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Evaluation of red currant cultivars' technological effectiveness for mechanized harvesting

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ABSTRACT

This study aimed to identify the optimal red currant cultivars for mechanized harvesting by evaluating the bush's morphological structure and the berries' mechanical parameters. Fourteen red currant cultivars were assessed during the 2021-2022 season, and their berry quality indicators and mechanical parameters, including separation force (Fs) and crushing force (Fc), were measured. The results showed that the cultivar plays an important role on the bush's morphological structure, while the berries' mechanical parameters impact the efficiency of harvesting process. The high correlation between Fs and Fc allowed for predicting the optimal harvesting periods of the cultivars. Among the cultivars, 'Rolan', 'Jonkheer Van Tets', 'Rovada', 'Red Lake', 'Asya', 'Vika', and 'Niva' were considered as technological cultivars and suitable for mechanized harvesting. This study emphasizes the importance of considering genetic and morphological factors when selecting red currant cultivars for mechanized harvesting and provides valuable insights for breeding and developing new cultivars adapted to mechanized harvesting.

Keywords: bush habit, optimal harvesting, qualitative characteristics, technology, yield.

INTRODUCTION

Small fruits are highly valued for their biological and nutritional benefits to human's health (Kirina *et al*., 2020; Kahramanoğlu *et al*., 2022) and are widely cultivated for their commercial potential (Asănică, 2019; FAO, 2021). Among the berry crops, red currants are particularly valuable due to their numerous biological and pharmacological properties (Bilici, 2021). Many European countries (i.e. Poland, Germany, Hungary, United Kingdom, etc.) grow certain red currant cultivars in industrial volumes. One of the most important factors that negatively affect red currant production

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is harvesting costs, which can reach up to 60-70% (Wróblewska *et al*., 2019; Brondino *et al*., 2021; FAO, 2021). Many modern cultivars of currants do not meet the requirements for intensive cultivation (Wang *et al*., 2009; Sarig, 2012; Čejka *et al*., 2018; Szmajda and Nowakowski, 2020; Perekopskiy *et al*., 2021). The main parameters of suitability for mechanized harvesting are the architectonics of the bush, high yield, resistance to various stressors, simultaneous ripening of berries in the raceme, and the rapid recovery characteristics of shoots after the combine (Sava and Bodiu, 2012; Djordjević *et al*., 2014; Rakonjac *et al*., 2015). The physico-mechanical criteria of currant berries have also been developed to reduce the percentage of berry loss during mechanized harvesting (Gurin, 2000). As a result, adjustments are being made to the breeding programs for currants and an important criterion is the mechanization of harvesting (Wang *et al*., 2009; Rakonjac, 2015; Sasnauskas *et al*., 2019). One of the main criteria is the placement of berries on bushes, simultaneous ripening of berries, the strength of the skin and the separation of berries from the raceme. Secondary features include the habitus of the bush (height, width and compactness of the bush, flexibility of branches), as well as a long harvest period (Masny *et al*., 2018).

The objective of this study is to evaluate the technological qualities of some cultivars based on the architectonics of the bush and the mechanical properties of the berries. In particular, the research is aimed at identifying promising technological cultivars for inclusion in breeding programs, as well as for industrial cultivation.

MATERIALS AND METHODS

The study was conducted over two seasons (2021-2022), at the growing and testing site of the Russian Research Institute of Fruit Crop Breeding (VNIISPK), located at 52◦96′ north latitude and 36◦07′ east longitude. The two years-old bare rooted plants were planted in 2017 to evaluate the suitability of cultivars for machine harvesting using a planting scheme of 3.5×0.5 m. The experimental design included 3 replications for each cultivar, with 10 plants in each repetition. The experimental site was on loamy haplic luvisol, and the organic horizon was 50-55 cm thick. The soil of the experimental site was medium acidic (pH=4.82). The content of Potassium and Phosphorus varied depending on the depth of the soil profile and was low for berry crops. The content of Potassium at a depth of 0-0.2 m was 41.75mg·kg^{-1}, Phosphorus - 66.50 mg·kg^{-1}. The content of Potassium at a depth of 0.2-0.4 м was 12.00 mg·kg^{-1}, Phosphorus - 45.00 mg·kg^{-1}.

The weather during the growing seasons of 2021 and 2022 was contrasting. While the weather conditions in 2021 were close to the average annual values for the Central region in terms of temperature and precipitation, 2022 was characterized by a 10-12-day delay in spring, and the average temperature in May was 2.5°C lower than usual. The temperature during the summer months (June-August) was also lower by 3 °C compared to the climatic norm for the region. These variations in temperature and precipitation over the years allowed us to calculate the maximum possible duration of the currant harvest.

