Agronomy Research **20**(2), 241–260, 2022
https://doi.org/10.15159/AR.22.031

Efficiency of productivity potential realization of different-age sites of a trunk of grades of columnar type apple-trees

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Received: April 15th, 2022; Accepted: May 15th, 2022; Published: May 17th, 2022

Abstract. An article provides information about buds organogenesis in plants of columnar apple cultivars in the Forest-Steppe of Ukraine (Kyiv), which allows to establish the features of this process in complex fruit formations of different ages, and their productivity and longevity. We recommend studying of apple trees productivity in the process of its formation by analyzing of rudimentary organs formation and their consistent development into vegetative and generative organs, which are elements of productivity. Studies of organogenesis different-age fruit formations of columnar apple cultivars were conducted in the northern part of the Forest-Steppe of Ukraine during 2016–2020. It was established that separate age sections of columnar apple trees trunk formed different initial productivity potential. In plants of all studied varieties and age groups, the laying of generative buds, the implementation of reproductive elements in V–IX and X–XI stages of organogenesis were more effective in older age areas of the trunk. Complex fruit formations, regardless of the trunk age where they are placed, form a high potential for productivity, which is effectively realized. The dependence of the formation and productivity potential realization on the stages of organogenesis and meteorological factors is established.

Key words: columnar apple, productivity, organogenesis, differentiation of generative buds, fruit formations.

INTRODUCTION

According to Isaeva (1989), apple productivity is the sum of all organic matter formed during the process of photosynthesis, which is often identified with yield; the latter is only an integral part of biological productivity (Rather et al., 2018; Vasylenko et al., 2021; Havryliuk et al., 2022). The transition of apple plants from vegetative to reproductive is due to the differentiation of generative buds (Duric et al., 1997; Buntsevich & Sergeeva, 2014; Kohek et al., 2015, Mazurenko et al., 2020; Zavadska et al., 2021). This process is the key in the problem of creating early fruiting plantations with regular fruiting of apple trees (Zamorskyi, 2007). Its passage occurs during the III–IV stages of organogenesis, so, according to Isaeva (1989), the above stages are considered critical, because the environmental conditions in this period on the possibility of potential components of fruiting transition to the actual laying of flowers (El-Sabagh et al., 2012; Gavryliuk et al., 2019; Mezhenskyj, 2019; Mezhenskyj et al., 2020). Differentiation of generative buds is influenced by various factors of both external and internal nature: rootstock, age and type of fruit formation, moisture, mineral and organic nutrition, timing and degree of flowering, yield load (Isaeva, 1989; Palubicki et al., 2009; Amasino, 2010; El Yaacoubi et al., 2020; Shevchuk et al., 2021a, 2021b; Miloševic et al., 2022). More details on research methods can be found in Havryliuk et al., 2022.

MATERIALS AND METHODS

The study was conducted during 2016–2020 at the Department of Horticulture named after Professor Volodymyr Levkovych Symyrenko of the National University of Life and Environmental Sciences of Ukraine. The experimental basis for the research was the planting of apple trees of the primary variety test at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (IH NAAS).

The subject of research - 4 columnar type varieties of apples of Ukrainian and foreign selection (Varieties of Ukrainian selection - 'Bilosnizhka'('Bolero' × 'Reinette Symyrenko'), 'Favoryt' ('Trident' × 'Redfree'); Varieties of Russian selection - 'Valuta' (KV6 × OR38T17), 'President' (Free Pollination KV103)). The object of research is the processes of formation potential and real (economic) productivity of apple varieties formation.

The investigated orchard was laid in 2010 according to the primary variety testing method. Planting is not irrigated. Apple trees on rootstock 54–118 were planted according to the 4×1 m scheme.

The experimental site is located in the zone of the Western Forest-Steppe of Ukraine. The climate of the district is temperate continental and is characterized by mild winters and warm summers. The average annual temperature is 7.4 °C. The coldest month is January, with an average monthly temperature of minus 5.8 °C, and the warmest month is July (19.6 °C). The first autumn frosts are observed from the second decade of October. Winter begins in the second decade of November. Permanent snow cover is established in December and disappears in the second decade of March. Thawing during the winter period (December-February) lasts an average of 40 days (repeated 8 to 10 times lasting 5 days). Spring frosts are likely by mid-May.

The growing season in fruit crops, according to long-term data, begins in the first decade of April. Active growth and development of fruit plants is observed in the third decade of April. The sum of active temperatures of 10 °C and above ($\Sigma_{act}t \geq 10$ °C) is 2850 °C, the number of days with temperatures of 10 °C and above - about 160. The average annual rainfall reaches 597 mm, most of which falls from April to October (400 mm). The wettest months are the summer months - from June to August, with an average of 68–81 mm of precipitation per month. In the period from November to March, about 230 mm of precipitation falls. The average number of days with precipitation is 160.

Meteorological data for the years in research were obtained at the Vantage Pro2 Plus weather station. The hydrothermal coefficient (HTC of Selyaninov) was calculated by dividing the amount of precipitation in mm by the sum of active temperatures of 10 °C and above for the period of fruits growth and development, the obtained data were decreased 10 times.

The soil of the study area is Greyic Phaezems Albic (Tonkha et al., 2020). The content of humus in the arable soil layer (0–40 cm) is 1.84 ± 0.07%, the pH of the aqueous extract is 6.1 ± 0.15.

Instruments. The buds, in which features of organogenesis were investigated, were selected in five repetitions from complex flushes located in the middle part of the trunk of a certain age, anatomical sections of buds 30–60 μm thick were made using a freezing microtome OmE. The obtained material was investigated using a microscope MBI-6 at a magnification of 90–180 times.

Methods. The height, trunk diameter and crown width of the trees were measured. Quantitative evaluation of productivity formation of apple varieties at III–IV organogenesis stages and the effectiveness of implementation of its elements into the real yield (V–XI stages of organogenesis) were performed according to Isaeva (1989) method. SEC (statistical evaluation coefficient) was calculated as the ratio of reproductive elements number at a certain organogenesis stage to the number of buds that reached stage II of organogenesis.

Description of the Experiment. The number of reproduction elements at certain organogenesis stages was analyzed during the research. Correlation analysis of influence weather factors over 5 years on the actual number of potential fruiting points depending on organogenesis stage was also conducted.

Sample preparation: The number of buds per plant was calculated in early August. When the air temperature was less than 5 °C, the number of buds that differentiated into generative ones was counted. From the onset of subzero temperatures, anatomical and morphological analysis of the buds was performed under a microscope to determine their condition in the pre-winter period. During the IX organogenesis stage (flowering), the total number of flowers per plant was counted. At the stage X of organogenesis (in June), the number of ovaries that did not fall was counted. The number of fruits was counted at the XI stage of organogenesis.

Number of samples analyzed: four varieties of columnar-shaped type apples took part in the research. Each variety is represented by five plants (20 trees in total). On each of the trees counted the number of reproductive elements at certain stages of organogenesis, respectively, at all trunk ages (Havryliuk et al., 2022).

