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Study of physical and mechanical properties of plant fruits on the example of walnut

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Perennial plantations that are zoned in Ukraine allow to obtain high-quality fruits (nuts), which are widely used in the perfumery, pharmaceutical, oil, confectionery and other industries, as well as in the production of feed and feed additives. The known technologies of mass processing of walnut kernels mostly work well with crops that have a spherical or close to spherical external shape. The simplest, but least productive, are primitive manual devices for peeling walnut shells. Despite the simplicity of their design, these devices are inefficient and unsuitable for adjusting their operation to different varieties and physical and mechanical properties of biological fruits. The analysis of the known designs of walnut shell destruction machines and mechanisms showed the need to study the physical and mechanical properties of biological fruits (walnuts), to develop technical recommendations for the design of impact mechanisms to improve the quality of shell destruction and the possibility of their application in mass production technologies. A research methodology was developed, a laboratory setup was manufactured, and experiments were conducted. To determine the strength characteristics, the author designed and manufactured a device. It consists of a lever mechanism and a deforming device. The dimensions and load measurements were carried out according to well-known methods of physical mechanics. The statistical analysis of the results showed the need for in-depth scientific research of the geometric parameters of the design of the working bodies of machines for destroying the walnut shell in the mechanisms of fruit peeling machines, taking into account the quality indicators performance of works with certain conditions of their implementation. We conclude that according to the results of the experiments, there is a fairly high dependence between the geometric dimensions of the walnut fruit at the level of 0.72, 0.57 and 0.49, respectively. The weight of the fruit also depends on its dimensional characteristics, which is logical at the level of 0.6–0.75. The force of critical static fracture has a weak correlation with the dimensional characteristics at the level of 0.3. And it depends little on the plane of its application.

Keywords: walnut, nut cracker, mechanism, physical and mechanical properties.

Дослідження фізико-механічних властивостей рослинних плодів на прикладі горіха волоського

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Багаторічні насадження які районуються в Україні дозволяють отримати високоякісні плоди (горіхи), що досить широко застосовують в парфумерній, фармацевтичній, олійній, кондитерській та інших галузях, виготовляють корми та кормові добавки. Відомі технології масової переробки ядра горіху, переважно, добре працюють з культурами, плоди яких мають сферичну, або близьку до сферичної зовнішню форми. Для лущення горіхів використовуються найрізноманітніші за конструкцією механізми чи машини, але всі їх можна поділити на такі типи як: автоматичні, ручні, напівавтоматичні, саморобні, промислові. Найпростішим, але найменш продуктивним є примітивні ручні пристосування для лущення оболонки горіху. Попри простоту конструкції, ці пристосування малопродуктивні та малопридатні до налаштування їх роботи до різних сортів та фізико-механічних властивостей біологічних плодів. Проаналізовані відомі конструкції машин і механізмів руйнування шкарлупи волоського горіху показали необхідність досліджень фізико-механічних властивостей біологічних плодів (горіху), розробити технічні рекомендації до конструкції механізмів впливу для підвищення якості руйнування оболонки та можливості їх застосування в технологіях масового виробництва. Розроблена методика досліджень, виготовлена лабораторна установка та проведені експерименти. Для встановлення характеристик на міцність, автором сконструйовано та виготовлено пристосування. Яке складається з важільного механізму та деформуючого пристосування. Розміри та вимірювання навантаження проводилося за загальновідомими методиками фізичної механіки. Статистичний аналіз результатів показав необхідність поглиблених наукових досліджень геометричних параметрів конструкції робочих органів машин для руйнування оболонки горіху волоського в механізмах машин для лущення плодів з врахуванням якісних показників виконання робіт та умов їх проведення. За результатами експериментів існує достатньо висока залежність між геометричними розмірами плоду горіху на рівні 0,72, 0,57 та 0,49 відповідно. Вага плодів також залежить від його розмірних характеристик, що є логічним на рівні 0,6–0,75. Зусилля критичного статичного руйнування має слабку кореляційну залежність від розмірних характеристик на рівні 0,3. Та мало залежить від площини його прикладання.