Red currant cultivars of Russian and foreign breeding were selected as the plant materials of the research: 'Red Lake' (USA), 'Lozan' (Slovakia), 'Viksne' (Latvia), 'Jonkheer Van Tets' (Netherlands), 'Rondom' (Netherlands), 'Englische Grosse Weisse' (Netherlands), 'Rovada' (Netherlands), 'Hollandische Rote' (Netherlands), 'Rolan' (Netherlands), 'Natali' (Russia), 'Vika' (Russia), 'Niva' (Russia), 'Osipovskaya' (Russia), and 'Asya' (Russia). Full fruiting of the studied cultivars, when berry harvesting equipment can be used, occurred four years after planting due to the peculiarities of generative bud formation.

Parameters of the study

The morphological features of each cultivar were assessed in triplicate. Biometric indicators of plants such as the height of the bush, the width of the bush, the height of the laying of berries from the ground surface were determined using a technical ruler with an accuracy of 0.1cm. The determination of the volume of the bush was defined as the product of the height of the bush, the width of the bush along and across the row. The compactness of the bush (C) was calculated as the ratio of the height of the bush to the width of the bush across the row.

The bush form is compact if the angle between the main fruiting branches and soil surface is 60-75° (coefficient 0.7-0.9) (Sava *et al*., 2012; Utkov, 2015).

The percentage of broken shoots after mechanized harvesting was calculated as the number of broken branches to the total number of shoots of the cultivar on the production plot. Harvesting of berries by the combine harvester was performed at the stage of biological maturity, considering the berries' mechanical characteristics for each cultivar. The weight method determined crop loss from the bush using electronic scales CAS SWN-6 (South Korea). Crop losses refer to undamaged berries left on the bushes after machine harvesting. Repeated mechanized harvesting of the remaining berries on the bushes leads to additional damage to the bush, breakage of annual and perennial shoots, and can result in a prolonged recovery period for the bushes and a significant reduction in yield for the following year. After the combine harvester, the remaining berries on the bushes harvested by hand from each bush, using plastic containers, and weighed on electronic scales in the field. Accounting was conducted on three bushes of the same cultivar, and the average value was calculated. Mechanized harvesting was carried out by the Joonas-2000 combine harvester (Finland), which has no technical design for lifting shoots from the soil.

The degree of illumination of the bushes was measured using a luxmeter Light Meter H.S. 1010A (China). The mechanical parameters of the berries were evaluated by separation force (Fs) and crushing force (Fc) during the period of biological ripening of the berries. Fs was determined using the "Dina-2" device (Russia); Fc - using the "Plodtest-1" device (Russia). The measurement interval was 3 days. The measurement was carried out on 5 racemes of each cultivar (an average of 40 berries) in threefold repetition. The strength of the skin (σ) was determined as the Fc ratio to the cross-sectional area of the crushing plunger (Mikhailova, 2014). The strength coefficient (*C*) of berry depended from the crushing force and crushing separation is given by Equation by Equation (1) (Aleynikov and Mineyev, 2016).

$$C = \frac{Fc - Fs}{Fs} \quad (1)$$

The cultivar is suitable for mechanized harvesting if $C \geq 0.8$. The multiple regression equation was used to determine the duration of the mechanized harvesting period (Draper and Smith, 1998). Microsoft Excel 2017 was used to calculate the average and standard deviations for the studied indicators and to present the figures. Statistical analysis was carried out using the software package SPSS 22.0 (ANOVA) and Tukey's HSD test ($p < 0.05$). To analyze the similarities and differences between the analyzed groups and build a correlation, the program R 4.2.2 was used; for cluster analysis, the program FactoMineR R was used; the RSA analysis was carried out using the program factoextra R.

RESULTS

The volume of the bush of the studied cultivars varied in the range from 0.37 ('Red Lake') to 5.16 ('Osipovskaya') m^3 (Table 1). The optimal area for placing the bush harvest ranges from 0.30 m to 1.10 m from the soil surface (Korovin, 2011). The cultivars 'Viksne', 'Niva', and 'Osipovskaya' exhibited an optimal berry placement zone in their large and tall bushes. However, the bush shape of 'Viksne' and 'Osipovskaya' is spreading, which may result in difficulties during mechanized harvesting. On the other hand, 'Niva' has the highest bushes and an erect habit, but the combined harvester can cause damage to the upper part of the shoots. The problem above results in need for additional technical operations such as contour pruning of bushes. This issue is no observed in cultivars such as 'Englische Grosse Weisse', 'Red Lak'e, and 'Lozan', where despite the smaller volume of the bush, the majority of the yield is concentrated in a zone closer to the base of the bush, as shown in Table 1.