Statistical analysis. The strength of the connection between meteorological elements years of research and the number of reproduction elements at a certain stage of organogenesis was calculated using correlation analysis. Factor influence by the correlation coefficient is weak ≤ 0.29, moderate: 0.30–0.49, noticeable: 0.50–0.69, high: 0.70–0.89, very high: 0.90–0.99 (LSD: Least significantly difference at $P < 0.05$). Statistical processing was performed in Microsoft Excel 2016 in combination with XLSTAT.

RESULTS AND DISCUSSION

During the III–IV stages of organogenesis due to the flowers formation in the generative buds the laying of tree productivity elements occurs (Kohek et al., 2015), at this time there is already a loss of productivity potential due to vegetative buds on simple and complex rings, on which generative buds are not differentiate (buds with incomplete cycle of organogenesis) (Yareshchenko et al., 2012). Kolomiets (1976) and Kobel (1984) investigated the dependence of generative buds differentiation on meteorological conditions. Isaeva (1989) experimentally found that this process begins earlier in warm and fairly dry summers than in cold and rainy. Kondratenko (2003) found a varietal difference in the timing of generative buds differentiation, in the degree of development of the latter in the pre-winter period, as well as in the timing and duration of IX–X stages of organogenesis for traditional apple genotypes. There is currently no information on the buds organogenesis in plants of columnar apple cultivars, which would make it possible to establish the features of this process in complex rings of different ages, as well as the levels of their productivity and longevity.

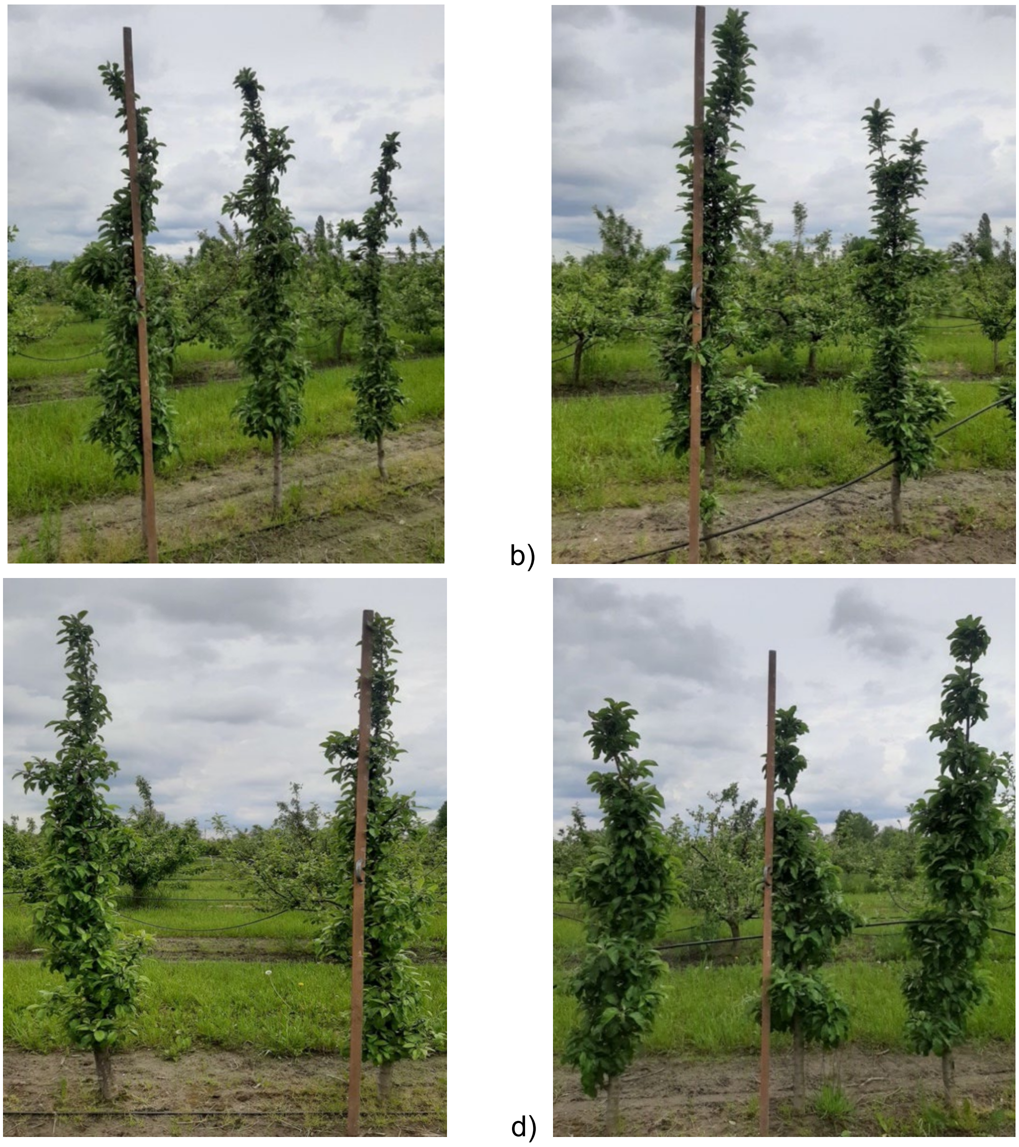
Plants of columnar apple varieties differ from traditional ones by almost complete lack of lateral branching, crop formation on simple and complex rings (fruit formations) located on the trunk of the tree, as well as dwarf growth, early fruiting and high yields (Lapins, 1969; Tobutt, 1984; Zakharov, 2011). According to research, the trunk of columnar varieties is densely covered with fruit formations, their location on the main and singular tree trunk in the first 5–7 years is uniform (Fig. 1), later perennial fruit formations are formed clustered, often unevenly.

a) b)

Figure 1. Symmetrical placement of fruit formations on the trunk of columnar apple trees: (seven-year plants of the variety 'Valuta', 2017).

The height of plant trunks of all varieties is insignificant (about 45 cm), the height of the crown exceeds its size 4–6 times (Fig. 2).

In studies, trees of columnar varieties, on a medium-sized rootstock 54–118 differed significantly in height, trunk diameter, crown width and density of fruit formations on the trunk (Table 1). Plants of 'Valuta', 'President', 'Bilosnizhka' and 'Favoryt' varieties at the age of 10 were at the level of 2.54–2.93 m.



a) b) c) d)

Figure 2. Height of 10-year-old plants of columnar varieties: a – 'Valuta'; b – 'President'; c – 'Favoryt'; d – 'Bilosnizhka'.

The diameter of the trunk varies between 5.63–8.00 cm. The width of the crown of columnar varieties is determined by the length of fruit formations (rings, fruit, fruit twigs) located on the trunk. This parameter in 'Bilosnizhka' is 20% less than in 'President'; this is due to the increased shoot-forming ability of this variety. The largest number of buds per running meter of the trunk was placed on plants of the 'Valuta' variety, the smallest - on the 'Bilosnizhka'.

