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Mechanised Harvesting of Safflower (*Carthamus tinctorius* L., *fam. Asteraceae)* – a review

Muscalu Adriana,
Tudora Cătălina,
Cristian Sorică,
Dragoş Anghelache

Testing Department of INMA Bucharest
National Institute of Research – Development for Machines and Installations Designed for Agriculture and Food Industry – INMA Bucharest
Bucharest, Romania
amuscalis@yahoo.com

***Abstract*—Safflower (*Carthamus tinctorius* L., *family Asteraceae*) is part of the species with a "wide biodiversity portfolio", which has genetic potential, but is underutilized for commercial cultivation. Such species offer viable agricultural alternatives in response to climate change, being adapted to cultivation on less fertile, even marginal, land. The cultivation potential of Safflower is high, but in our country there are few cultivated areas. The lack of documentation regarding the cultivation technology, as well as the lack on the market of biological material necessary for sowing the crops, led to the disinterest of the growers in this plant. However, in recent years, the attention given to this crop has increased, due to more and more intense lack of water and limitation of precipitation, which cause a huge deficit in the production of oilseeds, the Safflower being, however, resistant to these conditions. To these added are the consumers' preference for the healthy oil, with less saturated fat, for which Safflower oil is well known. Also, the species has medicinal properties, and edible dyes are extracted from its flowers. Every part of the Safflower plant can be used after processing, as food, phytomedicine, biofuel, for ornamental purposes, etc. Collecting the petals is a difficult operation, especially for the thorny varieties of the species, and it is done manually. The high labour costs, as well as the difficulty of finding it, create problems for the development of the processing industry of this plant. The paper presents a brief summary of the technical systems for the mechanized harvesting of Safflower depending on its uses, including the current state of research regarding the design and experimentation of robots intended for the collection of inflorescences.**

***Keywords*—Safflower, mechanized harvesting, seeds, petals/inflorescences**

I. INTRODUCTION

Among the oldest annual crops used by man, there is the Safflower (*Carthamus tinctorius L.*) belonging to the Asteraceae family [1]. It is a plant from the temperate zone, which tolerates drought well, similar to a thistle, originally from the Middle East, Iran being, it seems, one of the centres of origin [2]. Its centuries-old history of cultivation spans a vast region, from China, India, South Asia, to the Mediterranean Basin and along the Nile Valley to Ethiopia [3,4]. It was cultivated mainly for its flower petals, which contain red and orange pigments, used to colour food and textiles [4]. After the discovery of synthetic dyes based on aniline, much cheaper, it was cultivated for oilseeds and as birdseed, as well as for applications in traditional medicine [1,4]. Although Safflower shows adaptability with high yields to various growing conditions, to which are added numerous uses, for a long time it was treated with negligence, being considered a minor crop, compared to other oil crops [3,5]. The reconsideration of its position was determined by the current context of climate change and the increase in demand for safe and healthy foods [3,6,7]. Nowadays, the interest in this plant is due to: the drastic decrease in the production of oilseeds (e.g. sunflower) in the countries where it can be cultivated, because of the drought; consumers' preference for oil with less saturated fat, such as Safflower oil; preference for the use of natural dyes for food [3,6]. The pigments of the Safflower petals are very soluble and stable in water, in the presence of light, and can be used at different values of temperature and pH [1]. Moreover, numerous studies have shown that this multifunctional plant can be fully exploited. Safflower has medicinal properties for the treatment of several ailments, it can be used as fodder, biofuel, ornamental plant, in cosmetics, etc. [3,4,5,6].

According to the FAO in 2021, of the 18 main producing countries, Kazakhstan ranked first (maintained since 2017) in the production of Safflower seeds, with 223.895 tons, followed by Russia and the USA, all together holding a share of 69.2% of the total production in the world [8].

In Romania, Safflower has been cultivated since 2003, on small areas. Being in the area of high risk of drought and desertification in Europe, for local farmers, it represents a viable alternative to the traditional sunflower culture, for the areas of the country with a lack of moisture and less fertile soils, but important for food resources. These are the south and southeast areas most affected, the Central Moldavian Plateau, the centre of Transylvania [9].

This paper presents the current state of achievements in the field of mechanized harvesting of Safflower seeds and, respectively, of its flower petals.

