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Method for determining the energy consumption for dynamic tearing off the peanut gynophores

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Abstract

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One of the main reasons for the losses in mechanized harvesting of peanuts is the insufficient strength of the gynophores that bind each fruit to the stem of the plant.

A method for determining the energy consumption for dynamic tearing off single peanut fruits from gynophore is justified and based on the pendulum principle. The derived dependencies show that the mentioned energy is influenced by the generalized inertia moment of the rotating parts and the angular velocity of the pendulum before and after the tearing off the fruit. An experimental device for determining the mentioned energy consumption has been developed. It provides opportunities to study the influence of factors that determine the dynamic strength of gynophore, which is crucial for fruit loss at mechanized peanut harvesting. The device can be used for breeding and selection of peanut varieties that are suitable for mechanized harvesting.

Keywords: peanut; mechanized harvesting; losses

Introduction

Peanuts are one of the most important crops in the world (Grotta et al., 2008) because they have great economic potential (Bencheva, 2002). Until recently, they were grown by small farmers with high manual labor costs, mainly for harvesting (Bencheva & Georgiev, 1997). The mechanization of peanut harvesting makes this crop more efficient, because reduces the cost of production (Bertonha et al., 2014; Câmara et al., 2007).

The losses of scattering peanut fruits in the soil or on its surface have become a significant problem with the introduction of their mechanized harvesting (Thomas et al., 1983). Studies show such losses from 5 to 35% in the US (Beasley, 1970) and from 3.1 to 47.1% in Brazil (Santos et al., 2013, Cavichioli et al., 2014). Losses from 9.7 to 30.6% were reported after two-phase mechanized harvesting of peanuts from approved varieties Kremena, Tsvetelina and Kalina in Bulgaria. 45% of the losses are caused by the digging the peanut plants and the rest – by the picking up dried plants by the harvester (Stamatov & Ishpekov, 2020). The main reason for these losses is the insufficient strength of the gynophores that bind each fruit to the plant stem (Bencheva et al., 2008; Zerbato et al., 2017). Many authors believe that 70% of bean losses in mechanized picking of peanuts are due to the variety. The other causes of loss are due to the humidity of the fruit, soil type and harvester (Rafael et al., 2018 (Carvalho et al., 2014; Cunha et al., 2014); Jackson et al., 2011). The need for selection and introduction of peanut varieties with increased strength of gynophores, as well as their connection with fruits, is emphasized. So far, this strength has been estimated through the static force for tearing off gynophore from the fruit. But in the digging and picking up plants, the fruits and the gynophores are subjected to dynamic impacts that differ from static, both in manner and in value. Therefore, for an objective evaluation the strength of the gynophore and its relationship with the fruit, it is better to apply dynamic indicators, one of which is the energy to tear off the fruit from the peanut plant (Triffonov et al., 1999).

The purpose is to substantiate a method and an experimental device for determining the energy consumption for dynamic tearing off single peanut fruit from gynophore.

Method

The pendulum principle is applied to achieve the purpose (Ishpekov et al., 1997). The energy consumption for tearing off a single peanut fruit is determined by the measurements of an experimental system. It consists of a pendulum apparatus, tools for stem attachments and an electronic data acquisition system that registers and records the pendulum rotation angle – ϕ (Figure 1). The pendulum apparatus is composed of a base – 1 which allows levelling, pendulum – 4, ballast – 6, trigger – 9, pendulum rod – 14 and stand – 15. The electronic system includes laptop – 10, data acquisition module MC-USB-1208HS-2AO – 11 (www.mccdac.com), incremental encoder – FRP-7K-1024 – 12 (www.zgpu.com/bg) and a clutch – 13.