Therefore, depending on the variety, such tree parameters as height, trunk diameter and crown width vary. As the height of the trees increases, the number of fruit formations on the plant increases, resulting in an increase in the potential for higher yields.

Table 1. Parameters of trees of columnar apple varieties. IH NAAS, 2019

Variety	Tree height, cm	Trunk diameter, cm	Crown width, cm	Number of buds, pcs/running m of trunk
'Bilosnizhka'	2.54^{b}	6.57^{b}	52.00^{a}	60.47^{a}
'Valuta'	2.81^{a}	5.70^{c}	40.33^{c}	74.36^{a}
'President'	2.69^{b}	5.63^{c}	38.67^{c}	69.87^{a}
'Favoryt'	2.93^{a}	8.00^{a}	46.00^{b}	66.00^{a}

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$).

Anatomical and morphological analysis of buds studied columnar varieties showed that in conditions of the Forest-Steppe of Ukraine (Kyiv) at the end of July they are in the II stage of organogenesis in their development. This period corresponds to the formation of productivity potential, which is quantified by the total number of buds, which have reached this stage (Havryliuk et al., 2019). Separate age sections of tree trunks columnar apple varieties form different initial productivity potential. Thus, in seven-year-old trees of the 'Valuta' variety, the five-seven-year-old sections of the trunk had the largest share in the formation of potential productivity - 57% of the total number of buds, formed on the whole tree, were located on them (Table 2).

Table 2. Involvement of 'Valuta' tree trunks of different ages in productivity formation (%). IH NAAS, 2016–2018

Age of the trunk segment	Stage of organogenesis / Year of research											
	II			III–IV			X			XI		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
1	6.8	8.9	9.4	0.0	1.3	0.0	0.0	1.1	0.0	0.0	1.2	0.0
2	12.6	6.7	7.0	6.0	6.0	0.0	10.5	6.2	0.0	12.4	7.1	0.0
3	7.6	8.2	5.9	8.4	10.2	11.1	19.2	10.5	8.3	24.4	10.9	9.5
4	15.3	7.6	7.0	20.3	10.5	23.3	29.4	10.9	25.2	35.5	11.5	17.8
5	20.5	10.9	8.3	30.3	14.5	5.6	40.9	14.2	8.3	27.7	9.1	9.5
6	25.2	13.9	10.4	25.9	15.1	13.3	0.0	17.1	10.0	0.0	15.6	13.3
7	12.1	20.3	13.3	9.1	19.7	19.4	0.0	21.6	20.2	0.0	22.4	20.6
8		23.6	20.3		22.7	6.7		18.4	6.7		22.3	6.7
9			18.4			20.6			21.3			22.5
Total	100	100	100	100	100	100	100	100	100	100	100	100

The same pattern is observed in the following years, the oldest age areas formed the largest number of fruit formations of the total number on the tree.

During the III–IV stages of organogenesis in 2016 (mid-July-November inclusive) trees of the variety 'Valuta' laid 90 pieces/tree generative buds, the largest number of which was recorded in five to six-year sections of the trunk (Table 2). No flower buds were formed on the shoot. In 2017, trees of this variety were laid 121 pieces/tree generative buds, and in 2018 - 5 pieces/tree. The most effective differentiation of generative buds in 2017 took place on the complex rings of the eight-year-old section of the trunk, and the following year - in the four- and nine-year. The highest level of productivity potential realization at the III–IV stages of organogenesis in seven-year-old plants was observed on fruit formations located on a five-year section of the trunk, although no significant difference between three-six-year sections was found (Table 3). In eight-year-old trees, no significant difference was found between three- to eight-year-old sections of the fruit tree trunk, and three- to nine-year-old trees the following year. Over the years of research, the lowest productivity potential at the III–IV stages of organogenesis was characterized by one-year fruit formations.

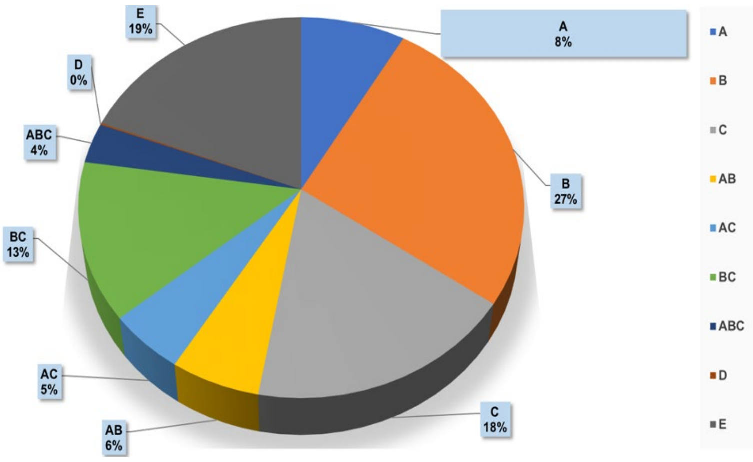
In 2017, during the IX–X stages of organogenesis, were observed Frosts-damaged ovaries plants (Fig. 3). In 2018, during the IX–X stages of organogenesis, favourable meteorological conditions were observed for flowering, fertilization, and fruit growth. One-year-old fruit formations this year retained the fewest elements of reproduction during these stages; the largest - the oldest.

In 2019, 10-year-old plants showed a critically low level of flowers and fruits formation in different age areas of the trunk. At the end of the X stage of organogenesis, the most productive were complex fruit formations located on four-seven-year sections of the trunk.

Figure 3. Frosts-damaged ovaries in 'Valuta' plants (IX–X stages of organogenesis), 2017.

At the end of the XI stage of organogenesis in eight-year-old plants (2017), the largest share of fruits from the total number on the tree was recorded on three-year-old rings. The following year, the reduction during phase XI was minimal. The smallest share of formed fruits from the total harvest was observed on rings of one-year growth, the largest - on fruit formations, which are located on four-year sections of the trunk (Table 3).

A diagram is constructed according to the determined values of the shares of the influence of individual factors and their interaction with the real harvest (Fig. 4).



A, Age of tree section; **B**, Stage of organogenesis; **C**, Year of research; **D**, Factors not taken into account; **E**, Other factors.

Figure 4. The structure of various factors influences the real harvest formation of the variety 'Valuta', IH NAAS of Ukraine, 2016–2020.