II. MATERIAL AND METHOD

According to [10], in the literature there is little information about the harvesting of Safflower seeds. This occurs when the leaves of the plant are brown, it being completely dry, the seeds having a humidity of 8-11% [9,11].

Fig. 1. Safflower crop in flowering stage and at physiological maturity [11]

The collection is carried out with a combine harvester, equipped with a header for wheat, adjusted according to the characteristics of each Safflower crop [9,10]. The working speed will be lower than that for grain, and the speed of the thresher correlates with it, so as not to shake the seeds. The speed of the shakers will be adjusted, being higher than that used for grains with small seeds, and that of the fan will be adjusted to remove the empty pods [11]. The experiments for the mechanized harvesting of Safflower seeds were carried out in Sardinia (Italy). The plants were sown at 45 cm between rows, with an effective density of 42 plants per 1 m^2, with an average height of 131.1 cm (without dormant plants), the flower heads having an average diameter of 23.4 mm, with an average number of 8 ,4 per plant and approx. 354 per 1 m^2 [12]. A Laverda combine was used for collection, having: threshing drum speed of 800 rpm; concave clearance of 54 mm; fan speed of 400 rpm; upper sieve clearance of 11 mm; lower sieve clearance of 6 mm [10].

Manual harvesting of Safflower petals is a cumbersome, tiring, slow and expensive operation, because most cultivated varieties are thorny. Added to these are the losses of petals that occur during collection [13]. For one hectare cultivated with Safflower, the mass of the petals, which depends on several factors, was estimated at approx. 60-70 kg in India and respectively at approx. 96 kg in Iran [13, 14]. The lack of labour has determined studies and research for the development of technologies for collecting Safflower petals, based on easy-to-handle and efficient equipment. [13,14, 15, 17]. Experimental models of portable petal harvesting equipment were made, based on their aspiration, operated with an electric motor (fig. 2) or a heat engine (fig. 3).

Fig. 2. Battery powered petal collector [13]

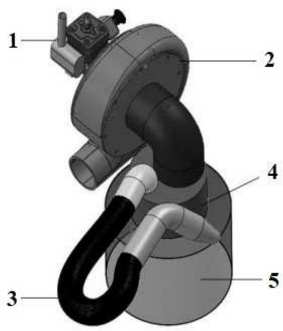

Fig. 3. Safflower petal harvester machine [14]

Battery powered petal collector consists of: direct current electric motor (U=12 V, P=27 W; n=5000 rpm) mounted on a fan, powered by a battery (U=12 V, I=14A), having a suitable housing, which also contains a cyclone. The pipes are made of PVC, and the end that approaches the flower has a shape suitable for weakening the position of the petals on the inflorescence, so that they can be sucked in by the depression created by the fan. The elements are mounted on a portable support, the overall dimensions of the equipment (LxWxH) being 250x230x500 mm, and the mass being 9.4 kg [13]. According to the scheme (fig.3) Safflower petal harvester machine has a composition similar to the previous model: 1-engine, 2-fan, 3-suction system, 4-diffuser, 5-storage enclosure. The elements were mounted on a cart for easy movement in the culture. The two-stroke heat engine, fuelled with gasoline, intended to operate the fan, has a power of 0.7 kW and a maximum speed of 5500 rpm. For suction, a radial fan with 12 blades is used, having a diameter of 0.3 m, a width of 0.06 m, a speed of 4400 rpm, an air flow rate of 0.384 m^3 s^{-1} and respectively a specific speed of 6.157 m s^{-1}, at a static pressure of 3161 Pa. The suction system is connected to the diffuser, consisting of a flexible tube with an inner diameter of 0.03 m and a suction head. At a dynamic pressure of approx. 388.57 Pa, the determined speed of the air current was 25.55 m s^{-1} (temperature in the tube approx. 28^0C, relative humidity 20.9% and air density 1.19 kg m^{-3}). The cylindrical diffuser, with a radius of 0.0536 m, was dimensioned so that the dynamic pressure and air velocity decrease inside it to approx. 2 m s^{-1}, the petals falling by their own weight into the storage enclosure. Its volume of 4 litres was determined by the density of the petals and the performance of the equipment [14].