In this experiment, the morphological characteristics of the bushes were found to be relatively stable with low variation coefficient (CV) values not exceeding 30%: CV (h) was up to 22.98%, CV(B1) up to 19.74%, and CV(V) up to 22.85%. The phenotypic variability of the red currant bush habit was insignificant. In most of the studied cultivars, the percentage of broken branches after the mechanized harvesting did not exceed 10%. A low percentage of damaged branches was not critical for reducing the duration of plantings exploitation. The high flexibility of the ‘Osipovskaya’ branches led to significant damage to the bush. The percentage of broken shoots ranged from 24.32 to 27.39%. The sanitary pruning carried out to remove damaged branches has shown a high regenerative ability of bushes for most cultivars. Nevertheless, 'Rovada' and 'Englische Grosse Weisse' demonstrated a weak regenerative ability of the bush, and the number of new annual shoots did not exceed 2-3 pieces per bush for 6 months. The complete restoration of these cultivars took place after 24 months.

Table 1. Morphometric parameters of red currants.

Cultivar	H (m)	B (m)	A (m)	V (m^3)	K	H (m)	B (m)	A (m)	V (m^3)	K
			'Asya'					'Viksne'		
2021	1.45±0.66^{ab}	1.03±0.26^{bc}	1.32±0.19^{b}	1.97±0.90^{c}	1.10±0.31^{bcd}	1.62±0.12^{ab}	1.47±0.50^{ab}	1.79±0.07^{a}	5.51±1.82^{a}	0.70±0.07^{de}
2022	1.15±0.11^{cd}	1.47±0.80^{ab}	1.35±0.76^{bc}	2.28±0.88^{d}	0.85±0.23^{ab}	1.58±0.06^{ab}	1.33±0.38^{ab}	2.13±0.14^{a}	4.48±0.83^{a}	0.74±0.02^{b}
Mean	1.30±0.38^{cd}	1.25±0.53^{c}	1.33±0.47^{abc}	2.13±0.89^{c}	0.98±0.27^{de}	1.60±0.09^{ab}	1.40±0.44^{ab}	1.80±0.11^{a}	5.00±1.33^{ab}	0.72±0.05^{de}
			'Niva'					'Rondom'		
2021	1.72±0.19^{a}	1.57±0.63^{a}	1.40±0.25^{b}	3.78±1.67^{b}	1.23±0.39^{bc}	0.98±0.19^{e}	0.73±0.50^{fg}	0.75±0.16^{fg}	0.54±0.19^{ef}	1.31±0.28^{ab}
2022	1.68±0.19^{a}	1.37±0.81^{ab}	1.80±0.25^{ab}	4.14±2.11^{a}	0.94±0.20^{ab}	1.07±0.19^{de}	0.77±0.38^{de}	0.92±0.26^{dc}	0.75±0.02^{cd}	1.16±0.18^{a}
Mean	1.70±0.19a	1.47±0.72a	1.60±0.25b	3.96±1.89^{b}	1.08±0.30^{de}	1.03±0.19^{df}	0.75±0.44^{de}	0.84±0.21f^{g}	0.65±0.11^{fg}	1.23±0.23^{a}
			'Vika'					'Englische Grosse Weisse'		
2021	1.37±0.14^{bc}	0.88±0.18^{de}	1.03±0.29^{cd}	1.24±0.58^{de}	1.32±0.39^{ab}	1.28±0.19^{cd}	0.89±0.05^{fg}	0.92±0.07^{fg}	1.05±0.24^{de}	1.40±0.22^{ab}
