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A study of physical characteristics of three walnut cultivars (*Juglans regia* L.) for creshing on centrifugal nutcracher

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Morphological and physical characteristics of three walnut cultivars (*Juglans regia* L.) 'G-139', 'Franquette' and 'Domači oreh' were examined in the trial to determine the parameters of centrifugal machine for mechanical crushing of walnuts. Four morphological characteristics (height, diameter, weight and volume) and three physical characteristics (force, shell deformation and energy impact for shell crushing) were measured in the laboratory device. The maximum force (293.14 N) for crushing walnut shells was measured with 'Franquette', followed by 'Domači oreh' (248.30 N) and 'G-139' (202.5 N). The biggest shell deformation during crushing by the height (4.69 mm) was measured with 'Domači oreh', 4.62 mm with 'Franquette' and 2.58 mm with 'G-139', which correlate with the air volume of walnut 'Domači oreh' (6.33 %), 'G-139' (3.04 %), 'Franquette' (4.44 %). The most energy for crushing the shell by the nut height was required for 'Franquette' (1.35 J), while for crushing the shell of 'Domači oreh' 1.16 J and 0.52 J for 'G-139'. According to the morphological and mechanical characteristics of the shell, the 'Franquette' cultivar was shown to be the most suitable for mechanical crushing on centrifugal nutcracker.

Key words: walnut, phisilogical characteristics, centrifugal nutcracker

INTRODUCTION

Walnut crushers exist in many construction cultivars, which are divided into two groups according to direction of the crushing force. The first group includes machines which enable a two–sided application of forces onto a walnut. The rigid crushing surfaces in the crusher have a constant tapered cylinder interspaces, allowing a constant shift of plates in translator motion, with an opening on the bottom, through which walnuts which have been crushed are passed. Because walnuts of the same cultivar are not of the same thickness or height, kernels can be severely damaged. To avoid losses of kernels a preliminary sorting of walnuts according to their thickness should be processed. The second group of walnut crushing machines operates by the impact principle with the force being applied to a walnut only from the upper or from the lateral side. The deformation of a walnut shell occurs in the form of shell destruction or shell damage (i.e. a crack in the shell) caused by an internal tension in the shell.

Since the cracking process is the most critical and delicate step for achieving high–quality kernels, mechanical properties of walnut cultivars is a pre–requisite for the design and development of a cracking machine (Pliestic et al. 2006). Özdemir and Özilgen (1997), stated that the kernel extraction quality depend on shell moisture content, shell thickness, nut size, and loading positions in nuts. Dursun (1997) found that the compression position influenced the amount of force applied to crack walnuts and other nuts. In this study, the maximum force (244 N) required to crack walnuts occurred at right angles to the longitudinal axis while the minimum force (149 N) occurred when the force was applied along the suture line. Similarly, both Braga et al. (1999) and Aydin (2002) found that the maximum force required to crack nuts was measured when nuts were placed at right angles to the longitudinal axis whereas the minimum force required to crack nuts occurred when the force was applied along the longitudinal axis.

After a machine for mechanical crushing of walnuts was developed and patented by Bernik (2000), important technical characteristics of walnuts affecting its operation had to be determined, which include basic morphological and physical characteristics of walnuts as stated by Őzdemir and Özilgen (1997) and Güner et al. (2003).

MATERIALS AND METHODS

Our research was divided into two parts. First, a height and diameter of each walnut were measured by sliding calliper while the volume was calculated volumetrically. In the second part a compression test with measurement of shell firmness, deformations and required energy needed for the crushing of nuts was performed. The aim of the study was to detect minimal forces, which could prevent damages of the kernel of the three walnuts cultivars 'G-139', 'Domači oreh' and 'Franquette' occurring because of the friction on the newel designed centrifugal nutcracker.

Walnut cultivars

'G-139' is German cultivar. A broad oval fruit is large and weight about 12 g (Ocepek 1995). The shell is moderately thick, nearly smooth and tightly closed. The kernel can be shelled medium, whereby the yield is 48%.

'Franquette' is one of the most common French walnut cultivars in the world originates from the region of Grenoble

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in France. The fruit is oblong, tapered, thick, and weighs between 9.5 and 12 grams (Ocepek 1995). The shell is thin, firm, furrowed, and tightly shut. It is easily shelled, whereby the yield is 48 %.