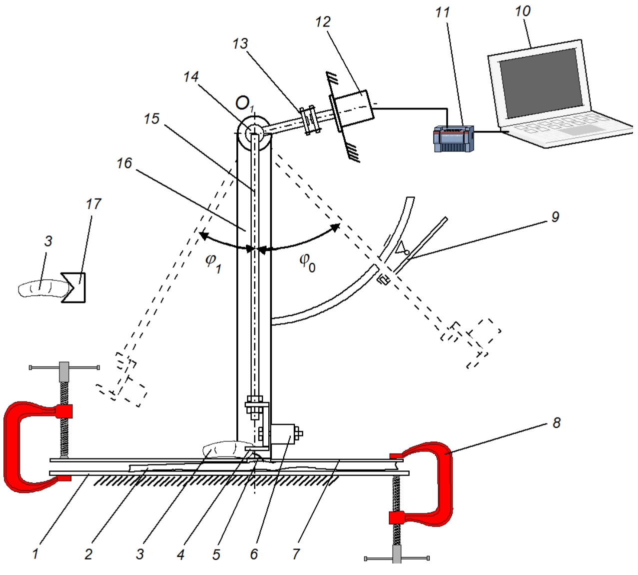

Fig. 1. Scheme of the experimental system
1 **– base,** ***2*** **– peanut stem,** ***3*** **– peanut fruit,** ***4*** **– pendulum,** ***5*** **– gynophore,** ***6*** **– ballast,** ***7*** **– slab,** ***8*** **– clamp,** ***9*** **– trigger,** ***10*** **– laptop,** ***11*** **– data acquisition module MC-USB-1208HS-2AO,** ***12*** **– incremental encoder FRP -7K-2000,** ***13*** **– clutch,** ***14*** **– bear,** ***15*** **– pendulum rod,** ***16*** **– stand,** ***17*** **– the peanut fruit and the pendulum at the moment of impact**

The experiments are carried out after levelling the base 1. From a peanut plant is cut a stem with a length of 0.2 – 0.3 m with attached a fruit through gynophore (Figure 1). The stem 2 is pressed between the base 1 and the plate 7 through two clamps 8, so that the fruit 3 is positioned next to the pendulum in its equilibrium position. The positioning of the fruit is done without bending and breaking the gynophore, which would reduce its tensile strength.

The measurement starts at the equilibrium position of the pendulum – 17 and with the peanut fruit in contact – 3 to the groove – 15 which has been cut off in the pendulum – 4. By the laptop – 10 are started the virtual instrument, the data acquisition module – 11 and the incremental encoder – 12 (point *A* on Figure 2). The pendulum is deviated and locked at the initial angle ϕ_0 by the trigger – 9. In a second, the pendulum is released (point *C*) and lowered to equilibrium position. After tearing and moving the fruit (point *D*), it deviates to an angle of ϕ_1 (point *E*) and after a few oscillations, remains in equilibrium position (point *F*). The pendulum – 4 rotates the clutch – 13 and rotor of the incremental encoder – 12 by the rod – 15. Its signal is read from the data acquisition module – 11 and is visualized on the laptop screen – 10 (Figure 2).

The energy consumption for tearing off the gynophore is determined through the kinetic impulse change theorem in integral form (Pisarev, 1975). It is applied to the moving parts of the experimental system –

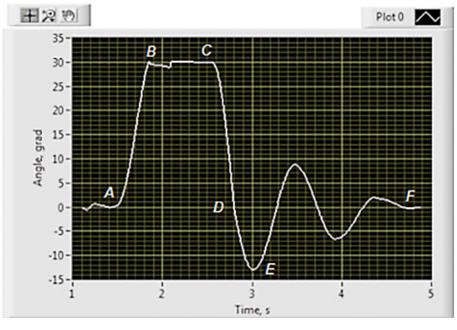

Fig. 2. Signal from the virtual instrument at tearing off a peanut fruit
A **– the pendulum is in the equilibrium position,** ***B*** **– the pendulum is deviated and locked at the 30°,** ***C*** **– the pendulum is unlocked ,** ***D*** **– the pendulum knocks the fruit and tears off the gynophore,** ***E*** **– maximum deviation of pendulum after tearing off the gynophore,** ***F*** **– the pendulum stops in equilibrium position**

$$E_{k1} - E_{k0} = A_{01}, \quad (1)$$

where: E_{k1} is the kinetic energy of the moving parts after the knock of the pendulum to the fruit, *J*;

E_{k0} – the kinetic energy of the moving parts before the knock, *J*;

A_{01} – the work of the pendulum to tear the gynophore and to move the fruit, *J*.

We express the two kinetic energies as a function of the angular velocity of pendulum. The total kinetic energy of moving parts after the knock is

$$E_{k0} = E_k^p + E_k^b + E_k^{cl} + E_k^{en} = \frac{1}{2} J_{RO_1}.\omega_0^2, \quad (2)$$

where: E_k^p is the kinetic energy of the pendulum with the ballast, *J*;

E_k^b – the kinetic energy of the rod, *J*;

E_k^{cl} – the kinetic energy of the clutch, *J*;

E_k^{en} – the kinetic energy of the rotor of incremental encoder, *J*;

J_{RO_1} – the reduced mass moment of inertia of the moving parts relative to the axis of rotation of pendulum – O_1.

ω_0^2 – the pendulum angular velocity before the knock, *rad/s*.

