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PRODUCTIVITY POTENTIAL OF DRUPE FRUIT VARIETIES — BIOMORPHOLOGICAL FEATURES OF FORMATION AND REALIZATION UNDER THE CLIMATIC CONDITIONS OF SOUTH RUSSIA

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Abstract

Productivity, the main characteristic of a variety of fruit crops, which is due to a set of elements, determines the resistance of a crop to environmental stress factors and its suitability for industrial growing conditions. The impact of climatic stresses annually results in only 30-40% realization of productivity potential of fruit plants. In fruit plants, including sweet and ordinary cherries, fruit-bud differentiation takes a long time. In the conditions of the southern Russia (Prikubanskaya gardening zone of the Krasnodar Territory), it begins in July of the current year and ends in April-May of the next year. The climate in the Krasnodar Territory is quite mild, generally favorable for the cultivation of sweet and ordinary cherries. Nevertheless, even in the south of Russia, there is a high risk of annual abiotic stresses, negatively affecting fruit plants and impeding realization of their productivity potential. In the present work, a comprehensive biomorphological study was first undertaken to assess the regional productivity potential of sweet and ordinary cherries of various ecological and geographical origins. Our research aimed to establish the regional patterns of productivity element formation during morpho- and organogenesis in *Prunus* L. species and hybrids, to identify the most vulnerable stages in plant annual development cycles, and to distinguish the varieties with high and sustainable yielding under risky weather conditions. Three introduced *Cerasus avium* (L.) Moench varieties of different ecogeographic origins (Valerii Chkalov, Melitopolskaya Chernaya, and Polyanka), six domestic *C. avium* varieties (Kavkazskaya, Sashen'ka, Volshebnitsa, Dar izobiliya, Alaya, and Mak), four introduced *C. vulgaris* Mill. varieties (Kelleris, Nefris, Fanal, and Erdi Botermo), and seven interspecific hybrids *C. vulgaris* × *C. avium* (Kirina, Dombaziya, Duk Ivanovna, Duk Khodosa, Igrushka, and Shalun'ya) were studied during 2006-2019 (Experimental Production Center of the North-Caucasian Federal Scientific Center of Horticulture, Viticulture, Winemaking, Krasnodar; 6×4, 7×3, and 5×3 m plant spacing patterns). *Cerasus mahaleb* (L.) Mill. and *Cerasus avium* L. plants were rootstock plants, all experiments were arranged in three replications. Phenology of all stages and sub-stages of the annual (vegetative and generative) plant growth was described as per BBCH system (Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie, Germany). Morphogenesis of yield components was investigated in 15 generative buds two times in December and February, weekly in March-April, and weekly in July-November by light microscopy (Olympus BX41, Olympus Corporation, Japan). In spring, flowers, ovaries, and fruits were gradually counted on third-order skeletal branches, and the degree of their reduction were calculated to estimate biological productivity. The number of fruit buds and growth buds was estimated twice a week in August and September. To assess the winter hardiness, 90 vegetative buds and 180 fruit buds from different sides of the lower and upper branches of 3 trees of the same variety were collected in 3 replicates. It was found that the reduction of productivity elements in the stressful conditions of southern gardening occurs annually at the same (critical) stages of development of fruit plants. These stages are i) reproductive organ initiation; ii) archesporium formation in anthers; iii) pollen mother cells, iv) mono- and binuclear pollen grains, and v) macrosporogenesis. The critical periods of yield formation in the conditions of the Krasnodar Territory are II-III decades of March, and I-II decades of April, May and July, when special agrotechnology should be applied to reduce the impact of stress and to increase yields. A direct correlation was revealed between temperature and air humidity during each critical period, the fruiting coefficient and the final yield ($r = +0.97$, $p < 0.001$). In our tests, the following samples are characterized by high fruiting rates and sustainable yields: domestic cherry varieties Kavkazskaya (62% and 31.3 t/ha, respectively), Alaya (46% and 30.0 t/ha), Sashen'ka (45% and 26.6 t/ha), and Volshebnitsa (42% and 23.3 t/ha), interspecific hybrids Duk Khodosa (46% and 23.3 t/ha), Kirina (44% and 23.3 t/ha), and Duk Ivanovna (44 % and 20.0 t/ha), and an ordinary cherry variety Kelleris (45% and 20.0 t/ha). These varieties and hybrids can be cultivated in commercial orchards and used as genetic donors in breeding for sustainable productivity.

Keywords: drupe fruit, sweet cherry, ordinary cherry, varieties, abiotic factors, adaptive potential, biological productivity, generative development, organogenesis, yielding

Stresses caused by current global climatic changes negatively affect the productivity of agricultural plants, including drupe fruit plants of the genus *Prunus* L. [1, 2]. According to the forecasts, in the future, an increase in the average air temperature by 1.5-2.7 °C is likely [1, 3], which can lead to a shift in the annual biorhythms of fruit crops and disrupt the production process [4]. Obviously, under the influence of stress factors, varieties will be unable to maximize their yield potential [5]. A deeper understanding of how the reproductive parts of a plant develop underlies measures to preserve future fruit harvests at critical, most vulnerable stages of plant ontogenesis.