2022	1.35±0.37^{bc}	1.10±0.35^{de}	1.33±0.29^{bc}	1.98±0.39^{cd}	1.01±0.40^{ab}	0.86±0.36^{e}	0.65±0.12^{de}	0.92±0.26^{d}c	0.51±0.11^{cd}	0.94±0.30^{ab}
Mean	1.36±0.25^{bc}	0.99±0.26^{de}	1.18±0.29^{de}	1.61±0.49^{de}	1.17±0.40^{dc}	1.07±0.28^{df}	0.77±0.08^{de}	0.92±0.17^{fg}	0.78±0.18^{fg}	1.17±0.26^{bc}
			'Lozan'					'Red Lake'		
2021	1.02±0.19^{de}	0.60±0.04^{fg}	0.64±0.13^{g}	0.39±0.07^{ef}	1.58±0.51^{a}	0.91±0.07^{e}	0.50±0.38^{g}	0.70±0.24^{fg}	0.32±0.10^{f}	1.29±0.35a^{b}
2022	0.95±0.22^{de}	0.75±0.12^{de}	0.95±0.33^{dc}	0.68±0.18^{cd}	1.00±0.13^{ab}	0.98±0.10^{de}	0.58±0.07^{e}	0.72±0.26^{d}	0.41±0.11^{d}	1.36±0.37^{a}
Mean	0.98±0.20^{f}	0.67±0.08^{de}	0.80±0.23^{g}	0.53±0.13^{g}	1.29±0.32^{a}	0.94±0.09^{f}	0.54±0.23^{e}	0.71±0.25^{g}	0.37±0.11^{g}	1.33±0.36^{f}
			'Rovada'					'Rolan'		
2021	1.02±0.21^{de}	0.79±0.31^{de}	0.93±0.14^{ef}	0.75±0.15^{ef}	1.09±0.37^{bcd}	1.37±0.01^{bc}	0.75±0.39^{df}	1.03±0.16^{de}	1.06±0.28^{de}	1.34±0.21^{ab}
2022	0.97±0.26^{de}	1.18±0.19^{cd}	1.10±0.12^{dc}	1.26±0.42^{cd}	0.88±0.03^{ab}	1.13±0.19^{cd}	0.87±0.19^{de}	1.03±0.52^{dc}	1.01±0.36^{cd}	1.10±0.12^{ab}
Mean	0.99±0.23^{f}	0.99±0.25^{de}	1.02±0.13^{fg}	1.00±0.29^{ef}	0.99±0.20^{de}	1.25±0.10^{cd}	0.81±0.29^{de}	1.03±0.34^{fg}	1.04±0.32^{ef}	1.22±0.17^{ab}
			'Natali'					'Hollandische Rote'		
2021	1.05±0.17^{de}	1.20±0.25^{ab}	1.23±0.35^{bc}	1.55±0.76^{de}	0.85±0.30^{de}	1.07±0.09^{de}	0.83±0.28^{de}	0.77±0.15^{fg}	0.69±0.26^{ef}	1.39±0.37^{ab}
2022	1.02±0.07^{de}	1.43±0.34^{ab}	1.33±0.17^{bc}	1.94±0.72^{cd}	0.76±0.16^{b}	1.05±0.22^{de}	0.93±0.14^{de}	1.27±0.14^{dc}	1.24±0.16^{cd}	0.83±0.27^{b}
Mean	1.03±0.12^{df}	1.32±0.29^{b}c	1.28±0.35^{de}	1.75±0.74^{de}	0.81±0.23^{de}	1.06±0.16^{df}	0.88±0.21^{de}	1.02±0.15^{ad}	0.96±0.21^{fg}	1.11±0.32^{bc}
			'Jonkheer Van Tets'					'Osipovskaya'		
2021	1.19±0.08^{de}	1.02±0.19^{bc}	1.41±0.03^{b}	1.70±0.18^{cd}	0.84±0.05^{de}	1.66±0.15^{a}	1.20±0.43^{a}	2.43±0.29^{a}	4.85±0.91^{ab}	0.68±0.07^{e}
2022	1.08±0.07^{de}	1.38±0.19^{ab}	1.48±0.19^{bc}	2.22±0.49^{bc}	0.73±0.07^{b}	1.50±0.25a^{b}	1.63±0.29^{a}	2.23±0.52^{a}	5.47±1.41^{a}	0.67±0.06^{b}
Mean	1.14±0.07^{df}	1.20±0.19^{cd}	1.45±0.11^{bc}	1.96±0.34^{cd}	0.79±0.06^{de}	1.58±0.20^{ab}	1.42±0.36^{bc}	2.33±0.41^{a}	5.16±1.16^{a}	0.68±0.07^{e}