For efficiency, a portable device was experimentally created that uses the combination of suction and cutting to harvest the Safflower petals. Starting from the previous models, instead of the suction tube, a positioning mouth of safflower heads was used, with a cutting system. The depression generated by the fan acts on the petals, which reach a vertical position. They are detached from the flower head by cutting. The cutting system is driven by a motor, through a planetary gear. Once cut, the petals are sucked towards the collecting box, whose shape allows them to fall in its lower area, following the expansion of the air current [15]. Starting from the previously described combination, a robot (fig. 4) for harvesting Safflower petals was created and tested in the laboratory, consisting of: 1- electric drive wheels, 2-frame, 3- parallel manipulator device, 4-controller, 5 -servomotor, 6-suction fan, 7-transport hose, 8-collecting box, 9-travel wheels, 10- picking device [16].

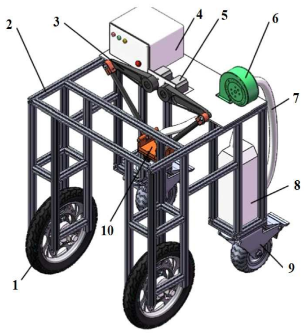

Fig. 4. Safflower harvesting robot [16]

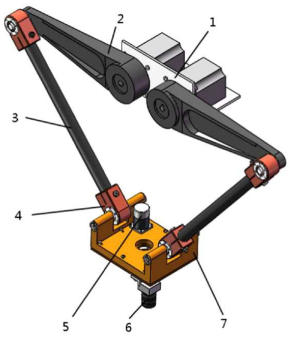

Fig. 5. Coupling of positioning and harvesting systems [16]

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Parallel manipulator device, whose arms move independently, ensures parallel plane movement for the picking device (fig.5), the main elements being: 1-motor plate, 2-actuation arm, 3-driven arm, 4-adapter, 5-stepper motor, 6-CCD camera (video camera that contains a charge-coupled device), 7-picking device. The machine moves and stops when it reaches the area where there is mature safflower to be harvested. The position of the Safflower head, through its coordinates, is registered and processed in advance. Afterwards, a PLC (programmable logic controllers) controls the rotation of the shaft of each motor connected to each active arm of the positioning system, so that the picking device moves vertically to the target position. The flower head enters the cutting hole of the picking device, the petals being directed vertically due to the negative pressure generated by the fan, from the end of the transport hose. The petals are cut by alternate shearing, being sucked into the collecting box, through the transport hose [16].

Parallel manipulator device having two degrees of freedom is a type of mechanism used often in robotics, in this case representing one of the main elements of the machine. A kinematic analysis of the mechanism and a modeling were performed. The purpose was to study the influence of errors for driving angle Ψ (fig.6) on the final position of the picking device platform, expressed by the coordinates of the centre of the cutting hole base. The point was noted with T, the coordinates of the position being T (T_x, T_y) for ideal conditions, and when there were errors it became T'(T_x', T_y'). The deviation from the position of point T was calculated with (1), [16]:

$$\Delta T = \sqrt{(T_x' - T_x)^2 + (T_y' + T_y)^2} \quad (1)$$

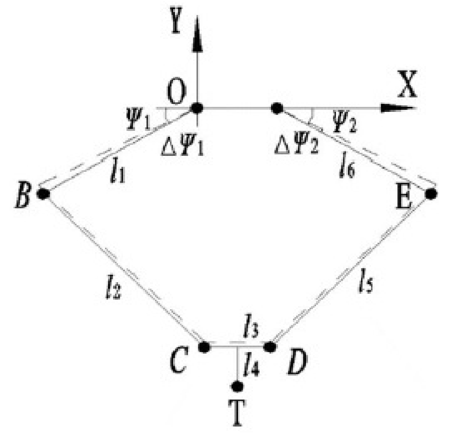

Fig.6. Scheme of the mechanism and the influence of the errors of the driving angles on the position of the picking device platform (CD), Ψ_1, Ψ_2–driving angle of the actuation arms (l_1 and l_6); $\Delta\Psi_1$, $\Delta\Psi_2$–the eror values for the driving angle; T - the centre of the cutting hole base [16]

The modeling was done with a system of non-linear equations that allowed the calculation of the coordinates of the T', when there were errors [16].