Krasnodar Territory is a southern Russian region with quite favorable weather and climatic conditions for fruit plant cultivation [6]. Nevertheless, even in the south, the risk of annual abiotic stresses is high [7]. These are frosts during the dormant period, return spring frosts, precipitation, fog, dry winds and high temperatures during the flowering period, which cause damage to reproductive organs, partial or complete yield loss [8, 9]. About 50% of fruit yields depend on weather conditions [10], 40% depend on a varietal biological potential [11], and 10% on anthropogenic factors [7, 12]. Other researchers report a higher level of specific influence of the variety on the yield of drupe fruit plants [6, 8].

The fruit yield formation is preceded by a long period, including initiation and differentiation of fruit buds, which are the consecutive stages in the annual development cycle. At each stage, processes occur that determine the productivity of a particular crop and variety [10, 13]. In fruit plants, including sweet cherries and ordinary cherries, bud differentiation takes a long period [5, 14]. In the conditions of the southern region of Russia (Prikubanskaya zone of gardening in Krasnodar Territory), it begins in July of this year and ends in April-May of the next year [5]. In the apple tree, differentiation lasts on average 140-150 days [10, 12], in the sweet cherry it takes 117-130 days [6]. By the beginning of the dormant period (December), floral pistil primordia and stamen primordia appear in fruit buds of sweet cherry and ordinary cherry [15], which makes the flowers less frost-resistant and more vulnerable [8]. Unlike cherry plants, the fruit buds of apple plants are less differentiated, which determines their greater winter hardiness [12, 16].

It was found that frosts from –26.0 to –28.0 °C during dormancy lead to significant freezing or death of fruit buds in sweet cherry [17], and temperatures from –29.0 to –30.0 °C cause freezing or death of reproductive shoots in ordinary cherry [14]. Data are given that open flowers of sweet cherry and ordinary cherry die at temperatures from –2.0 to –2.2 °C, closed buds at –2.4 to –5.0 °C [17], and that pistils of flowers are especially sensitive to spring frosts [9, 18]. It has been proven that some drupe fruit crops (apricot, cherry plum, Russian plum, sweet cherry) are caused to early wake up if the sum of low negative temperatures during dormancy is below the required values [19]. This biological feature increases the frost impact on generative organs [20, 21], leading to asynchronous development of flower organs [22, 23] and male generative dysfunctions with a decreased viability and quality of pollen and impaired fertilization [21, 24].

High temperature stress also adversely affects the generative sphere of fruit plants [25]. It has been established that differentiation of apple fruit buds is optimal at 23.0-30.0 °C [26] and stops at temperatures above 30.0 °C [27]. It is believed that maturation of sweet cherry and ordinary cherry pollen begins at 22-23.0 °C [24, 28], whereas the temperature of 25.0 °C is fatal for the cherry plum ova [29]. According to some studies, extremely high temperatures shorten the period of effective pollination [30], and when flower buds are set in such conditions, the morphogenesis and, hence, the future harvest are under threat [31, 32].

Thus, it is obvious that temperature stresses do not allow fruit plants to maximize their yield potential, since the plants generate a physiological stress response that allows cells to survive [33]. To summarize, the pattern of yield component formation and yield potential realization in fruit crops under temperature stress remain fragmentarily studied and insufficiently clarified, which prompted us to perform this research.

Here we present data on yield potential of sweet cherry and common cherry varieties of various ecogeographic origin assessed in the conditions of Krasnodar Territory by complex biomorphological parameters. Five critical stages of organogenesis and their timing under stresses have been identified. It has been found out that the observed yields depend strongly on the types of temperature stress during these periods and on the number of fruiting elements after reduction.

This research aimed to identify patterns of morpho- and organogenesis in the genus *Prunus* L., which determine the development of yield components under environmental stress, to reveal the most stress-sensitive stages of annual plant cycle based on the resultant yielding, and to recognize the most productive sweet cherry and ordinary cherry varieties for intensive gardening in the southern region of the Russian Federation.

Materials and methods. In the research we used 3 introduced varieties of sweet cherry *Cerasus avium* (L.) Moench of different ecological and geographical origin (Valery Chkalov, Melitopolskaya chernaya, Polyanka) (Ukraine), 6 varieties of domestic selection (Caucasian, Sasha, Volshebnitsa, Dar Izobiliya, Alaya, Mak) (Russia), 4 introduced varieties of ordinary cherry Cerasus vulgaris Mill., the Kelleris (Denmark), Nefris (Poland), Fanal (Germany), Erdi Botermo (Hungary), and 7 interspecific hybrids (sweet cherry × ordinary cherry), the Kirina (Russia), Dombazia (Central Asia), Duk Ivanovna (Ukraine), Duk Khodosa (Ukraine), Igrushka (Ukraine), Shalun'ya (Ukraine). The trials were performed at Tsentralnoe Experimental Production Center (the North Caucasian Federal Research Center of Horticulture, Viticulture, Winemaking, Krasnodar, Prikubanskaya zone of gardening) in 2006-2019. Agrotechnologies were common for the region. Tree planting patterns were 6×4, 7×3 and 5×3 m. Seedlings of antipka (Mahaleb cherry) *Cerasus mahaleb* (L.) Mill. and wild sweet cherry *Cerasiis avium* L. were used as the rootstocks (one cultivar — one variant according to the methodology of cultivar study), the experiments were arranged in three replications.

Phenological characterization of annual vegetative and generative growth stages and substages was carried out as per BBCH international coding system (Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie, Germany) [34]. Biological productivity and the frost damage to fruit buds were assessed according to [35, 36]. During observations, the phenophases were documented (Canon EF-S camera, Japan), and the stages of organogenesis were examined using light microscopy (an Olympus BX41, Olympus Corporation, Japan).

