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Experimental study of an agricultural machine for pneumatic oil-bearing rose harvesting

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Abstract

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In the cultivation of the oil-bearing rose, only the harvesting of the flowers in the rose plantations is completely manual. Research on the mechanization of the harvesting operation has been going on for the past few years. Partially improving the working conditions and speeding up the harvesting operation are provided by the developed technical means for transporting the hand-picking flowers pickers and their collected produce in the rows of the plantations with the oil-bearing culture. The attempt to fully mechanize the harvesting operation through the creation of a rose harvester that only picks off the petals was received skeptically by the specialists in the rose-producing branch both from the point of view of functional suitability and due to doubts about the economic inexpediency of the development.

Preservation of the traditional hand-picking method of picking off the rose flower under the ovary, picking off the flowers to be harvested without injuring the adjacent undissolved buds and foliage, limiting to a minimum the contact with the thorns on the rose stems and stinging insects, etc., advantages provides a newly developed agricultural machine for pneumatic harvesting in oil-bearing rose plantations, field test results of which are presented in the paper. Experimentally established during the testing of two of its variants (one-row and two-row) are the advantages of machine picking over traditional manual picking – better working conditions for the pickers, complete harvesting of the rose flowers to be picked for the day, higher productivity. The main factors (the condition of the rose plantation, the amount of blooming rose flowers, the qualification of the rose pickers) on which the efficiency of the pneumatic rose harvesting machine depends are determined. The ability to ensure the productivity of the tractor/implement combination formed on the basis of the two-row variant of the machine, with which, within the specified time range to harvest the production from plantations with an area of 1.2 ha and more, has been proven.

Keywords: oil-bearing rose; pneumatic harvesting; agricultural machine; test; operational parameters

Introduction

The oil-bearing rose has been cultivated for centuries (Zarev, 1996; Gorcheva, 2011; Mahboudi, 2016), but the flowers in rose plantations continues to be harvested by hand. The uneven flowering of rose buds in the bushes, the requirement for a differentiated approach to flowers, not allowing the picking of undissolved buds, overbloomed flowers and their adjacent foliage, proving the economic expediency of the development of technical means for picking rose flowers determine the complexity of the problem with the mechanization of the technological operation.

Until now, there is no published information about the use of agricultural machinery for an oil-bearing rose harvesting in the rose-producing practice. Research on the mechanization of the harvesting operation was started at Institute of Soil Science, Agrotechnologies and Plant Protection (ISSAPP) "Nikola Poushkarov" (Sofia, Bulgaria) more than a decade ago. A farm implement for mechanizing the oil-bearing rose harvesting, which allows the picking of the blooming flowers and the transport of the pickers and the production collected by them in the rows of the rose plantations during rose picking period, were developed and registered in the Patent Office of the Republic of Bulgaria (Mihov et al., 2014). Two variants of the farm implement (single modular and three modular) for manual picking of oil-bearing rose flowers were manufactured. Their strength and functional suitability for working in various operational situations, including connection to different types of tractor hitch systems, different position occupied by the pickers (standing/sitting) on the loading platforms, different number and distribution of the pickers on the loading platforms, presence of support running wheels and others, were experimentally proven. The optimal conditions for their use have been determined for the realization of labor productivity two or more times higher than the traditional non-mechanized manual picking of the rose flowers. A pneumatic picking off system was developed to equip the three modular machine, which provides the possibility of pneumatic picking of the flowers from the rose bushes.

The two variants of the farm implement allow the harvesting operation to be partially mechanized. An attempt to ensure full mechanization of the technological operation is the rose harvester[1] announced in 2019. With the ability declared by its creators to pick off with the help of powerful pulsed air jets only the ready-to-pick rose petals, it caused disapproval among a number of rose growers, because in addition to the petals, essential oil is also contained in the sepals, pistils and stamens of the rose flowers, as well as doubts about the functional suitability of the harvester to pick rose flowers with two or three open petals, as is the practice in rose production (Atanasova & Nedkov, 2004). The economic expediency of the development was also questioned, taking into account the low purchase prices of the oil-bearing flower in recent years.

