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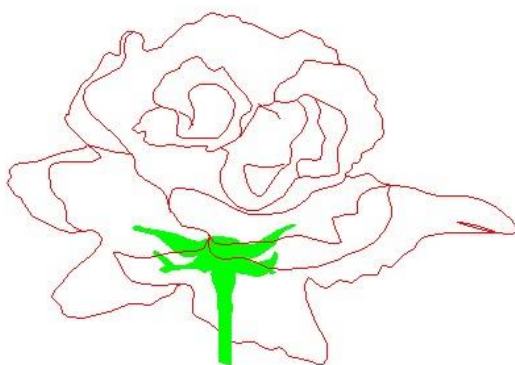
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MECHANISED GROWING AND HARVESTING OF OIL-BEARING ROSE

A B S T R A C T

of the dissertation for acquiring the scientific degree
“DOCTOR OF SCIENCES”
in the field “Technical Sciences”,
professional direction "Mechanical Engineering"
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Production”



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The dissertation written on 518 pages, contains: introduction; list of entered abbreviations and acronyms; list of notations of parameters and indicators; eight sections (including 183 figures and 89 tables) with conclusions - 408 pages; a list of the main contributions based on the obtained research results - 20 items; list of cited literature – 189 titles, of which 128 in Cyrillic (30 in Russian language) and 61 in Latin alphabet; attachments to individual sections; list of publications on the dissertation; evidentiary material for recognition by international and national organizational structures of the achieved results on the topic (including useful models registered in the Patent Office of the Republic of Bulgaria and received awards); short summaries in Bulgarian and Russian languages; content.

Date and place of presentation of the dissertation to the attention of a Scientific Jury on, a.m. at the "Nikola Poushkarov" ISSAPP, Sofia (Bulgaria).

The materials on the procedure are available on the official website of ISSAPP "Nikola Poushkarov" at the address: **<http://issapp-pushkarov.org>**

I. GENERAL CHARACTERISTICS OF THE DISSERTATION

Research relevance

The oil-bearing rose is one of the most significant symbols of national pride, and the essential oil extracted from the flowers of a rose grown in the Republic of Bulgaria has qualities that have given it a leadership position in the world for hundreds of years.

Growing of the oil-bearing rose is characterized by features that are rare or completely absent in other agricultural crops, incl. and oil crops. The analysis of the spectrum of activities carried out in rose plantations showed that an increase in the efficiency of the technological process can be achieved by developing and implementing in rose-growing farms technical means for the mechanization of technological operations related to the care of plants and the picking of rose flowers. Pruning operations and spraying activities related to the pest control and regulation of physiological processes in plants were targeted for mechanization from those carried out in the care of plants in rose plantations. Considering the extremely high importance on the final effect that the timely and complete harvesting of the flowers in the rose plantations has, a significant part of the research has been dedicated to the mechanization of the only completely non-mechanized operation - the picking of the flowers in oil-bearing rose plantations.

Research methods

Scientific research on the creation of technical means for the mechanization of activities in the growing and harvesting of oil-bearing rose included conducting theoretical studies and experimental tests. The development of each technical means was an independent research, which was characterized by its own peculiarities, caused by the specifics of the technological operation being performed. In a general way, each study started with raising a hypothesis and its verification, when it was accepted, it continued with the development of a simulation model and conducting computer modeling to determine the main design parameters and operational indicators of the technical device under development, and ended with the creation of a prototype and its testing of structural strength and functional suitability in laboratory and field conditions. In the process of research implementation, preliminary and parallel theoretical and experimental studies were conducted to obtain information necessary for the realization of the main studies. The methods of mathematical statistics were applied to process the obtained results.

Scientific novelty and significance of the obtained results

A two-phase scheme combining pneumatic suction and mechanical cutting of the peduncle under the ovary is theoretically substantiated and verified experimentally, on the basis of which a method is defined for the mechanized detachment of the oil-bearing rose flowers from the plant.

A pneumo-mechanical method for mechanized picking of oil-bearing roses is defined, 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 moved by air flow to the place of collection.

The parameters of technical solutions for spraying of the rose bushes and treating the soil surface under their crowns, for pest control and regulating the physiological processes in the plants, for mechanizing the picking of rose flowers, for carrying out selective pruning with simultaneous removal of the cut plant mass outside the plantation, and for pruning to form the height and cut the bushes close to the base, directing the cut plant mass into the inter-row space of the oil-bearing rose plant are substantiated.

Practical usefulness of the research results

Agricultural machines (farm implements) for oil-bearing rose production are researched and created within the framework of the dissertation work, allowing the mechanized implementation of a wide range of activities related to the care of plants and the harvesting of rose flowers, namely:

- a machine for implementing care in oil-bearing rose plantations by spraying the rose bushes;
- a machine for implementing care in oil-bearing rose plantations by spraying the soil surface under the crowns of rose bushes;
- a machine for selective pruning in oil-bearing rose plantations;
- a single-modular machine for mechanizing the oil-bearing rose harvesting with manual picking of the flowers;
- a three-modular machine for mechanizing the oil-bearing rose harvesting with manual and pneumatic picking of the flowers;
- a machine for pneumatic harvesting of oil-bearing roses;
- a pruning machine for forming the height and cutting close to the base of the bushes in rose plantations.

The modular assembly principle of the first four of the specified machines allows them to be combined into one "multifunctional machine", with which, under certain conditions, transport activities can also be carried out.

A classification of rose-growing farms in the Republic of Bulgaria is developed according to the "utilized agricultural area" criterion and the optimal types of power means for the mechanized growing of the oil-bearing culture in each of them are determined. On their basis, farm owners can assess the necessary, but also adequate to their capabilities, investments for the purchase of agricultural machinery, and the state executive authorities can specify the distribution of funds to support agricultural farms, according to their capabilities for effective use.

The parameters of a universal hitch-point triangle for farm implement are substantiated. Its use allows the attachment of mounted and semi-mounted agricultural machines to the three-point linkages of medium-power tractors, the connecting elements of which are made in accordance with the national BDS-standard and the international ISO-standard.

Approbation of research results

According to the results of the research obtained within the framework of the dissertation work, 14 scientific reports have been presented at international and national forums, 28 scientific papers have been published, 4 useful models have been registered in the Patent Office of the Republic of Bulgaria, 4 awards have been received from international and national organizational structures. Scientific papers have been published in the journals *"Bulgarian Journal of Agricultural Science"*, *"Journal of Balkan Ecology"*, *"Applied Researches in Technics, Technologies and Education"*, *"Bulgarian Journal of Soil Science"*, *"Bulgarian Journal of Crop Science"*, *"Agricultural Science"*, *"Mechanization of Agriculture"*, *"Agricultural Engineering"* (Bulgaria), *"Agricultural engineering"* (Russia), *"Plant Science Today"* (India), in proceedings of international and national scientific forums and in other periodicals.

The AIM of research in the dissertation:

Increasing the efficiency of oil-bearing rose production and improving the working conditions of the persons employed in it by optimizing the use and development of new methods and technical means for the mechanization of

operations of the technological process in the growing and harvesting of oil-bearing rose.

TASKS to solve in the dissertation:

- Classifying the rose-growing farms in the Republic of Bulgaria with a view to optimal mechanization of activities in the growing of oil-bearing rose.
- Substantiation of the requirements for the agricultural machinery (mobile power means, farm implements, tractor/implement combinations) for the mechanization of the activities of the technological process in the farms growing oil-bearing rose.
- Development of a technical solution of a hitch-point triangle for farm implements, which allows the attachment to tractors with medium power used in Bulgarian and world agriculture.
- Development of a multifunctional machine for the mechanization of operations of the technological process in rose-growing farms.
- Development of an agricultural machine for the mechanization of the picking of the flowers in oil-bearing rose plantations.
- Defining a method for mechanized picking of oil-bearing rose, substantiation of the parameters and composition of a technical means for its application.
- Development of an agricultural machine for pneumatic harvesting of the flowers in oil-bearing rose-growing farms.
- Development of an agricultural machine for carrying out all pruning operations to form the height and cut the bushes close to the base with simultaneous removal of the cut plant mass to the inter-rows of the oil-bearing rose plantations.

II. STRUCTURE AND CONTENT OF THE DISSERTATION

Section 1. Oil-bearing rose - general characteristics, condition and possibilities for mechanized growing

The section contains general information about the oil-bearing rose, the activities carried out and the technical means used in its cultivation, information on the main problems in the rose production practice and the possibilities for solving a number of them.

An analysis of the agricultural land used in modern rose production in the Republic of Bulgaria was carried out on the basis of information which, according to the Ministry of Agriculture, includes 90% of the total area and 80% of the number of rose-growing farms. The unequal degree of mechanization and efficiency of the use of technical means was noted in farms of different sizes. It is concluded that increasing the efficiency of the technological process in the oil-bearing rose growing can be achieved by developing and implementing in practice technical solutions for the mechanization of activities related to plant care and rose flowers harvesting. Suitable for implementation, it is uncomplicated in construction, reliable and easy-to-use farm equipment with the possibility of attachment to all agricultural tractors that meet the requirements for movement in rose plantations. Smaller farms would prefer technical means of the "multifunctional" type, allowing for the performance of a greater number of technological operations.

The general aim of research in the dissertation and the tasks to be solved for its achievement are formulated.

Main findings and conclusions from Section 1

- Bulgarian oil-bearing rose is part of the cultural heritage of the Bulgarian people, an indisputable symbol of the Republic of Bulgaria in the international community. It is characterized by extremely high qualities, being the best in the world according to a number of indicators.
- In modern rose production, a number of activities in the growing of oil-bearing rose - the raw material from which rose oil is produced - are fully mechanized, others are partially so. To this day, the picking of the flowers in the rose plantations continues to be done entirely by hand.
- The analysis of the use of agricultural land in rose production in Bulgaria showed that the sizes of the farms where oil-bearing rose is grown, as well as the potential of their owners for implementing new techniques and technologies, differ. The differentiation of rose-growing farms, according to the necessary technical means for the mechanization of the technological process, would allow their farmers to make a correct assessment of the necessary, but also adequate investments to achieve maximum results.
- Increasing the efficiency of the technological process in the oil-bearing rose growing can be achieved by developing and implementing in rose-growing farms technical solutions for the mechanization of activities related to plant care and rose flowers harvesting. Suitable for implementation in practice are uncomplicated in construction, reliable and easy-to-use farm machines (preferably of the multifunctional type) with the possibility of attachment to all agricultural tractors that meet the requirements for movement in rose plantations.
- Special attention in the mechanization of the operations of the technological process requires the only completely non-mechanized activity in the rose production practice – harvesting the rose flowers in oil-bearing rose plantations, the costs of which in a flowering plantation are about two-thirds of the labor costs, and in recent years even of the purchase price of the harvested produce.
- A mandatory condition when starting the developments on the creation of technical means for the mechanization of activities in the growing and harvesting of oil-bearing rose is to find a balance between necessity, possibility of realization and economic expediency.

Section 2. Methodological grounds of scientific research

Based on the two main directions for the implementation of scientific research with an engineering (technical) orientation in agricultural practice, the concept of "**scientific research in engineering agricultural practice**" is defined as *"ideological, personnel and economically substantiated complex of activities for creating new or improving existing technical means for the mechanization of technological operations in growing and harvesting agricultural produce"*. Methodological foundations are summarized and a general scheme of scientific research in engineering agricultural practice is developed.

Taking into account the variety of technological operations, for the mechanization of which technical means are created, a general methodology of the scientific research on the mechanized growing and harvesting of oil-bearing rose has been developed in the two aspects (theoretical and experimental), which are characteristic of the engineering agricultural practice. The specifics regarding the methods and means used in the realization of the research in the dissertation are indicated in the sections dedicated to each specific object and subject of research. The conducted preliminary and parallel tests, which are used to verify raised hypotheses, collect information and identify restrictive conditions necessary for the implementation of the main theoretical and experimental research, are also methodically formed.

Section 3. Substantiation of the parameters of technical means for farms with oil-bearing rose plantations

After preliminary studies on the parameters of the oil-bearing plant and the rose plantation, the requirements for the technical means of mechanization in the rose production practice (agricultural tractors and equipment) were formulated. To ensure their effective use in the technological process, a classification of rose-growing farms in Bulgaria was developed according to the "utilized agricultural area" criterion. Five types of farms were defined, each of which corresponds to a size of areas with rose plantations (table 3.1).

Table 3.1.

Classification of oil-bearing rose farms in Bulgaria according to the utilized agricultural area and the recommended power potential of the agricultural tractor

Type of rose-growing farm	Size of area with rose plants, ha	Tractor engine power, hp
"micro"	up to 0.5 incl.	8 – 20
„small“	over 0.5 to 2.0 incl.	20 – 30
„medium sized“	over 2.0 to 5.0 incl.	35 – 50
"medium large"	over 5.0 to 10 incl.	65 - 80
„large“	over 10	80 hp for every 15-20 ha

The limits of the ranges were selected, taking into account the sizes of time-proven and currently existing forms of agricultural land use in rose production, as well as the sizes specified in regulatory documents relating to the financial support of agricultural farms under the Common Agricultural Policy of the European Union (CAP) in the past (CAP 2014-2020) and the current (CAP 2021-2027) periods. The provision of the various types of rose-growing farms with energy resources optimal for their size was carried out on the basis of the ratio "size of the farms - power potential of the agricultural tractor" recommended in practice.

To neutralize the problems when attaching machines to agricultural tractors caused by existing differences in the standards of the International Organization for Standardization (ISO) and the Bulgarian Institute for Standardization (BIS) for three-point linkages, a universal hitch-point triangle for farm implement was developed (Fig. 3.1).

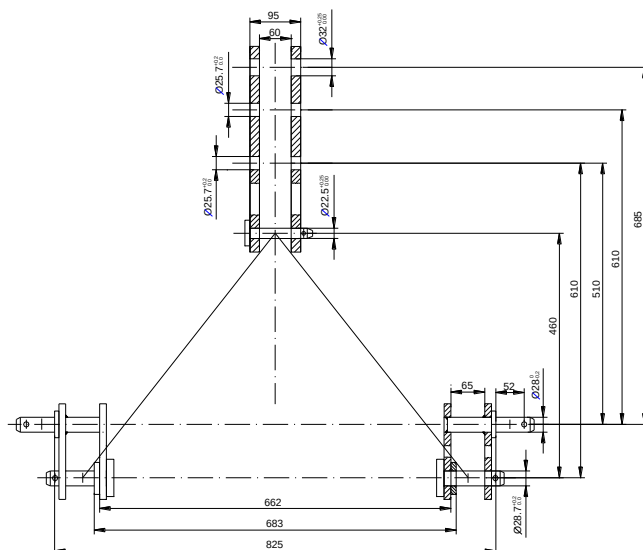


Figure 3.1.
 General view of a
 universal hitch-point
 triangle for farm implement

The main attachment dimensions of the universal hitch-point triangle, which allows mounting of agricultural machines to five types of hitch mechanisms, with which medium-power tractors are equipped, are presented in the Table 3.2.

Table 3.2.

Attachment dimensions of universal hitch-point triangle for connection of agricultural implement to medium-power tractors

Type of tractor three-point linkage	l	h	d ₁	Note
TNU-2 ("Execution A") under BIS	825	510	25.7	
TNU-2 ("Execution B") under BIS	662	460	22.5	
ISO category 2	825	610	25.7	
ISO category 2N	683	610	25.7	Additional washers
ISO category 3N	825	685	25.7	Adapter bushings

Main findings and conclusions of Section 3

- The requirements for the mechanization of the operations of the technological process are satisfied by the technical means which: have dimensions that ensure free movement between the rows of the rose plantations; possess resistance to movement on slopes, characteristic of the terrains on which the rose plantations are grown; have ground clearance allowing them to move on terrain with an uneven profile; guarantee safety for the health of the service staff, safety of the rose plants and other plantations adjacent to them.
- Suitable for use in rose production practice are mobile power means (agricultural tractors) with medium and lower power, which have traction and speed qualities, linkage points for connection with farm implement and load capacity of the hitch mechanism, satisfying the requirements for mechanization of the activities of the technological process in the growing of oil-bearing rose.
- A classification of rose-growing farms in the Republic of Bulgaria is developed according to the "used agricultural area" criterion and the optimal (by engine power) energy means for mechanized growing of the oil-bearing culture in each of them. The classification of farms by types, taking into account the specifics of the sector, allows their farmers to estimate the necessary investments for the purchase of agricultural machinery and eases the executive authorities in allocating funds to support agricultural farms, according to their capabilities for effective use.
- The parameters of a universal hitch-point triangle for farm implement are determined, which allows the attachment of mounted and semi-mounted agricultural machines to the hitch mechanisms of medium-power tractors, regardless of the variant of execution and the standard according to which the connecting elements are made.
- A unified approach has been developed for choosing a mobile power means for work in rose-growing farms of a certain type, regardless of the system for evaluating its aggregatability - by traction force or by the power realized through the main power take-off shaft.

Section 4. Development of a multifunctional agricultural machine for rose production

The formula for successful implementation of "multifunctional" type machines in practice is "simple construction - quick configuration - reliable operation - easy maintenance - acceptable price". An important element in the preparation of the concept of

a multifunctional machine is the determination of the technological operations for mechanization. The analysis of the activities and technical means of mechanization in the rose production practice showed that the greatest labor resources require the weed control in the rows (requires several times manual hoeing), the selective pruning and the harvesting of oil-bearing rose flowers.

The scientific research aimed to create a multifunctional agricultural machine for the realization of technological operations through spraying, selective pruning, picking rose flowers, transport activities in rose-growing farms. The development had an analytical-experimental character and included conducting theoretical and experimental research.

