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Investigation of the interactions between tomatoes and handling devices in mechanized processes

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Abstract: Tomatoes are a major vegetable crop worldwide. Production costs for large due to high harvesting costs and difficult mechanization. An increase in labour productivity, the profitability of production, the increase in production and the decrease in cost is possible through the introduction of mechanization of production processes, the most important of which is harvesting [19]. It absorbs over 50% of total costs [5, 10]. Mechanized harvesting reduces labour costs 10 times, and according to Bakulev [1], the profitability of production reaches 200%. Research by the University of California [18] indicates that the price of mechanically harvested tomatoes is $9.84/t, and for hand-harvested tomatoes - $17.19/t. Depending on the qualifications of the workers, mechanization saves from 70 to 440 man-hours per hectare. The mechanization of harvesting also has a biological side [6]. The short period of harvesting allows to control the ripening. Thus, the degree of de-esterification of the pectin content beyond the desired can be avoided. A lot of research has been done to create a robot that picks tomatoes but it is still only in the research field. A practically implemented mechanization of the process is achieved with a tomato harvester that harvests the entire crop at once. Due to the large losses due to damage to the fruit and leakage of juice, this method also needs improvement. In the present study, dependencies have been derived that make it possible to determine the parameters of the handling devices in the tomato harvester in order to obtain a better result from the mechanized harvesting of tomatoes.

1 Introduction

Many studies have been conducted on the problems related to the mechanization of tomato harvesting [2-4, 8, 12, 24, 26], but they are related to the design of a tomato-picking robot, which has not yet found practical application due to slow action and low productivity. The processes of one-time mechanized harvesting of tomatoes with a tomato harvester have not been investigated [14, 25]. When studying the operation of a tomato harvester, it is necessary to know the interactions between the elements involved in the system. In this case, the elements of interaction are the tomato plants consisting of fruits, leaves, stems, branches of the stems, fruit stalks, and other elements that can be combined as a leaf-stem mass. The other element of the interaction is the working body that performs the manipulation of the first element in order to obtain a result. In this case, the process of manipulating tomato plants with the elements of a tomato harvester will be considered, but this type of interaction can be used in similar processes of interactions with transporters, sorting, and other types of manipulators. In this case, tomato plants consisting of fruits and leaf-stem mass enter the entrance of the fruit separation system. In this regard, the aim of the present study **is to determine the parameters of the interactions between tomatoes and handling devices in mechanized processes.**

2 Material and methods

In the study, the methods of the system analysis of the process, schematization of the systems, mathematical formulation, the laws of dynamics, geometry, trigonometry and the theory of probabilities were used.
During the mechanized harvesting of tomatoes with a tomato harvester [15], the plants are cut from the soil, lifted by a conveyor at a certain height, and fed to a fruit-separating conveyor. During this transition, the plant is in flight, with a certain initial speed, and under the action of its own mass, it falls onto the fruit separator from a known height. Two cases are possible here. The first is when the transport chain on which the plant falls moves in the direction of the plant's movement. This is most auspicious. In this case, part of the adverse consequences of the moment are avoided, since the change in the parameters of the plant's movement is the smallest. The second, most unfavorable case is when the fruiting chains move in a direction opposite to the direction of the plant's movement. The damage to the production is the greatest. It is further strengthened by the following fact: So far, the movement of the mass is carried out under the action of continuous forces causing smooth changes in velocities. Now a phenomenon of an entirely different class arises. The velocities of the points of the mechanical system change for a very short time interval with some finite value [20, 21]. Then the interaction between the plants and the fruit

separator proceeds with a shock. For the creation of a theory of this phenomenon, neither of the two extreme cases known in mechanics can be accepted [22]. The impact cannot be considered fully elastic since residual deformation is present in the fruit. The laws of conservation of mechanical energy and momentum, which are in force [17] could not be used for such an impact. It cannot be absolutely inelastic due to the fact that fruits have a certain elasticity. For these reasons, the law of conservation of total energy could be used. This suggests the following approach.

The contact of the tomato fruit with the finger of the fruiting chain is considered (Fig. 1).

The following designations are accepted for the description:

O_1 is the starting point of the impact axis;

$OX_1 -$ axis of impact passing through the centre of gravity of the fruit and the point O_1;

$X_1OY_1 -$ coordinate system associated with the point O_1 and the axe OX_1;

$V_{УП} -$ the velocity of the fruit at the instant before impact, projected along the direction of the assumed axis O_1Y_1;

$V_{ХП} -$ the velocity of the fruit at the instant before impact, projected along the direction of the assumed axis O_1X_1;

$V_B -$ the speed of the chain from the fruit separator and the finger;

$V_{ПВ} -$ the speed of the fruit at the moment of impact;

$q -$ coefficient of elasticity of the tomato fruit;

$S -$ the impact pulse of the fruit under consideration.