On the tertiary skeleton branches, flowers, ovaries, and fruits were counted in spring, and their reduction was assessed. Fruit and growth buds were counted in August and September twice a week [5].

To study fruit morphogenesis by light microscopy, 15 generative buds were collected twice in December and February, and weekly in March-April and July-November.

For temporary slides, the fruit bud was cut with a razor blade from base to top, and transverse sections were fixed in distilled water on a glass slide. The slides were viewed under a microscope at a 50-100× zoom. The anthers were removed from fruit buds with a needle, pre-stained with acetocarmine on the microscope stage, pressed down with a cover glass and viewed at a 100-200× zoom (an Olympus BX41 microscope). The stages and substages of organogenesis and microsporogenesis were described as per Isaeva [37]. Specimens for anatomical study of fruit buds by light microscopy were prepared according to the improved method of Kiseleva [38].

Yield components appeared on short spurs with bud fascicles and on annual shoots with fruit buds were counted in August-September on 1-2 typical tertiary branches from the southern and eastern sides of a tree (a total of three trees per variety in a 3-fold repetition). The coefficient of productivity (Cp) was calculated as a fruit-to-flower percent ratio (the flowers per 1 m of fruiting branches were taken as 100%).

Winter hardiness was assessed in 90 vegetative and 180 fruit buds collected from three trees of each variety (from different sides of the lower and upper branches) in 3 replicates.

The arithmetic means (*M*), standard deviations (±SD) and LSD_{05} (a 95% probability level) were calculated using a standard Microsoft Excel 2013 software package. The coefficient of variation (*Cv*, %) and the relative standard error of the sample mean (sampling error) ($Sx = SD/\sqrt{M}$, %) were calculated [35]. Correlation analysis of damage to fruit buds depending on the cultivar and the year conditions was performed using the Statistica package (StatSoft, Inc., USA) (2019).

Results. The climate in the Prikubanskaya zone of the Krasnodar Territory is rather mild, generally favorable for the cultivation of sweet cherry and ordinary cherry. The average annual air temperature is 11.9-12.1 °C. The maximum temperatures in July-August reach 40.0-40.7 °C, the minimum temperatures in January-February can drop to –33.0 °C.

Weather conditions during study years showed dynamism and were indicative of a complex of stably recurring temperature stresses. So, in January 2006, abnormally low temperatures were observed (from –32.0 °C to –33.0 °C), which led to the death of all fruit crops [17]. In February 2014, freezing rain at –22, 2 °C caused the death of the harvest of all fruit plants. In January 2015 and December 2016, during the dormant period, after a long period of warm weather, the air temperature dropped to –21.0 °C and –17.0 °C, respectively, resulting in freezing of fruit buds in sweet cherry. During our observation, almost every two

1. Reduction of yield components (fruit buds, flowers and ovaries) in sweet cherry *Cerasus avium* (L.) Moench and ordinary cherry *Cerasus vulgaris* Mill. varieties as influenced by weather stresses during critical periods of plant ontogenesis (Tsentralnoe Experimental Production Center, the North Caucasian Federal Research Center of Horticulture, Viticulture, Winemaking, Krasnodar, 2006-2019)

Phenophase (BBCH stage)	Stage of organogenesis and microsporogenesis (timing)	Temperature and air humidity		Reduction, %
		optimal conditions	unfavorable conditions	
Initiation of flower organs in fruit buds	IV — emergence of generative parts (July decades I-II)	Below 30-33 °C at 40-47% air humidity	Above 35-37 °C at air humidity below 40%	20-30
Dormancy (00)	VI — archesporial tissue in anthers (December-January)	Above –24 °C at 65-75% air humidity	Below –28 °C at 75-80% air humidity	85-100
Bud scale elongation (bud burst) (51)	VII — pollen mother cells (March decades II-III)	Not lower than 9-10 °C at 60% air humidity	Below –10 °C at 65% air humidity	15-70
First flowers bloom—full flowering (60-65)	IX — mono- and bicellular pollen grains (April decades I-II)	Within 16-25 °C at 55-58% air humidity	From –3.0 to –6.0 °C; below 16 °C at 60% air humidity	20-95
Ovary emergence and growth (71-72)	X — macrosporogenesis (May decades I-II)	Within 25.0-28.0 °C at 54-60% air humidity	Above 28.0-30.0 °C at 75% air humidity	40-46

N o t e. For description of the varieties and hybrids, see section Materials and methods.

years (2009, 2010, 2014, 2015, 2018) in July-August, in the period of fruit set and differentiation, abnormally high temperatures (38.0-40.0 °C) combined with drought were noted for 4-5 days or more. During the flowering of sweet cherry and ordinary cherry plants, recurrent spring frosts (from –3.0 to –6.0 °C) occurred annually, leading to freezing and death of stamens and stigmas of pistils, and at temperatures below 16 °C and 60% air humidity the fertilization was disturbed (Table 1).

Of the 12 morphogenetic stages that we studied in sweet and ordinary cherry plants, five stage with a high rate of yield component mortality were the most vulnerable across study sites and years. We also determined the optimal and extreme conditions for each phenophase (organogenesis stage) (Table 1). Similar studies on apple trees identified only four critical stages [37].