Theoretical research on the development of a multifunctional agricultural machine for rose production

A concept project of a multifunctional agricultural machine for the mechanization of technological process activities in small and medium-sized rose-growing farms (hereinafter referred to as "*multifunctional machine for rose production*" and abbreviated as "*MMR*") has been developed, including technical solutions for the implementation of technological operations by spraying, selective pruning, rose flowers picking, transport activities. The machine is built on a modular principle. A basic element in its construction is the base module, which, depending on the technological operation performed, is equipped with executive and auxiliary modules. MMR is performed in a mounted and semi-mounted version.

The base module (Fig. 4.1) of the MMR includes a carrier frame (1) and a loading platform (3).

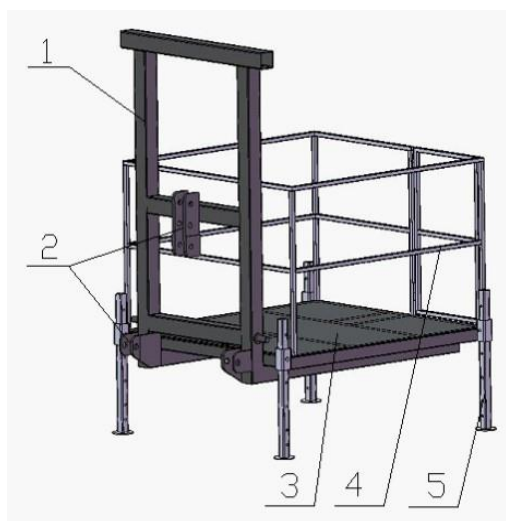


Figure 4.1.
Concept project of the base module
of the multifunctional machine for
rose production:

1 – carrier frame; 2 – hitch-point
triangle; 3 – loading platform; 4 –
protective parapet; 5 – support.

The carrier frame (1) has a hitch-point triangle (2) formed in its front part for attaching to an agricultural tractor. The loading platform (3) has a protective parapet (4) installed along its perimeter. At the rear of the loading platform is attached a central flange for connecting a running wheel (for the semi-mounted version of the multifunctional machine). Height-adjustable supports (5) are located at its four ends. The carrier frame (1) consists of two L-shaped frames connected to each other by three cross booms. The uppermost of the cross booms is joined to the L-shaped frames by means of fastening assemblies (not shown in the figure).

Concept projects for the technical solution of the variants of the multifunctional machine

The concept project of the *variants of MMR for implementing technological operations by spraying* envisages their use for introducing preparations to control of pests

(weeds, diseases and enemies) and to stimulate plant growth, for sprinkling in order to increase air humidity in dry periods, for watering young plants. The variants are completed with the base module being equipped with "boom-type" spraying systems with vertically located booms, allowing the working solution to be sprayed according to the simplest scheme, namely "with mechanical spraying and inertial transfer of the drops". The concept project includes three versions of the spraying system for treatment of the rose bushes (with line booms, L-shaped booms and П-shaped booms) and one version of the spraying system for treating the soil surface under the crowns of the bushes.

The concept project of the *MMR variant for mechanizing the picking of the rose flowers* envisages placing the pickers and containers for collecting rose flowers on the MMR loading platform. The variant is completed by setting up two workplaces for pickers on the loading platform of the base module for the simultaneous service of one half of two adjacent rows of rose bushes. Each workplace includes a seat and a stand for a removable container for the collected produce, located behind the seat of the other workplace. The safety of the pickers on the loading platform during operation is ensured by the protective parapet. Lighting fixtures, powered by the electrical equipment of the agricultural tractor, illuminate in the hours before sunrise the areas of the rows of the oil-bearing plantation serviced by the rose pickers. A light and sound signaling system serves for communication between the pickers and the tractor driver during work.

The concept project of the *MMR variant for pneumatic selective pruning* envisages the implementation of selective pruning with simultaneous removal of the plant material removed from the bushes. The variant is formed by equipping the base module with two pruning modules, each of which consists of a pneumatic shear with an extension and a flexible air duct, a pneumatic distributor, elements for connecting to the tractor's pneumatic system, etc. Side panels are fitted to the protective parapet to prevent plant material collected in the loading platform from falling out. Pneumatic selective pruning is carried out by self-propelled operators who, with the help of pruning modules, cut the rose stems to be removed from two adjacent rows and collect them on the loading platform.

The idea of *using MMR for the implementation of transport activity* envisages the formation of a tractor/implement combination only with the base module and an agricultural tractor. For the transport of bulk and small-size loads, the loading platform is equipped with side panels.

Possibility of connecting the MMR to tractor linkage, the load capacity of which is lower than its operational mass, allows the semi-mounted version of the machine. It is realized by attaching to the flange in the rear part of the loading platform of the base module by means of a console structure a running wheel. The wheel support of the running wheel allows its free rotation around its axis, as well as adjustment of the positioning height of the base module in relation to the supporting surface.

Determining the parameters of the base module of the multifunctional machine

The parameters of the MMR base module are defined in two stages:

- I stage - determination of constructional dimensions of the base module;
- II stage - determination of the materials for making the base module.

The basis for determining the dimensions of the base module of the MMR was the technological operation "picking rose flowers". The constructional dimensions of the base module were chosen according to the morphological features of the oil-bearing plant, the applied schemes for the formation of the rose plantation and the requirements for ergonomic and safe work of the rose pickers located on the loading platform. The research of the constructive solution for determining the materials for making the base module was realized with the mounted version of the MMR through computer simulation modeling. For this purpose, on the basis of the developed concept project for a multifunctional machine

and with the help of the *Solid Works* software product, a physical functional-geometric simulation 3-D model of its base module was created (Fig. 4.2).

In the process of the computer research, variants of the construction of the base module were modeled using different profiles for its main elements. The materials for the production were determined by applying on the simulation model forces external to the structure, the places and the nature of application of which are in accordance with the technological operation performed by MMR. Two types of load distribution on the loading surface of the base module were adopted: evenly distributed over the entire loading platform and localized in certain areas of the loading platform (ie unevenly distributed). The simulation model with the applied forces from the action of the operating mass of the reservoir with the working solution and the elements of the system for its spraying on the rose plants is presented in Fig. 4.2.a, and with the applied forces from the action of the mass of the pickers and the production collected by them - in Fig. 4.2.b.

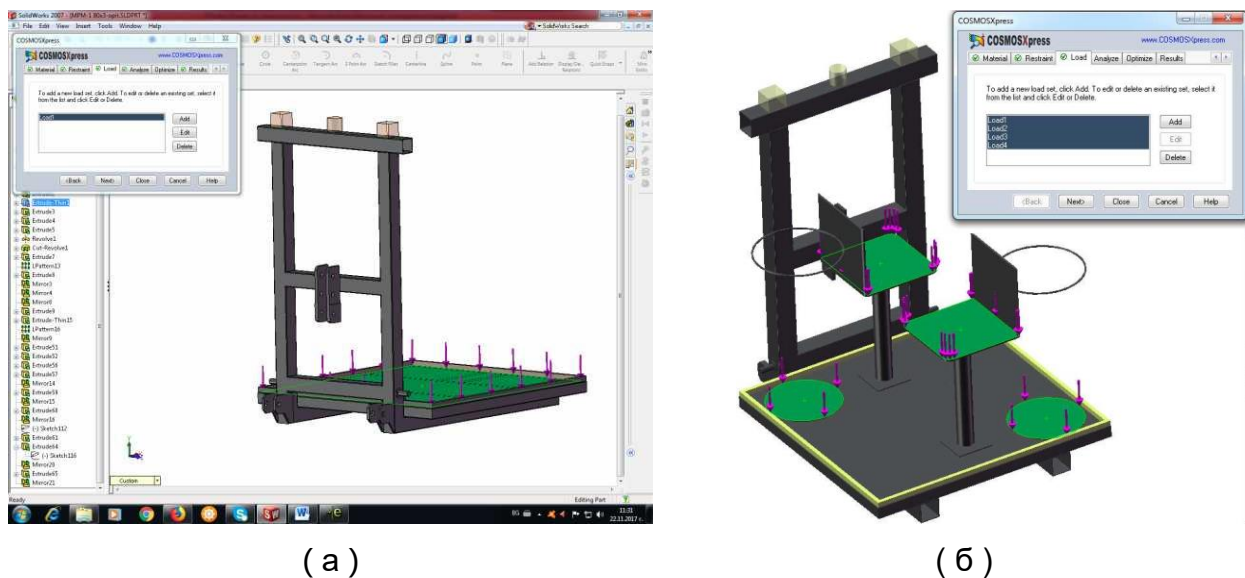


Figure 4.2. Simulation model of the base module with external forces applied to the construction in different variants of MMR assembly

- a – load evenly distributed on the loading platform;
- b - load localized in certain areas of the loading platform.

Situations where the multifunctional machine is attached to four types of tractor linkages, all standardized by current national and international standards, have been investigated. The influence of the type of profiles on the construction mass of the machine, the stresses in the construction and the places where their limit values occur was observed (Fig. 4.3). A comprehensive assessment of the structural strength of the MMR base module was performed using the indicator "Factor of Safety (FOS)" calculated by the *Solid Works* program. The values for FOS were also calculated when using steel profiles with different strength qualities.

Constructions were modeled, the carrier frame of the base module, which is made of hollow square profiles with dimensions 100x100, 80x80 and 60x60, with a wall thickness of 3, 4, 5, or 6 mm. The optimal profile for the production of the base module is sought in the ratio "allowable Factor of Safety - minimum construction mass". The hollow square profile with dimensions 80x80x4 turned out to have the best performance indicators for the carrier frame of the base module. With approximately the same value of FOS and a slightly larger construction mass (about 10%) would be MMR with a carrier frame from a profile with dimensions 80x80x5 or 100x100x4.

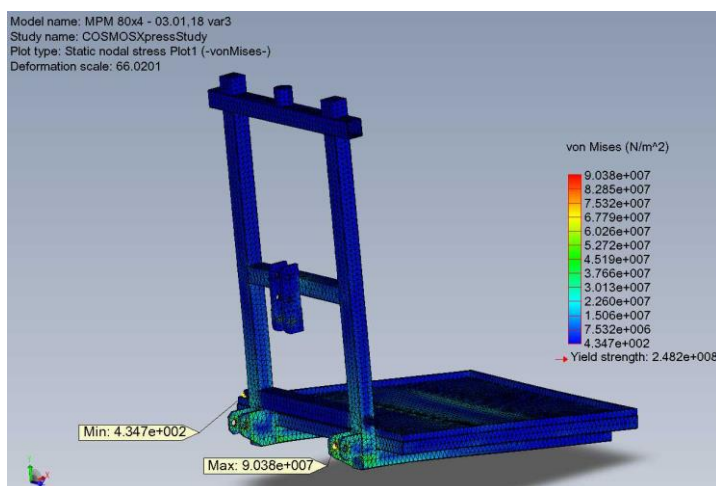


Figure 4.3.
Simulation model of the base
module with the emerging
stresses in its construction
during MMR operation

In order to evaluate the influence of the operating factors on the strength of the base module construction, situations typical of the use of the technique in agricultural practice were modeled. In order to neutralize problems identified during the theoretical research, technical solutions have been developed, ensuring structural strength to guarantee the trouble-free use of the multifunctional machine in rose production practice. Simulation modeling was conducted with the modified structures under the same test conditions.

In the implementation of the theoretical studies on the creation of the *variant of MMR for the treatment of the oil-bearing plant and the variant of the MMR for the treatment of the soil surface under the crown of the oil-bearing plant by spraying*, a unified approach was applied, including the experimental proof of the raised hypothesis, the development of graph-analytical models of spraying schemes, derivation of mathematical dependencies giving the relationship between the determined parameters, creation of an application program with which different variants of the arrangement of the spraying elements in relation to the support surface and the rose bush are modeled. Calculations were carried out for the three most widely applied in agricultural practice technological schemes for the formation of oil-bearing rose plantations, respectively with a width between the rows of 2.8 m, 3.0 m and 3.2 m. On the basis of the obtained results, boom spraying devices were formed for the assembly of the MMR variants.

The theoretical studies on the creation of the *MMR variant for treating the soil surface under the crown of the oil-bearing plant by spraying* were realized after experimentally proving a raised hypothesis regarding the possibility of using boom-type devices for spraying the area around and between the bases of the rose bushes. Using the software program *AutoCad*, graph-analytical models of two treatment schemes for the area under the crown of the rosebush were developed: the full width of the soil surface - "full row" (Fig. 4.4.a) and half of the width of the soil surface - "half row" (Fig. 4.4.b). With their help, mathematical formulas were derived, based on which an application program was created with the software product *Excel*. With the application program, various variants of positioning of the spraying element were modeled in relation to the treated area of the soil surface (h) and the rose bush (X). The results obtained for the spray angle (α) and the nozzle position angle with respect to the horizontal (γ) are graphically presented using the software product "STATISTICA". The results of the theoretical research can also be used by the regression mathematical models derived on their basis (Table 4.1).

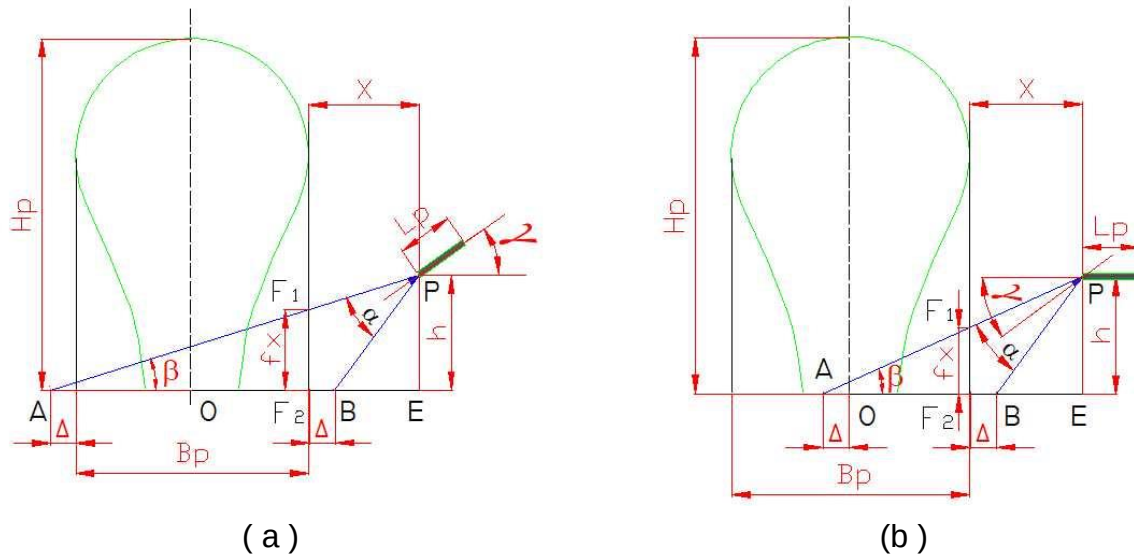


Figure 4.4. Graph-analytical models for determining the position of the spreader for treating the soil surface under the crown of the oil-bearing rose bush

a - spraying the full width of the undercrown area of the soil surface;

b - spraying half of the width of the undercrown area of the soil surface.

Table 4.1.

Mathematical formulas for determining the spray angle and the angle of the nozzle inclination to the horizontal in respect of the occupied position

Sprayed area	Calculated parameter	Mathematical formulas	Coefficient of determination, R^2
The full width of the soil surface under bush crown	Spray angle	$\alpha_1 = 107,7793 - 0,3779.X + 0,0343.h + 0,0003.X^2 + 0,0003.X.h - 0,0001.h^2$	0.934
	Angle of the spreader inclination to the horizontal	$\gamma_1 = 54,2789 - 0,1929.X + 0,068.h + 0,0001.X^2 + 0,0001.X.h - 5,4583E - 5.h^2$	0.974
Half of the width of the soil surface under bush crown	Spray angle	$\alpha_{1/2} = 107,9102 - 0,3785.X + 0,0018.h + 0,0003.X^2 + 0,0003.X.h - 9,7083E - 5.h^2$	0.913
	Angle of the spreader inclination to the horizontal	$\gamma_{1/2} = 56,4957 - 0,2169.X + 0,1052.h + 0,0002.X^2 + 4,8741E - 5.X.h - 4,9375E - 5.h^2$	0.987

On the basis of the results obtained during the theoretical research, a composition of a boom spraying system was developed for treating the area under the crowns of the rose bushes. In Fig. 4.5 is a schematic 3-D image of the spraying system mounted on the base module of the MMR. Increasing the pressure of the working fluid in the system is provided by a pump driven by the PTO or by a hydraulic motor from the tractor's hydraulic system (not shown in the figure).

schemes when assembling the spraying system is to position the first spreader at a height of 200-400 mm from the support surface. Its positioning above 400 to 600 mm is permissible in plantations with high-shaped crowns of the bushes.

Taking into account the condition of the drop coating on the rose bush along the entire height of its outside and the requirement for the overlapping of the spray flows of adjacent spreaders inside the bush, by graphical modeling the positions of the spreaders on the sprayer boom are corrected so that the lower end of the jet of the lowest spreader is directed not along the boundary of the zone from the soil surface under the crown (see Fig. 4.6.a), but along the outline of the base on the bush (see fig. 4.6.b). Situations were modeled to assess the possibility of reducing the number of spreaders on the bars.