Ключові слова: волошський горіх, горіхокол, механізм, фізико-механічні властивості.

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Introduction

Ukraine has been growing perennial plants for quite a long time. Some of the fruits (nuts) obtained from such plants are widely used in the perfumery, pharmaceutical, oil, confectionery and other industries, as well as in the production of feed and feed additives [1–10]. The need to create equipment for fruit processing is due to the fact that walnut is a valuable nut crop and an indispensable raw material for the confectionery industry.

Some fruits have similar geometric properties. It is known that the more the fruit conforms to the correct geometric shape, the easier it is to mechanically break the shell and separate the core. The known technologies for mass processing of walnut kernels mainly work well with crops that have a spherical or close to spherical external shape.

The technical means to break the shell qualitatively, as exemplified by the walnut, are not perfect and inefficient. In the industrial processing of nuts by separating the shell from the kernel, there is a technological problem of preserving it without damage and destruction. Existing devices for destroying the shell of nuts in one pass destroy 70–80 %, and about 20 % of the peeled kernels are damaged after machine shell destruction [11–17].

The design of machines and their mechanisms is based on the physical, mechanical, and geometric properties of the object of impact. The study of these properties and the methodology of their implementation is an urgent task that is basic for the development of technologies for mechanical destruction of walnut shells, which can be used in both piece and mass production machines.

The purpose of the study

The aim of the work is to develop technical recommendations for the design of impact mechanisms to improve the quality of shell destruction and the possibility of their application in mass production technologies, taking into account the analysis of the results of studies of the physical and mechanical properties of biological fruits (walnuts).

To achieve this goal, the following tasks were formulated and set:

1. To develop a methodology for determining the geometric and physical and mechanical properties of biological fruits (walnut) on the example of walnut.
2. To develop a research methodology and a laboratory setup for determining geometric parameters, shell hardness, and static fracture force.
3. Analyze the research experiments. To give recommendations for the design of impact mechanisms to improve the quality of shell fracture.

Materials and methods

The subject of the study is the identification of develop technical recommendations for the design of impact mechanisms to improve the quality of shell destruction and the possibility of their application in mass production technologies. The methods of mathematical analysis and statistical processing of the empirical data are used.

Results and discussion

The real leader among all types of nuts in terms of popularity and useful properties is the walnut, which grows well in our region and pleases with a generous harvest every year. This year, some people have already harvested walnuts, while others are just now picking them in ***Fig. 1***.

Nuts are not only a delicious snack. They are rich in carbohydrates, fats, proteins, vitamins, iron, potassium, magnesium, phosphorus, zinc, copper, manganese, etc., so they are very useful for the body and have a beneficial effect on various organs and systems: They stimulate brain function, improve memory and concentration, have a positive effect on the heart and cardiovascular system, strengthen the walls of blood vessels, normalize cholesterol levels, prevent diabetes, reduce the risk of bowel cancer, boost immunity, etc [18].

Figure 1. Walnut (*Juglans regia*)
Source: [19].

Walnuts can be stored for up to a year, and their beneficial properties are preserved. The ideal storage temperature is between +10 and -5 degrees. It is best to store them in a wooden box.

Walnut is the most common species in Ukraine. It was first grown on land from Eastern Turkey and Lebanon to Northwest India. They are 65 % fat, and only healthy fats. They are high in omega-3 essential fatty acid [18].

Machines and technology of nut shelling.

A wide variety of mechanisms or machines are used for shelling nuts, but they can all be divided into types, such as automatic, manual, semi-automatic, home-made, and industrial.

The simplest, but least productive, are primitive manual devices for peeling walnut shells in ***Fig. 2***. Despite the simplicity of their design, these devices are inefficient and unsuitable for adjusting their operation to different varieties and physical and mechanical properties of biological fruits.

Figure 2. Hand tools for cracking walnuts
Source: [20].