Research on the development of an agricultural machine for pneumatic picking the oil-bearing rose flowers in plantations of rose farms (hereinafter also called “rose harvesting machine” and abbreviated as “RHM”) was carried out in the period 2019–2021. The idea of agricultural machine is based on a pneumatic-mechanical method for mechanizing the picking of rose flowers, according to which the flower is detached from the rose bush by pneumatic suction and mechanical cutting of the peduncle under the ovary and is carried by air flow to the place of its temporary storage (Bozhkov, 2022). The conceptual model for a technical solution of the RHM was developed, taking into account the parameters of rose bushes, the three most applied technological schemes for the formation of rose plantations (with a row spacing of 2.8, 3.0 and 3.2 m), the requirements for the dimensions of the farm machinery for movement between the rows, the specifics of the harvesting activity in rose plantations, the conditions for safe work of the rose pickers and other factors. It was registered as a utility model in the Patent Office of the Republic of Bulgaria (Bozhkov & Kachanov, 2021).

In accordance with the conceptual model (Figure 1), the rose harvesting machine includes a main frame (2) with a three-point hitch (1) formed in its front part for attachment to agricultural tractor, a vacuum pump (14) positioned behind the three-point hitch and driven mechanically by a tractor power take-of (PTO) or hydro-mechanically by a hydraulic motor through the tractor’s hydraulic system, a common container (13) for the collected rose flowers, a support-running unit (3) with supporting sliders or running wheels attached respectively to the upper and lower sides of the main frame (2), detachable modules for pickers on the machine (4), detachable modules for self-moving pickers (10), means of adjustment and control, auxiliary elements and assemblies. Each of the detachable modules (4) and (10) consists of a rose flower pick-off device (8) with a cutting element (7) located near the edge of its suction hole, and a pneumatic tube (9) with which it is connected to a module tip (12) of the common container (13). The detachable modules for self-moving pickers (10) are located on module holders (11) hinged to the common container (13). In Figure 1 one of the module holders (11) with detachable modules is in the working position and the other in the transport position.

The workplaces of the rose pickers (up to four in number) are positioned on both longitudinal sides of the machine. The workplaces on the machine include a movable tread (5) and a protective railing (6) which are hinged to the main frame (2) and the common container (13) respectively and are capable of horizontal positioning during operation and vertical fixing during transport. The inner space of the common container (13) is equipped with movable stands for replaceable containers for collecting rose flowers. Access to it is through an airtight door located in the back wall of the common container (13).

Based on the conceptual model for a technical solution of a rose harvesting machine, a prototype was made. In laboratory conditions, tests were carried out with it to check the strength of elements and assemblies of the structure, preliminary tests were conducted to verify the functionality of the detachable modules, to determine the optimal operating modes of the PTO and the tractor engine and the settings

[1] The first rose harvester in the world (2020). *Agricultural Machinery, 3*(722), 14. Bulgaria.