The analysis of the results showed that, in theory, the L-boom spraying system gives greater possibilities for precision spraying of the oil-bearing rose bush. There are opportunities to reduce the number of spreaders without compromising bush drop coating requirements. A disadvantage of the L-boom spraying system is its larger dimensions, which the tractor driver must take into account when performing maneuvers in the rose plantations and when transporting the agricultural implement on public roads. The results obtained for L-boom spraying system can also be used to assemble the spraying system with Π -shaped booms, allowing the formation of tractor/implement combination for simultaneous spraying of two rows of rose bushes.

On the basis of the results obtained during the theoretical research, a composition of a boom spraying system for complete spraying of the rose bushes was developed. In fig. 4.7 is a schematic 3-D image of the spraying system with L-shaped booms mounted on the MMR base module. Increasing the pressure of the working fluid in the spraying system is provided with a pump (not shown in Figure 4) driven by the PTO (power take-of) or hydraulic system of the tractor. The variant of the spraying system with L-shaped booms differs from that shown in fig. 4.7 by the absence of a horizontal boom (1).

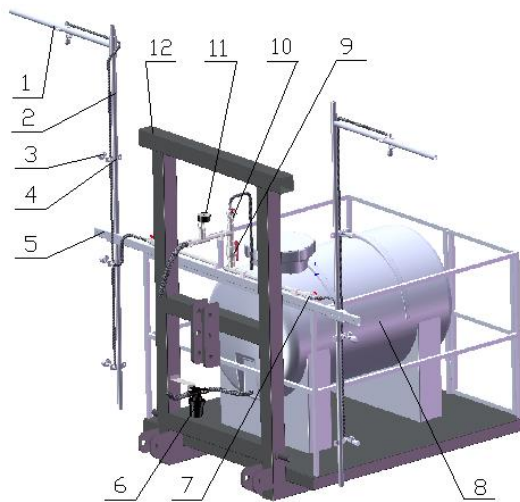


Figure 4.7.
Concept project of the MMR variant for the treatment of the oil-bearing plant by spraying with L-shaped booms

1- horizontal boom; 2 - vertical boom; 3 - spreader; 4 - attachment unit; 5 - horizontal bar; 6 filter element; 7 - section shut-off tap; 8 - tank; 9 - main shut-off tap; 10 - regulating tap; 11 - pressure gauge; 12 - base module.

The theoretical research on the creation of the *MMR variant for pneumatic selective pruning* was realized after an experimental verification of a raised hypothesis, proving the possibility of using the potentials of the pneumatic system of an agricultural tractor in the implementation of selective pruning in rose plantations. It included conducting analytical-experimental studies to substantiate design parameters and performance indicators of a technical means (pruning module) for remote cutting of the stems to be removed from the

oil-bearing bush. A schematic 3-D image of the MMR variant for pneumatic selective pruning in oil-bearing rose plantations is shown in Fig. 4.8

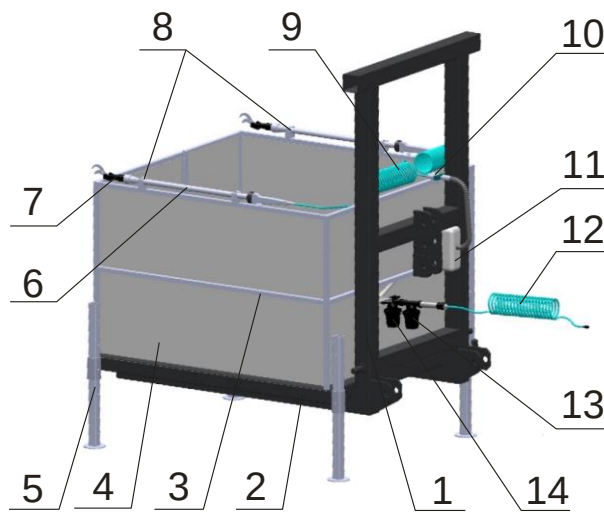


Figure 4.8.
Concept project of the MMR variant
for pneumatic selective pruning in
oil-bearing rose plantations

1 - basic module; 2 – loading
platform; 3 – protective parapet; 4
– side panel; 5 - support; 6 –
extension; 7 - pneumatic scissor;
8 - pruning module; 9 - pruning
module's air duct; 10 - pneumatic
distributor; 11 - pressure regulator,
12 - main air duct; 13 - filter
precipitator; 14 – lubricator.

Pneumatic pruning is carried out with two pruning modules (8), each of which consists of a pneumatic scissor (7) with an extension (6) for remote pruning and a flexible air duct (9) with a "quick-connect" type tip. Their simultaneous operation is ensured by a pneumatic distributor (10). The maximum working pressure is limited by a pressure regulator (11). The scheme also includes a precipitator filter (filter with water separator) (13) and an oiler (14), with which the compressed air entering through the flexible air duct (12) from the tractor pneumatic system is prepared in the form necessary for the normal operation of the pneumatic scissors.

Theoretical research on the creation of the *variant of the MMR for mechanizing the picking of the flowers from the oil-bearing rose plantations* included determining the parameters of the rose picker's work place and designing the variant itself. A schematic 3-D image of the MMR variant developed based on the results obtained is presented in Fig. 4.9.

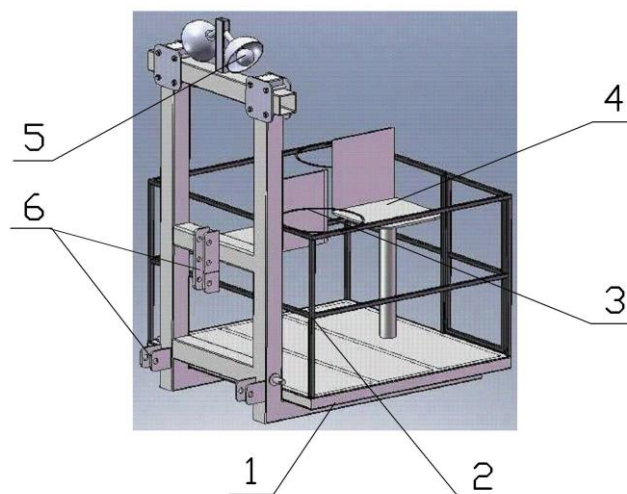


Figure 4.9.
Concept project of the MMR
variant for picking oil-bearing
rose flowers

1 – loading platform; 2 –
protective parapet; 3 – stand
for the replaceable container;
4 – seat; 5 – luminaries; 6 –
hitch-point triangle.

Experimental research of a multifunctional machine for rose production

For the experimental research of the multifunctional machine for rose production based on the base module, test prototypes of four of the five variants of the machine were assembled, as follows: for pest control and other care in rose plantations by spraying – 2 variants; for pneumatic selective pruning; for the mechanization of the picking of rose flowers. The conclusion regarding the admissibility of forming a variant for transport activities is based on the results of the test of the specified four variants.

The prototypes were tested for structural strength and functional suitability. Tests carried out in three stages (in laboratory, in close to real and in field conditions) proved the structural strength of all variants of MMR. The tests for functional suitability were carried out during the rose picking periods of 2015 and 2019 in the experimental production complex of the Institute of Roses, Essential and Medical Cultures (IREMC) in the town of Kazanlak. The bushes in the plantations had optimal parameters for an active flowering plant, namely: height - 1.6 m; width 1.0 - 1.2 m. The rows in the plantations were 120 m long with a width of 3.0 m between them. The prototypes were tested in the composition of machine/tractor combinations formed on the basis of agricultural tractors of medium power. The evaluation of the functional suitability of each of the variants of the MMR was formed on the basis of the results of the measurements, the opinions of the immediate executors of the technological operation and the specialists controlling the conduct of the experiments.

Tests to evaluate the functional suitability of the *MMR variant for spraying the soil surface under the crowns of rose bushes* (Fig. 4.10) were realized for the most part in rows with increased weediness. The analysis of the test results showed that regardless of the spraying scheme ("half row" or "full row"), positioning the spreader within 30-40 cm above the support surface fully satisfies the coverage requirements of the treated area. The working fluid did not fall on the leaf mass of the bush located more than 50 cm from the support surface, which is a basic condition for effective weed control.



Figure 4.10.
Visual control of the operation of the spraying system for treating the soil surface under the crowns of the oil-bearing rose bushes

It was determined that with a low density of weeds, spraying with the boom spraying system is possible according to the "full row" scheme with a pressure in the range of 0.12 - 0.2 MPa. In areas with heavy weeding, the required density of the drop coating on the weed vegetation is provided by spraying according to the "half-row" scheme and pressure values between 0.2 - 0.3 MPa.

The analysis of the results of the final tests for assessing the functional suitability of the farm implement showed that at a forward speed of tractor/implement combination 4-5 km/h with the boom spraying system can be provided consumption rates of 300 to 400 l/ha. The opinion of the IREMC experts supervising the field tests was that the MMR variant can also be successfully used for root nutrition of plants with liquid fertilizers, watering of young plantations, etc.

stems with a diameter determined to be nominal for the pneumatic scissors - 25 mm. Pruning of thinner stems was possible at pressure values below the specified range. The operation of the air scissors did not cause a pressure drop that would require waiting for the compressed air volume and pressure in the pneumatic system to recover. A conclusion was formulated that the optimal length of the extension for the pneumatic scissors would be between 80-100 cm.



Figure 4.12.
Testing the MMR
variant for pneumatic
selective pruning in
rose plantations

In the functional suitability test of the *MMR variant for mechanized rose picking* (Fig. 4.13), the parameters and indicators controlled during the tests were the passability of the tractor/implement combination in the interrows of the oil-bearing rose plantation, the accessibility of each of the pickers to the area of the row of rose bushes that he has to serve, the convenience of working on the machine (including the optimal placement on the loading platform of the seat, the stand with the replaceable container and the buttons for notifying the tractor driver, the shape and dimensions of the protective parapet, etc.), the stability of the picker on the loading platform when the tractor/implement combination is moving, the success of the pickers in performing their functions at different speeds of the movement, the condition of the support surface, the stages of development and the condition of the rose bush, etc.

The high professional experience of the rose pickers who participated in the tests ensured the necessary synchronization between them for the efficient operation of the harvesting tractor/implement combination. The movement of the tractor/implement combination in the rows was stable, regardless of the position taken by the pickers (standing/sitting) during picking. Fluctuations that would interfere with the collection of the rose flowers were not detected by either the pickers or the persons supervising the execution of the technological operation.

The results of the tests showed that the effect of the mechanization of picking was the highest if the rows are well maintained, the crown of the plants is symmetrically developed, the bushes are 1.5 - 1.6 m high, and the plantations are in the period of active flowering (ie after the 4-5th year of planting or rejuvenating plants). In the specified conditions, full control over the area served by the pickers, convenience and safety at work, passability and stability of the picking tractor/implement combination during movement ensured the positioning of the MMR above the support surface within the limits of 300 - 350 mm. The work of pickers in a sitting position was episodic, but nevertheless it was greatly relieved by the elimination of the need to move "back and forth" in the rows, to carry collected produce on themselves, to overcome other inconveniences accompanying

the collection of rose flowers. It was completely possible to work with two hands, which significantly speeds up the harvesting process.



(a)



(b)

Figure 4.13. Field tests of the MMR variant for the mechanization of oil-bearing rose flowers picking

a – in rows with *Rosa Damascena Mill*; b - in rows with *Rosa Alba*

It has been found that the skillful variation with the speed of movement of the harvesting tractor/implement combination (especially in plantations with uneven development of rose plants and flowering) is the decisive factor in achieving optimal performance for the specific conditions. According to the results of the conducted tests with measurement of the time for their realization, the conclusion was made that a forward speed in the interval 400-600 m/h provides the possibility of harvesting in the permissible time range for picking all the blossomed flowers in plantations with an area of up to 1 ha, such as manage more than a third of the rose producers in Bulgaria. It has been estimated that the productivity of mechanized picking is 3 to 5 times higher than that achieved by traditional manual picking of rose flower.

Observations conducted during the field tests of the MMR variants proved the possibility of *using the MMR for the realization of transport activities*. A tractor/implement combination, formed by the basic module and an agricultural tractor, allowed to conduct the intra-farm transport and the transport of agricultural loads at close distances. Depending on the load capacity of the tractor hitch mechanism, the type of MMR is chosen - mounted or semi-mounted. For the transport of bulk and small-sized loads, the loading platform requires to be equipped with side panels.

Main results, conclusions and recommendations of Section 4

- Developed on the basis of the modular principle of assembling the technique is a concept project of a multifunctional machine for the mechanization of activities in the growing and harvesting of oil-bearing rose. The parameters and materials for making the base module, the executive and auxiliary modules are theoretically substantiated, and the MMR variants are completed (all with the possibility of mounted or semi-mounted execution) for the realization of technological operations by spraying, selective pruning, picking rose flowers, transport activities.
- Determined by computer modelling with the help of developed application programs are the type, number and parameters for positioning the spreaders on the booms of

the spraying system of the MMR variant for treating the soil surface under the crowns of the bushes and of the MMR variant for treating rose bushes in oil-bearing rose plantations with inter-row widths of 2.8 m, 3.0 m and 3.2 m. Regression mathematical formulas were derived for precise determination of the spray angle and the inclination of a spreader for applying herbicides, according to the technological scheme of planting, the condition of the rose plantation, the spraying scheme, etc. factors, in order to prevent the working liquid from falling on the foliage of the oil-bearing plant.

- For the variant of the MMR for pneumatic selective pruning, providing the possibility of remotely cutting the rose stems to be removed and collecting them on the loading platform for subsequent export outside the borders of the rose plantation, it is estimated that the pneumatic systems of the agricultural tractors operated in the rose production practice are able to supply two pneumatic scissors with compressed air for continuous selective pruning in oil-bearing rose plantations.
- The structural strength and functional suitability of all variants of the multifunctional machine for rose production have been proved during three stages of experimental research:

- Tests in field conditions of the *MMR variant for treating the soil surface under the crowns of rose bushes by spraying* showed that in both spraying schemes ("half row" and "full row") the placement of the spreader within the limits of 30-40 cm above the support surface satisfies the coverage requirements of the treated area of the soil surface. It was established that, with a low density of weeds, spraying with the boom spraying system in rose plantations was possible according to the "full row" scheme with a pressure in the range of 0.12 - 0.2 MPa. In plantations with heavy weediness, the necessary density of the drop coating on the weed vegetation is provided by spraying according to the "half-row" scheme and pressure values between 0.2 - 0.3 MPa. Movement of the tractor/implement combination for weed control with a forward speed of 4-5 km/h allows herbicides to be applied with the boom spraying system in the accepted norms of 300-400 l/ha.

- Field tests of the *MMR variant for spraying rose bushes* showed that, regardless of the type of booms (line booms or L-shaped booms), the spraying system provides a droplet coverage on the foliage of the rose bushes, which is sufficient to carry out effective fight against diseases and enemies. It was established that when the tractor/implement combination is moving at a speed of 4-6 km/h, a consumption rate in the range of 400-600 l/ha is achievable, satisfying the requirements for the volume of the working solution for the implementation of the main activities by spraying in oil-bearing rose plantations. Consumption rates around and above 1000 l/ha are achievable at forward speeds up to 2.5 km/h.

- Field tests of the *MMR variant for pneumatic selective pruning* proved that it is possible to prune rose stems using the tractor's pneumatic system, with the pressure and volume of air available in the air reservoir being sufficient and allowing the pruning operation to be carried out without interruption. It was established that with the developed pruning module, the cutting of stems with diameters close to the nominal for pneumatic scissor - 25 mm, is realized at a compressed air pressure in the pneumatic system of 0.5 - 0.7 MPa. Pruning in young oil-bearing rose plantations can be carried out with a lower air pressure, the value of which can be adjusted using an additional pressure regulator installed before the pneumatic distributor. The optimal extension length for the pneumatic scissors was determined - between 80-100 cm.

- Tests in field conditions of the *variant of MMR for the mechanization of the picking of rose flowers* showed that the optimal conditions for its operation are the

clean and aligned interrows, formed with a symmetrically developed crowns rose plantations with a height of the bushes 1.5 - 1.6 m in stage of active flowering. Complete collection of the daily production in the time range allowed for harvesting, incl. in the peak flowering period of the oil-bearing rose, can be carried out from areas up to about 1 ha, from which it follows that the mechanization (albeit partially) of the harvesting operation provides 3 - 5 times higher productivity compared to the traditional manual picking of rose flowers.

- With its compactness and high maneuverability, the MMR is a suitable solution for rose-growing farms whose production areas are irregular in shape and small in size. The flexibility in positioning the machine in relation to the support surface allows it to be used in oil-bearing rose plantations at different stages of age development of the rose plants. An additional advantage of MMR is the possibility of transporting agricultural loads (including bulk) at close distances.

Section 5. Development of a three-modular agricultural machine for mechanizing the picking of the flowers in oil-bearing rose plantations

The analysis of the results obtained during the experimental research of the variant of the MMR for mechanization of the picking of the rose flowers revealed reserves for the development of the construction. The scientific research aimed to create a three-modular agricultural machine, with which to multiply the effect of the mechanization (albeit partially) of the only technological operation in the rose production practice, carried out completely manually. The development had an analytical-experimental character and included the conduct of theoretical and experimental research.

