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# *Crocus sativus* (L.) Grown in Pots with High Volume Capacity: From a Case of Study to a Patent

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**Abstract:** Saffron (*Crocus sativus* L.) cultivation is widespread in different parts of the world, including various Mediterranean areas. The crop management techniques, requiring intensive manual labor from planting, weeding, flower picking to the collecting of stigmas, contribute greatly to the high price of the spice. Traditionally, the corms are cultivated in field soil and only stigmas are collected to obtain the spice while the flower's remaining parts, corresponding to about 90% of the total biomass, are discarded and thrown away. In this study, in order to overcome some difficulties occurring during the whole crop cycle (pathogens, fungi, pests, weeds, etc.), as well as to ease and increase floral bioresidue recovery, an alternative planting way for *Crocus sativus* L. was proposed relying on the use of large pots. For this aim, corms with 3.0–3.5 cm diameter size, from two different geographical origins (Spain, Holland), were planted in plastic pots with a volume of 250 L or 350 L, placed in two different areas of the Basilicata region (Italy). The effect of this new growing condition on dry stigma yield as well as daughter corm yield and size was evaluated. Although this cultivation system is more expensive than the traditional one, it offers numerous and huge advantages. Among them, it allows us to maintain a more correct posture and to preserve flower integrity during harvesting. The structural integrity of the tepals is a very important factor to obtain innovative dried flowers in their original tridimensional shape (3D). Consequently, the proposed cultivation system facilitates the achievement of a real "niche product" with high added value (absence of pollen grains). Moreover, the qualitative analysis of the spice, performed according to the International Standardization Organization Normative 3632 (ISO 3632-2/1:2010/2011), classified all investigated saffron samples in the first qualitative category. The results of the first three trial years are very exciting and promising as they are similar to those from the literature carried out in ground soil. However, corms from Spain gave the best results. Further investigations are in progress in order to optimize this alternative cultivation system.

**Keywords:** saffron; cultivation system in large pot; 3D dried flower; biodiversity; patent

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## 1. Introduction

Saffron is the spice obtained by drying the dark red stigmas of the flowers of *Crocus sativus* L., a geophyte belonging to the Iridaceae family [1]. *Crocus sativus* L. blossoms in autumn presenting dainty, and attractive flowers, a perigonium formed by six tepals typically violet or purple in colour with darker veins [1–3]. The androecium is made up of three stamens with yellow anthers due to the pollen content while the gynoecium or pistil consists of an inferior ovary which extends into a stylus which in turn crosses the entire tube of the perigonium and divides into three parts to form the stigmas, the most valuable part of the flower [1,4]. Saffron is a triploid and sterile plant propagated by corms, originating naturally from the mother corm playing a pivotal role in the lifecycle of saffron, as they are the source of the photosynthetic plant material, both after the dormant stage and in the early stages of growth [5]. Generally, daughter corm numbers increase with increasing mother corm size. Moreover, large-sized daughter corms are more important than small ones because they lead to more flower production, thus increasing stigma yield [6].

Saffron cultivation is widespread in different parts of the world (Iran, India, China, California) including various Mediterranean areas (Spain, Greece, France, Italy, Tunisia, Morocco) [5]. The best climate for growing saffron is the Mediterranean climate with its warm and dry summers [2].

Saffron is one of the most prized spices for both its bitter flavoring and coloring powers, due to the presence of picrocrocin, safranal and crocins, respectively, and its nutraceutical properties [7–9]. In fact, saffron has been called the "king of spices" for the well-known food characteristics and healthy properties attributed to its biocomponents [3]. Moreover, saffron has always been defined as "red gold" since it is the most expensive spice on the world market due to the intensive manual labour that this crop needs from corm planting, weeding, flower picking, to separating of stigmas to the drying and packaging of them. In particular, the phases of flower harvesting and stigma separating ("mondatura") have a greater impact on the final price since they require very meticulous, laborious and time-consuming manual operations. This is even more true when the aim is to obtain the highest saffron quality which can only be reached by reducing as much as possible the contamination by foreign material (floral and plant waste). The normative ISO 3632-1:2011 reports the values of reference for classifying saffron in the first qualitative category on the basis of both chemical and physical criteria [10]. Obviously, contamination by extraneous matter (e.g., pollen grains, styles, leaves, petals) is associated with the delay with which the collection of flowers is carried out with respect to the moment at which the flowers begin to open. The greater the delay, the greater the possibility of contamination, also because of insects attracted to the flower. Furthermore, such contamination increases with the increasing speed at which flower harvesting and stigma separating processes are carried out.

