PHYSICAL PROPERTIES OF SEA BUCKTHORN FRUITS AT THE TIME OF THEIR HARVESTING

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Detachment properties of sea buckthorn fruits have been studied at the time of their ripening. The detachment force in axial tension, cutting-off energy, and compression strength of fruits have been experimentally determined. Moreover, the cutting-off energy for thorns and twigs has also been studied. Two parts of the ripening period can be determined on the basis of the results obtained. In the first part, which ends in the middle of September, the measured parameters sharply decrease in the comparison to the relatively stable values in the second part. Difficult harvesting of the fruits is caused by the high detachment forces, very high detachment accelerations and relatively low strength of the fruits. The coefficient of friction between the fruits and the picker's fingers would have to be higher than 0.5, if the fruits were to be picked undamaged.

berry-like fruits; sea buckthorn, mechanical properties; harvesting; detachment force; compression

INTRODUCTION

Berry-like fruits of some bushes are soft at the time of picking and, at the same time, they have very firm stalks. This is why the picking of such fruits is very difficult. Even if picked manually the percentage of fruits damaged in picking is very high, and the fruit losses a large amount of biologically valuable substances it usually contains. In many cases the lost substances belong to the most important components of the final products of fruit processing. A typical representative of this type of bush is the sea buckthorn (*Hyppophae rhamnoides* L.); its fruits contain very valuable health-supporting substances in high concentrations (C z a k h o v s k i i , 1986). At the present, utilization of *Hyppophae rhamnoides* fruits is limited mainly due to the difficulties with its picking.

Some institutions in the countries of the former USSR have the best practical experience with large-scale picking of the sea buckthorn (C z a k - h o v s k i i , 1986). In addition to traditional manual picking methods, the two following methods of picking are usually used: shake-harvesting of frozen berries (during winter under natural conditions and/or from cut branches after freezing under artificial conditions) and suction detachment of the berries in an intensive air flow. The practical use of both the latter methods is connected with some problems (large losses in picking of the frozen fruits under natural conditions, high cost and damage of plants under artificial freezing, and high cost of harvesting fruits in air flow).

It is clear that the choice of the optimal harvesting method should be based on a profound knowledge of physical properties of the fruits, including a good knowledge of the detachment force, strength of the fruits and the binding properties of fruit stalks. As opposed to most other fruit plants (see, for example, Mohsenin, 1970), these properties are not known for the sea buckthorn.

In this paper the usual methods (Mohsenin, 1970; Bareš et al., 1992, 1994; Blahovec et al., 1994) are used to evaluate the basic physical properties of the sea buckthorn fruits. Especially the detachment force, strength of the fruit and the resistance of fruit stalks to cutting are carefully studied at the time of the potential harvesting.

MATERIAL AND METHODS

Experimental material in the form of whole branches with fruits was obtained from production orchards of the horticultural company ADAVO, located near Velký Osek about 50 kilometres to the east of Prague. The branches were cut off from the bushes in the morning, then transported to the Prague laboratory, and all the experiments were performed on the same day. The time schedule of the experiments is in Tab. I.

The experiments consisted of three simple tests: detachment test, cutting tests, and fruit compression between two plates. All the test were performed using the universal testing machine Hecker FZP 10/01.

The detachment experiments were performed by hand. Whole branches were hung on the load cell of the universal testing machine and single fruits were plucked by hand in the directions of the single fruit stems. The maximum plucking forces, i.e. the detachment forces, were detected by the recording device of the universal testing machine. The mass (m) of each fruit (some exceptions were in the first measurements) was determined. The measurement was usually repeated for sixty fruits of both varieties.

Cutting experiments were also performed on the sea buckthorn branches hung from the load cell of the universal testing machine. Fruits were cut off by a special cutting jig, connected to the moving cross bar of the testing machine – see Fig. 1a. The cutting jig moves downwards with the cross bar at a rate of approximately 2 mm per second. At the same time the fruits