'Domači oreh' is also called 'Italian walnut' or 'Long thin-shelled walnut'. Fruits are medium thick, long, round, with smooth skin and weighs between 11 and 13 grams. The shell is thin, firm, furrowed, and tightly shut. It is easily shelled.

A random sample containing 70 nuts of each cultivar were taken from the selection plantation of Biotechnical Faculty Ljubljana in 2007. Measurements were carried out at the laboratory of the Chair of Agricultural Technology at the Biotechnical Faculty and at the laboratory of the Faculty of Mechanical Engineering in Ljubljana.

Centrifugal nutcracker

A centrifugal nutcracker (Fig. 1), which operates on the principle of a centrifugal force created by the electric engine through the rotor, was used for cracking the walnuts. The rotor case consists of a cylinder with an opening at the top to allow the nuts to drop through, while at the bottom, the cylinder divides into two parts and widens in the direction of rotation. The nuts enter the rotor from the top and due to the centrifugal force exit at the bottom and hit the rotor case with a considerable force. For a better result, the rotor case can be replaced with different materials, or brackets can be fitted to crack nuts with stronger shells. The nutcracker's electric engine is equipped with a frequency regulator, with which prior to every cracking, the rotational frequency of the rotor was adapted according to the shell's moisture level.

After cracking, the cracked walnuts of each group were divided according to the position of the impact that caused the shell break. Then, in each group, the amounts of undamaged halves, partly damaged halves and residues were weighed.

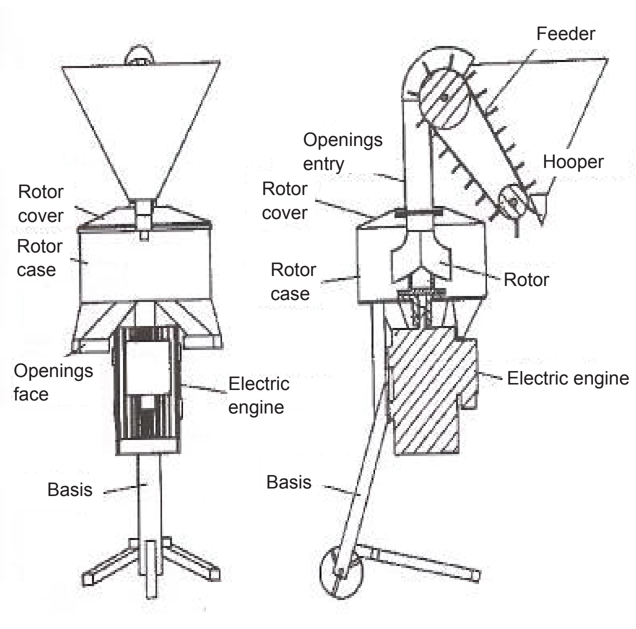

Figure 1: Centrifugal nutcracker (Bernik 2000)

Nut size measurements

Measurements of the nuts regarding their height, width and thickness were carried out using a sliding caliper. A sliding caliper consists of a straight edge guide with a fixed jaw and a movable jaw. A locking lever was used for fixing the moving part. The measurements were taken so that the measured nuts were held between the moveable jaws and then the measurements were read. Thus, dimensions with a relative error of approximately one hundredth of a percent were measured.

Nut weight measurements

Weight measurement always began by steadying the scales. Then, each walnut was placed on it separately and the result was read. The scales used had an accuracy of 0.01 g and the capacity of weighing samples with a weight of up to one kilogram. Measurements were carried out in a tightly sealed area, since otherwise, deviations from the real weight due to draught and exhaled air might have occurred.

Nut volume measurements

The volumes of the entire nut, shell, and kernel were measured. Based on the obtained parameters, the air volume was calculated. Measurements were carried out by immersing the fruit, shell or kernel into water in the measuring cylinder. A measuring cylinder was used for immersion, the volume of which was calculated in advance. The difference in the height of the water column in the measuring cylinder was the basic parameter for the calculation of the total volume. The result — the actual volume of the fruit, shell or kernel — was obtained by deducting the volume of the instrument from the total volume.

Testing the strength of the shell

The test consisted of two parts. The first part was conducted with a special press (Bernik and Stajnko 2008) at the laboratories of the Faculty of Mechanical Engineering — the measurement of the deformation and force needed to break the shell. For each measurement, the nut was held between jaws to ensure the sample was secure during measurement, and then the data was entered into the computer which is an integral part of the pressure tester device. The force needed to crack the walnut shell was measured and observed.