To increase the economic yield of the saffron, it is necessary to quicken the above mentioned phases; thus various solutions for mechanization through the use of semi-automatic devices have been proposed. The article by Louis Gracia et al. (2009), discloses a semi-automatic device that separates the stigmas from the flower through the action of the air produced by a fan [11]. This device increases the flower cutting rate approximately eight times with respect to that obtained with the traditional hand method. The traditional manual act of peeling or stripping the stigmas from the flowers, takes about 4 s per flower. In detail, with one hand, the operator picks up a flower and separates the petals; with the other, the operator strips the threads from the yellow style to which they were attached, taking care not to include the styles themselves which would diminish the saffron's value, as would also happen with the presence of stamen and tepal parts. In contrast, the semi-automatic machine exploits a vision system, using image analysis, to obtain the optimal cutting point for flowers which move one by one in front of it. Then, the stigmas are definitively separated from the petals with an air flow, exploiting the different aerodynamic resistances of the floral elements. The acquired image is analyzed in order to compute where to cut the flower (with the cutting plane perpendicular to the flower axis) to properly separate the three stigmas. Nevertheless, the main disadvantage of this mechanization is that low quality saffron is obtained. In fact, the stamens of the flower and parts of tepals can also be separated together with the stigmas. Therefore, a subsequent phase of manual elimination of the stamen and of tepal pieces is required. During this cleaning phase it is very likely that the pollen grains contaminate the stigmas, further affecting the quality of the final product.

It is known that a high quantity of flowers is necessary to obtain small quantity of spice. In fact, about 170,000 flowers of *Crocus sativus* L. are needed to obtain only one kg of saffron [12]. While 217 fresh flowers weigh about 100 g [12], generating only about 7.4 g fresh stigmas [13], the biomass of floral bioresidues is equal to about 93% ($w/w$) with respect to total floral biomass of which tepals constitute about 78.4% [14,15] and generally are considered as agricultural waste [16].

Besides the huge amount of floral bioresidues, mainly represented by tepals, it is well keep in mind some considerations such as (1) the difficulty in finding an available low-cost labour force during the traditional harvesting phase of saffron flowers because of the inevitable, prolonged and incorrect body posture which workers are forced to assume [16,17]; (2) the fact that an operator can produce only a few grams of saffron per day [11]; (3) the cost required for food safety control which should to be secured, especially for quality products [16]. As a result of the above mentioned considerations, large quantities of cheap saffron are obtainable only where labour costs are low and food safety control is not guaranteed at the expense of saffron quality.

Therefore, saffron is not economically suitable for country with high labour wages [17] as expensive labour costs have made saffron production unprofitable despite its high market price [16]. The aspect of production costs is one of several difficulties of this crop.

Another difficulty to keep in consideration can be represented by the pests, with rodents such as rats, rabbits, moles and wild boars which bring significant damage to the saffron crop in some countries [18].

Traditionally, saffron flowers are collected into wicker baskets, which are then emptied, amassing the flowers on a table for the following phase of "mondatura". These operations promote the flower contamination by pollen due to possible damage of the anthers. Hence, the traditional methods of harvesting and transporting of saffron flowers, as well as that of stigma separating, inevitably make it difficult to obtain allergen-free saffron.