I. Experimental material

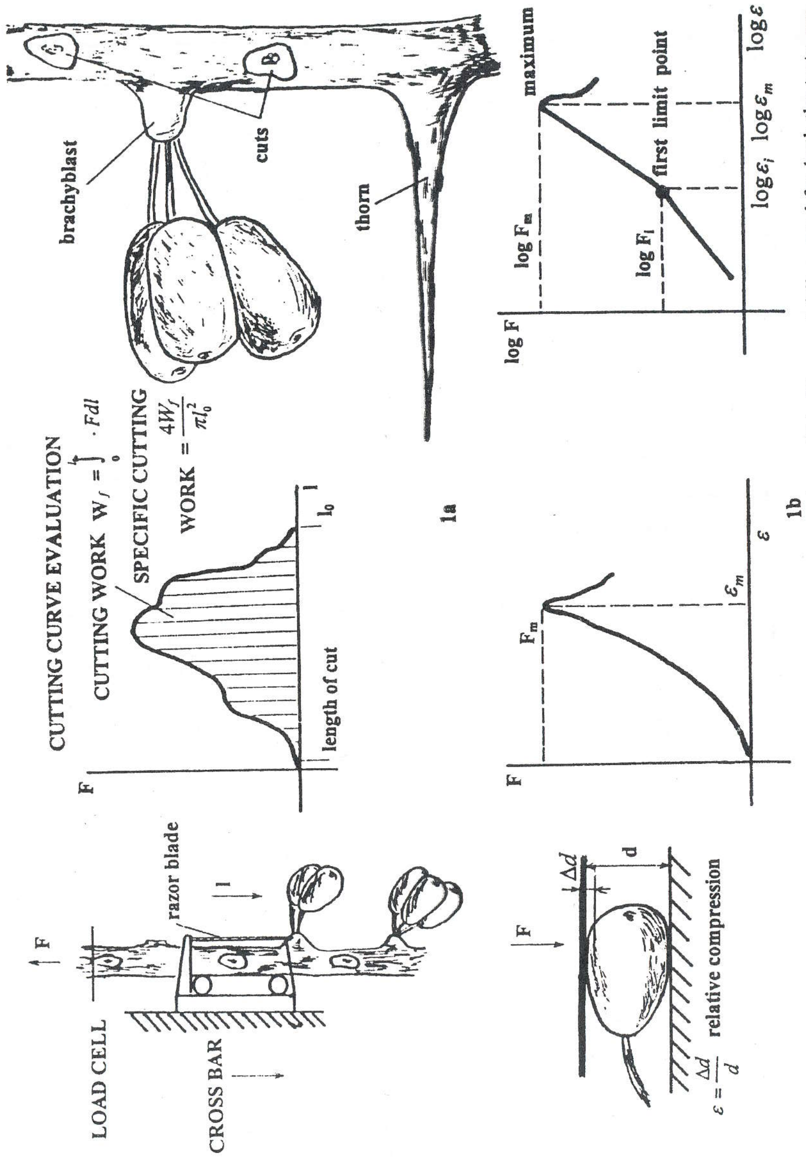
Variety	Testing and harvesting date	Floating time (days)	DM (%)
Leikora			
(1.1)	21. 8. 1994	1	21.3
(1.2)	7. 9. 1994	17	19.8
(1.3)	14. 9. 1994	24	16.8
(1.4)	21. 9. 1994	31	17.8
(1.5)	28. 9. 1994	38	17.2
Hergo			
(2.2)	7. 9. 1994	17	19.5
(2.3)	14. 9. 1994	24	17.8
(2.4)	21. 9. 1994	31	17.8
(2.5)	28. 9. 1994	38	22.2

DM – dry matter content (w.b.)

passing through the jig are cut off by a razor blade, located in the jig (Fig. 1a). Cutting curves, i.e. the time functions of the cutting forces, are recorded by a computer, connected with the testing machine. Numerical integration of the cutting curves (Fig. 1a) yields the values of the work required to cut off the fruits. Another quantity which the cutting curve yields is the length of the cut, and this value can be interpreted as the diameter of the circular cutting area. The ratio of the cutting work to the corresponding cutting area defines the specific cutting work. Most cuts performed on the sea buckthorn are situated near the branch in the part termed as the brachyblast (see Fig. 1a).

The cutting jig and the above described method were also used to cut off the thorns and twigs, very frequent among the fruits on the sea buckthorn branches, and also frequently cut off by the jig in the course of our experiments.