Note: H – the height of the bush (m); A – length of the bush diagonally along the row (m); B – width of the bush across the row (m); V– volume of the bush (m^3); and K – compactness of the bush. The data represent the average values for three repetitions (n = 10) ± standard error (S.E.). Different letters show significant differences between the parameters of the bush according to Tukey's HSD test ($p < 0.05$).

One of the critical factors determining the suitability of a cultivar for combine harvesting is its ability to produce a stable yield with a minimum density of 2-3 kg of the bush. To assess the performance of various cultivars under mechanized harvesting, we measured their yield and crop losses, as shown in Figure 1. It should be noted that the reduction in yield during the second year of the experiment can be attributed to damage caused by the combine harvester to some of the perennial shoots, which are responsible for producing generative buds.

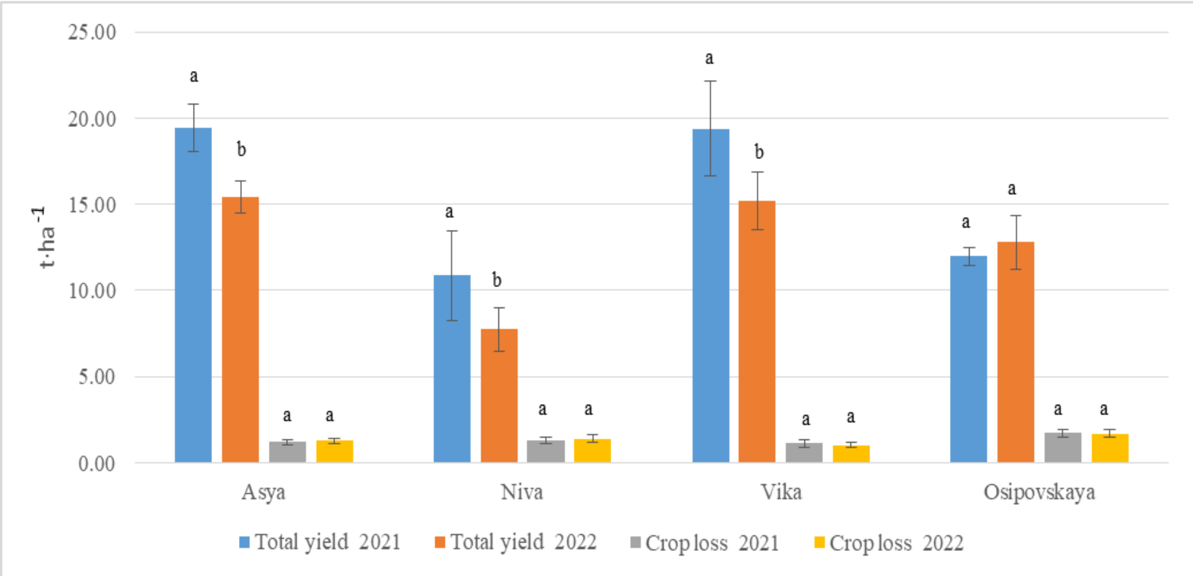


Figure 1. The total yield of cultivars and yield loss after the mechanized harvesting. The letters above the columns are used to compare yield data and its loss for each cultivar. Different letters indicate significant differences between the values according to Tukey's HSD test ($p < 0.05$).

The berries on the bushes should be positioned in such a way as to ensure maximum efficiency of berry harvesting by a combine harvester and the berries should have a simultaneous ripening period. The simultaneity of maturation is determined by varietal differences and bush lighting. The sparse architectonics of the bush in 'Jonkheer Van Tets', 'Asya', 'Vika', 'Natali', 'Red Lake' and 'Rovada' provided uniform illumination of berries on the bushes (687.2 Lx). By the beginning of the mechanized harvesting, more than 90% of the berries at the stage of biological maturation had a uniform color and met the quality standard of berry products. In 'Osipovskaya', the strong thickening of the bushes reduced the intake of sunlight (425 Lx). During mechanized harvesting, about 30% of the yield had unripe berries, which were poorly separated from the raceme and a large number of berries remained on the bushes. The mechanical parameters of the berries depend on the cultivar and weather and climatic conditions. Using the example of several red currant cultivars, changes in the Fs and Fc parameters and the duration of the biological maturation period in 2021 and 2022 are shown (Table 2).

The mechanical parameters of currant berries varied over two growing seasons. In 2022, the ripening period of the berries for many cultivars was quite long and began 7-10 days later than in 2021. In addition, by the period of full biological maturity, the Fs and Fc indicators decreased. The duration of the optimal berry harvest period for cultivars depended on the rate of decrease in the mechanical parameters of the berries. The dependence of the harvest duration on Fs and Fc and weather conditions is shown (Table 2).

Table 2. Changes in the mechanical parameters of berries during biological maturation, depending on the cultivar and the study period.