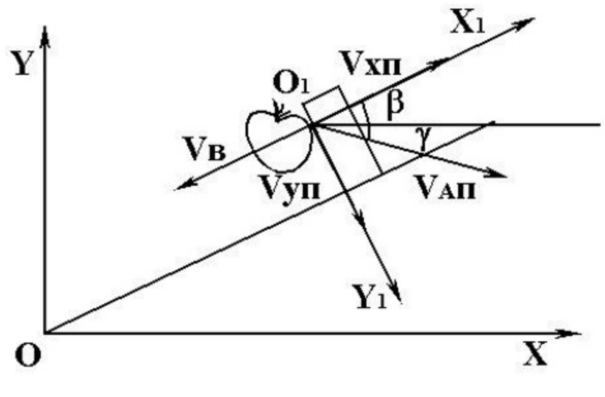

Fig. 1. Contact of the tomato fruit with a pin from the fruit separation chain.

It is assumed that the finger has a flat surface and the impact consists of the meeting of the plane of the surface of the finger, which is non-deformable, and the easily deformable fruit. From the first assumption, i.e., the impact of a body on a flat surface, the position of the axis Ox is determined. It is inclined at an angle β to the horizontal plane. On this axis, the forces of interaction during the impact itself are projected. The velocity of the fruit is deflected relative to the assumed impact axis at an angle $\gamma + \beta$. The determination of its projection on the impact axis is carried out with a trigonometric function from Fig. 1:

$$V_{ХП} = V_{АП} \cos(\beta + \gamma) \quad (1)$$

In this case, the force of the normal load is directed along the direction of the impact axis. Therefore, the projection of the fruit's speed on this axis will change as in the case of a direct impact of two not completely elastic bodies [7]:

$$V_{ПВ} = q(V_B - V_{ХП}) + V_B \quad (2)$$

The impact impulse of the considered fruit will be equal to:

$$S = m(V_{ПВ} - V_{ХП}) = m(1+q)(V_B - V_{ХП}) \quad (3)$$

The impact impulse determined by formula (3) must be smaller than the critical impulse S_{KP}. This is considered to be the one above which destruction of the fruit occurs. It can be considered that the modulus of elasticity up to the critical impulse does not change. The critical impulse is determined by formula (4):

$$S_{KP} = m(1+q)V_{KP} = m(1+q)\sqrt{2gH_{KP}}\ , \quad (4)$$

where

V_{KP} is the rate of fruit fall at which its destruction occurs;

$H_{KP} -$ the allowable fruit drop height at which the velocity reaches V_{KP} for canning tomatoes $H_{KP} = 0.5m.$ [9].

In order to prevent damage to the fruits from the fruit-separating fingers, it is necessary to comply with the condition:

$$S < S_{KP} \quad (5)$$

Expressions (3) and (4) are replaced in condition (5) and after the abbreviations, the result is:

$$V_B - V_{ПУ} < \sqrt{2gH_{KP}} \quad (6)$$

From the inequality (6) it is easy to determine the maximum permissible speed of the fruiting chain:

$$V\max < \sqrt{2gH_{KP}} + V_{ПУ} \quad (7)$$

After substituting the equations (25) from literature (Mortev, 2022) and (1) into the inequality (7), the final expression for finding the maximum permissible speed of the fruiting chain is obtained.

$$V\max < \sqrt{2gH_{KP}} + \cos(\beta+\gamma)\sqrt{V_H^2\cos^2\alpha + \left(-g\frac{L_H\cos\beta}{V_H\cos\alpha} + V_H\sin\alpha\right)^2} \quad (8)$$

Inequality (8) is of particular importance since a large part of product damage depends on its compliance or non-compliance.

Determining the probability of an impact between a fruit and a finger of the fruiting chain.