The last test that was usually performed is the compression test of the harvested fruits between two plates. About twenty perfect fruits with short stalks were separated from the branch by very careful hand cutting, using a razor blade. These fruits were tested by being compressed between two steel plates at a constant strain rate of appr. 0.1 mm/s (Fig. 1b). Compression was stopped immediately after the tested fruit ruptured. The most important parameters of the test are the initial diameter (d) of the fruit and the coordinates of two characteristic points on the compression curve. The characteristic parameters are the strain, defined as the ratio of the actual compression deformation and the initial diameter of the tested fruit, and the compression



1. Schemes of fruit cutting off (1a) and fruit compression between two plates (1b). The special jigs, used for both the tests, are simply described and the mathematical methods used to the evaluate the cutting and compression curves are also briefly outlined

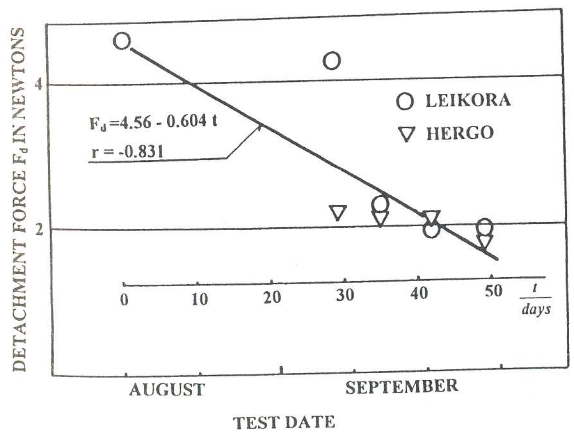
force. The most important point of the compression curve is the point corresponding to the fruit's rupture; this will be referred to as the maximum (maximum strain, maximum force). Another important point of the compression curve is determined as the common point of the two main parts of the compression curve that can be described separately by simple power functions (Fig. 1b). This point will be denoted as the first limit point.

RESULTS

The results of the detachment test are summarized in Tab. II. In the two first experiments (1.1, 1.2, and 2.2) only the mean mass of the fruit was determined from the total weight of about twenty destemed fruits. At the time of ripening, the detachment force generally decreases for both the varieties (Fig. 2). In most cases no difference in detachment force was observed for either inspected variety. One exception can be observed in the measurements made on 7th September, where the value observed for the Leikora variety was approximately twice as high (Fig. 2).

The results of the parallel cutting-off experiments, performed on the sea buckthorn fruits, are given in Tab. III. The cutting energy required to cut off the fruits is relatively stable for the higher dates of tests (14th September and later) and it amounts to about 5 mJ. But in the earlier stage of the ripening, the cutting energy also decreases with later date of test (Fig. 3). At that stage of ripening some small differences between the cutting energy for both the tested varieties were detected (Fig. 3).

The compression tests yielded the results given in Table IV. Similarly as for the cutting energy, also the characteristic compression forces (at the maxi-



2. Detachment force plotted against the date of test. Time of ripening t has been chosen in so that the first experiment (11. 8.) corresponds to t = 1

II. Mean values of the quantities obtained in the detachment experiments

Variety	Fruit number	Detachment force F_d (N)		Fruit mass m (g)		Ratio F_d/m (m.s^{-2})	
		mean value	SE	mean value	SE	mean value	SE
Leikora							
(1.1)	60	4.57	0.10	0.350	–	13 100	–
(1.2)	59	4.21	0.09	0.320	–	13 200	–
(1.3)	61	1.92	0.05	0.220	0.005	9 100	300
(1.4)	60	2.19	0.05	0.232	0.003	9 600	300
(1.5)	60	1.85	0.04	0.233	0.004	8 100	200
Hergo							
(2.2)	59	2.15	0.07	0.210	–	10 200	–
(2.3)	60	2.07	0.06	0.207	0.005	10 100	300
(2.4)	60	1.98	0.05	0.267	0.004	7 500	300
(2.5)	60	1.68	0.02	0.245	0.005	7 400	200

SE – standard error

III. Mean values of the quantities obtained in the cutting experiments (fruits)

Variety	Cut number	Cutting work W_f (mJ)		Cut area (mm^2)		Specific cutting work (J.m^{-2})	
		mean value	SE	mean value	SE	mean value	SE
Leikora							
(1.2)	44	12.05	0.20	22.1	0.9	605	19
(1.3)	14	6.35	0.24	18.2	1.2	401	29
(1.4)	51	4.63	0.18	23.5	1.0	207	9
(1.5)	27	5.69	0.30	25.5	1.1	236	18
Hergo							
(2.2)	50	9.18	0.34	16.4	0.6	587	21
(2.3)	28	4.39	0.26	20.9	1.0	211	11
(2.4)	25	4.14	0.28	19.2	0.8	214	14
(2.5)	31	4.66	0.24	20.8	1.2	237	11