Table 3. Participation of different age sections of the trunk in productivity formation of ‘Valuta’ trees at different stages of organogenesis, 2016–2020

Age of the trunk segment	The number of reproduction elements at certain stages of organogenesis (SEC)																
	Stage of organogenesis / Year of research																
	2016	2017				2018				2019				2020			
	II	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI
1	1.000	0.000	0.000	0.000	0.000	0.068[c]	0.340[c]	0.083[c]	0.067[c]	0.000	0.000	0.000	0.000	0.258[b]	1.300[b]	0.298[cd]	0.166[dc]
2	1.000	0.387[b]	1.834[ab]	0.431[b]	0.300[b]	0.477[b]	2.386[b]	0.647[ab]	0.574[b]	0.000	0.000	0.000	0.000	0.478[ab]	2.355[ab]	0.553[bcd]	0.383[cd]
3	1.000	0.732[a]	2.593[a]	1.284[a]	0.914[a]	0.705[ab]	3.526[ab]	0.858[ab]	0.696[ab]	0.035[ab]	0.175[ab]	0.053[b]	0.035[ab]	0.342[b]	1.745[b]	0.263[dc]	0.229[cd]
4	1.000	0.847[a]	2.903[a]	0.969[ab]	0.690[ab]	0.746[a]	3.728[a]	1.013[a]	0.821[a]	0.055[a]	0.275[a]	0.146[a]	0.055a	0.568[a]	2.803[a]	1.298[a]	1.025[a]
5	1.000	0.939[a]	3.361[a]	1.035[ab]	0.375[b]	0.758[a]	3.790[a]	0.846[ab]	0.456[b]	0.015[b]	0.076[b]	0.045[b]	0.030[ab]	0.456[ab]	2.195[ab]	0.715[bc]	0.603[bc]
6	1.000	0.657[ab]	2.647[a]	0.000	0.000	0.615[ab]	3.073[ab]	0.835[ab]	0.584[b]	0.022[a]	0.108[ab]	0.032[b]	0.022[a]	0.575[a]	2.874[a]	0.472[cd]	0.381[cd]
7	1.000	0.272[b]	0.894[b]	0.000	0.000	0.566[a]	2.832[a]	0.770[a]	0.619[b]	0.033[ab]	0.166[ab]	0.075[ab]	0.042[ab]	0.603[a]	3.053[a]	0.875[b]	0.638[b]
8	1.000					0.543[ab]	2.716[ab]	0.540[b]	0.514[b]	0.008[b]	0.039[b]	0.016[b]	0.008[b]	0.615[a]	3.054[a]	0.423[cd]	0.327[cd]
9	1.000									0.021[ab]	0.104[b]	0.049[b]	0.028[ab]	0.470[ab]	2.744[a]	0.401[cd]	0.233[cd]
10	1.000													0.457[ab]	2.193[ab]	0.369[cd]	0.225[cd]

Means in columns with the different letter are highly significantly different according to the Fisher’s test ($P \leq 0.05$).

The diagram shows the biggest dependence of productivity potential realization of variety ‘Valuta’ on the stages of organogenesis, as during the transition of buds from stages II to III–IV on average 62.4% of potential fruiting points were lost in three years. A significant factor in the impact was the year of the study - at a certain stage of organogenesis, weather factors negatively affected the maintenance of high potential productivity. The interaction of these two factors accounted for 58% of the impact on the actual harvest. The age of the tree (the age of complex fruit formations) in the ‘Valuta’ variety had a very small effect (8%) on the actual yield.

Observations of different trunk age sections' participation in productivity formation showed its clear dependence on the stage of organogenesis. Thus, in the second year of the study (Table 3), three- to eight-year-old complex rings during stages III–IX formed the largest number of reproductive elements. However, during stage X, the level of ovarian flower buds was higher in the two-year-old rings and low in the eight-year-old. During stage XI, the largest number of ovaries is preserved by three-four-year rings. Thus, the peculiarities of the various stages of organogenesis depend on environmental conditions, which in turn have a significant impact on the potential productivity realization of the rings of different trunk parts.

The largest share in the formation of potential productivity in seven-year-old plants of variety ‘President’ at the II stage of organogenesis belonged to seven-year-old sections of the trunk (Table 4). In the following years, too, the largest numbers of vegetative buds were located in older age areas.

Table 4. Involvement of ‘President’ different ages tree trunks in productivity formation (%). IH NAAS, 2016–2019

Age of the trunk segment	Stage of organogenesis / Year of research											
	II			III–IV			X			XI		
	2016	2017	2018	2017	2018	2019	2017	2018	2019	2017	2018	2019
1	15.8	6.7	5.1	0.0	1.3	0.0	0.0	0.7	0.0	0.0	0.9	0.0
2	4.9	12.1	7.7	4.1	9.5	0.0	7.8	18.5	0.0	12.8	17.6	0.0
3	13.4	8.5	10.8	22.1	6.4	16.7	39.4	10.0	16.7	28.3	9.9	13.3
4	9.9	8.2	7.8	15.1	8.3	16.7	24.1	12.9	14.3	33.2	13.5	16.7
5	9.6	11.8	9.9	18.9	18.3	16.7	28.7	14.5	19.0	25.7	15.3	16.7
6	17.9	17.0	13.1	9.5	23.6	0.0	0.0	14.6	0.0	0.0	14.1	0.0
7	28.5	16.8	16.8	30.2	16.9	11.1	0.0	16.6	16.7	0.0	16.0	13.3
8		18.9	14.3		15.7	27.8		12.2	33.3		12.7	25.0
9			14.6			11.1			9.5			15.0
Total	100	100	100	100	100	100	100	100	100	100	100	100

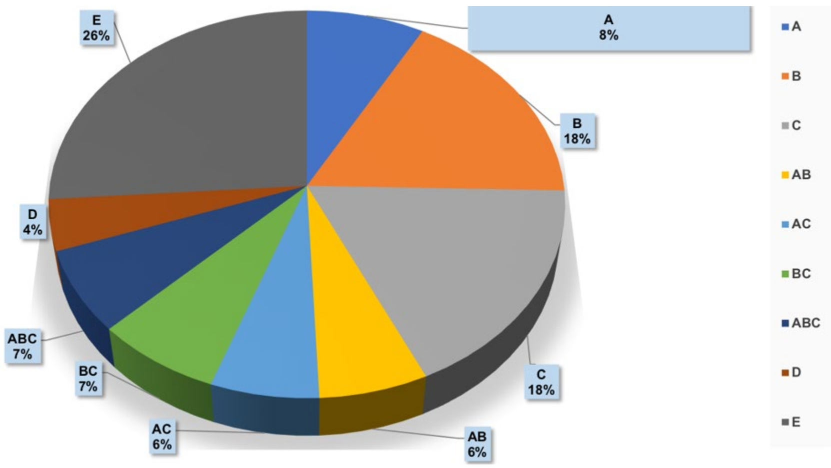
During the III–IV stages of organogenesis in seven-year plantations on each tree ‘President’ was differentiated 67 pieces/tree generative buds, most of which were located in the oldest part of the trunk. The following year, trees of this variety were laid 80 generative buds, and in 2018 - 5 pieces/tree.