The pendulum rotates without starting speed, so only the rod and the pendulum perform mechanical work, which is –

$$E_{k0} = A_0^b + A_0^p, \quad (3)$$

where: A_0^b is the mechanical work of the rot at falling from angle ϕ_0, *J*

$$A_0^b = \frac{m_b.g.l_{b.}(1 - \cos\varphi_0)}{2} \quad (4)$$

A_0^p – the mechanical work of the pendulum and the ballast at falling from angle ϕ_0, *J*

$$A_0^p = m_p.g.l_p.(1 - \cos\varphi_0) \quad (5)$$

After substitution of (3) in (2) and expressing the angular velocity of the pendulum depending on its work we get

$$\omega_0 = \sqrt{\frac{2\left(A_0^b + A_0^p\right)}{J_{RO_1}}} \quad (6)$$

The kinetic energy of moving parts after the knock E_{k1} is determined similarly. The change in kinetic energy before and after impact determines the energy consumption to tear off the gynophore and to move the fruit.

$$\Delta T_1 = E_{k0} - E_{k1} = \frac{1}{2} J_{RO_1}.(\omega_0^2 - \omega_1^2) \quad (7)$$

To obtain the energy to tear off the fruit from ΔT_1 we subtract the energy for moving it. This energy does not allow easy analytical determination because the way of moving of the fruit after detachment from the gynophore is influenced by many random factors. Most often is observed a flight and then the fruit is dragged onto the slab 7, which are different for each trial. For this reason, the detached fruit is positioned next to the pendulum in its equilibrium position. We restart the virtual instrument, deviate the pendulum at the same angle and release it with respect to receive the energy for movement the fruit ΔT_2 in the same way. The energy consumption for tearing off the fruit is:

$$\Delta T = \Delta T_1 - \Delta T_2 \quad (8)$$

The aforementioned energies allow determination at known the reduced mass moment of inertia of moving parts, the angle of initial deviation of the pendulum ϕ_0 and its deviation ϕ_1 after tearing off the fruit (Figure 1). The two angles are counted against the equilibrium position of the pendulum from the graph of the virtual instrument (Figure 2). The following coefficient is introduced to account the friction energy losses in the bearings of pendulum and incremental encoder –

$$f = \frac{\varphi_0}{\varphi_{01}} \quad (9)$$

where φ_0 and φ_{01} are the angles of inclination and deviation of the pendulum without any external resistance.

This coefficient is experimentally determined for the following values of the angle φ_0 = 15°, 30°, 45° и 60°. The received values change from 0.952 to 0.955 for the developed experimental device. They are applied to calculate the corrected pendulum deviation angle after the knock – φ_1', which values are used for determining the wanted energy consumption.

$$\varphi_1' = f.\,\varphi_1 \quad (10)$$

All calculations are done using a developed spreadsheet in an Excel environment. The developed method and experimental device are applied for determining the energy consumption for tearing off single fruit from the gynophore of the approved peanut varieties Adata, Kalina, Kremena, Tsvetelina and hybrid 11, which were selected at the Institute of Plant Genetic Resources – Sadovo (Georgiev and Bencheva, 2011), (Figure 3).

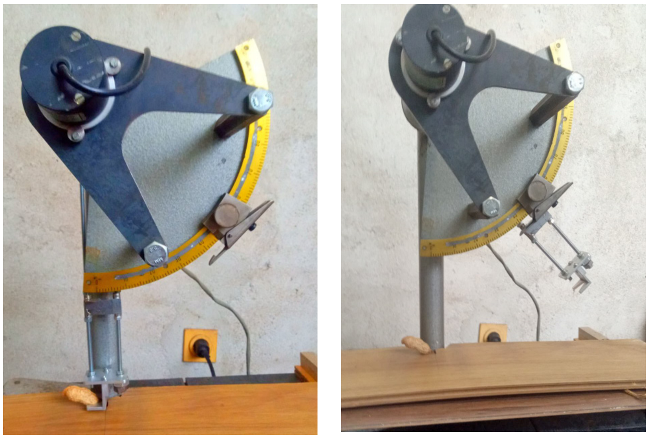

Fig. 3. The experimental device for measuring the energy consumption for tearing off a single fruit from the peanut gynophore

The change of the mentioned energy depending on humidity of peanut fruits, their mass, the days after digging from the soil and the thickness of the gynophore is investigated. The results obtained are presented in Figures 4, 5 and 6.