Once it is known how much it is possible to increase the speed of the transport chain of the fruit separator, it is necessary to justify the observance of this value. Given that the probability of such a blow occurring is negligibly small, it can be accepted to ignore it at the expense of obtaining a better fruit-separating effect. The probability of occurrence of the impact event is established. The geometric definition of probability, some of the theorems in probability theory, the geometric shapes of tomato fruits, and the elements of fruiting fingers will be used. To build the dependence, the notations presented in Fig. 2:

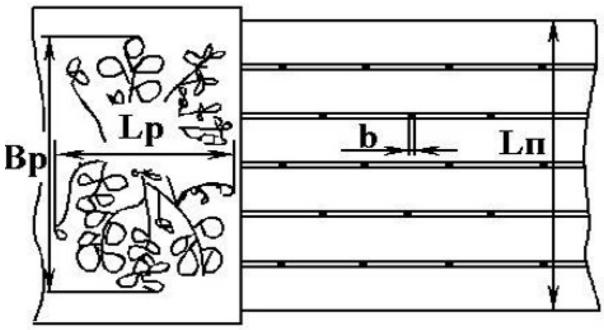

Fig. 2. Schematization of the quantities characterizing the probability of an impact occurring between a fruit and a finger from the fruit separation chain.

$P_У$ is the probability of a fruit-finger impact;

$P_П$ – the probability of finding a fruit in the impact space;

P_B – the probability that there is a finger of the chain in the same space;

B_P – the width of plant falling on the fruit separator;

L_P – the length of the plant measured longitudinally in the direction of movement;

$b_П$ – the width of the fruit-separating finger and at the same time of the chain;

$L_П$ – the width of fruit separator.

Probability $P_У$ is the product of two compatible and independent events. One of them is to find a finger in the space of the impact and the second is to find a fruit in the same space. Mathematically expressed, it looks like this:

$$P_У = P_П P_B = \frac{S_П}{B_M L_M}\frac{b_П}{L_П} \quad (9)$$

where $S_П$ is the area of the tomato plant occupied by fruits [23]:

$$S_П = \frac{\pi d_П^2}{4} n_П, \quad (10)$$

where

$d_П$ is the diameter of the fruit;

$n_П$ – the number of fruits in the plant's cross-section through the horizontal plane.

After substituting formula (10) into (9):

$$P_У = P_П P_B = \frac{\pi d_П^2 n_П b_П}{4 B_M L_M L_П} \quad (11)$$

The desired probability can be determined by this formula, once the design parameters of the inertial fruit separator are known.

3 Results and discussions

The results of the research are derived dependencies for the parameters of movement and the probability of the occurrence of an impact during the manipulation of fruits and vegetables. In this case, the study was conducted for mechanized harvesting of tomatoes with a tomato harvester, but the derived dependencies 8 and 11 can be used for all cases of handling fruits and vegetables with working bodies that move at certain speeds set by the kinematic mode of operation. When the research process implies the occurrence of an impact between the manipulated fruit or vegetable and the parameters of the manipulating working body are known, the derived dependencies can also be used to determine the permissible kinematic modes in order to reduce damages. Inequality 8 make it possible to determine the kinematic mode of operation of a manipulation mechanism and to adjust it so as to achieve a good result with minimal damages. Formula 11 is derived based on the geometric definition of probability and with known parameters of a manipulating mechanism to determine the probability of an impact occurring between the manipulated fruit and the impacting mechanism.

4 Conclusions

1. When handling fruits and vegetables with working organs, the fruits and vegetables always come into contact with moving elements, as a result of which the integrity of the fruits is violated, the juice leaks and the quality of the product decreases.
2. The theoretical study of the impact process makes it possible to influence the movement parameters in order to reduce damage.
3. The derived dependences for the movement parameters and the probability of jamming make it possible to adjust the mechanisms of the handling devices in order to achieve a good result with minimal damage losses.