The principle of operation of such devices is to manually press the handles, which leads to the destruction of the shell of a properly installed nut in a specially designed seat. The compression force and, accordingly, the force exerted on the shell directly depends on the user.

To simplify the operation of the mechanisms, a manual mechanism of improved design is proposed (***Fig. 3***).The walnut fruit is crimped using a lever mechanism in a cone-type press [21].

Figure 3. Improved manual walnut cracker
Source: [20].

This mechanical device has a more advanced design. It does not require force adjustments, as the nut is oriented by itself with the help of corners installed under the cone. Such a mechanism requires the ability to adjust the distance between the corners, as it regulates the deformation of the fruit walls and, as a result, the destruction of the shell.

A more productive machine based on the principle of crimping is the machine proposed in ***Fig. 4***.

Figure 4. Mechanized device for cracking walnut shells (for non-industrial production volumes)
Source: [21].

The advantage of its design is the possibility of automating the process, the presence of a dosing mechanism and an eccentric for applying an appropriate breaking force to the crimping mechanism. The disadvantage of the design is the lack of research on the configuration of the crimping surface.

A more advanced machine, recommended by the authors for industrial volumes of walnut kernel processing, is a walnut hulling machine by Etalon [21] (***Fig. 5***). It is a machine for fast and productive walnut cracking, which is used at large and medium-sized enterprises. It differs from other industrial walnut crackers by the ability to work without calibrating the nut and maximum productivity. This model of walnut cracker uses a cone type of cracking, which allows for a whole kernel yield of up to 80 %.

Figure 5. Nut sheller for industrial use Reference
Source: [21].

Advantages of installing the Standard: high power – a 1.5 kW motor is installed. Time saving – no preliminary calibration of the nut is required. High percentage of whole kernels – up to 80%.

Versatility – perfect for walnuts of any size. High performance – capable of processing up to 200 kg per hour. Easy to operate – 1 person can easily handle the

mechanism. Possibility to adjust the gap between the stabbing plates and the compression force (adjustable for shelling walnuts with different shell thickness and humidity levels).

The principle of operation of the peeling machine. Pour the walnut into the hopper and turn it on. The kernel of the nut is captured by the hooks of the chain conveyor and delivered to the splitting mechanism. The nut falls between the conical plates, falls according to its size, the plates are slightly compressed and the shell cracks, leaving the kernel intact. When the plates are released, the nut falls into a container.

Research methodology.

Proceeding from the fact that the known designs of walnut processing machines require improvement of the configuration of surfaces that are in direct contact with biological fruits (walnut) and their physical and mechanical properties have not yet been studied, it became necessary to develop technical recommendations for the design of impact mechanisms to improve the quality of shell destruction and the possibility of their application in mass production technologies.

The objective of the experimental research is to develop a methodology for determining the geometric and physical and mechanical properties of biological fruits on the example of walnut and to develop a research methodology and laboratory setup for determining geometric parameters, shell hardness, and static fracture force.

For the study, we have chosen the following indicators of fruit properties:

- dimensions in three planes;
- fruit weight;
- hardness of the fruit shell.

To study the characteristics of fruit for strength, we chose the indicator of the force on fruit destruction, which was applied and studied in three directions.

To determine the strength characteristics, the author designed and manufactured a device (***Fig. 6***). It consists of a lever mechanism and a deforming device. The dimensions and load measurements were carried out according to well-known methods of physical mechanics.

Figure 6. Laboratory equipment for determining the strength characteristics of walnut fruit

The results of the measurements were recorded in a table, a fragment of which is presented in ***Table 1***. The studies were conducted in the amount according to the known recommendations for multivariate experiments. The required number of repetitions was determined according to the recommendations of Dospekhov B.A. 90 samples were studied.