Days	2021		2022	
	Fs, N	Fc, N	Fs, N	Fc, N
'Jonkheer Van Tets'				
1	1.47 ± 0.12^{a}	6.04 ± 0.80^{a}	0.65 ± 0.25^{a}	5.57 ± 0.4^{9a}
4	0.89 ± 0.16^{b}	4.71 ± 0.85^{b}	0.69 ± 0.07^{a}	4.86 ± 0.46^{b}
7	0.78 ± 0.09^{c}	6.35 ± 0.18^{c}	0.68 ± 0.10^{a}	4.75 ± 0.69^{b}
10	0.62 ± 0.10^{d}	4.78 ± 0.90^{d}	0.42 ± 0.06^{d}	4.38 ± 0.84^{c}
13	0.33 ± 0.08^{e}	3.43 ± 0.19^{e}	-	-
'Englische Grosse Weisse'				
1	1.53 ± 0.06^{a}	3.98 ± 0.97^{a}	0.51 ± 0.03^{a}	3.19 ± 0.72^{a}
4	0.49 ± 0.02^{b}	1.64 ± 0.45^{b}	0.47 ± 0.07^{a}	4.02 ± 0.89^{b}
7	-	-	0.54 ± 0.03^{a}	3.21 ± 0.21^{b}
10	-	-	0.25 ± 0.08^{d}	1.59 ± 0.38^{d}
'Lozan'				
1	1.33 ± 0.08^{a}	9.06 ± 0.53^{a}	0.83 ± 0.19^{a}	3.39 ± 0.18^{a}
4	1.25 ± 0.08^{a}	6.19 ± 0.63^{b}	0.60 ± 0.09^{a}	4.41 ± 0.50^{b}
7	0.14 ± 0.04^{c}	4.69 ± 0.50^{c}	0.56 ± 0.05^{b}	3.74 ± 0.96^{b}
10	-	-	0.63 ± 0.08^{b}	2.63 ± 0.14^{d}
13	-	-	0.26 ± 0.04^{e}	2.34 ± 0.03^{e}
Red Lake				
1	0.80 ± 0.08^{a}	8.59 ± 0.33^{a}	0.52 ± 0.12^{a}	3.37 ± 0.36^{a}
4	0.69 ± 0.14^{b}	4.57 ± 0.46^{b}	0.46 ± 0.05^{a}	3.24 ± 0.23^{a}
7	0.63 ± 0.12^{b}	6.03 ± 0.41^{c}	0.50 ± 0.08^{a}	3.14 ± 0.80^{a}
10	0.36 ± 0.04^{d}	4.09 ± 0.28^{d}	0.26 ± 0.02^{c}	2.35 ± 0.41^{b}
13	0.29 ± 0.02^{e}	3.52 ± 0.47^{c}	-	-
Vika				
1	1.44 ± 0.04^{a}	6.57 ± 0.65^{a}	0.62 ± 0.09^{a}	4.10 ± 0.21^{a}
4	0.55 ± 0.07^{b}	5.02 ± 0.46^{b}	0.60 ± 0.07^{a}	5.02 ± 0.58^{b}
7	0.51 ± 0.08^{b}	5.96 ± 0.48^{c}	0.42 ± 0.02^{c}	4.19 ± 0.09^{a}
10	0.25 ± 0.02^{d}	4.02 ± 0.43^{d}	0.32 ± 0.08^{d}	2.87 ± 0.46^{d}

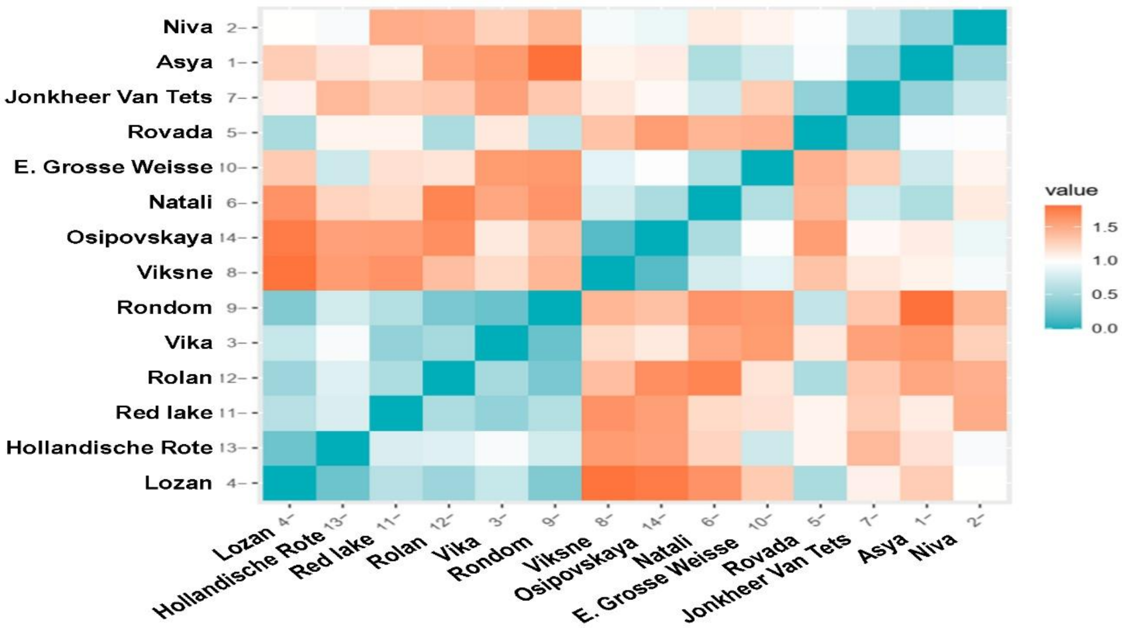
Note: «-»- berries at the stage of physiological maturity; biosynthetic processes stop; berries lose their characteristic taste and appearance.