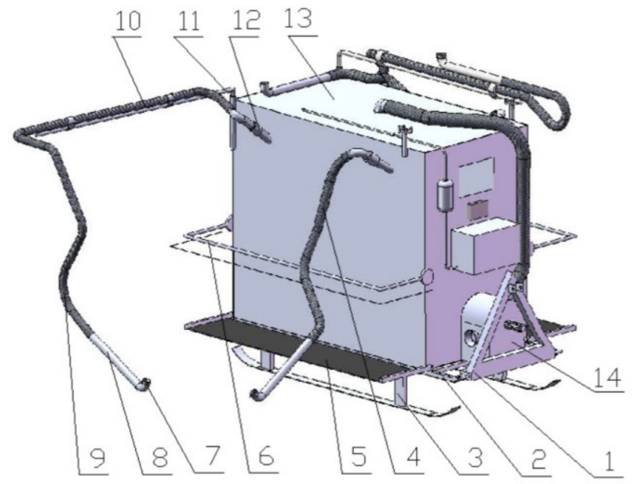

Fig. 1. Conceptual model of an agricultural machine for pneumatic harvesting of oil-bearing rose
1 – implement triangle; *2* – main frame; *3* – support-running unit; *4* – detachable module for picker on the machine; *5* – movable tread; *6* – protective railing; *7* – cutting element; *8* – rose pick-off device; *9* – module pneumatic tube; *10* – detachable module for self-moving picker; *11* – module holder; *12* – module tip; *13* – common container; *14* – vacuum pump

ensuring the detachment of the rose flowers at every attempt to do so without negative consequences for undissolved buds and their surrounding foliage, to specify parameters of auxiliary modules, etc.

The aim of the experimental study is to evaluate the structural strength, functional suitability and efficiency in field conditions of the developed agricultural machine for pneumatic harvesting of the oil-bearing rose flowers.

Materials and Methods

The experimental testing of the rose harvesting machine in field conditions was realized as a part of tractor/implement combination, formed on the basis of a small-sized agricultural tractor Kubota GL220. To implement the tests, two variants of it were assembled:

- one-row variant (RHM-1) – RHM with four workplaces, all located on the machine;
- two-row variant (RHM-2) – RHM with four workplaces, two of which are located on the machine and two are for self-moving rose pickers.

The tests of the variants of the RHM were carried out during the rose-harvesting period of two consecutive years (2020 and 2021) in the land around the town of Krun. The plantation in which the tests were conducted had a rectangular shape with an area of 1.2 ha, and the rows of rose bushes were 186 m long, located in the east-west direction. Rose bushes with *Rosa damascena* Mill. had well-formed crowns, in an actively flowering stage of age development. The tests were carried out in different periods of blooming of the rose flowers in the plantation.

The rose harvesting machine was tested in a series of tests with the tractor/implement combination moving in both directions at the location of the rose bushes in the plantation. In order to ensure the necessary vacuum for the harvesting operation, the tests were conducted with the vacuum pump driven with the “optimal” III gear of the PTO and the tractor engine speed within the range from minimum ($n_{eng}=n_{min}$) to $n_{eng}=1200$ min^{-1} determined in the preliminary tests. The speed of movement of the harvesting tractor/implement combination is chosen according to the specific operating conditions, including the condition of the support surface, the amount of blooming flowers on the rose bushes, the success rate of the pickers in picking the flowers to be harvested. The desired forward speed is achieved both by changing the gears in the tractor gearbox and by operating the tractor engine in partial modes.

The parameters and indicators that are controlled during the field tests are the tractor engine speed, the gear in the tractor gearbox, the length of the rows with rose bushes and the time for their harvesting, the time for performing maneuvers, the amount of the collected flowers. Observation was made on the success rate of the pickers in picking off all the rose flowers to be collected, the condition of the support surface, the stability of the tractor/implement combination movement. Linear dimensions were fixed using a tape measure with a measurement accuracy of 1 mm, time with a stopwatch with an accuracy of 1 s. The engine speed is determined by the tractor tachometer with an accuracy of 1.0%. The amount of collected flowers in the common container was measured with an electronic scale for a maximum load of up to 40 kg with a measurement accuracy of 5 g. The evaluation of the remaining parameters and indicators was carried out on the basis of the opinion of the specialists participating in the tests.

To evaluate the performance indicators of the RHM, the results of tests conducted after establishing the optimal operating modes of the harvesting tractor/implement combination were analyzed. The influence of pickers’ dexterity was evaluated in a separate series of tests. In parallel with the results of the RHM tests, data relating to the collection of the flowers in the plantations by pickers using the traditional manual way of picking the oil-bearing rose was recorded.

The results obtained during the field tests were collected and systematized. Depending on the evaluated parameter or indicator, variation series were constructed, on which the values of the sample mean were calculated (Bijma et al., 2017; Gocheva & Kulina, 2019).