Testing of the crushing work

Immediately before initial rapture of the shell, a work (J) required for the shell crushing was calculated on the basis of the deformation size (mm) and the force used (N).

We assumed that physical conditions for walnut crushing depended on the crusher force direction, which might be connected with the morphological characteristics of walnuts.

Statistical analysis

A data set of three walnut cultivars (n= 70) was analyzed and graphically represented by using the Statgraphics software (version 15.0). A multiple range statistical analysis (ANOVA) was applied to study a significant difference between means of groups with a significant level of $p<0.05$.

Table 1: Average, standard error and confidence intervals for the walnut weight, height and diameter

Dependent variable	Cultivar	n	Average	Standard error	The 95 % confidence interval	
					Lower limit	Upper limit
Weight (g)	'G-139'	70	9.04^{c}	0.77	6.20	11.80
	'Domači oreh'	70	14.70^{a}	0.77	10.98	17.80
	'Franquette'	70	11.62^{b}	0.77	8.80	14.16
Height (mm)	'G-139'	70	33.33^{b}	2.88	29.11	37.15
	'Domači oreh'	70	39.86^{b}	2.88	34.30	44.25
	'Franquette'	70	51.94^{a}	2.88	35.75	45.25
Diameter (mm)	'G-139'	70	28.26^{a}	1.99	24.30	31.70
	'Domači oreh'	70	32.15^{a}	1.99	28.20	35.65
	'Franquette'	70	31.98^{a}	1.99	29.90	34.10

[a, b, c] different superscripts indicates statistically significant differences according to Duncan's Multiple Range Test ($p<0.05$), where (a) is the highest average and (c) is the lowest average.

Table 2: Average, standard error and confidence intervals for the volume of the whole walnut, shell, kernel and air

Dependent variable	Cultivar	n	Average	Standard error	The 95 % confidence interval	
					Lower limit	Upper limit
Volume of whole nut (ml)	'G-139'	70	15.63^{b}	1.58	15.02	16.22
	'Domači oreh'	70	22.78^{a}	1.58	22.19	23.36
	'Franquette'	70	18.39^{a}	1.58	17.56	19.21
Volume of shell (ml)	'G-139'	70	7.62^{a}	0.50	7.37	7.88
	'Domači oreh'	70	7.94^{a}	0.50	7.32	8.56
	'Franquette'	70	7.92^{a}	0.50	7.49	8.29
Volume of kernel (ml)	'G-139'	70	4.95^{b}	0.67	4.64	5.27
	'Domači oreh'	70	6.00^{a}	0.67	5.66	6.33
	'Franquette'	70	6.03^{a}	0.67	5.19	6.88
Volume of air (ml)	'G-139'	70	3.04^{b}	1.97	2.37	3.71
	'Domači oreh'	70	6.33^{a}	1.97	5.73	6.94
	'Franquette'	70	4.44^{b}	1.97	3.47	5.42

[a, b] different superscripts indicates statistically significant differences according to Duncan's Multiple Range Test ($p<0.05$), where (a) is the highest average and (b) is the lowest average.

Table 3: Descriptive statistics for the maximum force applied by the nut height and by the nut diameter for all three walnut cultivars

Walnut cultivar	Shift (mm)	Force (N)	Work (J)
'G-139' Average	1.29^{b}	131.09^{b}	0.17^{b}
Std. error	0.79	50.36	0.04
Median	1.30	103.09	0.13
Maximum	2.58	202.50	0.52
'Domači oreh' Average	2.34^{a}	158.30^{a}	0.37^{a}
Std. error	1.36	63.45	0.09
Median	2.36	166.30	0.39
Maximum	4.69	248.30	1.16
'Franquette'Average	2.33^{a}	127.33^{b}	0.30^{a}
Std. error	1.33	54.50	0.07
Median	2.35	130.58	0.31
Maximum	4.62	293.14	1.35

[a, b] different superscripts indicates statistically significant differences according to Duncan's Multiple Range Test ($p<0.05$)

When ANOVA analysis revealed differences among groups, a post–hoc Duncan's Multiple Range Test analysis was preceded with 95 % confidence intervals for the average of all three cultivars at a significant level of $p<0.05$.