The high relationship between the mechanical parameters of berries (R=0.75-0.85) makes it possible to calculate the prediction of the optimal period for berry harvesting, taking into account the cultivar. For 'Jonkheer Van Tets', according to the multiple regression equation, the effective period for using the harvester was 7 days in 2021 (R =0.69) and 4 days in 2022 (R=0.71).

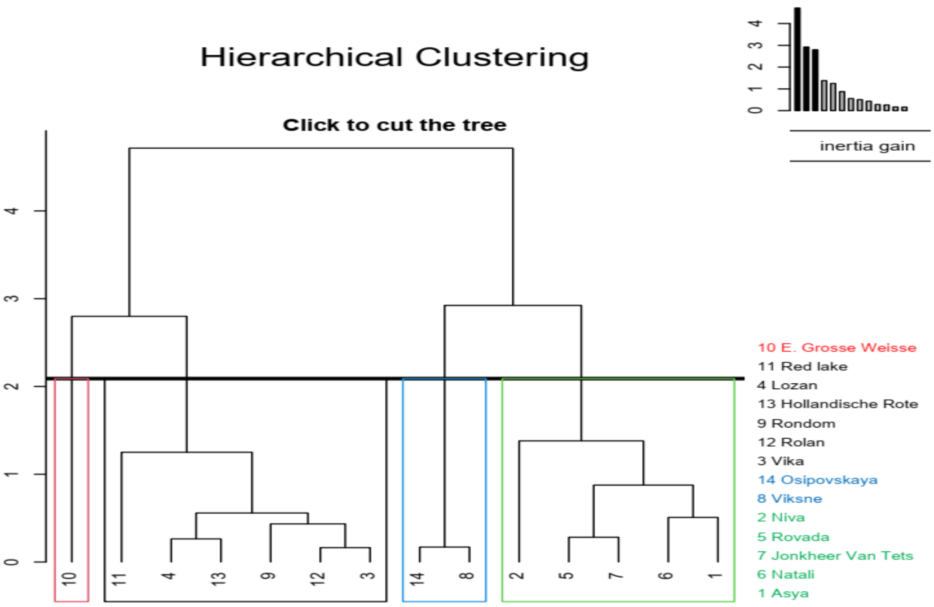
Fc depends on the strength of the skin and for most cultivars it was more than 2 N. In the process of biological maturation, the strength of the skin decreased in all cultivars. Reducing the strength of the skin during the ripening period of berries reduces the resistance of berries to mechanical damage and the quality characteristics of berries. Changes in the strength of the berry skin during maturation are associated with biochemical changes (for example, hydrolysis of protopectin, hemicellulose) (Giongo, L., 2019; Toushik *et al*., 2017; Spinei and Oroian, 2021). Of particular importance in mechanized harvesting is the separation of berries from the raceme without damage. This separation is called "dry berry separation". This separation allows to maintain the appearance and quality characteristics of berries at a high level during transportation (Kazakhmedov *et al*., 2017; Rivera, 2022). The strength of the attachment of berries to the raceme depends on Fs and Fc. According to the criterion of A.F. Aleynikov and V.V. Mineev (2016), most of the studied cultivars are considered suitable for mechanized harvesting (C≥0.8).

Relationships among study cultivars

Distance measures showed that 'Niva', 'Asya' and 'Jonkheer Van Tets' were similar in many studied indicators and differed from 'Rondom'. At the same time, 'Rondom', 'Rolan' and 'Vika' were different from 'Red Lake'. 'Viksne' and 'Osipovskaya' were similar in a number of indicators (Figure 3A). Cluster analysis combined the cultivars according to the studied parameters into 4 clusters (Figure 3B).