In the first year of the study, during the III–IV stages of organogenesis, complex rings in the two-five-year and seven-year sections of the trunk most effectively realized their potential for productivity (Table 5). In 2018, the coefficient of statistical estimation (the number of generative buds relative to their total number) was slightly higher for the five-year plot (SEC = 0.780). No differences were found between the four- and seven-year SEC plots. In the third year of the study, the effectiveness of differentiation of generative buds by age was uneven.

In 2017, three to five-year-old fruit formations of eight-year-old ‘President’ plants produced 2–3 flowers per potentially generative bud, none were formed on one-year growth. The following year, the most intense flowering was also observed on five-year-old fruit formations, and less abundant - on annuals. In the third year of the study, the number of flowers on the tree was much lower than in previous years, in one-two-year and six-year areas flowering did not occur at all.

During the X phase of organogenesis in eight-year-old ‘President’ plants, the fruits were tied in the largest number on the fruit formations of two-five-year-old sections of the trunk. Due to the frosts, there was a complete reduction of flowers and ovaries in six-seven-year areas. The following year, the intensity of fruit set was highest in the four-year period, although no significant difference in the number of ovaries between two- to eight-year-old fruit formations was found. In ten-year-old trees, there was no significant difference in the number of useful ovaries between the different age areas where the fruit was counted. The least intensive reduction of fruits during the XI stage of organogenesis was observed in 2017 and 2018 on two-five-year complex rings, in 2019 - on three-nine-year.

The calculation of the share of individual factors influences the productivity potential realization of plants variety 'President' showed that the stages of organogenesis have the greatest influence on real yield formation (65.2% of potential generative buds are lost during the transition from buds II to III–IV) also meteorological conditions during this or that stage (HTC, $\Sigma_{act}t \geq 10$) (Fig. 5.).



A, Age tree section; **B**, Stage of organogenesis; **C**, Year of research; **D**, Factors not taken into account; **E**, Other factors.

Figure 5. The structure of various factors influences the real harvest formation of the variety ‘President’, IH NAAS of Ukraine, 2016–2019.

The diagram shows that there is no significant difference between the ages of the trunk areas in the crop formation. We noted that from the end of the flowering phase to the end of the XI stage of organogenesis, the role of certain trunk parts in the formation of the actual harvest changes.

Table 5. Participation of different age sections of the trunk in productivity formation of 'President' trees at different stages of organogenesis, 2016–2020

Age of the trunk segment	The number of reproduction elements at certain stages of organogenesis (SEC)																
	Stage of organogenesis / Year of research																
	2016	2017				2018				2019				2020			
	II	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI
1	1.000	0.000	0.000	0.000	0.000	0.106^{c}	0.528^{c}	0.092^{c}	0.092^{cb}	0.000	0.000	0.000	0.000	0.167^{c}	0.754^{dc}	0.147^{cb}	0.066^{cb}
2	1.000	0.483^{ab}	1.750^{ab}	0.467^{a}	0.683^{a}	0.446^{b}	2.232^{b}	1.267^{ab}	1.037^{ab}	0.000	0.000	0.000	0.000	0.252^{bc}	1.168^{cd}	0.445^{bc}	0.218^{bc}
3	1.000	0.744^{ab}	2.611^{a}	0.745^{a}	0.429^{a}	0.406^{b}	2.032^{b}	1.176^{ab}	1.010^{ab}	0.048^{a}	0.238^{a}	0.048^{a}	0.032^{a}	0.273^{bc}	1.390^{cd}	0.752^{a}	0.515^{a}
4	1.000	0.696^{ab}	2.280^{ab}	0.778^{a}	0.754^{a}	0.546^{a}	2.731^{a}	1.560^{a}	1.393^{a}	0.032^{a}	0.159^{a}	0.048^{a}	0.032^{a}	0.483^{b}	2.303^{bc}	0.986^{a}	0.552^{a}
5	1.000	0.837^{a}	3.018^{a}	0.858^{a}	0.612^{a}	0.780^{a}	3.901^{a}	0.906^{b}	0.831^{ab}	0.043^{a}	0.217^{a}	0.058^{a}	0.029^{a}	0.306^{bc}	1.444^{bcd}	0.936^{a}	0.502^{a}
6	1.000	0.391^{b}	0.888^{b}	0.000	0.000	0.726^{a}	3.631^{a}	0.765^{b}	0.646^{bc}	0.000	0.000	0.000	0.000	0.429^{b}	2.127^{bc}	0.722^{a}	0.540^{a}
7	1.000	0.536^{ab}	1.656^{ab}	0.000	0.000	0.546^{ab}	2.732^{ab}	0.848^{b}	0.691^{bc}	0.013^{a}	0.063^{a}	0.019^{a}	0.013^{a}	0.538^{ab}	2.562^{b}	0.616^{a}	0.396^{a}
8	1.000					0.410^{b}	2.050^{b}	0.518^{bc}	0.461^{bc}	0.042^{a}	0.212^{a}	0.074^{a}	0.032^{a}	0.769^{a}	3.713^{a}	0.606^{a}	0.383^{a}
9	1.000									0.017^{a}	0.085^{a}	0.034^{a}	0.017^{a}	0.576^{ab}	2.788^{ab}	0.660^{a}	0.349^{a}
10	1.000													0.431^{b}	2.081^{bc}	0.527^{bc}	0.241^{bc}

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$).

Considering the formation of productivity in stages, we trace the trend of changing the participation of different age areas of the trunk (rings) in the realization of reproductive potential (Table 5). Thus, during stages III–IX in the second year of the study, complex rings placed on a four- to seven-year-old trunk section realized their potential most effectively at the end of the X stage the level of preservation of reproductive elements in two-four-year plots increased, and at the end of the XI stage six-seven-year fruit formations more intensively lost their potential. As a result, two- to five-year-old complex rings have proven to be more productive in terms of realizing their potential, and they have ensured the formation of the main crop of the tree.

In the seven-year-old 'Favoryt' plants, the largest proportion of buds that reached stage II organogenesis was located in the four-year-old trunk area (Table 6). The following year, there was a uniform placement of buds on the trunk. The oldest sections of the trunk of nine-year-old plants bore the largest number of fruit formations of the total number on the tree.

