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SAFFRON MECHANIZED HARVESTING

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Abstract: Saffron is the most expensive spice in the world, consisting of the stigmas of the flower, which dried and sprayed properly, are appreciated and used for colouring and flavouring food. In the production process, the collection of flowers and the separation of stigmas are the most difficult phases, requiring a lot of time and being carried out in some regions of the world, in cold periods of the year (October – November). Due to the high consumption of labour, there are concerns about the development of devices that facilitate the effort of the gatherers in the open field. The paper presents a brief summary of current achievements in the field of mechanized saffron harvesting.
Keywords: saffron, mechanized harvesting, flower collecting, stigma separation

1. INTRODUCTION

Saffron *(Crocus sativus* L., *Iridaceae Family)* is a perennial plant (Figure 1), cultivated for its aromatic properties, especially appreciated. It is called "red gold", the red stigmas of the flowers of *Crocus sativus* L., are considered the most valuable spice in the world, being used as flavouring and colouring agents. Its price is on average 1500–2200 euros/kg. To obtain 0.5 g of dried saffron it is necessary to process between 75 – 100 flowers, from which results 225–300 saffron threads. *(Mykhailenko O. et al., 2020, Kothari D. et al., 2021)*.

Saffron is also used successfully in medicine, as it contains substances beneficial to the whole body, with effects on reducing blood pressure and alleviating the symptoms of mild to moderate depression, to which are added antioxidant, anticancer, antifungal, etc. properties. (*Hashemi H. et al., 2020)*.

Figure 1 – Saffron on the field (Mazloumzadeh, M. 2017)

Figure 2 – Saffron flowers (Kothari D. et al. 2021)

Saffron is produced today in European countries (especially Spain, Italy, France, Greece, etc.), North Africa (Morocco, Algeria), Iran (with about 90% of total annual saffron production), India, China , etc. There are also saffron crops in Turkey, Israel, Russia, Switzerland, Australia (Tasmania) and the USA *Hashemi H. et al. 2020, Kothari D. et al., 2021*). In recent years, in Afghanistan the replacement of poppy plantations with saffron ones has been encouraged as an alternative source of income for small farmers. In fact, saffron is an important commercial crop for small farmers, who live in the marginal areas of the large producing countries and regions mentioned above (Iran, North Africa, Kashmir and the Mediterranean countries). *(Schmidt T. et al 2019, Ramezani M. et al. 2022).*

The saffron flower (Figure2) has 3–6 petals (violet), 3 stamens (yellow) and 3 stigmas (red). The stigmas characterize the saffron flower due to the dark red to reddish–brown colour and the length between 25–30 mm. They usually hang between the petals of open flowers. The petals are separated from each other, having lengths between 30–50 mm *(Moghanizadeh A. et al. 2015, Kothari D. et al. 2021).*

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Saffron harvesting begins when the flowers open in October–November and lasts for a few weeks. Being cultivated in the open field, the harvesting must be carried out quickly, in order to avoid the unfavourable weather, which destroys the extremely sensitive flowers. Harvesting takes place in two phases: the open flowers are harvested after the dew has risen, then the 3 stigmas are separated from the petals and stamens, being dried on the same day. The operation requires a very high consumption of manual labour, carried out in a short time. It takes approx. 45–55 min to collect 1000 flowers, and to remove the stigmas for drying, another approx. 100–130 min (*Asimopoulos N. et al. 2013, Girme A. et al. 2021)*.