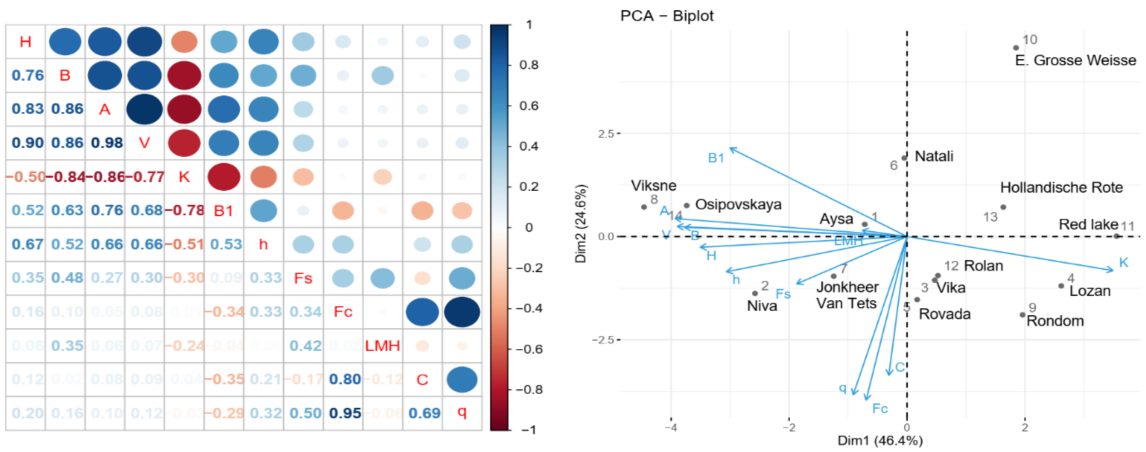
A



B

Figure 3. A. Distance measure (orange color shows differences, teal – how's similarities) between cultivars; B. Hierarchical clustering to group the cultivars.

The first cluster included 'E. Grosse Weisse'. According to PCA-Biplot analysis, this cultivar was very different from all the studied cultivars (Fig. 4). The second cluster combined cultivars in terms of bush compactness (K); the third cluster consisted of cultivars with high morphological parameters of the bush (A, B, and V) and average K values; the fourth cluster combined cultivars in terms of mechanical parameters of berries (Fc, Fs, σ, and C).



A B

Figure 4. Correlation (A) and PCA - biplot (B) analyses of characters and cultivars. Note: K - compactness of the bush, H - the height of the bush (m), B - width of the bush across the row (m), A - length of the bush diagonally along the row (m), and V - the volume of the bush (m3), Fs - separation force, Fc -crushing force, C - coefficient of the relative strength of berries, and σ - static crushing force.

DISCUSSION

In this experiment, the Joonas-2000 combine harvester (Finland) was used, its work is based on the vibration effect on shoots. Therefore, the habitus of the bush is important. For the normal operation of the harvester, the bushes should be either erect or slightly spreading and consist of 10-15 perennial fruiting shoots (Pluta *et al.*, 2008; Sava and Bodiu, 2012). For this trait, 'Viksne', 'Englische Grosse Weisse', 'Osipovskaya' (Table 1) did not meet these requirements and should not be included in currant breeding programs for suitability for mechanized harvesting, as well as for industrial cultivation. In experiments with blueberry cultivars, it has also been shown that certain parameters of plant height and bush volume are necessary for the use of berry harvesting equipment. The minimum yield losses were in blueberry varieties with a straight-growing, compact bush shape, which also made it possible to extend the life of these plantations (Patrick, and Li, 2017). The second disadvantage of the combine harvester of this model is the collection of ripe and unripe berries during vibration on shoots. This result was observed in this experiment with 'Osipovskaya' red currant and when harvesting sea buckthorn berries (Khabarov. 2014; Zubarev., 2022). When harvesting berries in bulk, it is important to determine the effective period of using the harvester, when berry losses will be minimal and the quality of the berries will meet the quality standard (Yu, 2012; Brondino, 2021). The dependence of the effective harvest period on climatic conditions and the cultivar has been proven in this experiment (Table 2), as well as on other cultivars of red and white currants (Paprstein *et al.*, 2016) and grape cultivars (Jobbágy, 2021). This experiment shows the use of mechanical parameters of berries as an informative feature for assessing the quality of berry products (Table 2). For blueberry cultivars, the possibility of using various upgraded combine harvester models is determined by the strength of the berries (Rivera, 2022.). However, it is not entirely correct to recommend using only the mechanical parameters of berries to predict the optimal period of using harvester, since it is also necessary to take into account long-term weather data and biometric characteristics of the bush. A similar conclusion was made by a comprehensive assessment of the mechanical parameters of the berry skin, the morphology of the blueberry bush (Rivera, 2022) and grapes (Zouid, 2010; Brillante, 2015). The current study confirmed the relationship between high Fc values of red currant berries and product quality. These indicators tended to decrease during the maturation process. A decrease in the strength of the skin of berries and the quality of products in the process of biological ripeness were noted in grapes (Rolle *et al.*, 2012). In addition, the current experiment did not reveal a relationship between Fs and the strength of the berry skin, which is consistent with the data obtained on grape cultivars (Giacosa *et al.*, 2013)

CONCLUSION

The suitability of red currant cultivars for mechanized harvesting should be assessed by the productivity of a berry harvester. In this study, the cultivars were rejected according to indicators that determine the profitability of berry production, including a high percentage of branch breakage during two years of using the harvester, low regenerative ability of the bush after sanitary pruning, as well as low mechanical parameters of berries. According to the architectonics of the bush, mechanical parameters of berries and testing of the harvester, 'Vika', 'Asya', 'Red Lake', 'Niva', 'Rolan', and 'Jonkheer Van Tets' are technological cultivars suitable for mechanized harvesting and promising for industrial cultivation and breeding programs.

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