Also for the harvesting of the Safflower petals, a roller harvesting device was designed, based on petal plucking by rubbing. In this method it is no longer necessary the precise positioning of the flower head (in the direction of the suction current), characteristic for the previous ones. The main element of the device consists of two cylindrical rubber rollers, of the same diameter that rotate in the opposite direction (fig.7). The distance between rollers can be adjusted, as well as their speed. The movement of rapid rotation of the rollers generates a stream of air, so that some of the petals are absorbed on the roller. Then the emptiness between the rollers is filled with the other petals, their movement continuing. Due to friction and extrusion, the petals are plucked, then they fall into the collecting box, due to gravity. Using a test bench, the factors that influence the process of harvesting the Safflower petals and their values were determined. The variation of the flower head form and the humidity of the petals during several days after flowering were taken into account [17].

Thus, considering the size of the flower necking h_0= 2.95~7.24 mm and for Δh (fig.7) defined by (2), roller clearance was set h_1=0.3-0.7 mm [17].

$$\Delta h = h_0 - h_1 = 0.9 h_0 \quad (2)$$

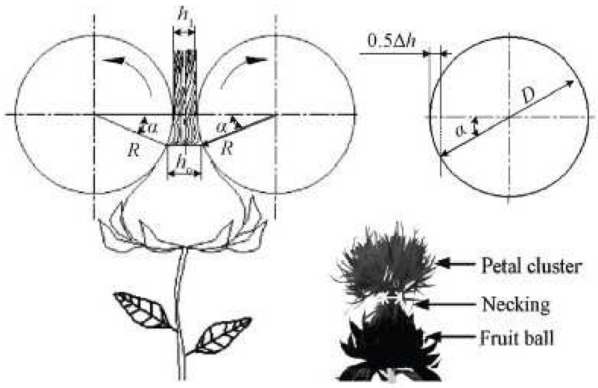

Fig.7. Geometric sketch of deformed area during plucking process, α-friction angle (⁰); R-roller diameter (mm); D- roller diameter (mm); h_0-flower necking diameter (mm); h_1-roller clearance (mm); Δh- difference between the diameters of Safflower petal cluster before and after deformation (mm) [17]

The value of the measured friction coefficient was μ=0.6(=tg α). The diameter of the rollers D=20-40 mm was determined from (3). The speed of the rollers was established between 600 and 1400 r min^{-1} [17].

$$\Delta h = 2(R - R\cos\alpha) = D(1 - \cos\alpha) \quad (3)$$

The efficiency of the harvesting process was evaluated by experimental determination of the following qualitative working indices expressed in percentage, as the report of some masses (g):

- removal rate- the ratio of the mass of extracted petals (collected + plucked, but fallen) to the total mass of the petals (collected + plucked but fallen + left) from a flower head;
- dropping rate - the ratio of the mass of the petals plucked but fallen to the total mass of the petals on a flower head;
- broken rate - the ratio of the mass of plant material plucked by the device from the Safflower head to the mass of the petals extracted (collected + plucked, but fallen) from the flower head [17.]

Based on the previously presented roller device, a Safflower petal harvesting robot (fig.8) was made consisting of: 1-Displacement system; 2-Frame; 3-Fan; 4-Collecting box; 5-Transport hose; 6. Roller collecting system; 7- Linear positioning system in three directions; 8-Visual recognition system; 9-Control box. The movement of the positioning system determines that the *Collecting system* set on it operates in a well-defined space [18].

The robot moves in the Safflower crop, harvesting plant by plant and stops above each safflower plant. Information on the three-dimensional coordinates of the flower head is received from the visual recognition system. According to this information, the controller positions the collecting system at the point of collection, following a specified track [18].

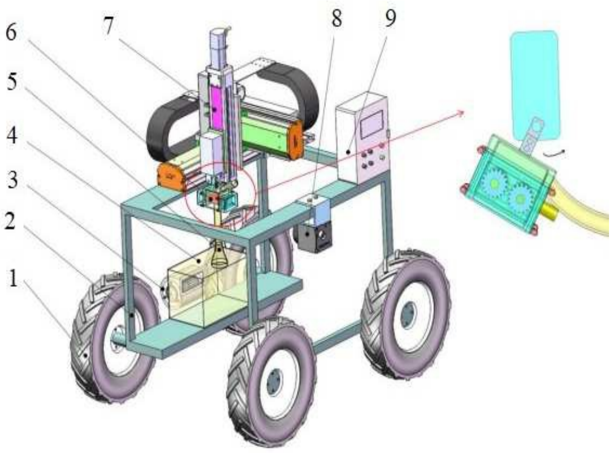

Fig. 8. Scheme of Safflower harvesting robot equipped with roller collecting system [18]