Table 6. Involvement of 'Favoryt' different ages tree trunks in productivity formation (%). IH NAAS, 2016–2019

Age of the trunk segment	Stage of organogenesis / Year of research											
	II			III–IV			X			XI		
	2016	2017	2018	2017	2018	2019	2017	2018	2019	2017	2018	2019
1	17.8	8.5	7.4	0.0	0.0	5.9	0.0	0.0	5.7	0.0	0.0	2.2
2	13.5	7.9	8.9	22.2	20.1	9.0	22.2	9.1	9.3	23.8	9.0	8.9
3	22.4	14.2	9.4	36.1	15.1	6.7	36.5	15.9	11.3	35.7	16.4	10.1
4	34.5	14.7	11.7	22.9	25.0	11.9	31.7	15.0	12.1	27.2	14.3	14.5
5	7.3	12.0	8.1	14.6	16.3	6.0	9.5	18.2	12.0	13.3	18.7	11.6
6	4.7	13.0	8.8	4.2	12.2	12.1	0.0	16.4	12.7	0.0	16.1	10.8
7	0.0	15.8	11.9	0.0	8.0	13.3	0.0	19.8	12.8	0.0	20.4	11.8
8		13.9	15.1		3.2	15.1		5.6	10.6		5.2	13.5
9			18.7			19.9			13.4			16.6
Total	100	100	100	100	100	100	100	100	100	100	100	100

The level of productivity potential realization at the III–IV stages of organogenesis in 2016 and 2018 was ambiguous; in seven-year-old plants, no significant difference was found between the plots where the generative buds were recorded (Table 7). In 2017, no significant difference was found between the two-four-year age areas, less effective differentiation of buds took place on the eight-year section of the trunk.

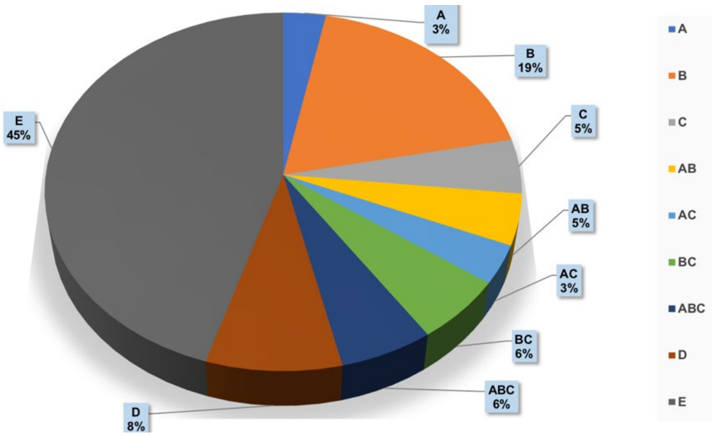
In 2019, the level of bud differentiation differed significantly between the age sections of the trunk, as evidenced by the different statistical coefficient, it was higher in the complex rings of older age sections of the trunk.

In eight-year-old trees at the IX stage of organogenesis, there was a low level of productivity potential realization, no significant difference between the age areas of the trunk was found. The following year, two- to six-year-old trunk plots best realized their potential, and less intensive flowering was observed on the fruits of eight-year-old plots. Ten-year-old trees bloomed more intensively on 6–9-year-old sections of the trunk.

At the X stage of organogenesis, the level of productivity potential realization differed depending on the age of the trunk area. In eight-year-old trees, there was no significant difference in the degree of fruit tying, in nine-year-old plants the intensity of fruit tying was highest in fruit-bearing six- to seven-year-old sections of the trunk, and in ten-year-olds to five-six-year.

At the XI stage of organogenesis, no significant difference in the number of tied fruits was found between the different ages of the eight-year-old plants' trunks. The following year, the oldest and youngest sections of the trunk realized their productive potential the least, no significant difference was found between other sections. In ten-year-old trees, the reduction of reproductive elements was most intense at one-year increments, and no significant difference in this factor was found between two- and nine-year-old complex fruit formations.

According to the research results and determined values of the shares of the organogenesis stages, years of research, age of the trunk, and their relationship and impact on the actual harvest, a diagram to illustrate the structure of this impact was constructed (Fig. 6).



A, Age tree section; **B**, Stage of organogenesis; **C**, Year of research; **D**, Factors not taken into account; **E**, Other factors.

Figure 6. The structure of various factors influences the real harvest formation of the variety 'Favoryt', IH NAAS of Ukraine, 2016–2020.

Other factors have the most significant influence on the real harvest formation, in particular the phytosanitary condition of the plantation, etc., as well as the organogenesis stages (79.3% of buds remain at the II stage of organogenesis); the insignificant influence of age area and year of research was established.

Depending on the organogenesis stage in 'Favoryt' plants, the role of different parts of the trunk in the real productivity formation also changes. Thus, in the second year of the study (Table 7), two- to six-year-old complex rings during stages III–IX best realized their productivity potential. At the X stage of organogenesis, the realization of potential productivity was most effective in three-seven-year rings, at the XI stage - two-seven-year rings. In 'Favoryt' there are no significant jumps in the loss of rings' reproductive potential of different ages during the transition from one stage of organogenesis to another.

In the 'Bilosnizhka' variety, the greatest participation in the potential productivity formation at the II stage of organogenesis during the first two years of the study was found in six-year trunk sections, and in nine-year-old plants - in the oldest section.

Table 7. Participation of different age sections of the trunk in productivity formation of 'Favoryt' trees at different stages of organogenesis, 2016–2020

Age of the trunk segment	The number of reproduction elements at certain stages of organogenesis (SEC)																
	Stage of organogenesis / Year of research																
	2016	2017				2018				2019				2020			
	II	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI
1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.162^{bc}	0.812^{bc}	0.174^{bc}	0.040^{b}	0.220^{a}	0.120^{bc}	0.100^{cb}	0.000
2	1.000	0.103^{a}	0.513^{a}	0.100^{a}	0.128^{a}	0.766^{a}	3.829^{a}	0.173^{b}	0.118^{b}	0.217^{bc}	1.084^{bc}	0.231^{bc}	0.147^{a}	0.222^{a}	1.097^{bc}	0.175^{ab}	0.159^{ab}
3	1.000	0.122^{a}	0.484^{a}	0.248^{a}	0.139^{a}	0.414^{b}	2.071^{b}	0.234^{ab}	0.179^{ab}	0.154^{cb}	0.770^{cb}	0.276^{ab}	0.154^{a}	0.290^{a}	1.437^{abc}	0.179^{ab}	0.124^{bc}
4	1.000	0.085^{a}	0.396^{a}	0.148^{a}	0.096^{a}	0.521^{ab}	2.607^{ab}	0.144^{b}	0.148^{ab}	0.220^{bc}	1.100^{bc}	0.243^{bc}	0.186^{a}	0.333^{a}	1.678^{abc}	0.188^{a}	0.164^{ab}
5	1.000	0.129^{a}	0.379^{a}	0.133^{a}	0.133^{a}	0.373^{bc}	1.863^{bc}	0.228^{ab}	0.210^{ab}	0.159^{bc}	0.794^{bc}	0.333^{a}	0.197^{a}	0.384^{a}	1.911^{ab}	0.224^{a}	0.190^{a}
6	1.000	0.061^{a}	0.303^{a}	0.000	0.000	0.311^{bc}	1.556^{bc}	0.289^{ab}	0.223^{ab}	0.299^{a}	1.496^{a}	0.332^{a}	0.185^{a}	0.444^{a}	2.182^{a}	0.182^{a}	0.148^{ab}
7	1.000	0.000	0.000	0.000	0.000	0.215^{bc}	1.075^{bc}	0.326^{a}	0.241^{a}	0.245^{ab}	1.225^{ab}	0.259^{ab}	0.157^{a}	0.257^{a}	1.316^{bc}	0.171^{ab}	0.149^{ab}
8	1.000					0.094^{c}	0.469^{c}	0.083^{b}	0.073^{b}	0.233^{ab}	1.163^{ab}	0.167^{cb}	0.136^{a}	0.325^{a}	1.641^{abc}	0.184^{a}	0.147^{abc}
9	1.000									0.233^{ab}	1.165^{ab}	0.187^{bc}	0.157^{a}	0.263^{a}	1.330^{bc}	0.159^{abc}	0.142^{abc}
10	1.000													0.215^{a}	1.071^{cb}	0.111^{bc}	0.086^{cb}

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$).

