 2021—15.09)
7th harvest (in 2021—01.10)

The time of reaching harvest maturity largely depends on the climatic conditions (temperature, rainfall) and the cultivar. The average period of harvesting Polish cultivars is 20–30 days, but it can be extended up to 50 days. Under the conditions of the Lublin region [6], individual Cornelian cherry ecotypes matured from the first decade of August to the third decade of October, and the harvest period was from 18 to 67 days. The fruit of the Cornelian cherry ripens unevenly within the tree, and even within the infructescence, which results from the different time of development of individual flowers [45]. In our experience, the differences in the maturation date of the fruits of individual cultivars were more clearly marked in 2021 (Figure 9). In both seasons, the fruits of the cv. 'Ugoliok' ripened the earliest and for the longest period. In 2021, the fruits of cv. 'Bolestraszycki', 'Jubilejnyj', and 'Pervenets' ripened at the latest. The maturation of the Polish cultivars ('Bolestraszycki', 'Dublany', and 'Szafer') coincided with the maturation date given by Kucharska et al. (2011) [23]; however, the maturation date of Ukrainian cultivars was delayed and extended compared to what Klymenko [50] reports.

Climatic conditions, apart from the cultivar and age of the trees, also influenced the yield. More favourable conditions for fruit growth and ripening were in 2021, due to the appropriate distribution of air temperature and rainfall (Figure 3). In 2020, the period of intensive fruit growth, i.e., in July and August (Figure 2), resulted in lower yields and a shorter ripening period. Cornelian cherry, like other soft-fruit stone plants, requires a sufficient temperature and amount of rainfall for growth [64,65]. A shortened period of fruit development could reduce Cornelian cherry yield. Moreover, advanced flowering after warmer winter months could increase the risk of spring frosts.

There is no universal cultivar suitable as both a dessert crop and for processing. Due to their large mass and high extract content, Ukrainian cultivars 'Wydubieckij' and 'Semen' and Polish cultivars 'Szafer' and 'Dublany' are recommended for cultivation as a dessert crop. The 'Dublany' cultivar, already at young age, stands out among other cultivars in terms of yield, and in this study, it bore the most fruit among eleven analysed cultivars. It is also characterised by good separation of flesh from stone, making it suitable for drying and candying. Because they reach large sizes, the cultivars are also suitable for pickling. The 'Prezent' cultivar with yellow skin and red spots could be an interesting addition to the fruit basket, although the fruit is relatively small. A small share of the stone in total fruit mass is characteristic of the 'Jubilejnyj', 'Ugoliok', and 'Bolestraszycki' cultivars. Therefore, they can be recommended for processing where the flesh of fruit is valuable, i.e., for the production of beverages, jams, or pestil. A large stone occurs in the Semen and 'Radist' cultivars, making them useful in processing where this part of the fruit is important.

4. Conclusions

Intensive cultivation has already resulted in the purchase of many cultivars of Cornelian cherry, differing in features in terms of growth and fruiting. Moreover, differences in particular physiological processes such as flowering and fruit ripening depend on the climatic and environmental conditions. In the conditions of Central Europe, Cornelian cherry blooms very early (even at the end of February). Frosts that occur during the flowering stage reduce the yield of young trees with still insignificant crown surface.

The first phenological stage of Cornelian cherry is the appearance of inflorescences before the development of leaves. The start of particular phenophases depends on temperature and precipitation.

Cornelian cherry is suitable for cultivation in ecological conditions in Central Europe. Cultivated in such conditions, it produces fruit with satisfactory size, and usually a small stone share. The fruit weight is closely correlated with the stone weight.

Most cultivars have an elongated shape of fruit, and the ratio of length to width decreases with growth and ripening.

The fruit grows along a double sigmoid and its first intensive growth occurs after the end of intensive shoot growth, concurrently with the end of the cell division stage in the fruit.

Cornelian cherry reproduced by budding produces fruit already in the second year after planting. Fruiting is non-uniform, and the degree of non-uniformity depends on the cultivar. The analysed cultivars differ in the term and duration of the period of fruit ripening. Their cultivation can provide a supply of fresh fruit from mid-August to early October.

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