Depending on the information received regarding the inclination angle of the flower head to be harvested, the controller commands the appropriate rotation of the collecting system. Only then its engine starts for effective harvesting and, due to rubbing, petals pass through the transport hose in the collecting box. After that, in accordance with the picking points sequence planned by the algorithm, the controller runs the collecting system along the picking track specified at the following collecting point. After collecting all the heads of a Safflower plant, the robot moves to the next plant, where the cycle starts again [18]. The efficiency of the robot harvesting process is influenced by the following factors: the angle of inclination of the head from the vertical, the distance between the Safflower flower and the rollers and the distance between the heads. The aim was to optimize the harvesting process by improving the ant colony algorithm (ACA) of the harvesting track [18].

III. Results and Discussions

A. Safflower seed harvesting

The results obtained when harvesting the Safflower seeds were: working speed of 3.7 km h^{-1}, the effective working capacity of 1.32 ha h^{-1}, and the seed losses were 3.2%. Of these, 1.7% were damaged seeds and 22.8% impurities. Therefore, the efficient mechanical harvesting of this oil culture can be performed by a harvester to which fine adjustments were applied, equipped with conventional wheat header [10].

B. Petal harvesting

Following the experiments with Battery powered petal collector for Safflower petal harvesting, a productivity of 0.4 kg/day was registered, 1.6 times higher compared to that manually performed (0.25 kg/day). The use of the equipment is suitable for small surfaces, for experimental purposes, in organic farming [13].

Safflower petal harvester machine was used to collect petals with humidity of: 70%, 60%, 50%, 40%. The equipment functioned well, collecting the Safflower petals regardless of their rank or wilting. The economic analysis made highlighted the efficiency of the equipment compared to the manual harvesting (TAB.1) [14].

TABLE I. Economic Analysis [14]

Indicators	Safflower petals harvesting type	
	Mechanised	***Manual***
Cost of machine ($)	183	-
Labour cost ($/day)	30	30
Collected petals (kg/day)	2.3	0.35
Harvested area (m^2/day)	328	49
Fuels charges ($/day)	11	-

For the Safflower petal harvesting robot the driving angle of the active arm in the presence of an error value is: $\Psi_i' = \Psi_i + \Delta\Psi$, (i=1,2). ΔT_i (i=1,2) represents the error for the final position, when drive angles of each of the mechanism arms generates errors separately. ΔT represents the error of the final position, when the drive angles of each of the mechanism arms generates errors simultaneously. When the value of drive angle error ranged from 0.001° to 0.005° (fig.9) the calculated accuracy of the ideal movement of the mechanism varied between 0.2174–0.9387 mm, influencing to a small extent the harvesting process [16].

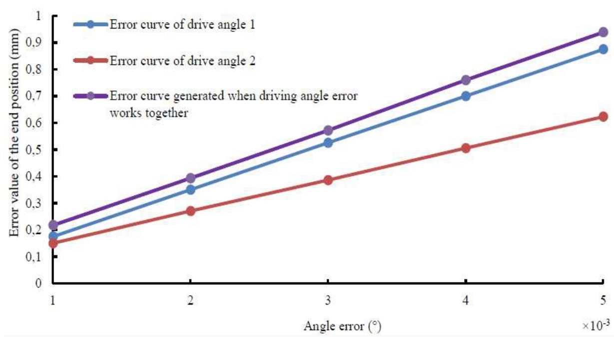

Fig. 9. Curve of drive angle error [16]

In order to verify the feasibility of the robot, it was tested in the laboratory, to collect the petals of some Safflower plants in pots. Thus the average period of a harvesting cycle was 16 s, and the average petal harvesting degree was 87.91 % (taking into account only the petals that reached the collection box). The picking cycle is defined as being the time from the end of the picking of the last flower ball to the end of the picking of the current flower ball [16].

For the roller harvesting device in order to optimize the constructive and functional parameters, the experimental results obtained in the laboratory have been statistically analysed using the regression functions. Thus, the dependence of the qualitative working indices (removal rate, dropping rate, broken rate) on the influence factors (independent variables) was expressed: the diameter of the rollers D, the rolling space (roller clearance) h_1, the speed of the rollers. A test plan and values for variables were established. The Design-Expert 6.0.10 data analysis software was used. After optimization, the area of efficient combination of the roller diameter and the rotation speed (fig.10) for roller clearance h_1=0.5 mm was obtained [17].