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References

1. L.S. Bakulev, Perspectives of tomato harvesting mechanization, Potatoes and fruits 1980. 11. 23.
2. M. Benavides, M. Cantón-Garbín, J. A. Sánchez-Molina, and F. Rodríguez, Automatic Tomato and Peduncle Location System Based on Computer Vision for Use in Robotized Harvesting, Appl. Sci. **10**(17), (2020) 5887; https://doi.org/10.3390/app10175887
3. D.M. Bulanon, T. Kataoka, H. Okamoto, S. Hata, *Development of a real-time machine vision system for the apple harvesting robot*, in Proceedings of the SICE Annual Conference, Sapporo, Japan, 4–6 August 2004; Hokkaido Institute of Technology: Sapporo, Japan (2004)
4. R. Ceres, J.L. Pons, A.R. Jimenez, J.M. Martin, L. Calderon, Design and implementation of an aided fruit—Harvesting robot. Ind. Robot 25, 337–346 (1998) https://www.emerald.com/insight/content/doi/10.1108/01439919810232440/full/html?utm_campaign=Emerald_Engineering_PPV_Dec22_RoN
5. F.A. Dallari, S.Di. Ciolo, M. Zoli, The most recent progress of the mechanical harvesting of tomatoes in Italy.
6. Deshpande S. N., at all, Role of Pectic Constituents and Polyvalent lone in Firmness of Caned Tomatoes, Journal of Food Science, **30**(4), pp. 594-600 (1965)
7. Didenko, N.F., V.A. Khvostov and V.P. Medvedev, 1973. Machines for harvesting fruits, Moscow, p. 76 (Ru).
8. Feng, Q., X. Wang, G. Wang, Z. Li, 2015, Design and Test of Tomatoes Harvesting Robot. In Proceedings of the IEEE International Conference on Information and Automation, Lijiang, China, 8–10 August; pp. 949–952. https://ieeexplore.ieee.org/abstract/document/7279423
9. Garanichev, B. V., 1979, Research and creation of means for the mechanization of transport when harvesting tomatoes for industrial processing. Dissertation for awarding the scientific degree "Doctor", Sofia (Bg).
10. Giameta G., 1985, Mechanical harvesting of vegetables, Earth and life, №20, 1985(It)
11. Jon A. Brandt and Ben C. French, 1983, Mechanical Harvesting and the California Tomato Industry: A Simulation Analysis, American Journal of Agricultural Economics, Vol. 65, No. 2 (May, 1983), pp. 265-272 https://www.jstor.org/stable/1240872
12. Li, B., Y. Ling, H. Zhang, S. Zheng, 2016, The Design and Realization of Cherry Tomato Harvesting Robot Based on IOT. iJOE 12, 23–26. https://pdfs.semanticscholar.org/64a3/384edae67504ed491367fd88ef0d66dac8ea.pdf
13. Machado, Tulio de Almeida, Haroldo Carlos Ferandes, Fábio Lucio Santos, Nerílson Terra Santos and Clarice Aparecida Megguer, 1918, Economic and operational analysis of tomato, mechanized harvesting systems for industrial processing, Instituto Federal Goiano - Campus Morrinhos, Goiás State, Brazi https://www.researchgate.net/publication/329745200_Economic_and_operational_analysis_of_tomato_mechanized_harvesting_systems_for_industrial_processing
14. Merkley M. Y., 1979, Shaker Chain Drive Assembly for Tomato Harvester or the like, United States Patent No 4 262 750, Int. Cl. A01D 17/08.
15. Mortev, I., 2005. Mechanized harvesting of tomatoes. Scientific Journal of Agricultural and Forestry Science, 2-3, p. 114. (Bg).
16. Mortev, I., 2022. Investigation of the movement of a tomato plant during the transition between transport devices. Mechanization in agriculture & Conserving of the resources, 68 (1), 32-34. Print ISSN 2603-3704, Online ISSN 2603-3712 https://stumejournals.com/journals/am/2022/1/32
17. Nancheva, N., 1995. Physical effects and phenomena, Ruse (Bg).
18. Parsons Ph. S., Costs of Mechanical Tomato Harvesting Compared to Hand Harvesting, Universiti of California, Agricultural Extension Service.
19. Patron P.I., 1985, Intensive fruit growing in Moldova, Kishinev 1985.
20. Pisarev, A. M., T. N. Paraskov and S. N. Bachvarov, 1975. Course in theoretical mechanics II part dynamics, Sofia (Bg).
21. Pisarev, A., 1985. Mechanical Vibrations, Sofia (Bg).
22. Saveliev, I. V., 1970. Course of General Physics, Mechanics, Oscillations and Waves, Molecular Physics, Moscow (Ru).

23. Simakova, S. A., 1972. About machine harvesting of tomatoes. Tractors and agricultural machines, 9, 30 (Ru).
24. Sarig, Y., 1993, Robotics of Fruit Harvesting: A State-of-the-art Review. J. Agric. Eng. Res. 54, 265–280. https://www.sciencedirect.com/science/article/abs/pii/S0021863483710206
25. Turold W. E., 1979, Fresh Market Tomato Harvester, United States Patent No 4 262 477, Int. Cl. A01D 17/08.
26. Zhao, Y., L. Gong, Y. Huang, C. Liu, 2016, A review of key techniques of vision-based control for harvesting robot. Comput. Electron. Agric. 127, 311–323. https://www.sciencedirect.com/science/article/pii/S0168169916304227