The evaluation of the quality of the spice is performed by laboratory analyses of UV–Vis spectrophotometry, to determine the content of the main components: crocin, picrocrocin and safranal, to which is added the content of non–stigmatization and other foreign matter, which must be within the limits imposed by ISO 3632. The bitter taste of the spice is given by picrocrocin, a component of saffron essential oil. Safranal terpene–aldehyde is the source of the saffron aroma, and the composition of the crocins (i.e. water–soluble cis– and trans–carotenoid glycoside crocins, glucosyl esters of crocetin) determines the colour of the spice. (*ISO 3632–1:2011, Mykhailenko O. et al. 2020).*

After processing the plant and obtaining the spice, there are many petals with an important mass, which is a cheap by–product, which currently has no industrial applications. Saffron petals contain many bioactive compounds. They can be used as a result of an extraction process, having economic potential as a source of natural flavours, dyes and antioxidants of high purity, with uses in the pharmaceutical and food industry *(Hashemi H. et al. 2020).*

Harvesters make a special effort to harvest the saffron, performing a tiring and repetitive activity, to which are added the high costs (25% of the price of the spice is the harvest). Therefore, in some of the producing countries it was considered important to pay attention to improving working conditions and increasing productivity, by mechanizing the process, which is necessary and inevitable *(Mazloumzadeh, M. 2017, Forozandeh M. 2021).*

The current trends regarding agricultural equipment refer to the mitigation of the negative impact on the environment, precision agriculture, digitization, robotization, etc. *(Matache M.G. et al. 2020).*

The paper presents a brief summary of the current state of research and achievements on portable mechanical devices for harvesting saffron (detachment of the flower and possibly its collection), which is in line with the new guidelines.

2. MATERIALS AND METHODS

Several devices designed for the mechanized harvesting of saffron, which use different working principles and methods of operation, will be presented.

Thus, a device was made that achieves the detachment of flowers by exploiting the difference between the mechanical and structural characteristics of the saffron stem and leaves, in order to avoid any preparatory process of separation between them. The device consists of a cam and a striker made as conjugate profiles, to which is added the frame and the servomotor (Figure 3a).

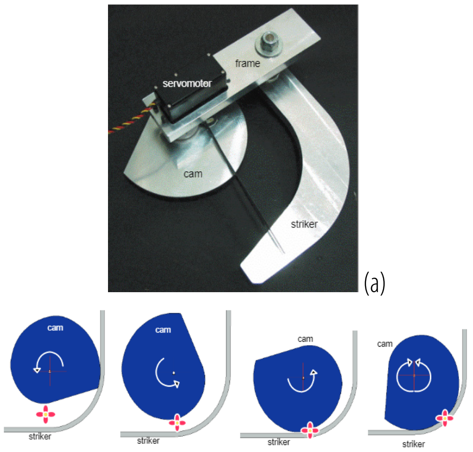

Figure 3 – Detachment device (Gambella F. et al 2013) (a) – structure; (b) – movement pattern

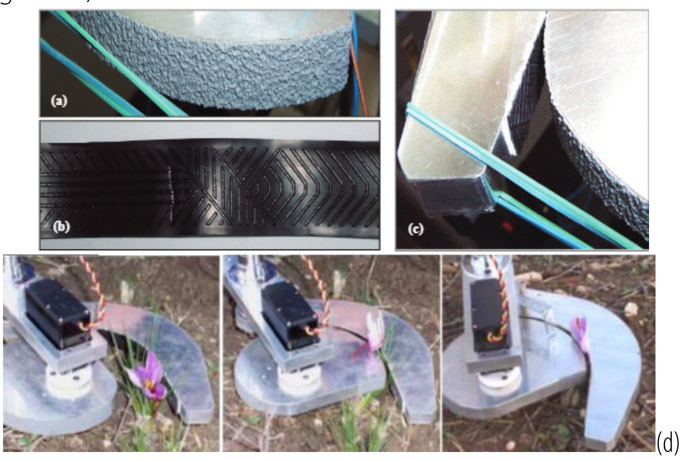

Figure 4 – Detachment device (Gambella F. et al 2013)
(a),(b),(c) – Device surface profile; (d) – The device during operation

As a contact force is required for cutting, a prestressed torsion spring has been mounted on the striker shaft mechanism. The friction surfaces of the cam and the striker, which hold both the flower and the leaves of the plant together, are made of aluminium sheet with a thickness of 15 mm, and are also covered with certain materials. These have the role of allowing the flower to move according to a precise kinematics, the stem having to roll over a very small part of the Archimedean spiral and then slide on the spring side of the cam, regardless