Theoretical research for the development of a three-modular machine for mechanizing the picking of the flowers in oil-bearing rose plantations

Taking into account the applied technological schemes for the formation of oil-bearing rose plantations, on the basis of the variant of the MMR for mechanization of the rose flowers picking, a concept project of the three-modular agricultural machine was developed to facilitate the picking of the blossomed rose flowers and to transport the pickers and their harvested produce in the rose plantations during rose picking period. The three-modular machine for mechanizing the picking of the flowers in oil-bearing rose plantations (Fig. 5.1), hereinafter referred to as the *"three-modular rose picking machine"* and abbreviated as *"RM-3"*, includes a carrier frame (12), in the front part of which is a shaped hitch-point triangle (13) for mounting the machine to an agricultural tractor. Operating modules (8) are attached to the carrier frame (12), each of which is located between two adjacent rows of rose bushes (1). Structurally, the operating modules (8) are identical to the one presented in fig. 4.1 with the difference that the carrier part of the side modules instead of two includes one L-shaped frame and they are without hitch-point triangle. The operating modules (8) are connected to the carrier frame (12) by means of fastening units (14), allowing their positioning according to the width between the rows of rose bushes (1) and their disconnection if necessary. Support wheels (10) are attached to the lower end of the L-shaped frames (2) of the side modules by means of console structures (9).

For use in rose production, the RM-3 is attached to an agricultural tractor. The tractor/implement combination, complete with pickers who have taken their work places, moves in the rose plantations at a forward speed that allows the collection of all the produce to be harvested. When the replaceable containers (6) for rose flowers are full, they are replaced with empty ones.

On the basis of the concept project, a physical functional-geometric simulation 3-D model of the construction of the three-modular rose picking machine was developed with the help of the *"Solid Works"* software product.

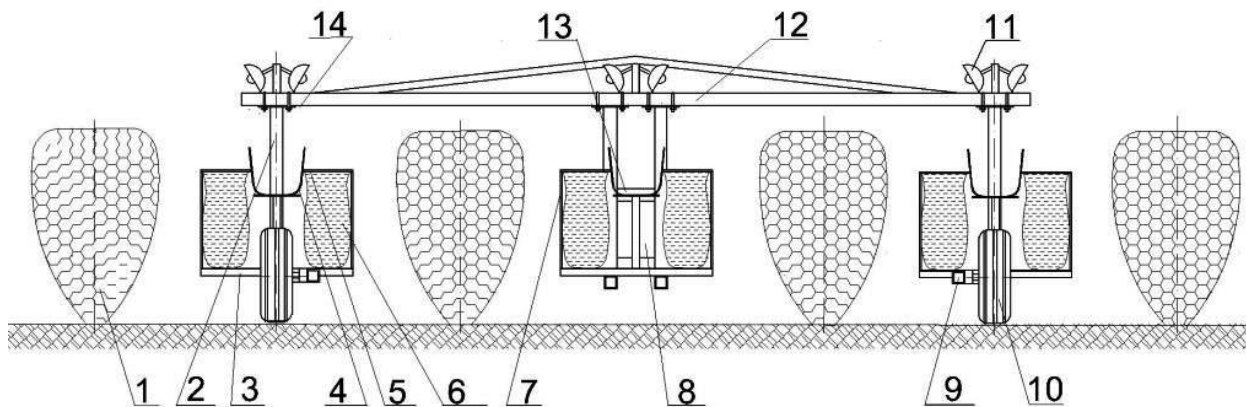


Figure 5.1. Concept project of a three-modular machine for mechanizing the picking of the flowers in oil-bearing rose plantations (back view)

1 – row of rose bushes; 2 – L-shaped frame; 3 – loading platform; 4 – picker's seat; 5 – stand for the removable container; 6 – removable container for the harvested rose flowers; 7 – protective parapet; 8 – operating module; 9 – console structure; 10 – running wheel; 11 – luminaries; 12 – carrier frame; 13 – hitch-point triangle; 14 – fastening unit.

The dimensions of the elements of the RM-3 structure and the materials for their manufacture were determined, applying the forces external to the structure on the simulation model, such as the tractive force of the agricultural tractor, the forces from the action of the mass of the pickers and the production collected by them, the support reactions in the running wheels and the reactions in the connection points to the tractor linkage. Operational situations were modeled, in which the three-modular rose picking machine is connected to the agricultural tractor according to different schemes, the position occupied by the pickers on the loading platform is different (standing/sitting), the number of pickers on the loading platforms is different. The design variant, in which the RM-3 is without running wheels, was investigated. The influence of the type of profiles on the following parameters and indicators was observed: the construction mass of the machine; the stresses in the construction and the locations of their maximum values ($\sigma_{\max}$); the deformations in the construction, including the maximum value and the place of occurrence of deviation of its element from its initial position (ie "no load"); the location of the center of mass. A comprehensive assessment of the structural strength of the RM-3 was performed using the indicator "factor of safety" calculated by the *Solid Works* program. Values for the FOS of the construction were calculated using steel profiles with different strength qualities for its manufacture. The obtained values are compared with those accepted in engineering practice, which for RM-3 type constructions vary in the range $\text{FOS} = 2.4 \dots 4$.

Constructions were modeled, the elements of the carrier part of which are made of profiles with different external dimensions (100x100, 80x80 and 60x60) and wall thicknesses of 3, 4, 5 and 6 mm. The analysis of the results of the simulation modeling of situations characteristic of the production practice allowed to identify the variants (Table 5.1) for making the elements of the carrier part of the RM-3 (carrier frame, L-shaped frames, console structures for the running wheels), ensuring strength of the construction and safe operation of the machine in the conditions of rose production.

The results of the computer modeling of the RM-3 variant without running wheels rejected the possibility of safe use of the machine when it is equipped with rose pickers,

but confirmed the possibility of safe maneuvering without rose pickers in the areas surrounding oil-bearing rose plantations, as well as for its transport over short distances.

Table 5.1

Results of RM-3 simulation modeling to determine the profiles for the fabrication of the elements of the carrier part of the construction

Parameter / Indicator	Thickness of the profile with external dimensions 100x100			
	Main beam of the carrier frame – 5mm; L-shaped frame - 5mm; Console structures - 5 mm	Carrier frame - 5mm; L-shaped frame - 4mm; Console structures - 5 mm	Carrier frame - 5 mm; L-shaped frame - 4mm; Console structures - 4 mm	Carrier frame - 4 mm; L-shaped frame - 4 mm; Console structures - 5 mm
Construction mass, kg	755.4	722.2	718.1	703.2
Factor of Safety (FOS) at the yield strength of the material: - $\sigma_s = 248.17$ MPa - $\sigma_s = 235$ MPa	3.610 3.418	3.555 3.367	2.732 2.587	3.313 3.138
Location of maximum stress in the construction (σ_{max})	Console structures of the running wheels			
Maximum deviation of an element of the construction from the "no load" position, mm place of occurrence:	3.08	3.10	3.27	3.30
	outer front end of side loading platforms			

The requirements for the agricultural tractor for the formation of the tractor/implement combination with the three-modular rose picking machine substantiated - a tractor of medium power (nominal power of the engine in the range of 75 - 85 hp) with a linkage of type TNU-2 according to BDS15648-83 or of category cat 2 according to ISO 730:2009 and a transmission providing super slow forward speeds.

To minimize the time for maneuvers, a movement scheme of the three-modular tractor/implement combination for picking roses was developed, which would allow it to maneuver at the end of the rose plantation in a strip commensurate with the overall width of the RM-3, with a turning radius no greater of 3.8 m, which is also provided by older models of agricultural tractors.

Experimental research of a three-modular machine for mechanizing the picking of the flowers in oil-bearing rose plantations

A test prototype of the three-modular rose picking machine was made at Nikola Poushkarov Institute of Soil Science, Agrotechnologies and Plant Protection. It was tested for structural strength in three stages - in laboratory conditions during the process of its manufacture, in close to real conditions after its assembly and in field conditions in oil rose plantations. On the basis of the observed and registered results, measures were taken in a timely manner to strengthen the problematic units and elements of the construction.

The testing of RM-3 for functional suitability was carried out during the rose-harvesting period of 2016 at the experimental and production complex of IREMC in

Kazanlak in plantations with *Rosa damascena* with a row spacing of 3.0 m. On the basis of the Fendt 209F agricultural tractor, a harvesting tractor/implement combination was formed (Fig. 5.2). By shifting the side modules of the three-modular machine 100 mm inwards towards the middle one, situations were simulated where two pickers were at distances from the rose bushes corresponding to tractor/implement combination movement in plantations with three different row spacings (3.2 m; 3.0 m; 2.8 m). Tests conducted with the specified RM-3 configuration in rows with well-maintained rose bushes proved the functional suitability of the machine for working in plantations built according to the three most common technological schemes.



Figure 5.2.
Operational testing of the three-modular rose picking machine

The field tests of the three-modular rose picking machine made it possible to establish important technological facts for its effective operation. A feature of the experiments on the functional suitability of the RM-3 was that the workplaces on its three modules were entrusted to pickers with different experience in picking oil-bearing roses. At a forward speed of harvesting tractor/implement combination between 300 - 350 m/h (0.3 – 0.35 km/h), the blooming flowers were almost completely collected from the rose bushes by all pickers. The movement of the tractor/implement combination with speeds in the range of 600 - 650 m/h (0.6 – 0.65 km/h) was characterized by more remaining nonpicked flowers on the bushes, but mainly in the areas where the pickers with lower qualifications worked.

The effectiveness of the RM-3 was evaluated on the basis of information obtained during the conduct of tests for functional suitability. Tests with a fixed running time were analyzed, in which the rose pickers succeeded in picking all or with small omissions the flowers to be picked. It is calculated with the obtained data that the productivity of the three-row harvesting tractor/implement combination varies between 0.25 - 0.33 ha/h, which for the time up to 10 o'clock, when the working day during rose harvesting must end, allows the collection of the flowers in rose plantations with areas from 1.25 to almost 1.7 hectares. Based on the formulae accepted in the recent past for ensuring the harvesting process "0.1 hectares - 1 rose picker", it can be calculated that at the same time six pickers (as many as are on the machine) that move between the rows and pick off the rose flowers in the traditional way, would collect the flowers from 0.6 ha. Comparing the data obtained during the calculations, it can be seen that along with the improved working conditions of the rose pickers, the use of RM-3 allows an increase in labor productivity from 2 to almost 3 times. It can be assumed that the effect of the mechanization of the technological operation with the three-modular machine is more significant, taking into account the fact that with the modern stricter requirements for the time period for collecting

the oil-bearing rose to finish the picking on time, the ratio between the areas and pickers is "0.2 hectares - 3 pickers", and in the peak and close to them periods it is even "0.1 hectares - 2 pickers".

The analysis of the reasons for the omissions in the collection of flowers when the harvesting tractor/implement combination moves at a speed of 600-650 m/h gives reason to assume that in off-peak rose picking periods, if the RM-3 is equipped with qualified rose pickers, movement at a higher speed can be realized, allowing the collection of blooming flowers from twice the area.

Main results, conclusions and recommendations of Section 5

- A concept project was developed for a technical solution of a three-modular agricultural machine, which would allow picking off the blossomed rose flowers and transporting the pickers and their collected produce in the rows of the rose plantations during the rose-harvesting period.
- A physical functional-geometric simulation 3-D model of a three-modular machine for mechanizing the picking of the flowers of oil-bearing roses was created, with which a computer study was conducted and the profiles and type of materials for making main elements of its construction were determined depending on significant construction parameters and operational factors, including the connection scheme of the three-modular machine to the tractor linkage, the position occupied by the pickers (standing/sitting) on the loading platforms, the number and distribution of the pickers on the loading platforms, the presence of supporting running wheels, etc.
- A test prototype of the three-modular rose picking machine was made, with which experimental tests proved its functional suitability for working in plantations formed according to the three most widely used schemes for their formation (with row spacing of 2.8 m, 3.0 m and 3.2 m). The range of 300 - 600 m/h (0.3 – 0.6 km/h) is recommended for optimal movement speeds of the harvesting tractor/implement combination, while the specific speeds are taken into account with the operating conditions.
- It was calculated on the basis of the results of functional suitability tests with a fixed running time, that the use of the three-modular rose picking machine allows for an increase in labor productivity two and more times. The effect of mechanizing the picking of the rose flowers can be higher if the three-modular machine is equipped with pickers with experience and motivation. The combination "qualified rose pickers - optimal movement speed of the harvesting tractor/implement combination" creates conditions daily within the permissible time range for picking to harvest the flowers of the oil-bearing rose from an area of 1.2 - 1.7 hectares in the peak periods of flowering and over 2.0-2.5 ha/day outside peak periods.

Section 6. Research on the mechanized picking of oil-bearing rose flowers

Harvesting flowers in oil-bearing rose plantations has been done by hand for centuries. The complexity of mechanizing the most labor-intensive operation of the technological process in the growing of the oil-bearing culture is associated with the requirement to preserve the way of separating the rose flowers from the plant and with the need to apply a differentiated approach when picking each of the rose flowers.

The scientific research aimed to define a method for mechanized picking of the flowers of oil-bearing rose, specify the parameters and compose a technical means for its application.

The main idea behind the mechanization of oil-bearing rose harvesting was that the detachment of the flowers from the oil-bearing rose plan is carried out remotely by the rose picker, by means of a suitable technical means, which allows him to reach every blooming flower on the bush while minimizing contact with the spikes on the rose stems, stinging

insects and other problems accompanying the harvesting operation. The development included theoretical and experimental research, which were preceded by or conducted in parallel with the experimental determination of parameters and indicators necessary for the realization of the basic research.

Theoretical studies on the mechanized picking of the flowers of oil-bearing rose

Theoretical research on mechanizing the picking of oil-bearing rose flowers were preceded by preliminary experimental studies, where it was proven impossible to separate the petals of all the flowers to be picked from their ovaries by vacuum alone. The functional suitability of a vacuum-mechanical scheme was developed and experimentally proven, which served as the basis for the formulation of a method for the mechanized detachment of the flower from the oil-bearing plant by pneumatic suction and mechanical cutting of the peduncle under the ovary. Based on the developed method, a technical means (hereinafter referred to as the "*detachable module*") was assembled, on which the parameters of the working environment (the pressure and flow rate of the airflow passing through the intake and outlet openings) ensuring its functionality were determined (Fig. 6.1).

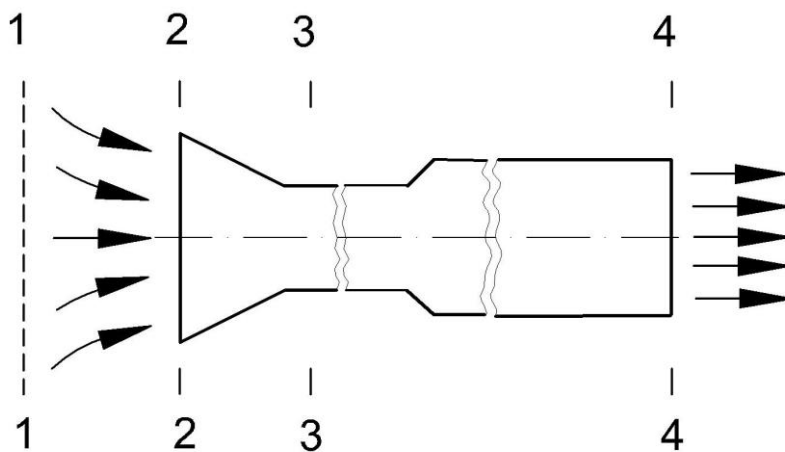


Figure 6.1.
 Scheme of a detachable module for determining the parameters of the working environment, ensuring its functionality

The values of the two parameters were performed on the basis of theoretical dependences on „Fluid Mechanics“ and on the results of experimental tests. The flow rate of the air providing the necessary conditions for the operation of the detachable module was calculated on the basis of the flow continuity equation. For pipelines with a circular cross-section, the airflow rate in the i^{th} cross-section of the detachable module was calculated by the formula:

$$Q_i = V_i \cdot S_i = V_i \cdot \frac{\pi \cdot D_i^2}{4} , \quad (6.1)$$

where: Q_i is the airflow rate in the i^{th} cross-section of the detachable module, m^3/s ;

S_i - the area of the i^{th} cross-section of the detachable module, m^2 ;

V_i - the speed of the airflow in the i^{th} cross-section of the detachable module, m/s ;

D_i - the diameter of the i^{th} cross-section of the detachable module, m ;

π - the Ludolf number, $\pi \approx 3.1416$.

Assuming that the detachable module, the area with the rose flowers in front of it and the area with the container for collecting the detached flowers behind it can be considered as lying in one plane and are elements of a streamline, the energy balance in the indicated in Fig. 6.1 sections was represented using the Bernoulli equation known as the "Bernoulli integral for potential steady flows of an ideal incompressible fluid". The

changes in the height of the location of the streamline elements were considered negligible and the gravity term in the Bernoulli equation was ignored. For the points of the sections in the area with the rose flowers "1-1", at the input "2-2", in the narrowest part "3-3" and at the output "4-4" of the detachable module from the streamline of Fig. 6.1 the general form of the equation is the following:

$$\frac{\rho \cdot V_1^2}{2} + p_1 = \frac{\rho \cdot V_2^2}{2} + p_2 = \frac{\rho \cdot V_3^2}{2} + p_3 = \frac{\rho \cdot V_4^2}{2} + p_4, \quad (6.2)$$

where: ρ is the density of air, kg/m³. Its value for the Rose Valley region during the rose picking period is within the limits 1.20 – 1.25 kg/m³;

$V_1 \dots V_4$ are the airflow speed in the defined sections, m/s;

$p_1 \dots p_4$ - the values of the airflow pressure in the defined sections, Pa.