Results and Discussion

The first tests of the rose harvesting machine were carried out with the one-row variant RHM-1 (Figure 2a).

Fig. 2. Experimental testing in feild conditions of the rose harvesting machine
a **– one-row variant RHM-1;**
b **– two-row variant RHM-2**

Pickers without any experience in machine harvesting and with diferent experience in manual rose picking were included in the test. The test period was characterized by a large amount of blooming flowers. The rose flowers harvested during the last tests carried out lasting over 1.5 hours (93 min) were 37.4 kg, which, applied to the area from which they were collected, represented 335 kg/ha. The average speed of the technological operation (taking into account the temporary stops) was 0.24 km/h. The average productivity of the harvesting tractor/implement combination achieved during the tests was 0.072 ha/h. Despite the absolute lack of experience of the rose pickers in operating the rose flower pick-off devices, their release from the need to self-move between the rows, carrying a part of the harvested produce, the possibility to safely pick off each flower, regardless of its location in the bush, the increased technological speed of the harvesting operation and others advantages of the introduction of the agricultural machine were found to be indisputable. It was assumed that the use of the machine would be particularly effective in rose plantations with the extremely difficult to self-move soil surface soaked by the rains common to the rose harvesting period. It was estimated that equipping the agricultural machine with experienced rose pickers would allow harvesting of 0.5 – 0.6 ha in the peak period of rose blooming and from twice as large areas in the off-peak period.

During the first day of tests of the two-row variant RHM-2 (Figure 2b), there were significantly fewer rose flowers subject to picking. The amount of flowers collected in the last tests lasting one hour was 22 kg, which, related to the area from which they were collected, represented 197 kg/ha. The hourly productivity of the harvesting tractor/implement combination, calculated on the basis of the data recorded during the tests, was 0.1116 ha/h at an average travel speed of only 0.186 km/h.

On the next day of the tests, the blooming flowers in the rose plantation were more than the previous day. The same rose pickers participated in the tests. The flowers harvested during tests lasting almost 3 h (172 min) were 52.2 kg, which, relative to the area from which they were collected, represented 234 kg/ha. The average speed of the technological operation calculated on the basis of all tests was 0.26 km/h, and the realized hourly productivity of the harvesting tractor/implement combination was 0.1557 ha/h.

Experimental field tests of the rose harvesting machine in 2021 continued with the two-row variant RHM-2, complete with rose pickers, two of which had not participated in the tests the previous year.

On the first day of the tests, the amount of blooming flowers in the rose plantation was close to the peak for the rose-harvesting period. The flowers collected during tests lasting 72 min were 30.1 kg, which, applied to the area from which they were collected, represented 269 kg/ha. The presence of inexperienced pickers, the loss of "experience" in handling the rose flower pick-off devices, etc. factors, several times caused the speed to be reduced, and the movement of the harvesting tractor/implement combination even stopped. The estimated average speed of the technological operation of 0.155 km/h was rated as particularly low, even though it was comparable to that achieved by pickers picking rose flowers by hand 0.145 km/h. The amount of hand-harvested rose flowers during the day, relative to the harvesting area, was 236.7 kg/ha, which was almost 14% (13.94%) less than machine-harvested. The specified hourly productivity of the harvesting tractor/implement combination was 0.093 ha/h.

Tests on the next day of experimental study of the RHM-2 were carried out with the movement of the harvesting tractor/implement combination at higher speeds. The basis was the smaller amount of blooming flowers in the plantation, as well as the expectations for more efficient work of the pickers participating in the test. The amount of flowers collected during the last test lasting 44 min was 12.8 kg, which, applied to the area from which it was collected, represented 224 kg/ha. The rose pickers' regained ability to operate the rose flower pick-off devices allowed a higher average speed to be achieved – 0.254 km/h. The presence of significant reserves for speeding up the technological operation, incl. and at the expense of increasing the personal responsibility of the pickers, stated the specialists participating in the tests and supervising their conduct. The realized hourly productivity of the harvesting tractor/implement combination was 0.152 ha/h.