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of the environmental conditions (Figure 3b). The sliding surfaces include a vinyl anti–slip tape for the cams (Figure 4a) and a neoprene rubber band for the striker, with several slots for rapid water drainage (Figure 4b, 4c). The coefficients of static friction between the surfaces were about 1.2 or 1.0, depending on the condition of the surfaces (dry or wet). The cutting process involves two stages: approaching and oscillation. The actuator–operated cam is approaching the flower. As the distance decreases due to the cam profile, it first touches the flower and then pulls it towards the torsion zone. Here, an oscillating motion cuts the stem by torsion (Figure 3b). Due to their rough surfaces and harder structure, the leaves favour the cutting process, in the last position of the cam. So the flowers are harvested by mechanical action. For testing, the cutting mechanism was mounted at the end of a tube. The cam movement was controlled by an open loop position controller, the motor being powered by a 6V DC battery. To rotate the cam during the cutting process, the user rotates a control knob mounted on the tube. During the testing, the steps of cutting the saffron flower were carried out as in Figure 4d *(Gambella F. et al 2013).*

Also, a portable automatic system for harvesting saffron flowers was made (Figure5). It consists of two main subassemblies: one intended to detach the flowers from the stem, and the other to collect them. In figure 5, the handle (1) is equipped with a manually operated pneumatic valve for performing the pneumatic grip; the body (3) supports the electric motor equipped with a fan to generate the vacuum necessary to aspirate the detached flower; the suspender (2) supports the equipment so that the operator can carry out the harvesting operation without bending over; pneumatic pipe (4); the vacuum tube (5) ends with the suction port (6) for collecting flowers; the link (7) makes the coupling to the gripper body (8), which supports the two fingers (9), which detach the saffron flowers, breaking the flower stem. *(Manuello Bertetto A. et al. 2014).*

Figure 5 – Portable automatic system for harvesting saffron flowers (Manuello Bertetto A. et al. 2014)

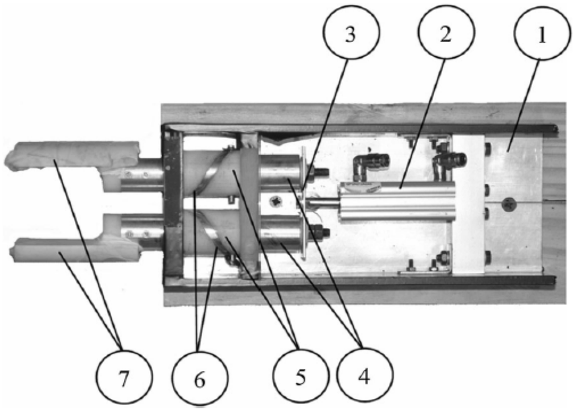

Figure 6 – The griper (Manuello Bertetto A. et al. 2014)

This link has a hinge elastically wound around a horizontal axis to allow rapid rotation of the gripper body when the flower is detached; this movement allows the flower to approach the vacuum system inlet. This link has a hinge elastically wound around a horizontal axis to allow rapid rotation of the gripper body when the flower is detached; this movement allows the flower to approach the vacuum system inlet. This link has a hinge elastically wound around a horizontal axis to allow rapid rotation of the gripper body when the flower is detached; this movement allows the flower to approach the vacuum system inlet.