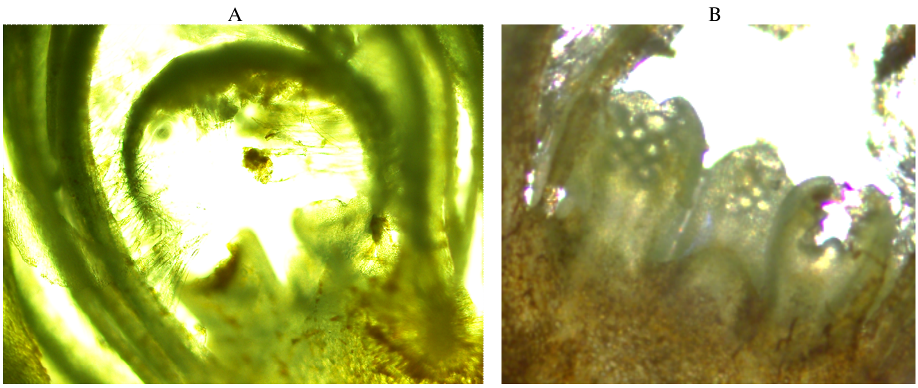

Fig. 1. Floral primordium in the fruit bud of sweet cherry *Cerasus avium* (L.) Moench variety Alaya at stage IV of organogenesis (A, July 23, 2017, unfavorable conditions of above 35-37 °C and air humidity below 40%) **and pistil primordium in the fruit bud of ordinary cherry *Cerasus vulgaris* Mill. variety Kirina at stage V of organogenesis** (B, November 10, 2018, above –6,5 °C at 65-75% air humidity are close to optimal conditions)**, the Prikubanskaya zone of gardening in Krasnodar Territory** (50-100× zoom, Olympus BX41, Olympus Corporation, Japan). For variety origin, see section Materials and methods.

During stage IV of organogenesis (July decades I-II), only 1-2 instead of 3-5 floral primordia emerged under unfavorable temperature conditions (see Table 1, Fig. 1, A), whereas, under those close to optimal, all the flower organs and archesporial anther tissue (three meristematic zones and more) were formed, which then reduced to floral primordia (see Table 1, Fig. 1, B). Under unfavorable temperature at stage IV, the reduction of flower organs averaged 20-30%.

Many researchers report that fruit buds have the highest winter hardiness at the state of primary archesporium, corresponding to stage VI [15, 29], which we noted in December-January (Fig. 2). We regard the stage VI as the second critical for organogenesis under the conditions of Krasnodar Territory (see Table 1) due to the high probability of frost and, thence, death of fruit buds. So, in 2006, the most abnormal in recent decades, temperature drop to –33.0 °C during the dormancy period killed 100% of flower buds in most sweet cherry varieties. We revealed a close correlation (r = +0.991, p <0.001) between exposure to critical temperature and the death of fruit buds. In particular, 100% death of generative organs was characteristic of the introduced sweet cherry varieties Polyanka and Valery Chkalov. For the local varieties Alaya, Volshebnitsa and Dar izoboliya, with 90% death of fruit buds, the yields were 5.0-5.5 kg per tree, which indicates frost resistance. Interspecific hybrids for which a fruiting rate of 4.0-6.0 kg per tree upon 90-95% death of fruit buds was indicative also showed high frost resistance. In the studied varieties of ordinary cherry, the rate of bud death was lower and averaged 85-90%, with a yield of 5.0-8.0 kg per tree.

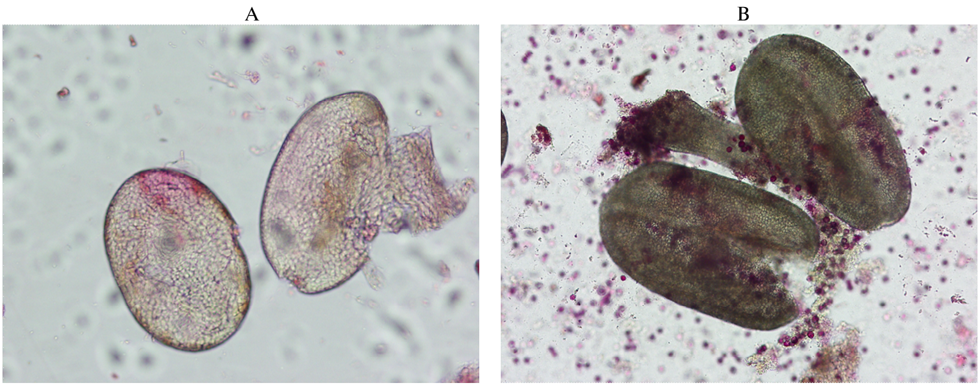

Fig. 2. Formation of archesporium tissue in anthers at stage VI of organogenesis (A, January 28, 2010, favorable temperature above –24 °C and 65-75% air humidity) **and mother cells of pollen at stage VII of organogenesis** (B, March 15, 2019 года, temperature not lower than 9-10 °C at 60% air humidity) **in sweet cherry *Cerasus avium* (L.) Moench variety Mak, the Prikubanskaya zone of gardening in Krasnodar Territory** (50-100× zoom, Olympus BX41, Olympus Corporation, Japan). For variety origin, see section Materials and methods.