The inlet pressure of the detachable module (p_2) was determined using the Bernoulli equation for the points of the streamline in the sections "1-1" and "2-2" in fig. 6.1. Given the fact that the section "1-1" is located far from the suction hole of the detachable module, i.e. $V_1 = 0$ (air is undisturbed) and the pressure is equal to atmospheric (p_a), the equation for calculating p_2 took the following form:

$$p_2 = p_a - \frac{\rho \cdot V_2^2}{2} \quad (6.3)$$

The second member of equation (6.3) shows the decrease in pressure below atmospheric and can be taken as an indicator assessing the potential of the detachable module to realize the first phase (pneumatic suction) of the two-component pneumo-mechanical scheme for detachment of the flowers from the rose plant.

The airflow pressure in the area with the smallest cross-sectional diameter along the detachable module (p_3) was calculated using a dependence derived from the Bernoulli equation for the points of the streamline in the section "2-2" and the section "3-3". The speed of the airflow in the section "3-3" was derived by the formula for continuity of flow (6.1):

$$V_3 = \frac{4 \cdot Q}{\pi \cdot D_3^2} \quad (6.4)$$

After substitutions to calculate the airflow pressure in the narrowest area of the detachable module, the equation was obtained:

$$p_3 = p_a - \frac{8 \cdot \rho}{\pi^2 \cdot D_3^4} \cdot Q^2 \quad (6.5)$$

The information about the pressure p_3 and the airflow speed V_3 reveals what is happening inside the detachable module and can be used to optimize its design parameters in order to increase its efficiency during operation.

The dependence for calculating the airflow pressure at the outlet of the detachable module (p_4) was derived by applying the Bernoulli equation for two points on one streamline with respect to the sections "3-3" and "4-4":

$$p_4 = p_3 + \frac{\rho}{2} \cdot (V_3^2 - V_4^2) \quad (6.6)$$

The value for p_4 is a reference for the fulfillment of the conditions for efficient operation of the detachable module. It must be higher than that at the inlet of the detachable module to allow the detached flowers to be carried away, and at the same time not too high so as not to damage them inadmissibly.

The formulas (6.1) – (6.6) show that to calculate the parameters characterizing the operating environment of the input and output of the detachable module, in addition to the values D_i , ρ , p_a (which can be considered constant for a particular case) it is enough to know the speed of the airflow at the inlet (V_2) and the outlet (V_4) of the module. The values

of the two speeds, which will guarantee the functionality of the detachable module, were determined experimentally in laboratory conditions.

The laboratory tests performed showed that at speeds below 10 m/s the airflow is weak or insufficiently stable for the realization of pneumo-mechanical detachment of the flower from the rose plant. The analysis of the obtained results determined that carrying out the harvesting operation would provide an airflow speed between 13.75 - 17.4 m/s, which gave reason to use the indicated interval in the subsequent calculations.

Using the derived dependencies (6.1) – (6.6) and the air flow speeds from the recommended operating interval obtained in the experimental tests, the values of the parameters of the working environment in the detachable module (flow rate and pressure of the air flow), which would provide conditions for flowers detachment and carrying them out of the module, were calculated. For the version of the detachable module with a suction hole diameter of $\varnothing 46$, a diameter in the narrowest cross-section of $\varnothing 36$ and an inner diameter of the lead-out part $\varnothing 50$, the air flow rate varies in the range of 80 – 100 m³/h. The value by which the pressure of the inlet hole of the detachable module must be lowered below the atmospheric one in order to provide the necessary conditions for drawing the flowers to the inside of the module is in the range 115 – 185 Pa. The low suction values indicated that the determining factor for the realization of the rose flower detachment is not the force of the vacuum, but the flow rate of the air, ensuring the movement of the flowers through the module. The established fact is important in the selection of a pneumatic unit to create the necessary vacuum in the detachable module.

The results of the theoretical research and the tests carried out in laboratory conditions with a detachable module for pneumatic-mechanical picking of oil-bearing roses gave the grounds for defining a method for mechanized picking of oil-bearing roses.

PNEUMO-MECHANICAL METHOD FOR MECHANIZED PICKING OF OIL-BEARING ROSES – *a method for mechanizing the picking of flowers in oil-bearing rose plantations, in which the rose flower is detached from the 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.*

Experimental research of a technical means for detachment of the rose flowers from the oil-bearing plant

Based on the pneumo-mechanical method for mechanized picking of oil-bearing roses, a technical means was developed that ensures the realization of the technological operation in accordance with the established practice in rose production for picking the whole flowers. With the help of a built test bench, tests were carried out, according to the results of which the optimal configuration of the suction tip, the place of installation of the cutting element, the diameters and lengths of the pneumatic tubes of the suction part of the detachable module with one and two rose pick-off devices, etc., were determined, as well as the vacuum values ensuring successful and uninterrupted detachment of blossomed flowers from the rose plant in various operating conditions were identified. The optimal values of the parameters and the basic requirements for the production of the elements of a technical means for picking rose flowers are presented in the Table 6.1.

Vacuum values were identified that create conditions for detaching the bloomed flowers from the rose plant with little or no effort on the part of the picker, without suctioning the surrounding undissolved buds and leaves, and without unacceptable injury to the harvested produce. For a technical means (detachable module) consisting of a rose pick-off device (total length 450 mm) with a suction tip with a suction surface diameter of $\varnothing 36$ and a pneumatic tube with an internal diameter of $\varnothing 50$ and a length of 500 mm, when

working with one and two rose pick-off devices they are respectively: at operation with one pick-off device - 3.5...4.0 kPa; when working with two pick-off devices 8.0...8.5 kPa.

Table 6.1.

Technical data and requirements for the elements of a technical means for picking oil-bearing rose flowers

Name of the element	Technical data		Requirements
	Construction parameter / Operating indicator	Optimal values	
Suction tip	- form; - diameter of the suction surface.	Arc 75-90° ø36 - ø40 mm	Lightweight, with a smooth inner surface, with a removable cutting element
Rose pick-off device	- total length	400 - 450 mm	Lightweight, ergonomic.
Pneumatic tube of the suction part of the detachable module	- type; - internal diameter; - length.	ø40 - ø50 mm 500 mm	Flexible, lightweight, with a smooth inner surface
Cutting element	- width of the cutting part; - angle of sharpening of the cutting edge.	5 - 10 mm up to 12°	One-sided sharpened and hardened. Located on the periphery of the suction tip with the sharpened part of the cutting edge inwards.
Vacuum module (vacuum pump)	- type; - working vacuum.	up to 30 kPa	- low-vacuum

Concept project of a three-modular agricultural machine for mechanizing the picking of the flowers in oil-bearing rose plantations with pneumatic detachment of the rose flowers

The results obtained in the research on the mechanized picking of oil-bearing rose flowers made it possible to realize the three-modular rose picking machine (see Section 5) in a variant with a system for pneumatic picking of the flowers, with which to improve working conditions and accelerated the harvesting process. On the basis of the technical means for detachment the flowers from the rose plant (the detachable module), a pneumatic system was developed for picking off and transporting the blossomed rose flowers to the container for their collection. A concept project of a three-modular rose picking machine with a pneumatic picking system mounted on it is presented in Figure 6.2.

The pneumatic picking system (16) consists of vacuum-pump, rose pick-off devices, pneumatic tubes, distributors, regulator, connecting elements and protective devices. The vacuum-pump (21) provides the needed vacuum in the system for realization of the picking of the rose flowers, and regulator (22), situated next to it allows for the vacuum rate to be adjusted according to the specific conditions. The vacuum-pump (21) is fixed in close proximity to the shaft power take-off-PTO (20) of the tractor and is driven by it. The central vacuum-tube (19) connects the vacuum-pump (21) with the central distributor (18), the sectional vacuum-tubes (17) connect the central distributor (18) with the sectional distributors (14), and container vacuum-tubes (25) connect the sectional distributors (14) with the removable containers (6). On each of the removable containers there is a sealing cover (27) with a built-in relief valve (28). Rose pick-off device's vacuum-tube (29)

connects the sealing cover (27) with rose pick-off device (30). The pneumatic tubes connecting the vacuum-pump (21) with the central distributor (18) and the rose pick-off devices (30) with containers' covers are flexible. The rest of the pneumatic tubes can be non-deformable.

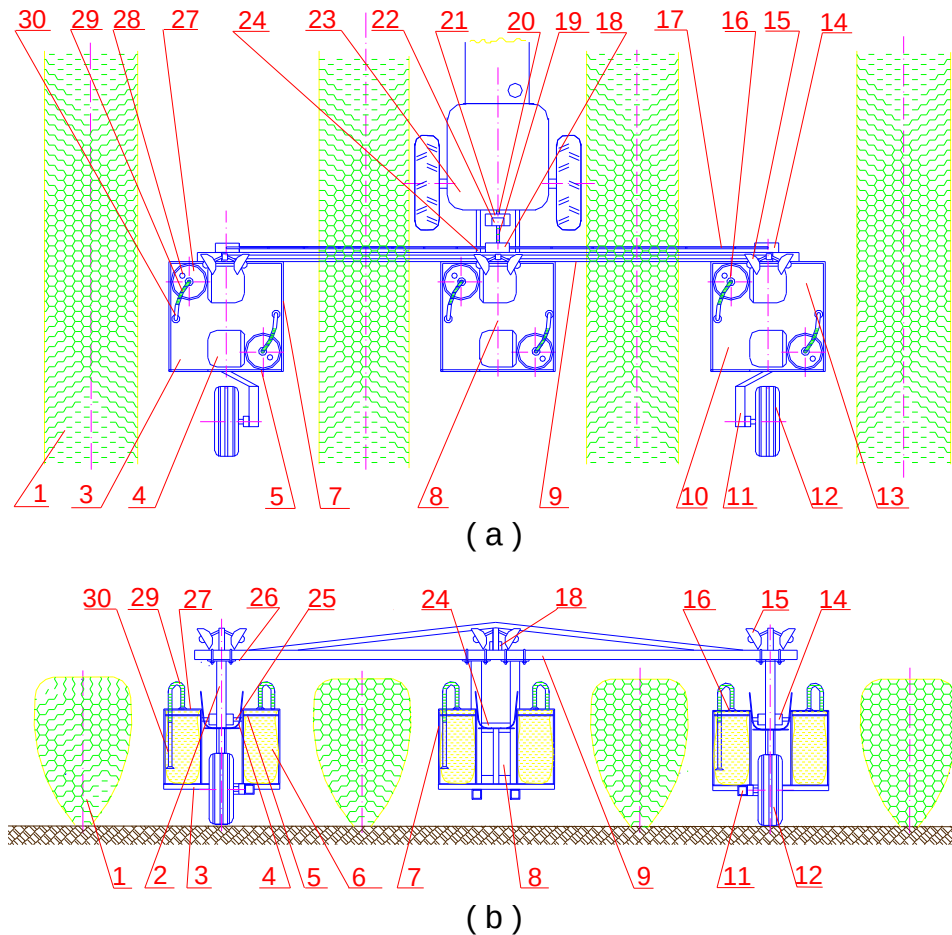


Figure 6.2. Concept project of a three-modular agricultural machine for mechanizing the picking of the flowers in oil-bearing rose plantations with pneumatic detachment of the rose flowers
 a) top view; b) back view

1 – row of rose bushes; 2 – L-shaped frame; 3 – loading platform; 4 – picker's seat; 5 – stand for the removable container; 6 – removable container for the harvested rose flowers; 7 – protective parapet; 8 – operating module; 9 – carrier frame; 10 – rear workplace; 11 – console structure; 12 – running wheel; 13 – front workplace; 14 – sectional way distributor; 15 - luminaries; 16 – pneumatic picking system; 17 – sectional vacuum-tube; 18 – central distributor; 19 – central vacuum-tube; 20 – shaft of Power take-off; 21 – vacuum pump; 22 – vacuum regulator; 23 – farm tractor; 24 – hitch attachments of implement's triangle; 25 – container vacuum-tube; 26 – fastening unit; 27 – sealing cover; 28 – relief valve; 29 – rose pick-off device's vacuum-tube; 30 – rose pick-off device.

The harvesting operation with the use of the pneumatic picking system proceeds as follows: Each of the pickers directs controlled by him rose pick-off device (30) to a blooming rose flower. The vacuum created by vacuum pump (21), having reached the suction hole of the rose pick-off device (30) along the whole chain of distributors and

connecting elements of the pneumatic picking system (16), using the cutting element of the suction tip breaks off the rose flower under the cup and through vacuum-tube (29) transports it to removable container (6) storing the harvested produce. After the removable containers are filled with rose flowers, they are replaced by empty ones. The relief valves (28) did not allow deformation of the container for the harvested rose flowers in the event of an accidental increase in the vacuum in the system.

Research on the possibility of using the potentials of the pneumatic system of an agricultural tractor in the picking of flowers in oil-bearing rose plantations

The registered low values of the vacuum required to suck and tilt the rose flower to the cutting edge for its mechanical cutting and detachment from the stem of the oil-bearing plant, gave reason to look for other ways of its creation. Analyzing the ways of obtaining a vacuum known in science and practice, the hypothesis was raised that the potentials of the pneumatic system of an agricultural tractor could be used for this purpose.

Following the sequence in the creation of technical means for agricultural practice, theoretical studies and experimental tests were carried out, in which a conceptual scheme of a pneumatic picking system was developed, the practical applicability of which was confirmed experimentally in laboratory conditions, a testing device was prepared, with the help of which the basic construction and working parameters, providing conditions for picking off the flowers and taking them to the place for their temporary storage. Test prototypes of pneumatic detachable modules with the possibility of using compressed air from the tractor pneumatic system were made.

The experimental test to check the possibility of using the potentials of the pneumatic system of an agricultural tractor was carried out during the rose-harvesting period of 2019 in the experimental and production complex of IREMC in Kazanlak. A tractor/implement combination was assembled based on the variant of MMR for the mechanization of the picking of rose flowers. The base module of the MMR, equipped for manual rose picking, is equipped with two pneumatic detachable modules.

Tests to evaluate the comfort of operation of the pneumatic detachable modules showed that the dimensions of the rose pick-off devices and their vacuum-tubes fully satisfy the requirement to reach every blooming flower in the area of the rose bush served by the picker. Ease of working with the rose pick-off devices was found to be satisfactory for practice. The technical solution for fixing the outlet end of the pneumatic detachable module to the stand for the removable container proved to be reliable.

Tests to evaluate the functional suitability of the pneumatic detachable modules using compressed air from the tractor's pneumatic system found that from the starting position, where the compressed air pressure is equal to or close to the limit value maintained by the pressure regulator, each of the detachable modules ensure that only a few rose flowers are detached from the rose plant and transported to the container for their temporary storage. Regardless of the possibility of pulsed release of compressed air, after several actuations of the shut-off pneumatic device, a pressure drop in the pneumatic system followed from 0.6 - 0.7 MPa to values that were insufficient to create a vacuum in the vacuum-former, capable of drawing inside the suction tip the flowers for their mechanical separation from the rose plant. The speed of the air flow was also falling, making it difficult to carry already picked flowers to the container for their temporary storage. A waiting period followed for an increase in air pressure in the pneumatic system above 0.3 MPa to achieve subsequent rose flowers detachment.

The obtained results gave reason to formulate the conclusion that *the tractor pneumatic system is not able to provide the necessary conditions for pneumatic picking of oil-bearing rose flowers without interruption*. Two main reasons can be named:

- 1st reason – the impossibility of the air pressure provided by the compressor of the tractor pneumatic system to be maintained constantly within the limits necessary to realize the vacuum-mechanical detachment;
- 2nd reason - insufficient volume of the air reservoir of the tractor pneumatic system to provide for a long time the necessary amount of air for picking off the rose flowers and their transportation to the place of temporary storage.

Main results, conclusions and recommendations of Section 6

- It has been experimentally proved that it is impossible to separate the petals of all the flowers to be picked from their ovaries, and to detach all the whole flowers from the oil-bearing plant, only with the help of a vacuum.
- A method for the mechanized detachment of the flowers from the oil-bearing rose plant was defined on the basis of a developed two-phase vacuum-mechanical scheme. The applicability of the method was proven experimentally.
- A pneumatic picking system has been developed for equipping the three-modular machine for mechanizing the picking of the flowers in oil-bearing rose plantations, which provides the possibility to realize pneumatic detachment of the flowers from the rose bushes with the machine.
- A pneumo-mechanical method for the mechanized picking of oil-bearing roses has been defined, according to which the rose flower is detached from the bush by pneumatic suction and mechanical cutting of the peduncle under the ovary and is carried by air flow to the place of collection. The application of the method ensures the realization of the harvesting operation in accordance with the established practice in rose production for picking off the whole flowers. Expectations from the method are improved working conditions, reduced picking costs, increased productivity.
- A general composition of a technical means (detachable module), assembled on the basis of the pneumo-mechanical method for mechanized picking of oil-bearing roses, has been developed. The type, dimensions and configuration of the elements of the rose pick-off device, ensuring ergonomic operation when picking rose flowers, have been established. The values of the parameters of the working environment (flow rate and pressure of the air flow) in the detachable module, which would provide conditions for picking off the flowers and taking them out of the module without unacceptable injury, were calculated on the basis of results obtained in an analytical-experimental way. Requirements for the manufacture of the components of the detachable module have been formulated to ensure maximum efficiency in the work process.
- It was established that with the adopted open system of operation of the detachable module, the tractor pneumatic system was not able to provide the necessary conditions for pneumatic picking of the rose flowers without interruption. The main reasons for this have been identified, recommendations have been formulated and technical solutions have been developed to neutralize them.