In a subsequent test, the movement of the harvesting tractor/implement combination was realized with its gradual acceleration. On sections with a length of 30-35 m, the speed was increased 4 times, and the time of movement at each new speed and the distance traveled were measured and recorded. The success rate of the pickers in collecting all the blooming flowers is monitored. The analysis of the obtained results showed that a full-fledged harvesting process can be realized when the tractor/implement combination is moving at a 1.5 times higher forward speed 0.380 km/h, and this is not a limit in the presence of qualified pickers and established synchrony in their work. The conclusion of the test is that speeding up the movement of the harvesting tractor/implement combination (the possibilities for which are significant) and equipping the agricultural machine with pickers of the same dexterity and professional attitude are the real steps to increase productivity to levels that will allow with one two-row rose harvesting machine daily, within the time range between 5:00 and 10:00 a.m., to collect the produce from plantations with an area of 1.0-1.2 ha and more, which are managed by more than 40% of rose growers in Bulgaria (Bozhkov, 2020).

The test results of the two variants of the rose harvesting machine (RHM-1 and RHM-2) are difficult to compare, due to the different conditions during the days of the experimental study – unequal amount of blooming rose flowers, lack of skill of the pickers to handle the rose flower pick-off devices in the first tests and its increase to a different degree in them in each subsequent test, unestablished agreement between the three factors "amount of blooming flowers – experience of the rose pickers – forward speed of movement of the harvesting tractor/implement combination", etc. The same applies to the comparability of the test results of the same variant (the two-row rose harvesting machine RHM-2) on different days of its testing. The only thing that did not change during the tests was the time for maneuvers at the end of the plantation, which, thanks to the compactness of the rose harvesting machine and the high professionalism of the tractor driver, did not exceed 30 s. Despite everything, it can be assumed that the better working conditions for the rose pickers and the possibility to speed up the movement of the harvesting tractor/implement combination give advantages to the one-row variant of the rose harvesting machine when working in plantations with a heavy support surface for self-movement and with a small amount of blooming flowers. The two-row variant would provide higher performance in operational situations other than those specified.

An indisputable fact found throughout the days of the experiments was that the amount of machine-harvested rose flowers per unit area was greater than that of hand-picking. Visually, this was also evident when comparing the areas of the plantation with a different method of picking – in the rows where the picking was carried out with RHM, there were practically no flowers left in the bushes to be picked. The reason for the difference between the two types of picking (machine and hand) can be pointed to the fact that the pickers who pick the flowers mechanized can safely pick off any flower, even those that manual picking pickers miss either because they can't reach it or by prioritizing their safety in case of contact with the thorns on the rose bushes and with stinging insects, or for other reasons.

Conclusion

An agricultural machine for pneumatic harvesting of flowers in oil-bearing rose plantations, allowing the picking off the flowers to be realized by the rose pickers remotely with rose flower pick-off devices, with which the rose flower is detached from the rose bush by pneumatic suction with mechanical cutting of the peduncle under the ovary and is carried by air flow to the place of its temporary storage, was manufactured and tested. Field tests confirmed the structural strength of the rose harvesting machine established in the laboratory tests and certified its functional suitability for use in rose production practice. The advantages of machine picking over traditional manual picking were established and experimentally proven – better working conditions for the pickers, complete harvesting of the rose flowers to be picked for the day, higher productivity. The main factors on which the efficiency of the rose picking machine in operation depends were determined, namely: the condition of the rose plantation; the amount of rose blooming flowers; the qualification of rose pickers. Finding a balance between them can ensure the productivity of a tractor/implement combination formed on the basis of a two-row machine for pneumatic rose harvesting, with which, within the designated picking hour range, the production of plantations of 1.2 ha and more can be harvested.

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