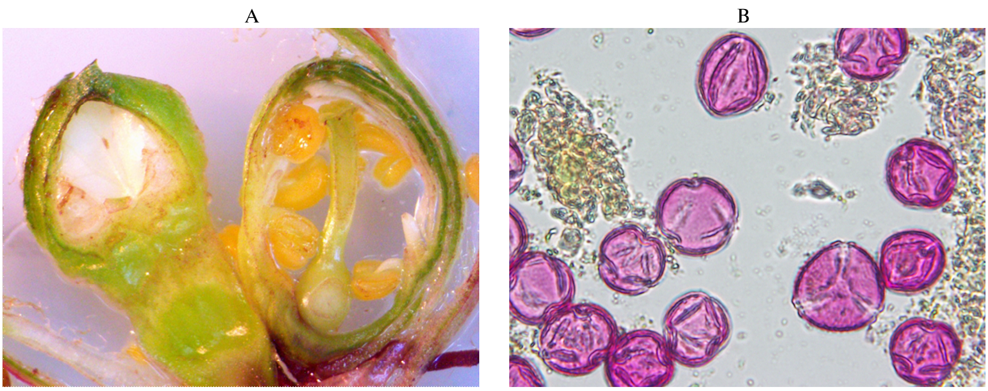

Fig. 3. Phenophases "first flowers bloom" in ordinary cherry *Cerasus vulgaris* Mill. variety Nefris at stage IX of organogenesis (A, April 5, 2018, favorable conditions) **and "full flowering" in ordinary cherry ordinary cherry *Cerasus vulgaris* Mill. variety Igrushka at stage IX of organogenesis** (B, 1-2-cell pollen, April 16, 2010, favorable temperature withing 16-25 °C at 55-58% air humidity)**, the Prikubanskaya zone of gardening in Krasnodar Territory** (50-100× zoom, Olympus BX41, Olympus Corporation, Japan). For variety origin, see section Materials and methods.

We regard the phenological phases "bud scale elongation" (stage VII of organogenesis) (see Fig. 2) and "first flowers bloom—full flowering" (stage IX) (Fig. 3) as the third and fourth critical stages that determine yield efficiency of sweet cherry plants. In the conditions of southern horticulture, stage VII of organogenesis falls on March-April, with recurrent spring frosts (see Table 1). At the beginning of the growing season, which coincided with the phenophase "bud scale elongation", the generative organs of sweet cherries are especially sensitive to temperature stresses. Some researchers believe that at air temperature from –3.0 to –6.0 °C at this stage, sweet and ordinary cherry varieties can almost completely lose their yield [11, 17], which is in line with our findings. Thus, frosts up to –6.2 °C on April 10, 2009, led to freezing and significant losses of yield components. In cherry varieties of local selection, the death of fruit buds was 80-85%, and in all introduced varieties it reached 90-95% with a reduced yield of 3.0-7.0 kg per tree in both genetic groups. In interspecific hybrids, there was a 90-95% death of fruit buds with a low yield, 2.0-4.5 kg per tree. European varieties of ordinary cherry showed higher resistance to spring frosts (the fruit bud death rate of 75-78% and a yield of 7.0-8.0 kg per tree).

On March 25, 2013, the temperature several times dropped to –3.0 °C and even –4.0 °C, that caused freezing of 40-50% of fruit buds. However, these climatic factors caused only 40% death of generative organs in the domestic varieties Alaya and Kavkazskaya, with a yield of 18.0-20.0 kg per tree, giving, therefore, the reason to deem these varieties resistant to spring frosts. In interspecific hybrids and in in ordinary cherry varieties, 30-40% and 15-25% of yield components, respectively, were frozen, with yields of 10.0 and 22.0 kg per tree, respectively. Light microscopy of fruit buds showed that both in sweet cherry and ordinary cherry the anthers during the period of return frosts retained high-quality pollen without visible anomalies, but the pistils were damaged. That is, a pistil is less frost-resistant than other floral organs, which is consistent with the data obtained earlier [9, 24]. We revealed a higher resistance to low negative temperatures during the dormant period and at the beginning of the growing season in the ordinary cherry varieties as compared to the sweet cherry varieties. We also established varietal specificity and a close correlation between the critical temperature and the reduction of generative organs ($r = +0.97$, $p < 0.001$)

The phenophases “first flowers bloom—full flowering” (stage IX) (see Table 1, Fig. 3) turned out to be the most vulnerable to temperature stresses. For this stage, according to some reports, the optimal temperature ranges within 16.0-25.0 °C [17, 28], which is consistent with our observations. We found that air temperatures above 26.0 °C during flowering period (April decades I-II) accelerate flower senescence both in sweet cherry and ordinary cherry due to the drying out of the pistil and ovule, which led to impaired fertilization and a significant loss of yields.

Ovary emergence phenophase (stage X of organogenesis) was less susceptible to stress than others. At this stage (May decades I-II), in the conditions of southern horticulture, anomalously high temperatures are adverse factors causing a 40% loss of the ovary in sweet cherry varieties, 42% in interspecific hybrids and 46% in ordinary cherries (see Table 1).