At the end of November, seven-year-old plants 'Bilosnizhka' formed 48 pcs/tree generative buds, the oldest age trunk sections formed the largest number of them, and none of them were formed on the shoot (Table 8).

Table 8. Involvement of ‘Bilosnizhka’ different ages tree trunks in productivity formation (%). IH NAAS, 2016–2019

Age of the trunk segment	Stage of organogenesis / Year of research											
	II			III–IV			X			XI		
	2016	2017	2018	2017	2018	2019	2017	2018	2019	2017	2018	2019
1	10.2	11.6	4.4	0.0	3.4	3.0	0.0	6.1	6.5	0.0	11.5	5.0
2	7.9	11.4	4.5	2.9	12.8	3.4	7.1	10.3	9.4	7.7	13.7	8.5
3	6.4	9.8	4.1	10.0	13.0	3.4	23.2	26.2	6.2	28.6	13.7	8.5
4	16.7	11.4	8.5	23.4	8.9	7.9	69.6	9.6	12.7	63.7	11.2	13.0
5	17.0	11.0	10.5	25.2	11.4	11.6	0.0	11.3	13.0	0.0	16.0	11.1
6	24.1	22.5	13.0	21.1	30.5	11.1	0.0	15.7	11.8	0.0	13.7	11.1
7	17.7	7.7	15.1	17.4	9.6	17.0	0.0	20.9	14.2	0.0	20.1	16.5
8		14.5	19.2		10.4	20.0		0.0	11.6		0.0	11.5
9			20.8			22.6			14.5			15.0
Total	100	100	100	100	100	100	100	100	100	100	100	100

The following year, the trees ‘Bilosnizhka’ were differentiated 68 generative buds pieces/tree, 30% of which were located on six-year trunk sections. In nine-year-old plants, generative buds formation was more efficient on the rings of the two oldest age sites (42.6%), and the total number of laid generative buds was 64 units/tree.

In the first and last years of the study, at the end of November, the lowest level of productivity potential realization was observed in the two youngest age areas, no significant difference was found between other parts of the trunk. In eight-year-old plants at stages III–IV, the highest coefficient of the statistical evaluation was in four-six-year-old complex rings (Table 9).

In the IX stage of organogenesis in eight-year-old trees ‘Bilosnizhka’ (2017), three-five-year-old trunk sections had three flowers per one potentially generative bud, and the lowest number of potential ‘fruiting points’ was located on one-year growth in three years of research. In 2018, on average, two to four flowers per one potentially generative bud were counted in all age areas, except for one-year growth. It is statistically proven that in ten-year-old plants (2019) there was no significant difference in the number of flowers per one potentially generative bud in the IX stage of organogenesis between three-nine-year-old sections of the trunk.

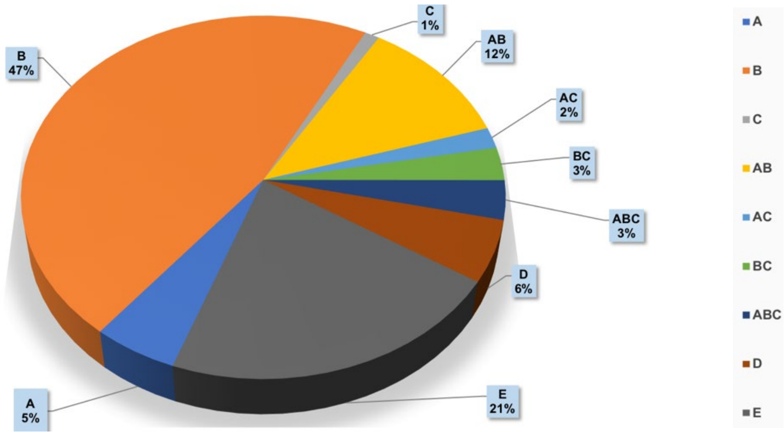
Due to frosts (minus 2–4 °C) at the X organogenesis stage in 2017, ‘Bilosnizhka’ trees reduced all ‘fruiting points’, which were located on six- to seven-year-olds, as well as a significant number on five-year-old trunk area. The reduction of flowers and ovaries in nine-year-old plants was less intense in five- to seven-year-old sections of the trunk. Analysis of variance proved that the intensity of reproductive elements reduction in 2019 was the lowest in two-four-year areas. A high level of ‘potential points’ of fruiting realization in the real harvest at the XI stage of organogenesis in eight-year-old trees was observed on three-four-year-old rings, on younger fruit formations the intensity of tying was lower. The highest coefficient of statistical evaluation in the following years was characterized by three-seven-year complex rings. Young fruit formations were less stable in realizing their productivity potential.

Table 9. Participation of different age sections of the trunk in productivity formation of 'Bilosnizhka' trees at different stages of organogenesis, 2016–2020