SE – standard error

IV. Mean values of the quantities obtained in the compression test of the simple fruits

Variety	FN	Diameter d (mm)		Strain (%)				Force (N)			
				1st limit		maximum		1st limit		maximum	
		MV	SE	MV	SE	MV	SE	MV	SE	MV	SE
Leikora											
(1.1)	20	6.92	0.05	12.4	0.7	26.6	1.0	0.69	0.07	2.78	0.18
(1.2)	23	7.63	0.08	7.0	0.5	17.9	0.5	0.43	0.02	1.81	0.07
(1.3)	20	6.88	0.06	6.0	0.5	15.5	0.4	0.46	0.04	1.72	0.07
(1.4)	20	5.99	0.08	8.6	0.3	21.5	0.3	0.46	0.02	1.85	0.08
(1.5)	20	6.88	0.08	6.4	0.4	15.9	0.5	0.44	0.02	1.51	0.05
Hergo											
(2.2)	22	5.93	0.06	7.8	0.3	16.8	0.4	0.53	0.03	1.64	0.05
(2.3)	19	6.40	0.08	7.7	0.4	15.4	0.4	0.54	0.04	1.39	0.05
(2.4)	20	5.81	0.07	9.8	0.5	21.2	0.8	0.51	0.04	1.69	0.05
(2.5)	18	6.92	0.09	7.6	0.4	16.9	0.4	0.43	0.03	1.51	0.04

FN – fruit number, MV – mean value, SE – standard error

V. Mean values of the quantities obtained in the cutting experiments with the woody parts of the plants (14. 9. 1994)

Variety	Cut number	Cutting work W_f (mJ)		Cut area (mm^2)		Specific cutting work (J.m^{-2})	
		mean value	SE	mean value	SE	mean value	SE
Leikora							
Thorn	10	3.3	0.3	3.4	0.5	1 079	58
Twig	7	13.0	1.8	21.1	2.0	611	66
Hergo							
Thorn	7	6.9	1.4	7.9	2.3	1 292	135
Twig	8	9.5	0.5	26.1	2.3	383	24

SE – standard error

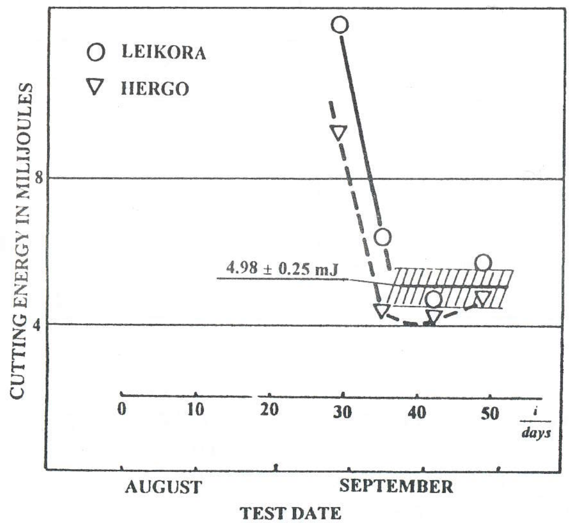
mum and first limit points) are relatively stable for higher dates of ripening (7th September or later), the values being 1.64 N (maximum point) and 0.48 N (first limit point), see Fig. 4. Both these characteristic forces decrease at the earlier stage of ripening with the softening of the fruit.

A few cutting experiments with thorns and twigs are evaluated in Tab. V. The values of the cutting energy obtained are comparable with the cutting energies observed in cutting off fruits (Tab. III).

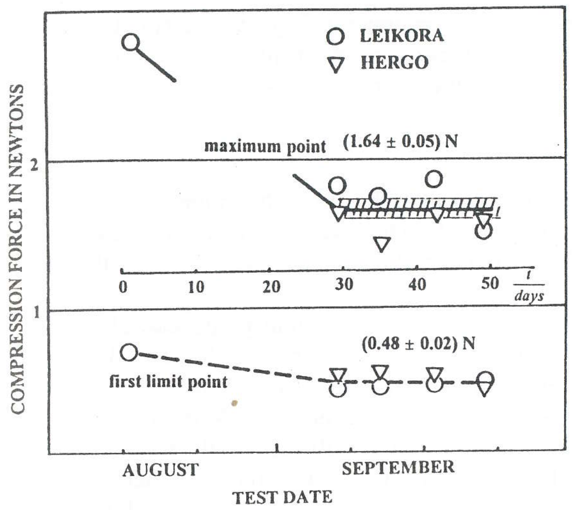
DISCUSSION

An inspection of the above results shows that the ripening period of the sea buckthorn can be divided into two parts. The first can be characterized by the softening of practically all parts of the fruits (stalks, flesh tissue, skin, etc.). In the second part of the ripening process, the characteristic values of the fruit are relatively stable. The boundary between the first and the second part of the ripening period was detected in the middle of September 1994 (Figs. 2–4).