Section 7. Development of an agricultural machine for pneumatic harvesting of oil-bearing roses

Harvesting the flowers from the rose plantations is the operation of the technological process that makes sense of all the activities and costs realized in the growing of oil-bearing rose. It is carried out under extremely unfavorable conditions and requires the presence of a significant labor resource. Picking the rose flowers is done manually, mainly by pickers with low qualification and experience, which determines the low productivity of the operation.

elements for movable supports (2). On the upper side of the main frame (1) a common container (18) for the collected rose flowers is mounted, and on its lower side the support-running unit (38) is attached. Centrally to the upper side of the common container (18) is attached an arcuate tip (21) for connecting the central pneumatic tube (22), which at its other end is connected to a vacuum pump (32) driven mechanically by the tractor PTO or hydro-mechanically by the tractor's hydraulic system via a hydraulic motor. Module tips (17) with vacuum regulators (16) for the detachable modules (6) and (12) of the pneumatic detachable system (23) are arranged on its longitudinal sides. Its interior is equipped with movable stands for replaceable containers for the collected rose flowers (not shown in Fig.7.1). Access to it is through an airtight door (35).

Each of the detachable modules (6) and (12) of the pneumatic detachable system (23) includes a rose pick-off device (9) with a cutting element (8) located near the edge of its suction opening and a module pneumatic tube (10) with which it is connected to a module tip (17) of the common container (18). The detachable modules of the self-moving pickers (12) are arranged on module holders (15) hinged to the common container (18). Each module holder (15) is two-section and rotatable in the horizontal plane about the axis of its sectional support (14), which is attached to the common container (18), and can be fixed with a module clamp (24) on the common container (18). Its outer section (11) is hinged to the inner section (13) and can be moved along its length, independently rotated on the horizontal surface and dismantled. In Fig. 7.1 one of the module holders with detachable modules is in working position and the other in transport position.

The workplaces of the pickers on the machine (3) are separated on its two longitudinal sides. They include a movable tread (5) and a protective parapet (4), which are hinged to the main frame (1) and the common container (18), respectively, and are capable of horizontal positioning during operation and upright fixing during transport.

The humidifying system (20) includes a water pump (26), to which the inlet is connected via a pump connection (29) to a hydraulic reservoir (30), and the outlet via a distribution pipe (25) with spray devices (19). The water pump (26) is electric with power supply from the electrical system of the tractor. The spray devices (19) and the humidity sensor of the electronic control system (28) are positioned inside the common container (18). The signals from the humidity sensor are a sign for the control unit of the electronic control system (28) for switching on and off the power supply of the water pump (26), which through the distribution pipe (25) supplies water to the spray devices (19) for controlled spraying of the interior of the common container (18).

The support-running unit (38) is possible in two variants, including a supporting structure (36) and support elements. The support elements are supporting sliders (37) or running wheels (7) with movable supports (2). The supporting structure (36) is attached to the lower side of the main frame (1). Its design is in accordance with the type of support elements.

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

The experimental research involved making a test prototype of the rose harvesting machine and testing it for structural strength, functional suitability and operational efficiency. The prototype was assembled with standard products and original elements and units. It was tested in laboratory and field conditions. In laboratory conditions, tests were carried out to check the structural strength of the RHM, tests were carried out to verify the functionality of the executive modules and adjustments were made to ensure their effective operation, parameters of the auxiliary modules affecting the output indicators of the main ones were determined.

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 an agricultural

compact tractor Kubota GL220. To implement the tests, three 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;
- three-row variant (RHM-3) - RHM with six workplaces, two of which are located on the machine and four 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 soil surface in the interrows was also well maintained. 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 ($n_{dB}=n_{min}$) to $n_{dB}=1200 \text{ min}^{-1}$, according to the forward speed of the harvesting tractor/implement combination, which can be realized in the specific conditions. In order to evaluate the operational indicators of the RHM, the results of the tests conducted after establishing the optimal operating modes of the harvesting tractor/implement combination were analyzed. In parallel with the results of the RHM tests, data relating to the collection of the flowers in the plantations by the pickers in the traditional manual way of picking the oil-bearing rose was recorded.

The experimental tests in 2020 were conducted with the rose harvesting machine equipped with four workplaces. Initially, the tests were carried out with the one-row variant of the RHM-1 (Fig. 7.2.a).



(a)



(б)

Figure 7.2. Experimental testing in field conditions of the rose harvesting machine equipped with four workplaces

a - one-row variant RHM-1; b - two-row variant RHM-2.

Pickers without any experience in machine harvesting and with different 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 mins) 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.

During the first day of tests of the two-row variant RHM-2 (Fig. 7.2.b), 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 flowers harvested during tests lasting almost 3 hours (172 mins) 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. The tests were carried out according to the methodology applied the previous year, and the majority of them were with an activated humidifying system.

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 minutes 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 pick-off devices, etc. factors, actors made it necessary to stop the movement of the harvesting MTA several times. 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 specified hourly productivity of the harvesting tractor/implement combination was 0.093 ha/h.

Tests on the next day of experimental research 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 minutes 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 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. 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 field experiments of the three-row variant of the machine for pneumatic harvesting of oil-bearing roses (Fig. 7.3) were carried out in 2021. RHM-3 was tested for functional suitability with 5 pickers, of which two on the machine and three self-propelled.



Figure 7.3. Experimental testing in field conditions of the three-row variant of the rose harvesting machine

The collected flowers in a test lasting 44 minutes was 14.5 kg, which, applied to the area from which it was collected, represents 104 kg/ha. The average speed of the technological operation was maintained - 0.254 km/h, but opportunities for its increase were found. The realized hourly productivity of the RHM-3 with five rose pickers, picking flowers simultaneously from two and a half rows of rose bushes, in 44 minutes was 0.19 ha/h. Recalculated for the situation when the RHM-3 is equipped with six rose pickers, the hourly productivity of the harvesting unit would be 0.228 ha/h, which is quite sufficient to harvest the rose flowers available on the day of the test in the plantation within the time interval guaranteeing the receipt of quality production.

The main conclusion of the tests of three-row rose harvesting machine is that speeding up the movement of the harvesting tractor/implement combination (for which the possibilities are considerable) and equipping the machine with pickers of equal skill and professional attitude are the real steps to increase productivity to levels that will allow with one RHM-3 daily within the permissible time range to harvest the production from plantations with an area of 1.5 ha and more, incl. in the peak flowering stage of the oil-bearing crop.

The test results of the three variants of the rose harvesting machine (RHM-1, RHM-2 and RHM-3) are difficult to compare, due to the different conditions during the days of the experimental research - unequal amount of blooming rose flowers, lack of skill of the pickers to handle the rose 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.

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 that 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.

The observation of the change of humidity in the common container of the harvesting machine under the influence of the rising daily temperature and the air flow passing through the container during the technological operation found that the decrease of humidity in a period of 45 minutes can reach 34% even in a moderately humid environment. The tests of the harvesting tractor/implement combination carried out with an activated humidifying system showed that it is quite possible to maintain the humidity in the common container and not allow the rose flowers to dry out. A three-minute sprinkling provided a 10% increase in humidity, and a minute-minute and a half sprinkling at intervals was sufficient to maintain the humidity in the common container in the range of 80-85%, recommended as optimal for preserving the condition of the harvested rose flowers in quantitative and qualitative terms.

Main results, conclusions and recommendations of Section 7

- An agricultural machine for pneumatic harvesting of oil-bearing roses has been developed, manufactured and tested. The picking of the flowers is realized by the rose pickers remotely with detachable modules, with which the rose flower is detached from the bush by pneumatic suction and mechanical cutting of the peduncle under the ovary and is carried by air flow to the place of collection.
- The rose harvesting machine allows three variants of formation with workplaces (one-row, two-row, three-row) and six variants of completeness with rose pickers depending on the amount of blossomed flowers, the operating conditions and the rose pickers available on the day of picking.
- The rose harvesting machine can be equipped with two types of support-running unit (with supporting sliders or with running wheels) and can be made in a mounted and semi-mounted version, which provides conditions for attaching it to tractors with linkage, the load capacities of which are lower or commensurate with the operating mass of the machine.
- The laboratory tests for structural strength of the rose harvesting machine proved, and the field tests confirmed the correctness of the choice for a technical solution, of the used standard products and original elements and assemblies for its manufacture.
- The rates of change of humidity in the common container of the rose harvesting machine under the influence of the rising daily temperature and the air flow passing through the container during the rose-harvesting period of the day were analyzed. The possibility of using a humidifying system to maintain a constant humidity in the common container during work in the range of 80-85%, in order to preserve the collected flowers and the essential oil contained in them in quantitative and qualitative terms, has been proven.
- Experimental field tests of the rose harvesting machine verified its functional suitability for use in oil-bearing rose production practice. The advantages of machine picking over traditional manual picking have been established and proven by experience - 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 harvesting machine in operation depends are determined, namely: the condition of the oil-bearing rose plantation; the amount of blooming rose flowers; the qualification of rose pickers. Finding a balance between them ensures the productivity with which the tractor/implement combination, formed on the basis of a three-row machine for pneumatic rose harvesting, within the specified time range, can collect the production from plantations of 1.5 ha and more, incl. in the peak flowering period of the oil-bearing crop.

Section 8. Development of an agricultural machine for pruning in oil-bearing rose plantations

Pruning in plantations with oil-bearing rose is carried out during all stages of growing of the oil-bearing plant. Its implementation in a new plantation aims at the initial formation of healthy rose bushes, and in a flowering plantation - ensuring the necessary conditions for achieving high yields of quality rose flowers. The general disadvantage of the technical means for pruning used in rose production, apart from their narrowly specialized purpose, is that the cut plant mass remains in rows with the rose plants. Its extraction in the inter-row spacing for its further processing is done manually at significant labor and time costs.

The research aimed to create an agricultural machine for carrying out all pruning operations for forming the height and cutting close to the base of the bushes in oil-bearing rose plantations with simultaneous removal of the cut plant mass in the inter-row. The development has an analytical-experimental character and included the conduct of theoretical and experimental research.

Theoretical studies for the development of an agricultural machine for pruning in oil-bearing rose plantations

Taking into account the morphological features of the oil-bearing rose, the specificity of the pruning activity in rose plantations and the resulting requirements for the mobile power means that can be used in the composition of a pruning tractor/implement combination, a concept project for a technical solution of an agricultural machine for pruning in oil-bearing rose plantations (Fig. 8.1), hereinafter also called "*rose pruning machine*" and abbreviated as "*RPM*", was developed.

The rose pruning machine (Fig. 8.1) includes a main frame (1), a pruning module (25), an upper (10) and a lower (9) guide rods. The main frame (1) has a triangle (4) formed in its front part for attachment to a farm tractor. Centrally located on it is an angle reducer (3). The drive belt pulley (2) of a two-stage belt drive (16) is attached to the output shaft of the reducer, and a safety clutch (6) with a cardan extension (5) is connected to its input shaft. The rotating elements of the two-stage belt drive (16), as well as the cardan extension (5) with the safety clutch (6), are protected by protective covers (not shown in Fig. 8.1) The upper (10) and a lower (9) guide rods are connected by hinges (8) to the main frame (1) and attached by hinged supports (24) to the pruning module (25). Both rods can be positioned and fixed near the main frame (1). The upper guide rod (10) is adjustable in height and inclination using the adjustable support (23) and the holes in the inclined beam (7) of the main frame (1).

The rose pruning machine is a mounted type of farm equipment for use in the conditions of agricultural production after it is attached to an agricultural tractor. The dimensions of the attachment elements of the hitch-point triangle (4) of the machine must correspond to those of the tractor's hitch mechanism. In the transport position (Fig. 8.1.b), the pruning module (25) is positioned behind the main frame (1). It is fixed in working position (Fig. 8.1.a) by rotating around the carrying axis of rotation (26). Its position in relation to the support surface is infinitely adjustable using the tractor linkage depending

on the required pruning height. The guide rods are fixed in positions that ensure their functional purpose.

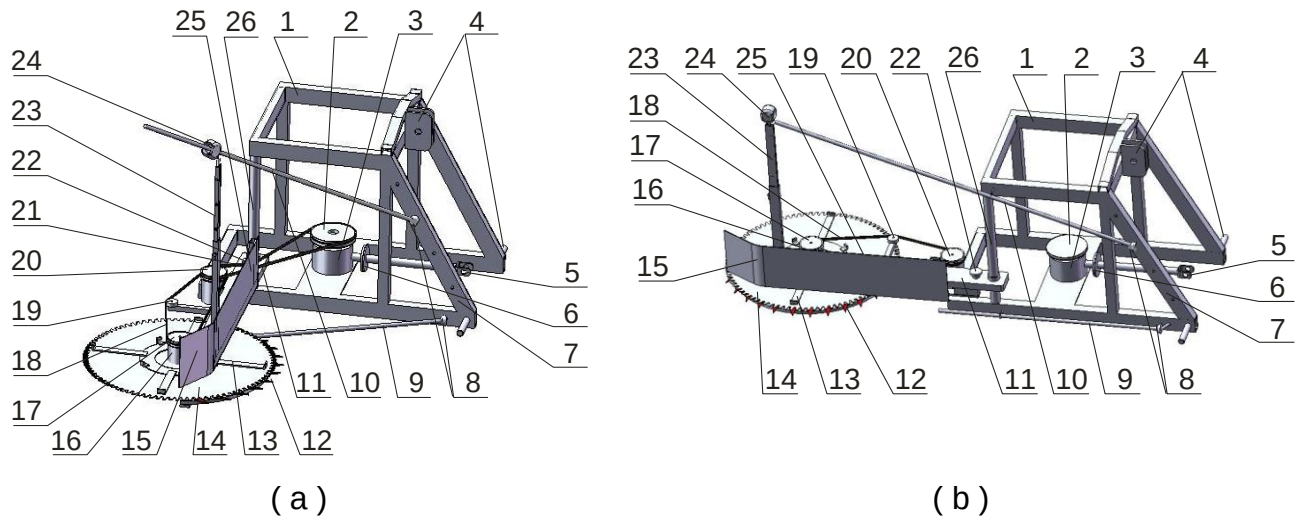


Figure 8.1. Concept project of an agricultural machine for pruning in oil-bearing rose plantations

a - in working position; b - in position for transportation

1 - main frame; 2 - drive belt pulley; 3 - angle reducer; 4 - hitch-point triangle; 5 - cardan extension; 6 - safety clutch; 7 - inclined beam; 8 - hinged connection; 9 - lower guide rod; 10 - upper guide rod; 11 - supporting bar; 12 - counter knife; 13 - perk cleaner; 14 - cutting disc; 15 - protective board; 16 - two-stage belt drive; 17 - driven belt pulley; 18 - drive belt of the second step; 19 - tensioning belt pulley of the second step; 20 - two-channel belt pulley; 21 - drive belt of the first step; 22 - tensioning belt pulley of the first step; 23 - adjustable support; 24 - hinged support; 25 - pruning module; 26 - carrying axis of rotation

During the movement of the pruning tractor/implement combination, formed with RPM, in the inter-row of the rose plantation, the cutting disc (14) is located above the row of bushes that is being processed. The forward speed of tractor/implement combination is adapted to the requirements of the technological operation. The cutting disc (14) receives its rotary movement by means of the two-stage belt gear (16) from the angle reducer (3), the input shaft of which is connected to the PTO of the tractor through the safety clutch (6) with the cardan extension (5) and cardan gear or by hydraulic motor driven by the tractor's hydraulic system. Rose stems directed by the upper and lower guide bars fall between the thumbs of the counter knife (12), which provides support for their cutting by the cutting disc (14). The perk cleaner (13) directs the cut plant mass into the inter-row. The protective board (15) picks up the plant residues remaining on the cutting disc (14) and with the help of the upper guide rod (10) pushes them out of the processed row. The cutting height is adjusted depending on the stage of vegetative development of the rose plantation and the type of pruning operation.

To transport the rose pruning machine, the upper and lower guide rods are released from the hinged supports (24) and clipped to the main frame (1). The belt (21) from the two-stage belt drive (16) is dismantled. The pruning module (25) is rotated around the carrying axis of rotation (26) and is fixed in the transport position (Fig. 8.1.b).

Based on the developed concept project for a rose pruning machine, a simulated 3-D model was built using the *Solid Works* software product. With its help, through computer modeling, the places of occurrence were identified and the values of stresses and

deformations in the construction of the RPM, caused by the acting external forces, were calculated, and on their basis, the main construction dimensions of the machine and the materials for its manufacture were determined, its weight and coordinates of the center of mass in the working and transport position were calculated (Table 8.1). The value of the factor of safety of the construction, whose elements are made with the materials and profiles defined as optimal, is $FOS=2.748$, which fully satisfies the requirements for ensuring its structural strength in the conditions of rose production practice.

Таблица 8.1.

Mass parameters of the rose pruning machine

Parameters	Dimension	Values
Weight		
- in the working position	kg	194.62
- in transport position	kg	194.0
Coordinates of the center of mass:		
- in the working position		
along the longitudinal axis „z“	mm	-737.5
along the transverse axis „x“	mm	-345.1
along the vertical axis „y“	mm	197
- in transport position		
along the longitudinal axis „z“	mm	-966.3
along the transverse axis „x“	mm	-96.4
along the vertical axis „y“	mm	196.4

In the construction of the rose pruning machine there is a possibility for pruning at a height of up to 160 cm. The hydro-mechanical drive of the cutting disc ensures positioning of the pruning module of the RPM at heights in the entire pruning range. With the simpler purely mechanical drive through the tractor PTO, prunings up to 110 cm are realized, which are the majority of those applied in the care of oil-bearing rose plantations.