Given the fact that the variety is the main factor providing stable high yields in fruit crops [12, 13], we evaluated the yield to distinguish among the studied varieties those that are the most productive under stress. Under favorable conditions, drupe fruit varieties form a significant number of vegetative and fruit buds the ratio of which differs significantly [8]. Our findings also confirm this statement ($Cv = 20\%$). In sweet cherry, depending on the variety, the number of fruit buds per 1 fruiting branch averaged from 68 (Kavkazskaya) up to 128 (Alaya), of vegetative buds from 26 (Dar izobiliya) up to 35 (Melitopolskaya chernaya). For the number of formed fruit buds, all sweet cherry varieties significantly exceeded the control ($LSD_{05} = 3.1$). In ordinary cherry varieties, the number of fruit buds per 1 fruiting branch varied from 68 (Fanal) up to 12 (Kelleris) and exceeded the control ($LSD_{05} = 3.5$). The number of vegetative buds in ordinary cherry varieties varied moderately ($Cv = 20\%$), from 25 (Fanal) up to 40 (Kelleris). In the ordinary cherry-sweet cherry hybrids, the fruit bud number was 64 for Dombazia and 118 for Kirina, and the vegetative bud number was 24 for Igrushka and 37 for Shalunya (Table 2). That is, the number of developing fruit buds was much higher than that of vegetative ones, which indicates a high yield potential of sweet and ordinary cherry varieties.

2. Yield components in studied sweet cherry *Cerasus avium* (L.) Moench and ordinary cherry *Cerasus vulgaris* Mill. varieties of various ecogeographic origin (Tsentralnoe Experimental Production Center, the North Caucasian Federal Research Center of Horticulture, Viticulture, Winemaking, Krasnodar, 2006-2018)

Variety	Biological potential, number/m (M±SD)					Coefficient of productivity (Cp), %
	buds		flowers	ovaries	fruit	
	fruit	growth				
			S w e e t c h e r r y *Cerasus avium* (L.) Moench			
			Varieties of North-Caucasian Federal Scientific Center of Horticulture, Viticulture, Winemaking			
Kavkazskaya (St)	68±12	30±6	310±22	226±7	192±4	62
Sashen'ka	75±15	31±10	237±17	134±5	107±5	45
Volshebnitsa	98±12	29±5	384±28	222±10	160±3	42
Dar izobiliya	85±10	26±8	255±31	159±4	102±7	40
Alaya	128±14	33±5	430±20	266±5	196±5	46
Mak	76±11	32±7	220±19	129±6	75±6	35
			Introduced sweet cherry varieties			
Valerii Chkalov	76±10	28±11	225±15	182±8	47±7	21
Melitopolskaya chernaya	94±18	35±6	405±23	173±10	98±3	23
Polyanka	80±15	29±15	325±20	186±9	125±5	35
LSD_{05}	3.1	2.8	7.4	5.5	5.6	3.1
SD, %	17.0	2.7	81.2	44.9	51.1	
$M_{average}$ for sweet cherry	89.0	30.0	310.1	186.3	122.4	
Cv, %	20.0	8.9	26.2	24.1	41.6	
Sx, %	5.6	0.9	27.1	14.9	17.0	
			O r d i n a r y c h e r r y *Cerasus vulgaris* Mill.			
			Introduced ordinary cherry varieties			
Kelleris	124±19	40±9	295±19	192±7	134±4	45
Nefris	103±16	29±5	322±25	164±11	120±2	37
Fanal	68±21	25±12	200±18	94±4	70±8	35
Erdi Botermo	88±18	30±10	228±16	110±5	87±5	38
			Ordinary cherry-sweet cherry hybrids			
Dombaziya	64±15	31±14	160±22	82±8	52±9	33
Dyuk Ivanovna	95±10	37±8	250±20	161±11	110±4	44
Dyuk Khodosa	88±19	30±15	198±18	125±5	90±8	46
Vstrecha	102±12	33±11	306±11	173±8	119±3	39
Kirina (St)	118±7	36±9	280±10	168±10	123±5	44
Igrushka	97±17	24±17	286±17	130±7	105±2	37
Shalun'ya	108±11	37±13	247±15	153±4	95±7	38
LSD_{05}	3.5	2.7	3.4	2.8	2.2	
SD, %	18.5	5.1	51.3	35.3	24.6	
$M_{average}$ for ordinary cherry	95.9	32.0	252.0	141.1	100.5	
Cv, %	19.2	16.0	20.4	25.0	24.5	
Sx, %	5.6	1.5	15.5	10.6	7.5	

N o t e. St — standard variety; *Cv* — coefficient of variation, SD — standard deviation, *M* — arithmetic mean, Sx — relative standard error of the sample mean (sampling error). For the description of varieties and hybrids, see section Materials and methods. On average, the sample size per year was 2700-4500 fruit buds and 4500-6800 flowers for sweet cherry, and 1500-3200 fruit buds, 2500-4700 flowers for ordinary cherry.

Initiation of a large number of fruit buds is an important adaptive mechanism developed during evolution and used as an "insurance fund" in case of reduction of flowers, ovaries and fruits after exposure to stress factors [10, 37]. Coefficient of productivity is a significant parameter to characterize the yield potential of a variety [5, 13]. Out data show that the potential for flowers per 1 m of fruiting branches in sweet cherry varieties varied significantly (*Cv* = 26.2%), from 220 (Mak) to 430 (Alaya), in ordinary cherry varieties moderately (*Cv* = 20.4%), from 160 (Dombaziya) to 322 (Nefris) (see Table 2). There is an opinion that natural losses, or "cleansing", at the stages of ovary and fruit formation are quite high [5, 11]. According to our data, given the reduction of non-pollinated or lagging flowers at the stage IX of organogenesis, sweet cherry trees formed 129 ovaries in the Mak variety and 266 in the Alaya variety, which exceeded the control value in the Kavkazskaya variety (226 ovaries on average) (LSD_{05} = 5.5). In ordinary cherry varieties, the number of ovaries (from 94 for Fanal variety up to 192 for Kelleris variety) was less than that in sweet cherry and significantly varying (*Cv* = 25.0%) (see Table 2).