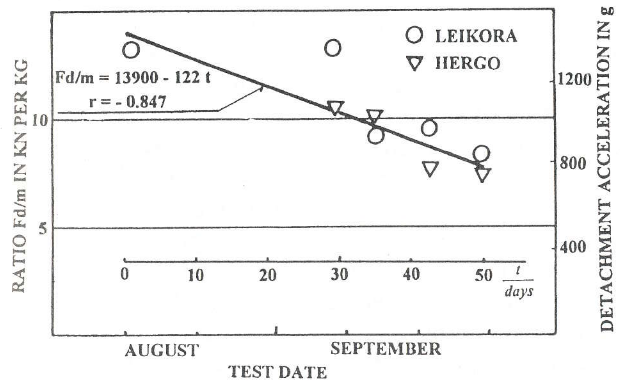
The ratio of the detachment force to the fruit mass can be understood as the axial detachment acceleration (B l a h o v e c et al., 1994). This quantity is evaluated in Tab. II and is plotted against the test date in Fig. 5. It also decreases with increasing test date; in comparison to the other properties mentioned above, this decreasing character is not limited to the first stage of ripening. The axial detachment acceleration for the sea buckthorn is very high, the values amounting to about a thousand g's (see Fig. 5 – g is the Earth's gravity acceleration), about ten-times higher than for olives (B l a h o v e c et al., 1994). This is indicative of the difficulties usually encountered in vibration harvesting of the sea buckthorn (C z a k h o v s k i i et al., 1986).



3. Cutting energy required to cut off the fruits plotted against the date of test. Time of ripening t is chosen as in Fig. 2



4. Compression forces corresponding to the maximum point of the compression curve and the first limit point of the same curve, obtained in compressing the fruit between two plates, plotted against the date of the test. Time of ripening t is chosen as in Fig. 2



5. Ratio of the detachment force of a fruit to its mass plotted against the date of test. Time of ripening t is chosen as in Fig. 2. Ratio F_d/m can also be understood as the axial acceleration require to separate the fruit by axial vibration (see the right-hand side of the figure with the acceleration scale given in g's).

Manual picking of the fruits consists in the picker's fingers gripping the fruit, followed by pulling the fruit approximately in the direction of the fruit stalk until the stalk breaks. At this critical point the detachment force must be balanced by the friction force between the fruit and the fingers. But the friction force is limited by the friction coefficient between the fruit and the fingers, on the one hand, and by the maximum force that can be used for gripping the fruit without damaging it, on the other. If a characteristic damage force F_{cr}, usually determined in the compression test between two plates, is used, the experimental value of the detachment force F_d has to be balanced by the friction force expressed as the product 2 $F_{cr} f_d$, where f_d is the critical value of the coefficient of friction between the fruits and the fingers. This condition yields the value of f_d in the form:

$$f_d = \frac{F_d}{2 \, . \, F_{cr}} \qquad (1)$$

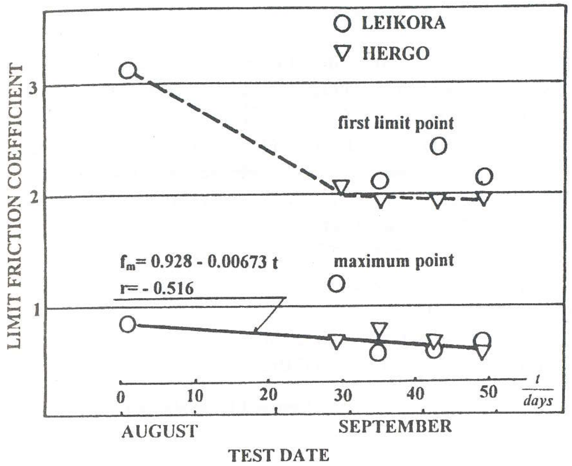
If the real coefficient of friction is higher than the value of f_d, given by equation (1), the fruit can really be detached without damaging it by squeezing it with the fingers, otherwise the fruit cannot be detached using the above procedure.