Verification of the possibility of safe operation of the pruning tractor/implement combination was carried out on the basis of the determined mass parameters of the RPM (Table 8.1) and data from the technical characteristics of the Kubota GL220 compact tractor. The influence of RPM on the safety of the pruning tractor/implement combination during operation was evaluated by its stability against lateral overturning. On flat terrains, the stability of tractor/implement combination is guaranteed, because the transverse coordinate of the center of mass of the RPM (345 mm) is within the limits of the transverse base of the tractor. The stability of the pruning tractor/implement combination when working on inclined terrains was evaluated with the angle of dynamic transverse stability (β_{dyn}). The angle β_{dyn} was determined with data on the limit static angle of transverse resistance (α_{st}) when pruning at heights in the range 0 – 160 cm for the two possible variants of positioning the tractor in relation to the cut rose bushes: on their upper side opposite the slope and on their underside side of the slope.

The analysis of the results of the theoretical studies to assess the influence of the RPM on safety at work showed that on flat and with a slope of up to 3° terrain, the pruning tractor/implement combination (regardless of how the tractor is located in relation to the rose bushes) retains the necessary stability to realize pruning at a height in the entire pruning range (from 0 to 160 cm). The location of the pruning module does not affect safety even when driving at low forward speeds on terrains with a slope of up to 9 - 10°, when pruning is carried out close to the base of the rose bushes (up to 30 - 35 cm). On all terrains on which the operation of the basic versions of the universal tractors is permissible

(with a slope of up to 10°), the movement of the tractor/implement combination across the slope with the pruning module located against the slope is completely safe and allows the execution of pruning applied in the growing of the oil-bearing crop.

The evaluation of the effect of the widening of the wheeltrack of the tractor on the stability of the pruning tractor/implement combination at pruning heights in the range 0 - 160 cm showed that with the available technical means it is feasible to increase it almost twice, thus expanding the possibilities for the operation of the pruning tractor/implement combination on terrains with greater slopes.

The results obtained for the transverse stability of the pruning tractor/implement combination, composed on the basis of a compact tractor, are grounds for assuming that the rose pruning machine can be attached and work safely also with universal tractors of medium power, which have wider wheeltracks and no lower stability, and are also widely used in rose production.

Experimental studies of an agricultural machine for pruning in oil-bearing rose plantations

Experimental research included the development of a prototype of the rose pruning machine and its testing in real conditions for structural strength, functional suitability and efficiency at work.

The structural strength (stiffness) of the rose pruning machine was tested both in the process of making its main assemblies and after its final assembly. Without any fact compromising the strength of the structure, the field tests of the machine were carried out.

The tests for assessment of the functional suitability for work in real conditions of the rose pruning machine were realized in autumn 2020 and spring 2021 in oil-bearing rose plantations in lands around the town of Kazanlak and the town of Tran. The machine was aggregated to the compact tractor Kubota GL220 (Fig.8.2), meeting the requirements for compiling the pruning tractor/implement combination.



(a)



(b)

Figure 8.2. Field tests of the agricultural machine for oil-bearing rose pruning
a - pruning at a height of 110 cm; b - pruning at a height of 30 cm

A series of tests were implemented in farms with rose plantations with an area of 0.4 to 15.0 ha with different shape and lengths of rows, stages of vegetation development of rose plants, slope and profile of the soil surface. The condition of the plantations in which the tests took place ranged from well-maintained to almost abandoned, incl. without tillage and other mandatory plant care, with lush plant mass, incl. and with unharvested rose flowers. Pruning has also been carried out in plantations with displacement between adjacent rows, reaching up to 50-60 cm. With the help of the tractor's hitch, the rose pruning machine was positioned at a distance from the soil surface, providing the required

height of the rose bushes after pruning. Pruning was carried out up to the limit value for rose plantings of 160 cm. At a cutting height in the range of 30 - 110 cm (Fig. 8.2), which are the most often applied by rose growers when caring for the oil-bearing rose, the drive of the cutting disc of the pruning module was mechanical through the PTO of the agricultural tractor, and at heights of cutting above the specified range - hydromechanical.

The parameters and indicators that were monitored during the tests were: the speeds of the crankshaft of the tractor engine, of the power take-off shaft (PTO) and of the cutting disc; the forward speed of the tractor/implement combination; the length of the cut rows and the time for their pruning. Monitoring was conducted for the success of cutting all the plant mass to be removed, the condition of the surface at the place of cutting the rose stems, the stability of the pruning tractor/implement combination when moving.

The field experiments were carried out at speeds of tractor/implement combination in the range of 0.5 - 8.4 km/h, which are typical for the technological operations performed in perennials. The desired forward speed was achieved both by changing the gears in the tractor gearbox and by operating the tractor engine in partial modes. Varying with the crankshaft speed of the tractor engine and the speed modes provided by the PTO, a series of tests were performed to establish the optimal operating conditions of the cutting disc.

Field tests were carried out in two stages with both types of drive of the cutting disc. With the defined as optimal settings and operating modes, tests were conducted to assess the productivity of the rose pruning machine under operating conditions typical for the rose-growing practice. The values of the sample mean of variation lines compiled with the results obtained in the first stage, which would be useful for practice, are presented in the table 8.2.

Table 8.2.

Summarized results of the experimental tests of the machine for oil-bearing rose pruning

Operating conditions		Type of pruning operation	Performance indicators	
Rose bushes	Soil surface		Forward speed (km/h)	Productivity, (ha/8 hours)
in new plantations	well maintained row spacing	upper pruning	5.0 – 6.0	4.5 – 5.5
in new plantations	poorly maintained row spacing	upper pruning	2 - 3	2.5 – 3.0
in plantations with active flowering plants	well maintained row spacing	pruning at a height of 100-110 cm	4-5	3.0 – 4.2
in plantations with active flowering plants	poorly maintained row spacing	pruning at a height of 100-110 cm	2 - 3	2.0 – 3.0
in plantations with active flowering plants	well maintained row spacing	pruning at a height of 70-80 cm	3 - 4	2.5 – 3.5
in plantations with active flowering plants	poorly maintained row spacing	pruning at a height of 30-40 cm	0.5 – 1.5	1.0 – 2.0

The functional suitability of the tractor/implement combination for pruning at greater heights was evaluated during the second stage of the field tests after the completion of the RPM with the elements for implementing hydro-mechanical drive of the cutting disk of its pruning module. Pruning was carried out on a strip separating neighboring fields, consisting of rose bushes with young trees growing in them. With the help of the tractor linkage, the RPM was positioned at a distance of 150-160 cm from the soil surface.

The tests were carried out at forward speeds of the pruning tractor/implement combination in the range of 4-5 km/h and rotation frequencies of the engine crankshaft around 1200 min⁻¹, which ensured the optimal working mode of the cutting disc. The obtained results proved the workability of RPM in this more complicated situation than the upper pruning of rose bushes. It was found that stems of plants with diameters of 40-50 mm can be cut without any problems, which significantly exceeds the maximum size of 25 mm determined for the main mass of rose stems. Cuts of young trees with diameters reaching 60 mm were found. Measures were identified to optimize the parameters of the cutting disc, in the direction of reducing its construction mass and production cost.

Tests of the rose pruning machine were also carried out together with a thumb-type device for realization of side pruning of the bushes attached to the front part of the farm tractor. It was found that the joint work of the two farm machines not only did not worsen the performance of the tractor/implement combination, but improved the working conditions of the tractor driver and increased the effect of the pruning operation.

The conducted experimental research allowed the formulation of recommendations, the consideration of which would increase the efficiency of the use of the machine for pruning roses in the rose-growing practice and in bushy plantations grown without supporting structures.

Main results and conclusions of Section 8

- An agricultural machine has been developed, manufactured and tested for carrying out all pruning operations to form the height and cut the bushes close to the base with simultaneous removal of the cut plant mass to the inter-rows of the oil-bearing rose plantations.
- The basic construction and operational parameters of a rose pruning machine has substantiated by computer modeling, including: its overall dimensions, ensuring free movement and operation of the pruning tractor/implement combination formed on its basis in oil-bearing rose plantations; its structural mass under 200 kg, allowing connection incl. and to "smallsize" type agricultural tractors; pruning height up to 160 cm, which is the maximum applied in rose production practice.
- The strength of the structure of the rose pruning machine was experimentally verified. Construction changes during the tests due to the action of external factors, which discredit the performance of its functions, were not found.
- The functional suitability of the rose pruning machine to perform pruning in the entire pruning range, incl. on sloping terrains with a deviation between adjacent rows of 50 cm and more, has been proven, as well as its advantage over agricultural machines similar in purpose to leave the cut bushes clean of plant residues after its passage.
- Average shift productivity in the range of 3-4 ha/working shift of the tractor/implement combination formed on the basis of the rose pruning machine was determined during operational tests, taking into account the influence of operating conditions on its increase or decrease. Recommendations were developed to increase the efficiency of using the rose pruning machine in rose production practice.

III. CONTRIBUTIONS FROM THE RESEARCH IN THE DISSERTATION

III-1. Contributions of original character

III-1.1. A definition of the concept of *"scientific research in engineering agricultural practice"* has been introduced as *"a conceptual, personnel and economically justified complex of activities for the creation of new or improvement of existing technical means for the mechanization of technological operations in the cultivation and harvesting of agricultural products"* and the methodological foundations of engineering research in agricultural practice are summarized.

III-1.2. A classification of oil-bearing rose-growing farms in the Republic of Bulgaria has been developed according to the "utilized agricultural area" criterion, and the optimal power means for mechanized growing of the oil-bearing crop in each of them have been determined. The classification of farms by types, taking into account the specifics of the sector, allows their farmers to estimate the necessary investments for the purchase of agricultural machinery and eases the executive authorities in allocating funds to support agricultural farms, according to their capabilities for effective use.

III-1.3. A two-phase vacuum-mechanical scheme combining pneumatic suction of the flower and mechanical cutting of the peduncle under the ovary has been theoretically substantiated and verified experimentally, on the basis of which a method has been defined for the mechanized detachment of the oil-bearing rose flower from the plant.

III-1.4. A pneumo-mechanical method for the mechanized picking of oil-bearing roses has been defined, according to which the rose flower is detached from the bush by pneumatic suction and mechanical cutting of the peduncle under the ovary and is carried by air flow to the place of collection.

III-1.5. Two variants of an agricultural machine for hand-picking of oil-bearing rose, which allow picking off the blossomed rose flowers and transporting the pickers and their collected produce in the rows of the rose plantations during the rose-harvesting period have been developed, manufactured and tested. The optimality of the design solutions, the structural strength and functional suitability of the machines for working with different schemes of connection to the tractor's linkage, the position occupied by the pickers (standing/sitting) on the loading platforms, the number and distribution of the pickers on the loading platforms, the presence of supporting wheels etc. have been experimentally proven. The optimal conditions for their operation have been determined to realize labor productivity two and more times higher compared to the traditional non-mechanized manual picking of rose flowers.

III-1.6. An agricultural machine for pneumatic harvesting of flowers in oil-bearing rose plantations has been developed, manufactured and tested. The structural strength and functional suitability of all three variants for completing the rose harvesting machine (one-row RHM-1, two-row RHM-2, three-row RHM-3) have been experimentally proven. The main factors on which the efficiency of the machine in operation depends were determined, namely: the condition of the rose plantation, the amount of blossomed rose flowers; the qualification of rose pickers. The applicability of the rose harvesting machine when working with a different (even and odd) number of pickers, its completeness with pickers of different qualifications, operating the pickers with two rose pick-off devices has been verified. Ways have been indicated to achieve productivity with tractor/implement combination formed on the basis of the three-row variant of the machine, which allows within the time range from 5:00 to 10:00 hours to harvest the production from plantations with an area of 1.5 ha and more, incl. in the peak flowering stage of the oil-bearing crop.

III-1.7. Based on the modular principle for the formation of the technique, a multifunctional agricultural machine has been developed in two versions of construction

execution (mounted and semi-mounted) for the realization of technological operations in rose-growing farms by spraying, selective pruning, rose picking and transport activities. The structural strength and functional suitability of each of the technological variants of the multifunctional machine have been experimentally proven.

III-1.8. An agricultural machine for carrying out all pruning operations to form the height and cut the bushes close to the base with simultaneous removal of the cut plant mass to the inter-rows of the oil-bearing rose plantations has been developed, manufactured and tested. Two options for driving the cutting disk of the pruning module of the machine (mechanically and hydro-mechanically) were constructively substantiated and developed, and the specific features for the use of each of them was indicated. The structural strength and functional suitability of the pruning machine have been experimentally verified to perform the technological operation with cutting heights of up to 160 cm, incl. on sloping terrains with a deviation between adjacent rows of 50 cm and more, as well as its advantage over similar in purpose machines to leave the cut bushes clean of plant residues after its passage. Average shift productivity in the range of 3-4 ha/shift of the tractor/implement combination formed on the basis of the rose pruning machine was determined during operational tests, and the influence of operating conditions on its increase or decrease was indicated.

III-2. Scientific-applied contributions

III-2.1. Developed and built into an agricultural machine was a universal hitch-point triangle that allows the connection of mounted and semi-mounted agricultural machines to linkages of categories 2, 2N and 3N approved by standards of the International Organization for Standardization (ISO), and to the two execution versions of the TNU-2 linkage (Version A and Version B), approved by the standards of the Bulgarian Institute for Standardization (BIS), with which medium-power tractors (the most widely used in world agriculture) are equipped. The technical solution for a hitch-point triangle for farm implement solves the problem of the lack of BIS-standardized analogues of all types of linkages with which the leading manufacturers of agricultural tractors equip their models with medium power, providing the possibility of connecting all mounted and semi-mounted agricultural machines to the hitch mechanisms of tractors with medium power, regardless of the variant of execution and the standards according to which their connecting elements are made.

III-2.2. A boom spraying system for treating the bushes in oil-bearing rose plantations, formed according to the three most widely used schemes (with row spacing of 2.8 m, 3.0 m and 3.2 m), when implementing care for plants by spraying during the growing season, such as fighting against diseases and enemies, foliar feeding, spraying in dry periods of time, etc., was developed, manufactured and tested. The type, number and positions of the spreaders on three varieties of the spraying system (with line booms and L-shaped booms for spraying two half-rows and with П-shaped booms for the simultaneous spraying of two rows of rose bushes) were determined, according to the type, stage of vegetative development and the way of forming the crowns of the bushes in the rose plantation.

III-2.3. A boom spraying system for treating the soil surface below the crowns of the bushes in oil-bearing rose plantations to implement plant care by spraying during the growing season related to weed control, the introduction of liquid root stimulators, watering young plants, etc., was developed, manufactured and tested. The spray angles and the parameters for positioning the spreaders on the booms of the spraying system (height from the soil surface, distance from the rose bush, angle of inclination to the horizontal) were determined, guaranteeing quantitative and qualitative treatment of the soil surface at the base of the bush, in two variants for the width of the sprayed area (half or full of the

width under the crown of the rose bush). Regression mathematical formulas were derived for precise determination of the spray angle and the inclination of a spreader for applying herbicides, according to the specific operating conditions (the technological scheme of planting, the condition of the rose plantation, the spraying scheme, etc. factors), in order to prevent the working liquid from falling on the foliage of the oil-bearing plant.

III-2.4. An agricultural machine for pneumatic selective pruning in oil-bearing rose plantations has been developed, manufactured and tested. The technological operation is conducted as the operator carrying out the pruning from the ground remotely, with minimal effort, cuts the rose stems to be removed and collects them on a loading platform for subsequent removal outside the borders of the rose plantation. It is estimated that the pneumatic systems of the agricultural tractors operated in the rose production practice are able to supply two pneumatic scissors with compressed air for continuous selective pruning in oil-bearing rose plantations. It is recommended for selective pruning in rose plantations the use of pneumatic scissors, which allow the cutting of wood up to 25 mm in diameter.

III-2.5. Construction and technological parameters (the diameter dimensions for the suction tips, the type and location of the cutting elements to be embedded in them, the values of the vacuum) of a technical means, which was developed on the basis of the method for the mechanized detachment of the oil-bearing rose flowers from the plant and provides conditions to detach the flowers from the rose stems at any attempt to do so, without sucking the surrounding leaves and undissolved buds, with no or minimal effort applied by the picker were defined.

III-2.6. A technical means (detachable module), assembled on the basis of the pneumo-mechanical method for mechanized picking of oil-bearing roses, has been developed. The type, dimensions and configuration of the elements of the rose pick-off device, ensuring ergonomic operation when picking rose flowers, have been established. The values of the parameters of the working environment (flow rate and pressure of the air flow), which would provide conditions for picking off the flowers and taking them out of the module without unacceptable injury, were calculated. Requirements for the manufacture of the components of the detachable module have been formulated to ensure maximum efficiency in the work process.

III-2.7. A humidifying system for moistening the collected oil-bearing rose flowers in the common container of the rose harvesting machine, with the aim of neutralizing the drying effect of the rising daily temperature and the air flow passing through the common container was developed, assembled and tested. Its functional suitability has been experimentally proven to maintain constant humidity in the range of 80-85%, with the aim of preserving in quantitative and qualitative terms the harvested rose flowers and the essential oil contained in them.

III-3. Contributions of a confirmatory character

III-3.1. It has been established that the sizes of the farms in the Republic of Bulgaria, where oil-bearing roses are grown, differ, as well as that the degree of mechanization and the efficiency of the technical means used are not the same in the rose-growing farms of different sizes. It is concluded that unification of production conditions and increasing the efficiency of the technological process in the growing of oil-bearing rose can be achieved by developing and implementing in practice technical means (farm implement) for the mechanization of activities related to the care of plants and the harvesting of the blossomed rose flowers, according to the size of the rose-growing farms and the possibilities of their owners to invest in new equipment. Suitable for implementation in small-sized farms are machines of the "multifunctional" type, allowing the realization of more than one technological operation, and the formula for their

successful adoption in practice is "simple construction - quick configuration - reliable operation - easy maintenance - acceptable price".