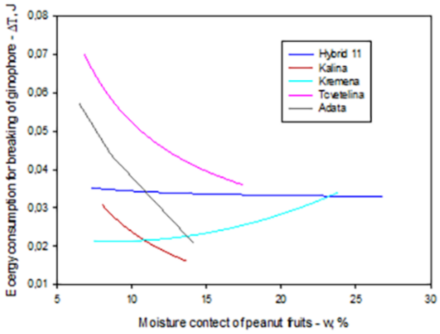

Fig. 4. Energy consumption for tearing off a single peanut fruit ΔT depending on its humidity – *w*

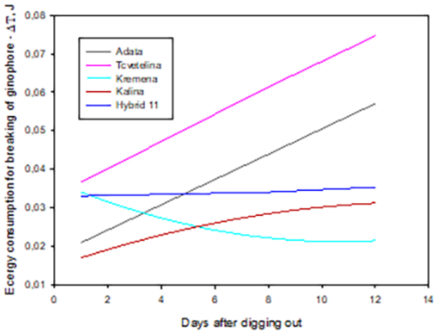

Fig. 5. Energy consumption for tearing off a single peanut fruit ΔT depending on the days after their digging from the soil

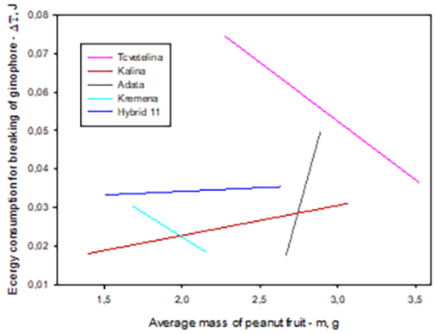

Fig. 6. Energy consumption for tearing off a single peanut fruit ΔT depending on its mass

The principal influence of the studied factors on the said energy can be estimated from the graphs obtained. The moisture of the peanut fruit differently influences the energy for its tearing off from the gynophore for the varieties studied (Figure 4). With increasing humidity it decreases for varieties Adata, Kalina, Kremena, Tsvetelina and for hybrid 11 but increases for Kremena variety. The days after digging fruit from the soil also affect the energy for its tearing off from the gynophore (Figure 5). The way of this influence differs from that of the humidity of fruits, although the opposite is expected. The most resistant to tearing off the fruits during their digging from the soil are varieties Tsvetelina and Kremena. After 12 days of field drying, the plants are picked up by the harvester. Then the most resistant are gynophores of varieties Tsvetelina and Adata. The experimental results show that the mass of fruits does not uniquely and steadily affect the energy for tearing off (Figure 6). There is also no positive correlation between genophore thickness and the energy for fruit tearing off.

Similar divergent results have been obtained about the effect of static effort for tearing off the fruit from gynophore (Thomas et al., 1983). To explain these results, the anatomical structure of the gynophores is studied through their cross section. It turns out that it differs significantly for different varieties. Some cross sections have from 80 to 90 cells and others 100 to 120 cells and form a secondary cell wall that strengthens the gynophore. Moreover, the gynophores of some varieties are dense and others are hollow. Apparently, the strength of the gynophore is a scar of the variety. It is therefore recommended that the strength of gynophores and their anatomical structure be used as criteria in the selection of peanut varieties in order to achieve their mechanized harvesting with reduced losses.

The results obtained provide valuable information on the susceptibility of tested varieties to loss of fruits due to mechanized harvesting. It should be expected when the energy consumption for tearing off the fruit from gynophore is greater than the losses from the mechanized harvesting of the variety are less. It turns out that some varieties are more susceptible to losses in the digging of peanut plants, and others – in their picking up by the harvester.

Contradictory results indicate that the Bulgarian peanut selection, which has been running for 30 years, has not directed to strengthen the gynophore (Georgiev & Bencheva, 2011). The developed method and experimental device make it possible to determine the energy consumption for the dynamic detachment of a single peanut fruit from the gynophore. This energy gives a more accurate and realistic estimate for the susceptibility of peanut to losses from mechanized harvesting than the static force to tear off a single fruit. Of course, further studies are needed to determine the relationship between the energy consumed for tearing off the fruit from the gynophore and the actual losses from mechanized harvesting of peanuts.

Conclusions

An analytical method for determining the energy for dynamic tearing off single peanut fruit from gynophore, which is based on the pendulum principle. Analytical dependencies show that the energy mentioned is influenced by the total moment of inertia of rotating parts and the angular velocity of the pendulum before and after tearing off the fruit.

An experimental device for determining the energy consumption for dynamic tearing off single peanut fruit from gynophore has been developed. It provides an opportunity to study the influence of factors that determine the dynamic strength of the gynophore, which is crucial for fruit loss at mechanized peanut harvesting. The experimental device can be used for breeding and selection of peanut varieties that are suitable for mechanized harvesting.

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