The maximum force, or the force at the first limit point was taken as the critical forces F_{cr} in Eq. (1); the former as the the rupture force, and the latter as the force at which internal bruising of the tested fruit can be detected (B a r e š et al., 1992, 1994). The results obtained are plotted in Fig. 6, and the decreasing character of the limit friction coefficient at the time of the fruit ripening is also shown clearly in this figure. But on the other hand, the observed values of this parameter are too high for safe hand-picking during the whole investigated period. According to Fig. 6, rupture of the fruit can be avoided only if the limit friction coefficient is higher than values appr. 0.5, and if internal bruising of the fruits is to be avoided, the friction values have to be in excess of 2. These results illustrate the difficulties of sea buckthorn fruit harvesting by picking.

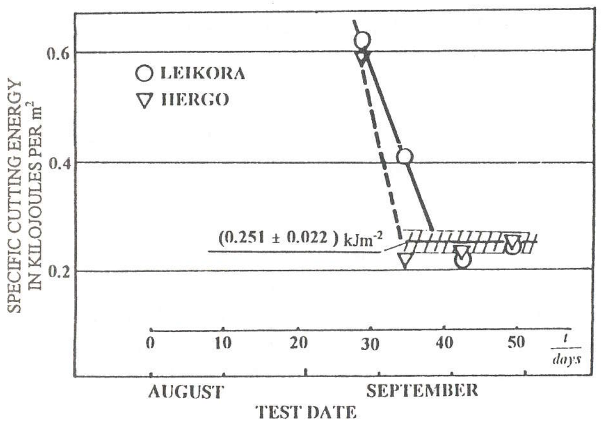
Fig. 7 shows the cutting energy required to cut off the fruits. In the first part of the ripening period, the cutting energy decreases and in the second part it is relatively stable, similarly as the other quantities studied in this paper. The cutting-off process is not limited by the other properties of harvested fruits, and that is why it can be carried out at the time of optimum composition of the harvested fruits. The influence of the brachyblast cuts on the growing ability of the harvested bushes has to be investigated in the future research because only the brachyblast damage due to cuts seems to be a serious problem in using the cutting-off methods in harvesting of sea buckthorn fruits.

CONCLUSIONS

Some physical properties of the sea buckthorn fruits have been studied in relation to their harvesting. The experiments performed at the time of their ripening show the principal problems the picking and vibration detachment of these fruits. Another alternative method of fruit detachment, i.e. the cutting off of the fruits, was also studied. It was shown that cuts are located usually in the brachyblast parts and the detachment of the fruits from the branches can be performed without problems, the energy required therefore being com-



6. Limit friction coefficient of the fruit surface against the picker's fingers, required to pick the fruit by hand without damaging the fruit, plotted against the test date (see also Fig. 2). In the lower part of the figure, the results are based on the rupture force (compression between two plates), and the results obtained for the first limit point are given in the upper part.



7. Specific cutting energy for cutting off sea buckthorn fruits plotted against the date of the test (see also Fig. 2).

parable to that required for cutting thorns or twigs. Technological problems and damage of the brachyblast have to be taken into account in future experiments.

A c k n o w l e d g e m e n t s

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Fyzikální vlastnosti plodů rakytníku řešetlákového v době jejich sklizně.

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Chování plodů rakytníku řešetlákového při jejich sklizni bylo studováno v období dozrávání. Experimentálně byly stanoveny: síla potřebná k oddělení plodů axiálním tahem, energie potřebná k jejich odříznutí a tlaková pevnost plodů. Navíc byla určena energie potřebná k odříznutí trnů a drobných větviček. Naměřené veličiny posloužily ke stanovení dvou období dozrávání. V prvním, které končilo v polovině září, měřené hodnoty silně klesaly ve srovnání s druhým obdobím s relativně stabilními hodnotami většiny měřených veličin. Obtížnost sklizně plodů rakytníku spočívá ve vysokých hodnotách síly potřebné k oddělení plodů od rostliny, vysokých hodnotách separačního zrychlení a relativně nízké pevnosti plodů. Bylo stanoveno, že koeficient tření mezi plody a prsty česáče musí být větší než 0,5, má-li být plod odtržen v nepoškozeném stavu.

bobuloviny; rakytník řešetlákový; mechanické vlastnosti; sklizeň; oddělovací síla; stlačování

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