III-3.2. It has been established that in modern rose production, a number of activities in the growing of oil-bearing rose are fully mechanized, others are partially, and the picking of the rose flowers is completely manual, the costs of which in an active flowering plantation are about two thirds of the labor costs, and in recent years, even from the purchase price of the harvested produce. A mandatory condition when starting the developments on the creation of technical means for the mechanization of activities in the growing and harvesting of oil-bearing rose is to find a balance between necessity, possibility of realization and economic expediency.

III-3.3. It has been experimentally proven the impossibility of separating the petals from the ovaries of all rose flowers to be collected using only a vacuum, as well as of detaching the whole flowers from the oil-bearing plant without negative consequences for the plant itself, the detached rose flowers and the essential oil contained in them.

III-3.4. It was established that with the adopted open system of operation of the pneumatic detachable modules, the tractor pneumatic system is not able to provide the necessary conditions for pneumatic picking of the rose flowers without interruption, and the main reasons for this are the inability of its compressor to maintain the necessary constant air pressure in it to realize the vacuum-mechanical detachment of the flowers from the bush and the insufficient volume of its air reservoir to provide without stopping the necessary amount of air to move the detached flowers to the place of their collection.

III-3.5. The advantages of machine picking over the traditional manual picking of flowers from oil-bearing rose have been substantiated and empirically proven, expressed in improved working conditions, reduced need for labor, completeness in harvesting the flowers to be picked for the day, higher productivity and etc.

IV. LIST OF PUBLICATIONS BY THE RESEARCH RESULTS IN THE DISSERTATION

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2. Bozhkov, S., Badrikov, E., Stanchev, S. (2014). Universal hitch-point triangle for agricultural implement. *Proceedings of the international conference "ECO-Varna 2014"*, May 15-17, 2014, Varna, Bulgaria, p. 248-255. ISSN 2367-6299. (In Bulgarian with English abstract)
3. Mihov, M., Bozhkov, S., Badrikov, E., Stanchev, S. (2015). Machine for mechanizing the picking of oil-bearing rose with pneumatic plucking of the rose flowers. *Mechanization of the Agriculture*, 1, p.19-21. ISSN 2534-8450 (online), ISSN 0861-9638 (print). (In Bulgarian)
4. Bozhkov, S., Stanchev, S., Mihov, M., Badrikov, E., Penyashki, T., Gorina, Ts., Todorova, T., Kabadiyski, K., Stefanov, K., Badzhelova, V. (2015). Experimental research of single modular implement for oil rose harvesting. *Agricultural Engineering*, 3-4: p.43-52. Sofia. ISSN 0037-1718 (print). (In Bulgarian with English abstract)
5. Stanchev, S., Bozhkov, S. (2016). Determination of the parameters of a system for pneumatic picking of the flowers from the oleaginous rose plantations. In: *Technics and Technologies in Mechanical, Agriculture and Transport, Proceedings of the International Conference on Technics, Technologies and Education "ICTTE 2016"*, November 17-18,

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V. SHORT DISSERTATION SUMMARIES IN BULGARIAN AND RUSSIAN LANGUAGES

МЕХАНИЗИРАНО ОТГЛЕЖДАНЕ И БРАНЕ НА МАСЛОДАЙНА РОЗА

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Резюме

Маслодайната роза е един от най-значимите символи за национална гордост, а извличаното етерично масло от цветовете на отглеждана в Република България роза е с качества, които от стотици години отреждат лидерската му позиция в световен мащаб. Голяма част от реализираните дейности при отглеждането на маслодайна роза са частично механизирани или напълно немеханизирани. Използването на ръчен труд и нископроизводителни технически средства е характерна особеност на технологичния процес, която и до ден днешен не може да бъде напълно елиминирана. Не е еднаква и степента на механизирание и ефективността на използваната за целта техника в различните по размер розопроизводителни стопанства.

Дисертационният труд на тема „Механизирано отглеждане и бране на маслодайна роза“ е посветен на разработването на методи и технически средства за механизирание на технологични операции в розопроизводителната практика. В рамките му се обосновават организационни форми и технологични схеми, издигат се и се проверяват хипотези, определят се параметри на конструктивни решения, дефинират се методи, създават се работни машини за розопроизводството, позволяващи механизираното извършване на широк спектър от дейности, свързани с грижите за растенията, брането на розов цвят и транспортирането на земеделски товари. От грижите за растенията в розови насаждения след проведен анализ за механизирание са определени резитбените операции и реализираните чрез пръскане дейности, свързани с борбата с вредителите и с регулирането на физиологичните процеси в растенията. Основен акцент в дисертационното изследване е поставен върху механизирането на единствената напълно немеханизирана операция – брането на цвета в насаждения с маслодайна роза.

Отчитайки морфологичните особености на маслодайната култура, типа на стопанствата и реализираните дейности при нейното отглеждане, необходимостта, възможността и икономическата целесъобразност от разработването на технически средства за механизирание на операции от технологичния процес, теоретично обосновани и експериментално изпитани са щангови опръскващи уредби за цялостно опръскване на розовите храсти и за третиране на почвената повърхност под техните корони, земеделски работни машини за реализиране на селективна, контурна и близко до основата резитби, едномодулна и тримодулна работни машини за механизирание брането на цвета в насаждения с маслодайна роза, метод за механизирание отделянето на цвета от розовото растение и техническо решение за прилагането му, пневмо-механичен метод за бране на маслодайни рози и технически средства за неговата реализация. Модулният принцип за създаване на техниката, на основата на който са комплектовани четири от разработваните работни машини, позволява обединяването им в една „многофункционална машина“, с която може да се реализирана и транспортна дейност.

Разработена е класификация на розопроизводителните стопанства в Република България по критерия „използвана земеделска площ“ и са определени оптималните енергетични средства за механизирано отглеждане на маслодайната култура във всяко едно от тях. На тяхна база собствениците на стопанства могат да

преценят необходимите, но и адекватни на възможностите им инвестиции за закупуване на земеделска техника, а държавните изпълнителни органи да прецизират разпределението на средствата за подпомагане на земеделските стопанства, съобразно техните възможности за ефективно усвояване.

Обосновани са параметрите, изработена и вградена в работна машина е универсална триточкова стойка, която позволява агрегатирането на навесни и полунавесни земеделски работни машини към тракторни навесни устройства от категории 2, 2N и 3N, утвърдени със стандарт на Международната организация по стандартизация (International Organization for Standardization - ISO), и към двата варианта на изпълнение на навесното устройство ТНУ-2 (Изпълнение А и Изпълнение Б), утвърдени със стандарт на Българския институт по стандартизация (БИС), с които се съоръжават тракторите със средна мощност - най-масово използваните в световното земеделие.

Обоснована теоретично и проверена експериментално е двуфазна схема, комбинираща пневматично засмукване на цвета и механично отрязване на цветната дръжка под чашката, на базата на която е дефиниран метод за механизирано отделяне на цвета на маслодайна роза от растението.

Дефиниран е пневмо-механичен метод за механизирано бране на маслодайни рози, в съответствие с който розовият цвят се отделя от храста чрез пневматично засмукване на цвета с механично отрязване на цветната дръжка под чашката и се предвижва от въздушен поток до мястото за събиране.

Разработени, изработени и изпитани са едномодулна и тримодулна земеделски работни машини за ръчно бране на маслодайна роза, транспортиращи в редовете на розовите насаждения берачите и събраната от тях продукция по време на розобера. Освобождавайки розоберачите от необходимостта да се самопредвижват по тежката (твърде често през розоберния период) почвена повърхност и да носят част от събраната продукция върху себе си, осигурявайки им позиции с подобрена обзорност на работните зони, редуцирайки контактите с шиповете по розовите храсти, всяка от двете машини създава по-добри условия за работа и възможности за повишаване на производителността на труда два и повече пъти. За вграждане в тримодулната работна машина е разработена откъсващо-транспортираща вакуумна система, даваща възможност за вакуумно откъсване на розовия цвят.

Разработена на базата на пневмо-механичния метод за бране на маслодайни рози е земеделска работна машина за пневматично бране на цвета от насаждения с маслодайна роза. Доказана експериментално е конструктивната здравина и функционалната пригодност на всичките й три варианти за комплектоване (едноредов, двуредов, триредов). Определени са основните фактори (количеството разцъфнал розов цвят, квалификацията на розоберачите, постъпателната скорост на движение на беритбения машинно-тракторен агрегат), от които зависи ефективността на работната машина при експлоатация. Удостоверена е приложимостта й при работа с различен (четен и нечетен) брой берачи, комплектоване с берачи с различна квалификация, опериране на берачите с по два цветоотделителя. Посочени са пътища за постигане на производителност с триредовия машинно-тракторен агрегат, която позволява в рамките на времеви диапазон от 5:00 до 10:00 часа да се прибира продукцията от насаждения с площ 15 и повече декара (1.5 ha), вкл. в пиковия етап на цъфтеж на маслодайната култура.

Разработена, изработена и изпитана е земеделска работна машина за провеждане на всички резитбени операции за формиране на височината и изрязване на храстите близо до основата с едновременно изнасяне на изрязаната растителна маса в междуредията на насажденията с маслодайна роза. Конструктивно

обосновани и изпълнени в натура са два варианта за задвижване на режещия диск на резитбения модул на машината (по механичен и хидро-механичен път), като са посочени специфичните особености за използването на всеки от тях. Удостоверена по експериментален път е конструктивната здравина и функционалната пригодност на работната машина да реализира технологичната операция с височини на рязане до 160 cm, вкл. и на наклонени терени с денивелация между съседни редове от 50 cm и повече, както и предимството ѝ пред аналогичните по предназначение работни машини да изнася отстранената растителна маса в междуредията на розовото насаждение, оставяйки изрязаните храсти чисти от растителни остатъци. Определена при експлоатационни изпитвания е средна сменна производителност в диапазона 3 – 4 ha/смяна на резитбения машинно-тракторен агрегат, формиран на основата на машината за резитба на рози, като е посочено влиянието на условията на експлоатация върху нейното нарастване или понижаване.

По резултатите от изследванията в дисертационния труд са формулирани 20 приноса с оригинален, научно-приложен и потвърдителен характер, регистрирани в Патентното ведомство на Република България са 4 полезни модела, представени на международни и национални научни форуми са 14 доклада, публикувани са 28 научни труда у нас и в чужбина, получени са 4 награди от международни и национални организационни структури.

МЕХАНИЗИРОВАННОЕ ВЫРАЩИВАНИЕ И СБОР МАСЛИЧНОЙ РОЗЫ

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Резюме

Масличная роза является одним из наиболее значимых символов национальной гордости, а эфирное масло, полученное из цветков розы, выращенной в Республике Болгарии, обладает качествами, благодаря которым оно на протяжении сотен лет занимает лидирующие позиции во всем мире. Большая часть операций, выполняемых при выращивании масличной розы, частично или полностью немеханизирована. Использование ручного труда и малопроизводительных технических средств является характерной особенностью технологического процесса, полностью устранить которую до сих пор не удастся. Степень механизации и эффективность оборудования, используемого для этой цели, неодинакова в розоводческих хозяйствах разного размера.

Диссертационная работа на тему «Механизированное выращивание и сбор масличной розы» посвящена разработке методов и технических средств механизации технологических операций в розоводстве. В ее рамках обосновываются организационные формы и технологические схемы, выдвигаются и проверяются гипотезы, определяются параметры конструктивных решений, разрабатываются методы, создается рабочий инвентарь для розоводства, позволяющий механизировать выполнение широкого спектра работ, связанных с уходом за растениями, сбором розовых цветков и перевозкой сельскохозяйственных грузов. Из работ по уходу за растениями в розовых насаждениях, после анализа, для механизации определены работы по обрезке кустов и осуществляемые опрыскиванием мероприятия, связанные с борьбой с вредителями и регулированием физиологических процессов в растениях. Основной акцент в диссертационном исследовании сделан на механизацию единственной полностью немеханизированной операции - сбора цветков масличной розы.

С учетом морфологических особенностей масличной культуры, типа хозяйств и мероприятий, проводимых при ее выращивании, необходимости, возможности и экономической целесообразности разработки технических средств механизации операций технологического процесса, теоретически обоснованы и экспериментально проверены штанговые опрыскиватели для сплошного опрыскивания кустов роз и обработки поверхности почвы под их кронами, сельскохозяйственные машины для осуществления выборочной, контурной и прикорневой обрезки, одномодульная и трехмодульная машины для механизации сбора цветков с плантаций масличных роз, метод механизации отделения цветков масличной розы от растения и техническое решение по его применению, пневмомеханический метод уборки масличных роз и технические средства для его осуществления. Модульный принцип создания техники, на основе которого собраны четыре из разработанных машин, позволяет объединить их в одну «многофункциональную машину», которую можно использовать и для транспортной деятельности.

Разработана классификация розоводческих хозяйств Республики Болгарии по критерию «используемая сельскохозяйственная площадь» и определены оптимальные энергетические средства для механизированного выращивания масличной культуры в каждом из них. На их основе собственники фермерских хозяйств могут оценить необходимые, но и адекватные их возможностям инвестиции для приобретения сельскохозяйственной техники, а органы государственной исполнительной власти могут уточнить распределение средств на поддержку хозяйств в соответствии с их возможностями эффективного использования.

Обоснованы параметры и встроена в сельскохозяйственную машину универсальная трехточечная навеска, позволяющая агрегатировать навесные и полунавесные машины к тракторным навесным устройствам категорий 2, 2N и 3N, одобренным стандартом Международной организации по стандартизации (ИСО), и к двум вариантам навесного устройства ТНУ-2 (Исполнение А и Исполнение Б), одобренным стандартом Болгарского института стандартизации, все предназначены для тракторов средней мощности - наиболее широко используемые в мировом сельском хозяйстве.

Теоретически обоснована и экспериментально проверена двухфазная схема, сочетающая пневматическое засасывание цветка и механический срез его стебля ниже чашечки, на основе которой разработан метод механизированного отделения цветка масличной розы от растения.

Разработан пневмомеханический метод механизированной уборки масличных роз, согласно которому цветок розы отделяют от куста пневматическим засасыванием цветка с механическим срезом его стебля ниже чашечки и перемещают воздушным потоком к месту сбора.

Разработаны и испытаны одномодульная и трехмодульная сельскохозяйственные машины для ручного сбора масличных роз, транспортирующие сборщиков и собранную ими продукцию в рядах розовых насаждений. Освобождая сборщиков роз от необходимости самостоятельно передвигаться по тяжелой (слишком часто в период сбора роз) поверхности почвы и носить на себе часть собранной продукции, обеспечивая им места с улучшенным обзором рабочих зон, уменьшая контакты с шипами розовых кустов, каждая из двух машин создает лучшие условия труда и возможности повысить производительность труда в два и более раза. Вакуумная система для отрыва и транспортировки розовых цветов была разработана для оснащения трехмодульной машины.

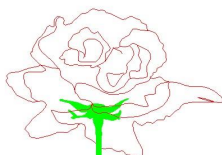
На основе пневмомеханического метода уборки масличных роз разработана сельскохозяйственная машина для пневматического сбора цветков с плантаций масличных роз. Экспериментально доказана конструктивная прочность и

функциональная пригодность всех трех вариантов ее компоновки (однорядная, двухрядная, трехрядная). Определены основные факторы (количество распустившегося розового цвета, квалификация сборщиков роз, поступательная скорость уборочного машинно-тракторного агрегата), от которых зависит эффективность рабочей машины при эксплуатации. Доказана ее применимость при работе с разным (четным и нечетным) количеством сборщиков, комплектации со сборщиками разной квалификации, работе сборщиков с двумя цветоотрывателями. Указаны способы достижения производительности с помощью трехрядного машинно-тракторного агрегата, который позволяет в интервале времени от 5:00 до 10:00 часов собирать урожай с плантаций площадью 1.5 га и более, в т.ч. в фазе пика цветения масличной культуры.

Разработана, изготовлена и испытана сельскохозяйственная машина для проведения всех операций по обрезке кустов для формирования их высоты и омоложения с одновременным удалением срезанной растительной массы в междурядьях насаждений масличной розы. Конструктивно обоснованы и реализованы в натуре два варианта привода режущего диска обрезающего модуля машины (механический и гидромеханический) и указаны особенности использования каждого из них. Прочность конструкции и функциональная пригодность рабочей машины для выполнения технологической операции с высотой обрезки до 160 см, в т.ч. и на наклонных участках с перепадом уровней между соседними рядами 50 см и более, а также его преимущество перед аналогичными рабочими машинами выносить срезанную растительную массу в междурядья розовых насаждений. В ходе эксплуатационных испытаний определена средняя сменная производительность в диапазоне 3–4 га/раб.смена обрезного машинно-тракторного агрегата, сформированного на базе машины для обрезки роз, и указано влияние условий эксплуатации на ее повышение или снижение.

По результатам исследований в диссертации сформулировано 20 положений, выводов и рекомендаций, отмеченных как вклад в науку, с оригинальным, научно-прикладным и подтверждающим характером, 4 полезные модели зарегистрированы в Патентном ведомстве Республики Болгарии, 14 докладов представлены на международных и национальных научных форумах, 28 научных работ опубликованы в Болгарии и за рубежом, получено 4 награды от международных и национальных организационных структур.

MECHANISED GROWING AND HARVESTING OF OIL-BEARING ROSE
Abstract of the dissertation for acquiring the scientific degree "DOCTOR OF SCIENCES"
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