The link (7) is fitted with a hinge elastically wound around a horizontal axis to allow rapid rotation of the gripper body when the flower is detached. This movement allows the flower to approach the vacuum system inlet. The gripper (Figure6) is a one degree of freedom pneumatically actuated device, being composed of: the body made of aluminium alloy (1), the pneumatic cylinder (2), with a diameter of 16 mm and a stroke of 22.5 mm, acting with its rod on a translating crossbar (3), which pushes the two cylindrical bodies (4), rototranslating into bushings (5), where a helicoidal guide (6) constrains two pins inserted into the cylindrical bodies (4) to obtain a helicoidal movement of the fingers (7). These are connected to the cylindrical bodies (4) and they detach the flower making a counter–rotating rototranslation, without sliding across each other. The elastically actuated hinge on the link (7) in Figure 5 is loaded when the pneumatic cylinder moves its fingers. This gripper is specific to robotics *(Manuello Bertetto A. et al. 2014).*

Based on the solutions presented above, to which are added new research by the authors, a new system for semi–automatic saffron harvesting has been developed. It has been designed to meet the following requirements: to be designed for small areas, to have a low mass for easy manoeuvrability, not to involve changes in the cultivation technology (changes in distance between plants per row or between rows), not to require additional sources of energy, compressed air, etc., difficult to transport in the field, to be made at an affordable cost for small businesses, saffron producers (*Denarda A.R. et al. 2021*).

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The *semi–automatic system* for saffron harvesting, called *DIMEG*, removes the saffron flowers (from the flower stem) and collects them in a storage enclosure. It consists of a gripper and a suction system, respectively. The gripper includes 2 mirror fingers (as a profile and as a direction of rotation). The profile of the fingers (Figure 7) has been designed so that following a rotational movement, the useful aerial parts (flower stems) can be gripped, avoiding excessive tightening. Once gripped, the flower can be detached from the flower stem by bending and applying a traction force. For this, a lamellar spring was combined with a cam, which determines the release of the mechanical energy loaded in the spring, whose vibration has the effect of bending and pulling the flower stem, involving the detachment of the flower. The rotation of the cam is synchronized with the movement of the two fingers. The release of the lamellar spring is done when the two fingers are in the completely close configuration, allowing the necessary detachment of the flower stem, only after they have firmly gripped a saffron flower. After this phase, the cam continues to rotate to automatically reload the lamellar spring for the next operation, while the fingers return to the fully open configuration. The gripper is equipped with two identical servomotors, one for driving the fingers, by means of a gear, and the other for driving the lamellar spring – cam combination (Figure 8a). Electric motors use low voltage direct current, running on batteries. Above the fingers was placed the suction head whose position can be adjusted (Figure 8b). The components of the device have small dimensions, being made of light materials (plastic, aluminium). (*Denarda A.R. et al. 2021*).

The suction system has been dimensioned to achieve the aspiration and transport of flowers in the collecting enclosure. Thus, the suction pipe has a diameter of 50 mm, the final air speed is 10 m/s, the pump ensures a pressure of 470 Pa, and the volume of the collection chamber is 14 litres. All elements of the suction system are part of an assembly worn by the user (*Denarda A.R. et al. 2021*).

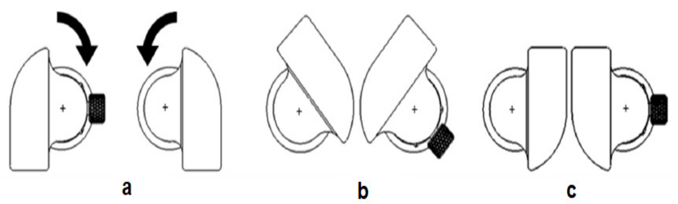

Figure 7 – Gripping fingers (Denarda A.R. et al. 2021)
a – open configuration with direction of rotation of the fingers denoted;
b – intermediate configuration; c – completely closed configuration

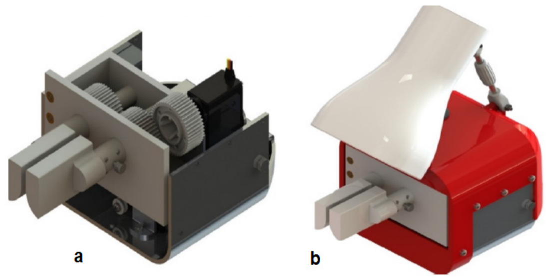

Figure 8 – Gripper
(Denarda A.R. et al. 2021)

3. RESULTS

For the analysed devices, only the results obtained in the process of detaching the flowers from the crop were highlighted, this being considered the essential operation in the harvesting technology.