On average, over the study years, the reduction at fruit set and fruit formation stages in sweet cherry varieties was 40%, in ordinary cherry 46%, in interspecific hybrids 42%.

Yield potential realization in sweet and ordinary cherries was assessed at XI-XII stages of organogenesis (i.e. at ripening). Sweet cherry varieties under favorable conditions generated 75-196 fruits, ordinary cherry 70-134 fruits, and interspecies hybrids 52-123 fruits per 1 m of fruiting branches.

At the final stages of development, the reduction of fruits significantly decreased, which made it possible to calculate the optimal coefficient of productivity. It averaged 43% in sweet cherry varieties, 40% in the hybrids, and 38% in ordinary cherry varieties. It should be noted that the varieties of local selection differed from a number of introduced ones by a higher rate of fruiting. So, it was 62% in the domestic variety Kavkazskaya, 46% in Alaya, 45% in Sashen'ka, and 42% in Volshebnitsa. The higher coefficient in sweet cherry varieties corresponds to a higher yield, averaging 45-50 kg per tree, or 29.9-33.3 t/ha, at the planting pattern of 5×3 m (see Tables 2, 3).

The varieties outstanding for a high percentage of fruits to flowers under the conditions of Prikubanskaya zone of gardening (the Krasnodar Territory) are Kelleris (45%) and Erdi Botermo (38%) of ordinary cherry, and Duk Khodoss (46%), Kirina (44%) and Duk Ivanovna (44%) of the interspecies hybrids. These varieties and hybrids also provide a fairly high yield (30-40 kg per tree, or 19.9-26.6 t/ha, at the planting pattern of 5×3 m) (see Tables 2, 3).

3. Yields of sweet cherry *Cerasus avium* (L.) Moench varieties and ordinary cherry *Cerasus vulgaris* Mill. varieties of various ecogeographic origin under climatic stresses of Prikubanskaya zone of gardening (the Krasnodar Territory) (Tsentralnoe Experimental Production Center, the North Caucasian Federal Research Center of Horticulture, Viticulture, Winemaking, Krasnodar, 2006-2018)

Variety	Productive performance							
	2006 (January, −33.0 °C)		2009 (April, −6.2 °C)		2013 (March, from −3.0 to −4.0 °C)		2018 (optimum)	
	R, %	kg/tree (*M*±SD)	R, %	kg/tree (*M*±SD)	R, %	kg/tree (*M*±SD)	R, %	kg/tree (*M*±SD)
Sweet cherry *Cerasus avium* (L.) Moench								
Varieties of North-Caucasian Federal Scientific Center of Horticulture, Viticulture, Winemaking								
Kavkazskaya (St)	90	5.5±1.0	80	7.0±2.0	40	18.0±2.5	0	35.0±5.0
Alaya	90	5.0±2.0	80	7.0±3.0	40	20.0±4.0	0	47.0±5.0
Dar izobiliya	92	4.5±1.5	82	5.0±2.5	45	17.0±3.5	0	40.0±3.5
Volshebnitsa	90	5.0±2.5	85	6.0±1.5	45	17.0±3.0	0	35.0±4.0
Mak	94	3.0±2.5	80	7.0±1.0	50	15.0±4.5	0	45.0±3.5
Sashen'ka	95	1.0±0.5	85	5.5±2.5	50	15.0±3.0	0	30.0±4.5
Introduced sweet cherry varieties								
Valerii Chkalov	100	1.0±0.5	95	0.0±0.0	52	12.5±4.0	0	15.0±5.0
Melitopolskaya chernaya	96	1.0±0.5	90	3.0±1.0	55	10.0±2.5	0	25.0±3.0
Polyanka	100	0.0±0.0	95	1.0±0.5	55	10.0±4.0	0	30.0±2.5
LSD_{05}	1.35	0.99	1.69	1.12	1.70	1.20	0	2.10
SD, %	4.0	2.2	6.2	2.7	5.8	3.5	0	10.0
$M_{average}$ for sweet cherry	94.1	2.8	85.7	4.6	48.0	14.9	0	33.6
Cv, %	4.3	75.8	7.2	58.0	12.0	23.0	0	29.0
Sx, %	1.3	30.7	2.1	0.9	1.9	1.2	0	3.3
Ordinary cherry *Cerasus vulgaris* Mill.								
Introduced ordinary cherry varieties								
Kelleris	85	8.0±2.0	75	8.0±1.5	20	22.0±4.5	0	30±4.5
Nefris	88	7.0±1.5	76	7.5±2.5	15	20.0±3.0	0	25±3.0
Fanal	85	7.5±2.5	75	7.5±1.5	20	18.0±3.5	0	20±3.5
Erdi Botermo	90	5.0±3.0	78	7.0±3.0	25	15.0±2.5	0	25±2.0