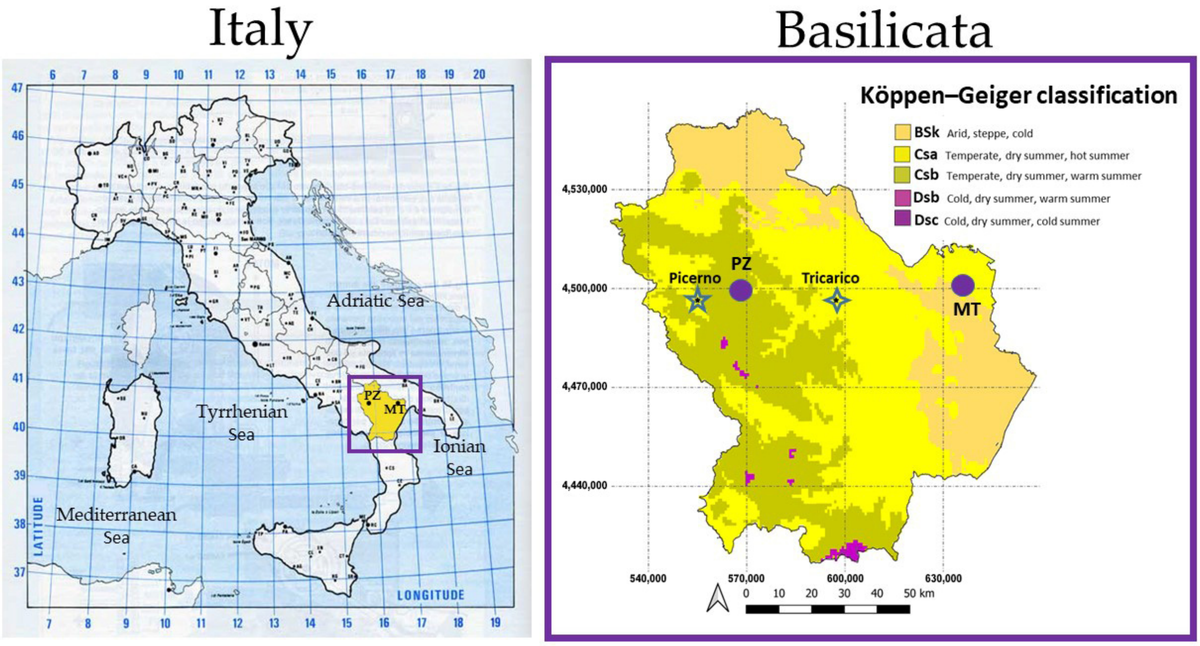
This report represents the first study on *Crocus sativus* L. cultivation in pots of a large size aiming to overcome some critical issues and some difficulties occurring during the whole crop cycle (pathogen fungi, pests, weeds, difficulty in finding workforce availability and more). Moreover, the aim of the research was to ease and to increase the recovery of the tepals, considered as waste by most saffron small producers, still today. Accordingly, here, an innovative device and a new method for the separation of the stigma are presented for the first time. These allowed us to consider tepals as a raw material from which to obtain, after the stigma separation process, 3D dried flowers and excellent quality saffron. This study led to the granting of a patent.

## 2. Materials and Methods

### *2.1. Experimental Sites and Meteorological Data*

Three experimental trials were conducted during the 2015–2016, 2016–2017 and 2017–2018 growing seasons in two different fields in the Basilicata region (Figure 1).

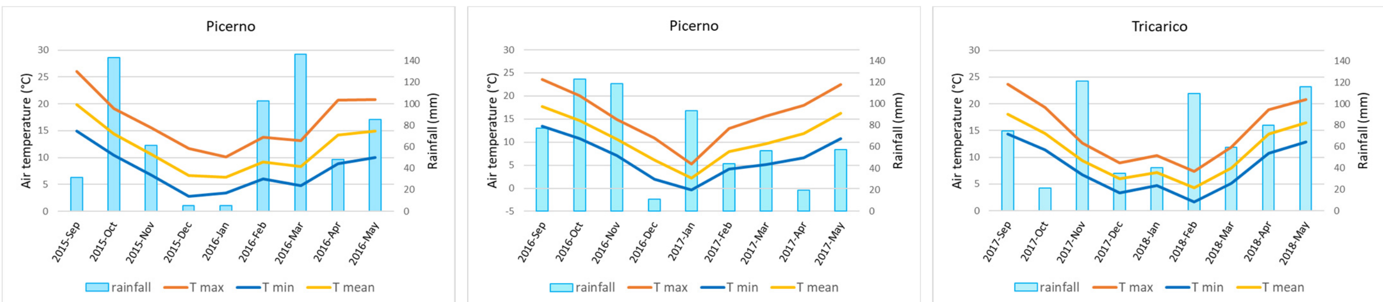
The 2015–2016 and 2016–2017 trials were carried out at the experimental field of Picerno (40°37′ N, 15°39′ E, or otherwise specified as 4,496,408 N, 554,982 E; 723 m a.s.l), located in the Potenza province, using corms from Spain with a horizontal diameter between 3.0 and 3.5 cm. The third experimental trial (2017–2018) was carried out at the experimental field of Tricarico (40°37′ N, 16°09′ E, or otherwise specified as 4,496,408 N, 597,276 E; 472 m a.s.l), located in the Matera province, using corms from two different geographical origins (Spain, Holland), both with the same size compared to that of previous years. The Picerno and Tricarico countrysides were chosen as experimental sites due to the abandonment of the saffron crop by some farmers because of damage caused mainly by voles, moles and wild boars. Both experimental sites in the countryside of Picerno and Tricarico are characterized by a temperate climate with dry and hot summers, based on the Köppen–Geiger climate classification updated [19–21], (Figure 1); as a result, the two experimental sites have both the same latitude and the typical Mediterranean climate.