RESULTS

Morphological characteristics of walnuts

Basic descriptive statistics which include the 95 % confidence intervals for the average of all three cultivars are presented in Table 1, while the analysis of variance for different volumes is given in Table 2.

The results of Multiple Range Test (Table 1) proved the existence of statistically significant differences in the average values of weight and height among the three cultivars ($p<0.05$). According to Duncan's Test, cultivars differ pair wise in two morphological characteristics. The 'Domači oreh' cultivar grows averagely the heaviest walnuts (14.70 g), followed by the 'Franquette' cultivar (11.62 g) and the 'G-139' cultivar (9.04 g). Averagely, the 'Franquette' grows walnuts with the largest height (51.94 mm), followed by the 'Domači oreh' (39.86 mm) and the 'G-139' (33.33 mm). Averagely, the 'Domači oreh' cultivar grows walnuts with the widest parameter (32.35 mm), followed by the 'Franquette' (28.26 mm) and the 'G-139' (28.26 mm).

As seen for the Table 2 the 'Domači oreh' grows the nuts with the highest volume (22.78 ml), followed by the 'Franquette' (18.39 ml) and the 'G-139' (15.63 ml). The same relations were measured by the volume of shell. However, the volume of kernel did not differ significantly between the 'Domači oreh' (6.00 ml) and the 'Franquette' (6.03 ml) as expected, due to the highest volume of the air by the 'Domači oreh' (6.33 ml). It was significantly higher then in the 'G-139' (3.04 ml) and the 'Franquette' (4.44 ml).

Necessary force for cracking

Figure 1 shows the required values of force for cracking the walnut shells of different cultivars. It is clearly shown that the greatest force was required for cracking the 'Franquette' walnuts (293.14 N), followed by the 'Domači oreh' walnuts (248.30 N). The smallest force was needed for cracking walnuts of the 'G-139' cultivar (202.50 N). Those results agreed with the study of Dursun (1997) who found that the maximum force (244 N) was required to crack walnuts at right angles to the longitudinal axis.

Necessary work for cracking the shell

Table 3 shows the basic descriptive statistics for the measurements of the work required for all three cultivars for cracking. A decrease in the amount of average work input may be seen according to increase in diameter of different cultivars. There are significant differences in the average work input between the 'G-139' with the smallest diameter (28.26 mm) and other two cultivars. However, there is no statistically significant difference between the 'Domači oreh' (32.15 mm) and the 'Franquette' (31.98 mm). Those results agreed perfectly with Koyuncu et al. (2004), who found a close correlation between the decrease of energy and increase of geometric mean diameter.

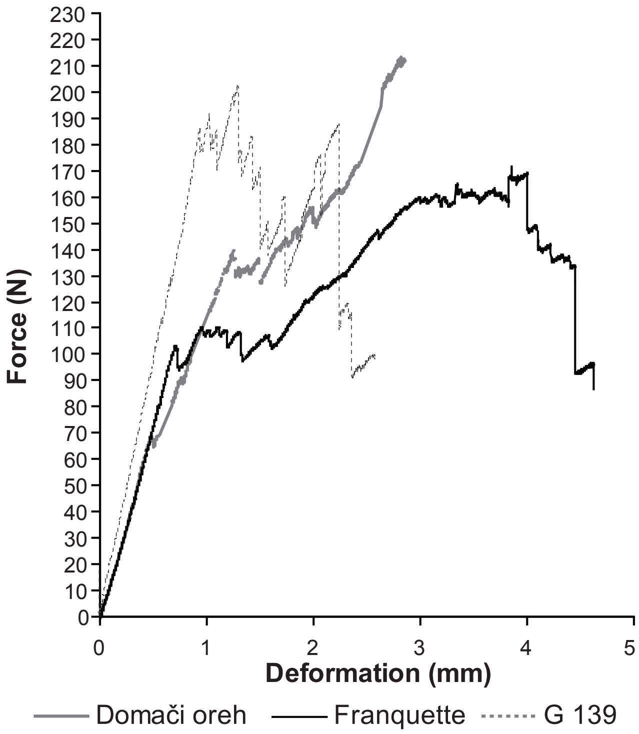

Figure 1: Force (N) in relation to deformation (mm) in cracking steamed walnuts

It can be additionally seen from the same table, that the greatest work was necessary for cracking the 'Franquette' walnuts (1.35 J) at a deformation of 4.62 mm, while for the 'Domači oreh' walnuts 1.16 J was required at a deformation of 4.69 mm. The smallest work was needed for cracking walnuts of the 'G-139' cultivar (0.52 N) at a deformation of 2.58 mm.