Age of the trunk segment	The number of reproduction elements per potentially generative bud at certain organogenesis stages (SEC)																
	Stage of organogenesis / Year of research																
	2016	2017				2018				2019				2020			
	II	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI	III–IV	V–IX	X	XI
1	1.000	0.040^{cb}	0.011^{cb}	0.000	0.000	0.183^{c}	1.000^{cb}	0.045^{c}	0.020^{c}	0.244^{cb}	1.711^{cb}	0.378^{bc}	0.137^{b}	0.217^{b}	1.022^{b}	0.094^{bc}	0.000
2	1.000	0.226^{bc}	1.774^{abc}	0.054^{cb}	0.096^{cb}	0.382^{b}	4.111^{a}	0.104^{bc}	0.078^{bc}	0.267^{bc}	1.867^{bc}	0.533^{ab}	0.233^{b}	0.296^{ab}	1.574^{ab}	0.213^{a}	0.056^{ab}
3	1.000	0.535^{ab}	3.137^{ab}	0.240^{ab}	0.288^{ab}	0.454^{b}	4.013^{a}	0.130^{b}	0.132^{ab}	0.328^{abc}	2.299^{abc}	0.706^{a}	0.456^{a}	0.340^{ab}	1.755^{ab}	0.142^{ac}	0.081^{ab}
4	1.000	0.715^{a}	3.636^{a}	0.300^{a}	0.320^{a}	0.592^{ab}	3.379^{ab}	0.149^{b}	0.158^{ab}	0.365^{a}	2.556^{ab}	0.466^{ab}	0.220^{b}	0.258^{ab}	1.383^{ab}	0.108^{bc}	0.092^{ab}
5	1.000	0.545^{ab}	3.207^{ab}	0.098^{bc}	0.128^{bc}	0.698^{a}	4.947^{a}	0.264^{a}	0.189^{a}	0.384^{a}	2.687^{a}	0.290^{bc}	0.117^{b}	0.414^{a}	1.959^{a}	0.145^{ac}	0.104^{a}
6	1.000	0.361^{bc}	1.614^{bc}	0.000	0.000	0.657^{a}	3.894^{a}	0.190^{ab}	0.158^{ab}	0.316^{abc}	2.212^{abc}	0.227^{bc}	0.091^{b}	0.378^{ab}	1.795^{ab}	0.087^{bc}	0.059^{ab}
7	1.000	0.554^{a}	0.859^{bc}	0.000	0.000	0.458^{b}	3.532^{ab}	0.187^{ab}	0.128^{ab}	0.401^{a}	2.809^{a}	0.219^{bc}	0.128^{b}	0.384^{ab}	1.878^{ab}	0.117^{bc}	0.042^{ab}
8	1.000					0.421^{b}	2.067^{bc}	0.144^{b}	0.114^{b}	0.374^{a}	2.617^{a}	0.151^{cb}	0.076^{b}	0.369^{ab}	1.841^{ab}	0.122^{bc}	0.045^{ab}
9	1.000									0.390^{a}	2.728^{a}	0.171^{bc}	0.090^{b}	0.432^{a}	2.135^{a}	0.077^{cb}	0.038^{b}
10	1.000													0.370^{ab}	1.828^{ab}	0.138^{ac}	0.021^{b}

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$).

A diagram is constructed according to the determined values of the particles of individual factors influence and their interaction on the real harvest (Fig. 7).



A, Age tree section; **B**, Stage of organogenesis; **C**, Year of research; **D**, Factors not taken into account; **E**, Other factors.

Figure 7. The structure of various factors influences the real harvest formation of the variety 'Bilosnizhka', 2016–2020.

The diagram shows the greatest dependence of the productivity potential realization variety 'Bilosnizhka' on organogenesis stages (58.4% of buds do not differentiate into generative ones). The age of the fruit tree has a very low impact on the final result of the production process.

During the transition of fruit formations buds of the 'Bilosnizhka' variety from one stage of organogenesis to another, there is a significant increase or decrease in the rate of reproductive potential preservation. Thus, in 2017, the largest number of generative buds was formed in the four-six-year trunk section, at the IX stage, the largest number of flowers per potentially generative bud had two-seven-year rings. At the end of the X stage of organogenesis, there was a significant loss of reproductive potential in the two- to four-year-old part of the trunk, the largest number of ovaries this year remained on the five-seven-year-old complex rings. In general, at the end of the XI stage of organogenesis, the largest number of fruits was placed on the three-seven-year section of the trunk.

Thus, in the conditions of the western Forest-Steppe of Ukraine, columnar apple cultivars react differently to environmental conditions at certain stages of organogenesis. The efficiency of generative buds differentiation of columnar varieties is influenced in one way or another by meteorological factors. For introduced varieties, the increase in the level of $\Sigma_{act}t \geq 10$, precipitation, and average daily air temperature has a negative effect on the generative potential formation at III–IV stages of organogenesis, as evidenced by the high negative correlation between the ratio of generative buds to their total number and these factors (*r*=-0.80–0.96). The influence of these meteorological factors on the varieties of Ukrainian selection is weak and moderate, which indicates the best adaptive properties of these varieties (Table 10).

Table 10. The correlation coefficient between SEC and weather factors during III-XI stages of organogenesis (data for 2016–2020 are processed)

Stage of organogenesis	Variety	HTC	$\Sigma_{act}t \geq 10$ °C	Σ precipitation	Average daily air temperature
III–IV	'President'	0.71	-0.91	-0.52	-0.80
	'Valuta'	0.78	-0.96	-0.60	-0.87
	'Favoryt'	0.52	-0.16	-0.69	-0.40
	'Bilosnizhka'	0.60	-0.60	-0.53	-0.61
V–IX	'President'	-0.78	0.48	-0.88	0.35
	'Valuta'	-0.75	0.45	-0.85	0.32
	'Favoryt'	-0.60	0.84	-0.31	0.88
	'Bilosnizhka'	-0.73	0.83	-0.53	0.82
X	'President'	-0.69	-0.54	-0.61	0.64
	'Valuta'	-0.81	-0.69	-0.75	0.60
	'Favoryt'	0.81	0.90	0.87	0.06
	'Bilosnizhka'	0.85	0.84	0.86	-0.27
XI	'President'	0.89	0.08	0.88	0.09
	'Valuta'	0.86	0.58	0.85	0.20
	'Favoryt'	0.38	0.65	0.39	0.80
	'Bilosnizhka'	-0.31	-0.09	-0.31	0.15

It was found that fruits reduction on plants of most of the studied columnar varieties during the XI organogenesis stage decreases with increasing $\Sigma_{act}t \geq 0$ and average daily air temperature, as well as increased rainfall. Increased precipitation (r = 0.85–0.98) had a high impact on the preservation of reproductive potential for cultivars 'President' and 'Valuta'. The increase in average daily air temperature had a positive effect on the increase in SEC in the variety 'Favoryt' (r = 0.77–0.80).

CONCLUSIONS

Individual age sections of the trunk columnar apple trees formed different initial productivity potential. In plants of all studied varieties and age groups, the laying of generative buds, the implementation of reproductive elements in V–IX and X–XI organogenesis stages were more effective in older age areas of the trunk. Complex fruit formations, regardless of the trunk age, where they are placed, form a high potential for productivity, which is effectively realized.

Differentiation of flower buds as well as the passage of V–XI stages of organogenesis depended on meteorological factors. The plants' generative potential formation of introduced varieties (III–IV stages of organogenesis) was negatively affected by the increase in $\Sigma_{act}t \geq 10$, the average daily air temperature, and the decrease in the level of HTC. The influence of these factors on the laying of flower buds on trees of domestic varieties was weak or moderate.

For plants of introduced varieties 'President' and 'Valuta', a negative correlation was found between the number of ovaries at the end of the X organogenesis stage and $\Sigma_{act}t \geq 10$ and the amount of precipitation, as well as a noticeable positive - with the average daily air temperature. With increasing rainfall during Phase XI, more ovaries remained (r = 0.85–0.98). Decreased $\Sigma_{act}t \geq 10$ and rainfall helped reduce the ovarian reduction in 'Favoryt' and 'Bilosnizhka' varieties; during the XI stage of organogenesis, the reduction was minimized by increasing the average daily air temperature.

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