Table 1

Fragment of experimental data on determining the strength characteristics of walnut fruits

Number experiment	Width, mm	Thickness, mm	Height, mm	Hardness HRC	Effort destruction	Plane 1-1
1	30.4	30.6	37.2	35.1	8.1	11.38
2	31.7	32.3	36.5	30.4	6	12.56
3	33.7	33.2	39.2	34	6.5	14.03
4	30.7	32.1	35.6	33.4	8.2	14.23
5	33	33.5	37.6	22.8	7	15.41
6	33	33.5	40	20.5	9	13.16
7	33	33.7	36.3	36.6	4	13.76
8	32	33	39.3	36	7.5	14.08
9	31.6	32.8	39	19.8	9.5	13.69
10	32.5	33.3	37	20.3	8	12.41
11	33.7	34	41	30.3	7.5	15.77
12	31.4	32.2	37.2	28.3	7.9	12
13	32.5	33.7	38.5	35.6	8	14.27
14	32.3	32.3	40.5	31.6	7.1	13.75
15	32.8	34.8	42.6	24.9	6.7	15.72

The mathematical processing of experimental data was carried out using the methods of the general theory of statistics and the theory of planning a multivariate experiment. The statistical characteristics of the sample were determined using the Statistica 7 program.

Analyzing Table 2, we conclude that according to the results of the experiments, there is a fairly high dependence between the geometric dimensions of the walnut fruit at the level of 0.72, 0.57 and 0.49, respectively. The weight of the fruit also depends on its dimensional characteristics, which is logical at the level of 0.6–0.75.

Table 2

Correlation matrix between the selected research parameters

Variable	Correlations Marked correlations are significant at p < ,05000 N=90 (Casewise deletion of missing data)						
	width, mm	thickness mm	height, mm	hardness hrc	weight	plane	effort destruction
Width, mm	1,00	0.72	0.49	0.15	0.69	-0.03	-0.27
Thickness mm	0.72	1.00	0.57	0.17	0,74	-0,11	-0.26
Height, mm	0.49	0.57	1.00	0.07	0,58	0.06	-0.15
Hardness HRC	0.15	0.17	0.07	1,00	0.07	-0.07	-0.21
weight	0.69	0.74	0.58	0.07	1.00	-0.04	-0.06
Plane	-0.03	-0.11	0.06	-0.07	-0.04	1.00	-0.13
Effort destruction	-0.27	-0.26	-0.15	-0.21	-0.06	-0,13	1.00

The force of critical static fracture has a weak correlation with the dimensional characteristics at the level of 0.3. And it depends little on the plane of its application.

Analysis of the research results

As a result of processing the experimental data, regression equations were obtained. Where F is the critical fracture force of a fruit with static characteristics, X is the hardness of the nut shell, and Y is the direction of application of the fracture force to the nut (***Fig. 7, 8***).

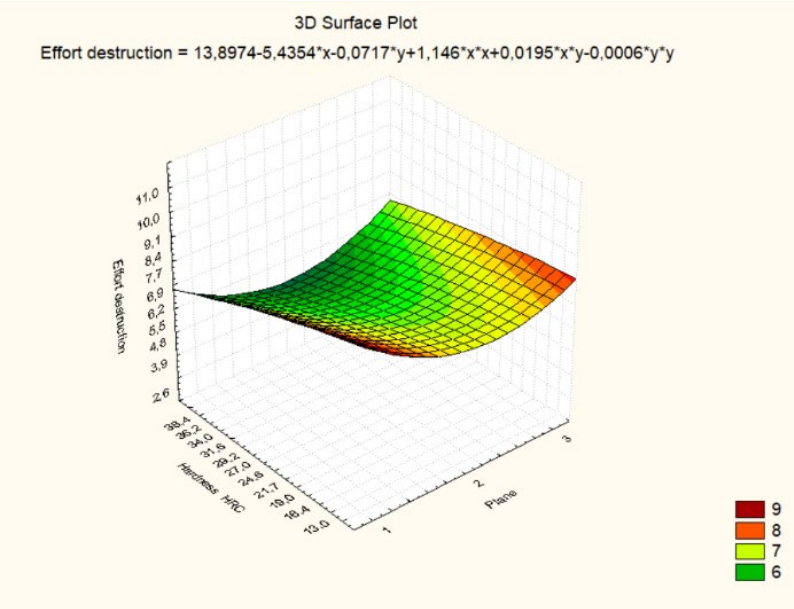

Figure 7. Level surfaces of the statistical dependence of the critical fracture force on the walnut on its hardness and the plane of application