Continued Table 3

Ordinary cherry-sweet cherry hybrids								
Dombaziya	90	6.0±2.5	90	4.0±3.5	40	10.0±4.0	0	28±1.5
Dyuk Ivanovna	95	4.0±3.0	93	3.0±2.5	40	10.5±3.0	0	30±1.0
Dyuk Khodosa	90	5.0±2.5	90	4.5±1.5	30	15.0±2.0	0	35±2.0
Vstrecha	90	6.0±2.0	92	3.0±2.0	35	13.0±5.0	0	28±1.5
Kirina (St)	91	4.0±1.5	95	2.0±1.5	30	15.0±3.5	0	35±1.0
Igrushka	95	4.0±2.5	90	4.0±1.0	35	15.0±2.0	0	25±2.5
Shalun'ya	95	4.0±3.0	95	2.0±0.5	35	15.5±2.5	0	28±2.0
LSD_{05}	1.1	0.8	2.0	0.9	2.1	1.1	0	1.6
SD, %	3.6	1.5	8.4	2.3	8.5	3.6	0	4.4
$M_{average}$ for ordinary cherry	90.4	5.5	86.3	4.8	29.5	15.4	0	28.1
Cv, %	4.0	27.0	9.7	48.0	28.8	23.3	0	15.6
Sx, %	1.1	0.46	2.5	0.7	2.6	1.1	0	1.3

N o t e. St — standard variety; *Cv* — coefficient of variation, SD — standard deviation, *M* — arithmetic mean, Sx — relative standard error of the sample mean (sampling error). R — reduction (death) of fruit buds. For the description of varieties and hybrids, see section Materials and methods. On average, the sample size in stressful years for sweet cherry and ordinary cherry was 2500-2700 fruit buds.

It should be noted that high yielding of sweet cherry and ordinary cherry trees can be realized given that the impact of stress factors is minimal at all stages of generation of yield elements. Table 3 presents actual data on yielding of the varieties in extreme years. So, in 2006, during the dormant period, the temperature dropped to –33.0 °C, causing a 90-100% reduction of yield components. In this conditions, the sweet cherry varieties Alaya and Volshebnitsa stood out, with a yield of about 5.0 kg per tree. In ordinary cherry and sweet cherry-ordinary cherry hybrids, the rate of yield component reduction was lower than in sweet cherry, up to 85-95%. Thus, cherry varieties Vstrecha, Dombaziya, Duk Khodosa, Kelleris and Fanal were significantly superior to the control variety Kirin for actual yields (HCP_{05} = 0.8). In 2009, as a result of periodic frosts (–6,2 °C) during the flowering period, yield component reduction was high. In particular, in sweet cherry, it was 85-95%, with low variation between the varieties (*Cv* = 7.2%). In ordinary cherry and interspecies hybrids, 75-95% of fruit buds died, with insignificant variation between the varieties (*Cv* = 9.7%). n 2013, when the first flowers were blooming, the temperature dropped to –3.0 °C and –4.0 °C, which led to the death of 40-55% of the generative organs in sweet cherry and 15-40% in ordinary cherry and interspecific hybrids (see Table 3

Yield values of sweet cherry and ordinary cherry varieties indicate that these drupe fruit crops have a high yield potential, which is utmost realized under optimal weather conditions. So, in a favorable 2018, sweet cherry varieties had an average yield of 33.6 kg per tree. For yield values, sweet cherry varieties Dar izobiliya (40.0 kg per tree), Mak (45.0 kg per tree), and Alaya (47.0 kg per tree) outstood, significantly exceeding the control variety. Among ordinary cherry varieties which also had a high average yield in 2018 (28.1 kg per tree), Dyuk Ivanovna (30 kg per tree) and Kelleris (30 kg per tree) outstood.

So, under the conditions of Krasnodar Territory, in varieties and hybrids of sweet cherry and ordinary cherry, we have identified five critical stages of organogenesis, or phenological phases, when plants are most sensitive to temperature stresses, and the probability is very high of the significant rate of yield component reduction. These stages are initiation of flower organs in fruit buds, emergence of archesporium in the anthers (dormancy), generation of pollen mother cells (bud scale elongation), formation of mono- and bicellular pollen grains ("first flowers bloom—full flowering) and macrosporogenesis (ovary emergence and growth). The clarified average terms for these critical stages in the conditions of the Kuban zone of gardening are December-January, decades II-III of March, decades I-II of April, decades I-II of May, and decades I-II of July, which allows us to detail recommendations ensuring sustainable yielding of drupe fruit crops. The realization of the yield potential of sweet cherry and ordinary cherry trees is closely dependent on the type of temperature stress and the number of yield components after their reduction at all vulnerable stages of organogenesis ($r = +0.97$, $p < 0.001$). The samples selected for productive performance, are domestic varieties of sweet cherry Kavkazskaya resistant to temperature stresses and the most productive in the conditions of southern horticulture (the fruits-to-flowers ratio of 62%, the yield of 31.3 t/ha), Sashen'ksa (45% and 26.6 t/ha, respectively), Volshebnitsa (42% and 23.3 t/ha), Alaya (46% and 30.0 t/ha), an ordinary cherry variety Kelleris (45% and 20.0 t/ha), and interspecies hybrids Dyuk Khodos (46% and 23.3 t/ha), Kirina (44% and 23.3 t/ha), and Dyuk Ivanovna (44% and 20.0 t/ha). They are recommended for commercial growing in the Krasnodar Territory and involved in breeding programs as genetic donors of high productivity and adaptability to temperature stresses.

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