Point of breaking

The point of breaking critically influences the quality of cracking, since the manner of breaking directly influences the damage of the kernel and its quality. As shown in Figure 2, the distribution in the 'G-139' is relatively even, only the breaking from the side and those that cannot be identified deviate slightly.

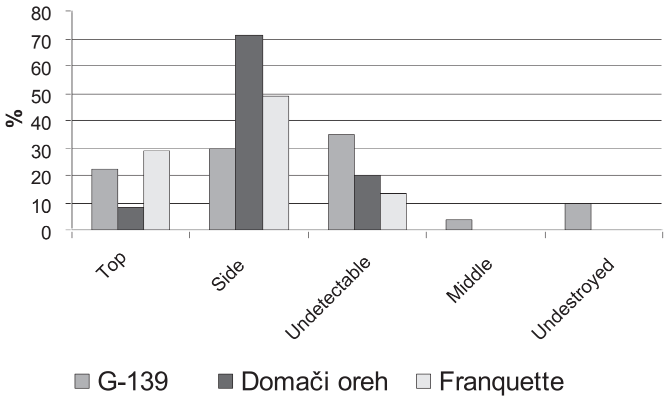

Figure 2: Point of breaking according to different cultivars

The 'Domači oreh' and 'Franquette' showed the greatest deviations by the breaking from the side, 71.59 % or 49.52 % respectively, followed by damages where the point of breaking could not be identified and the breaking on the top. In those two cultivars, there were no middle breakings or undamaged categories.

Kernel extraction quality

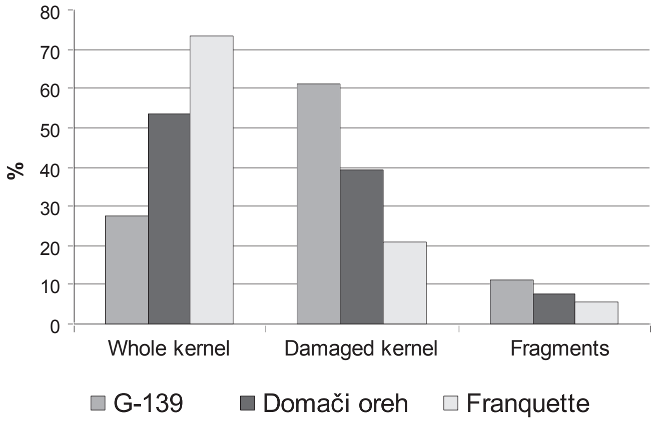

Figure 3: Residue percentage according to damage in different cultivars

Based on the analysis of the damage after cracking with the centrifugal nutcracker, it was established that on average, the cracking of the 'Franquette' walnuts was the most favorable, leaving 74.62 % of whole, undamaged halves. In the 'Domači oreh' the proportion of whole kernels was reduced to 55.89 %, and in the 'G-139' to only 28.47 %, meaning that the cultivar significantly affected the proportion of whole kernels.

CONCLUSION

Based on the measurement results of the physical characteristics of walnuts it can be determined that:

- the maximum force in walnut crushing by the diameter was required by the 'Franquette' cultivar (293.14 N),
- the largest shift in walnut during crushing by the height occurred in the 'Franquette' cultivar (4.62 mm),
- the largest amount of work in crushing walnut by was required by the 'Franquette' cultivar (1.35 J),
- measured crushing force values showed statistically significant differences due to the different mechanical characteristics of the three cultivars. These differences are essential for the planning of the basic walnut crusher parameters, since it is otherwise very hard to construct the machine in an efficient manner.
- it was proved in the experiment that the crushing force settings affect the point of breaking significantly, therefore in 'Domači oreh' and 'Franquette' it was mainly by a side and undetectable in 'G-139'.
- the residue percentage depended very much on cultivars therefore in 'Franquette' 74.62 % of samples remained in whole kernel, in 'Domači oreh' 55.89 % and only 28.47 % in 'G-139'.

Based on experimental results it can be assumed that the cultivar 'Franquette' is the most suitable cultivar for the mechanical crushing of walnuts on centrifugal nutcracker. In this cultivar, the most of the force appeared on the side, which is very important, because it resulted in the highest percent of whole kernels halves, which has got the best price.

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