The most satisfactory combination selected by the software was for: roller clearance h_1=0.5 mm, the diameter of the rollers D=40 mm, the rotation speed n=1400 r min^{-1}, the working width=60 mm, obtaining the following theoretical values for the model: removal rate=94.42%, dropping rate=2.63%, broken rate=2.21% [17].

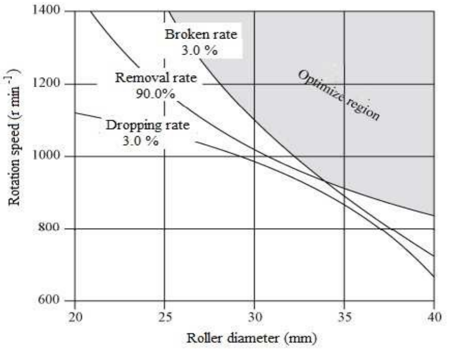

Fig. 10. The optimal combination area for influence factors when roller clearance is 0.5 mm [17]

The laboratory device was tested for the determined optimal dimensions. For fresh and semidry flowers (humidity between 78.4% and 44.6%) were obtained: removal rate>94.42%, dropping rate<1.81%, broken rate<2.13%. The roller harvesting device was made as a portable system, operated by a 1.5 kW heat engine, being tested in the field (fig.11,12) [17].

Fig. 11. Portable roller harvesting device [17]

Fig. 12. Safflower after harvesting [17]

The tests in the field were made in July, in a Safflower culture having: row spacing of 40 cm, 15 cm between plants in a row, the height of plants of 70-100 cm and the humidity of the flowers between 42.1% and 74.3%, on 5 plots of 2 m^2 each, located on the diagonal of the experimental surface. The average of the results obtained in experiments for each quality index was: removal rate=90.224%, (86.03<removal rate<93.4), dropping rate=2.256%, (0.99<dropping rate<2.99), broken rate=1.138%, (0.36<broken rate<3.20) [17].

For the Safflower petal harvesting robot, equipped with a roller collecting system, it was aimed to obtain the optimal sequence of harvesting by sorting the heads (points) to be harvested according to certain criteria and considering the factors of influence. As for the automatic planning of the safflower heads picking track, the ant colony algorithm (ACA) was improved by the three-dimensional organization of the harvesting direction, combined with the characteristics of the safflower heads and with the requirements imposed for the roller harvesting system. Thus, only the heads that fall between certain dimensional limits and are inclined at a certain angle as to the vertical are subject to the collection process. The collecting system is effective if it acts in the direction of the flower head. Therefore, in order to remove the unnecessary rotation times of the roller system, the flower heads inclined against the vertical at close angles, located at small distances between them, are taken into account (fig. 13). Based on the information received regarding coordinates, the algorithm calculates the area by drive height, then establishing the harvesting sequence with the shortest collecting track and the smallest rotation angle [18].

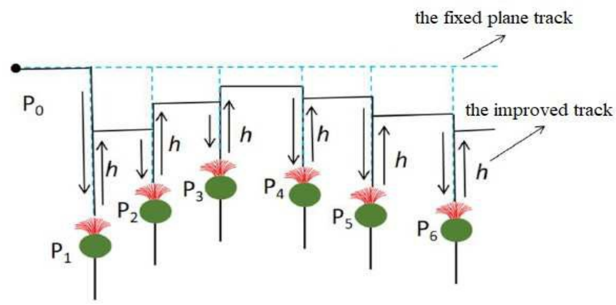

Fig. 13. Comparison of two picking track models [18].

IV. CONCLUSIONS

Unlike other oil crops, Safflower can be easily harvested by wheat harvester. This important feature supports the promotion of double cropping with traditional crops in both Mediterranean and temperate areas. Regarding petal harvesting, the presented equipment was made experimentally, and the relatively satisfactory test results that were obtained are important for the optimization of various types of component subassemblies. They constitute an important reference for further testing, the goal being the most efficient collection of petals in the shortest possible time.

Research in the field will be continued, because, due to the characteristics and multiple uses of Safflower, the upward trends regarding its cultivation and exploitation are intensively manifested in many areas of the world.

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