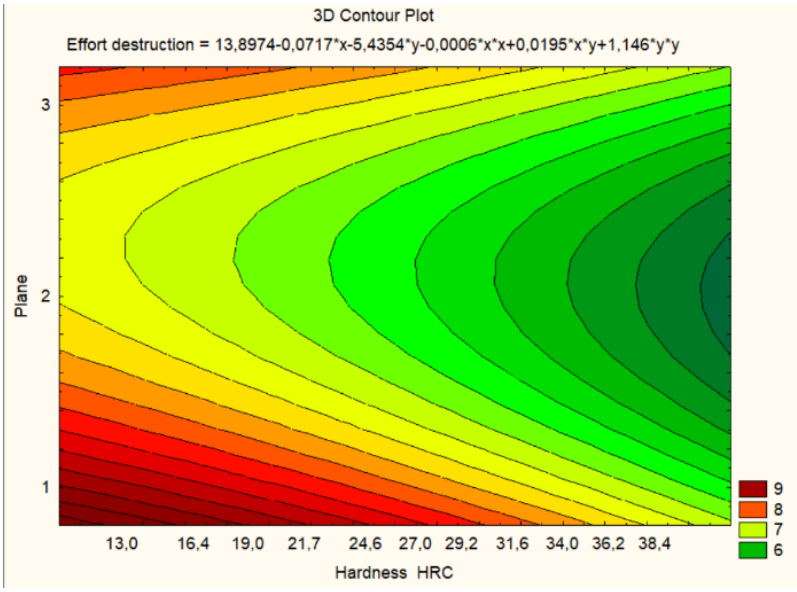

Figure 8: Dependence of the critical fracture force on the hardness of the nut and the plane of application

Analyzing the results obtained, it should be noted that under the conditions of the experiment, a research methodology was proposed for the main physical and mechanical properties. The physical and mechanical differences of walnut fruits can be considered depending on the variety, moisture content, harvesting and storage conditions, etc. According to the statistical analysis, no signs of significant dependence of the selected indicators were found. The obtained statistical regression equations can be used to develop and improve working bodies in machines for destroying nut shells.

Conclusions

The paper presents a generalization and a new solution to the scientific problem, which consisted in conducting and analyzing the results of studies of the physical and mechanical properties of biological fruits (walnuts), developing technical recommendations for the design of impact mechanisms for the quality of shell destruction and the possibility of their application in mass production technologies.

The plan of experimental research, measurements and accuracy of their implementation was developed. Laboratory equipment for determining the strength characteristics of walnut fruits was manufactured.

The results of the statistical analysis showed that under the experimental conditions, the physical and mechanical differences of walnut fruits can be considered depending on the variety, moisture content, harvesting and storage conditions, etc. According to the statistical analysis, no signs of significant dependence of the selected indicators were found. There is a fairly high dependence between the geometric dimensions of the walnut fruit at the level of 0.72, 0.57 and 0.49, respectively. The weight of the fruit also depends

on its dimensional characteristics, which is logical at the level of 0.6–0.75. The force of critical static fracture has a weak correlation with the dimensional characteristics at the level of 0.3 and has little dependence on the plane of its application.

There is a need for in-depth scientific research on the geometric parameters of the design of the working bodies of walnut shelling machines in the mechanisms of fruit peeling machines, taking into account the quality indicators of work performance under certain conditions. The obtained statistical regression equations can be used to develop and improve working bodies in walnut shelling machines.

Conflict of interest

The authors declare no conflict of interest.

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