During the tests, for the *Detaching Device*, the cutting/detaching process consisted of placing it, under each saffron flower, to locate the stem in the area between the cam and the striker. Once positioned, the cam was actuated to force the flower to perform the necessary kinematics. During cutting, the device was held stationary. After harvest, the mass of a flower was on average 0.5 g with a variation of approx. 10%. The variation of the flower size was between 20% and 25%, depending on the growth phase. Basic time (t_b) was defined as the time required for the cam to perform a semi–oscillation. The time required for the cam to approach the flower was decided to be equal to t_b. So the time t, which is the time required to harvest a flower, is a multiple of t_b. The t_b values used during the tests were 0.50 s, 0.75 s and 1.00 s. For each value of t_b 120 flowers were used. The efficiency of the equipment was evaluated by analysing the data obtained, which refers to the number of successes in terms of flowers collected in relation to the number of required semi–oscillations, which were 1, 2, 3, or ≥ 4. Thus, it was achieved a 35% success rate in the tests with two semi–oscillations of the cam, 31% for three semi–oscillations of the cam, 16% for a semi–oscillation of the cam and 18% for more than three semi–oscillations of the cam. The report was made on the total number of 360 flowers collected *(Gambella F. et al 2013)*.

For the *Portable automatic system for harvesting saffron flowers*, the efficiency of the detachment phase of the harvesting process depends largely on the dynamics of the system. The sequence of finger movements and the bending rotation of the whole gripping body around the elastically loaded horizontal hinge must take place in a certain sequence of time. Detachment is effective if the bending motion occurs once the finger movement has been completed. In order to have a strong enough shock at the end of the stroke of the cylinder, its dynamics must be fast. The gripper of the equipment was modeled and tested in the laboratory to highlight the dynamics of the fingers. Using traditional and optical techniques, the position of the fingers was evaluated over time, for different supply pressures of the cylinder. The gripper performs an efficient

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detachment operation for a cylinder supply pressure of more than 3 bar. The mathematical model, representing the dynamic behaviour of the gripper, was experimentally validated and used to test the sensitivity of the system to dynamic physical characteristics. Thus, the influence of finger mass and friction force in the pneumatic cylinder on the stroke was tested, depending on time. *(Manuello Bertetto A. et al. 2014)*
For the semi–automatic system for saffron harvesting – *DIMEG*, laboratory tests were performed to establish certain operating parameters. The distance between the axes of the fingers of the gripper was established experimentally, depending on the specific dimensions of the saffron flower stem, so as not to exert excessive mechanical stress on it. Other tests were performed using an accelerometer with a selected sensitivity range of ± 2 g. A data acquisition board was integrated in the circuit, for the management of the accelerometer and the 2 servomotors of the *DIMEG* device, the sampling taking place at an interval of 0.005 s. The experimental data were compared with those obtained from numerical simulations of the same operating conditions. Thus, using the software, the data related to the acceleration of a certain point were extracted, which correspond to the data taken from the prototype, by the accelerometer. The tests performed demonstrated the feasibility and effectiveness of the technical solution proposed for *DIMEG*, regarding the detachment of flowers. *(Denarda A.R. et al. 2021)*.

4. CONCLUSIONS

The experimental and analytical results obtained are promising, constituting an important capital, in order to improve the performance of this type of equipment, designed to reduce the effort and increase the productivity of workers, who harvest saffron in the open field. High manoeuvrability, low mass and low energy consumption are essential for this type of equipment.
Research will be continued by conducting additional field tests, including optimisations of current parameters and design. The aim is to create a device for harvesting saffron flowers, which can be marketed and used successfully in this niche sector for the cultivation of this species.

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