(a) (b)

**Figure 1.** Localization of the Basilicata region on the map showing the 20 regions of Italy (**a**); localization of the two experimental sites in the map of the Basilicata region classified according to Köppen–Geiger climate classification (**b**).

The specific meteorological data of the experimental areas were captured and collected in July 2022, based on meteorological database values registered by the Decentralized Functional Center of Civil Protection of Basilicata region (see http://www.centrofunzionalebasilicata.it, last accessed on 20 July 2022). The meteorological data have been elaborated in order to have data on the monthly precipitation, the mean, maximum and minimum temperature of the air during the three different saffron growth periods. The meteorological data recorded in the two experimental areas during the crop cycle, which occurs from September to May, are shown in Figure 2.

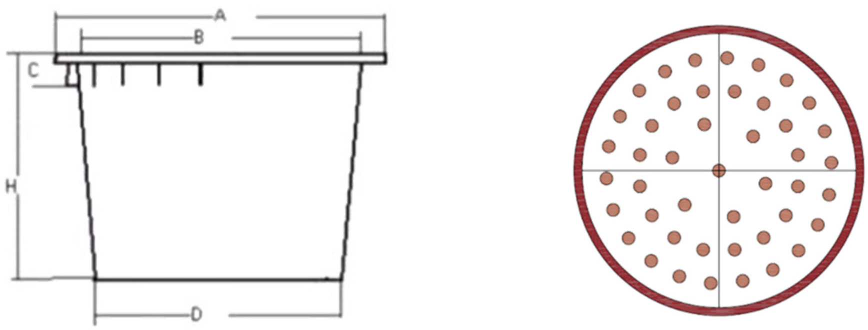



(**a**) (**b**) (**c**)

**Figure 2.** Meteorological data recorded in the area of experimental sites in the three different years: during the growing seasons 2015–2016 (**a**), and 2016–2017 (**b**) at Picerno; during growing season 2017–2018 at Tricarico (**c**).

### 2.2. Experimental Tests in Large Pots, Planting Schemes and Quantitative Determinations

On 16 September 2015, a first preliminary trial was carried out in the Picerno countryside using a plastic pot, generally used for wine fermenting, with the following dimensions: 97.0 cm external upper diameter (A), 89.0 cm internal upper diameter (B), 7.5 cm in height to the reinforced edge (C), 76.0 cm in diameter at the base (D), 70.0 cm in depth (H) and with the high volumetric capacity of 350 L (Figure 3a).




(**a**) (**b**)

**Figure 3.** Scheme of the dimensional parameters of pots used in the three trial years (**a**); scheme of the corm sowing in 2015 (**b**).

The pot was filled with a 20 cm layer of stones, a 10 cm layer of lightweight expanded clay (LECA 8–20 mm) in order to guarantee the absence of stagnation of water. Then, about a 30 cm layer of universal potting soil (Vigor Plant) was added to about 3 cm below the bottom of the reinforced edge C. This growing medium, allowed in organic farming, containing acidic sphagnum peat, composted soil conditioner, simple noncomposted vegetable soil conditioner, had a total porosity equal to 87 (% *v*/*v*), an electrical conductivity equal to 0.4 (dS/m) and a pH value of 7. Nine handfuls of pumice (about 1 kg) with different granulometry were added and mixed with the potting soil. Thus, it was possible to exploit the great water retention of pumice and its ability to release slowly liquids.

Forty-five corms from Spain were dipped in a 1% fungicide water solution of copper oxychloride (Sumitomo Chemical Italia S.r.l., Milano, Italy) for 2 min to minimize fungal diseases (e.g., *Fusarium oxisporum* f. sp. *Gladioli*) [22]. Then, they were drained and left to dry in a cool and ventilated place overnight. The day after, the corms were placed in the pot at a distance of 10–12 cm from each other and covered with a 10 cm layer of universal potting soil, above described, premixed with 3 handfuls of pumice (about 300 g).

No replication was performed in terms of pots. However, in order to obtain replicated results, the corms were sown according to the scheme reported in Figure 3b that ideally divided the cultivation area into four sectors (S1, S2, S3, S4) each containing 11 corms. The remaining corm was placed in the center of pot. This central corm was later found to be very useful since it replaced a corm, lifted from sector 3, as it showed a symptom of fungal attack (Figure 4).

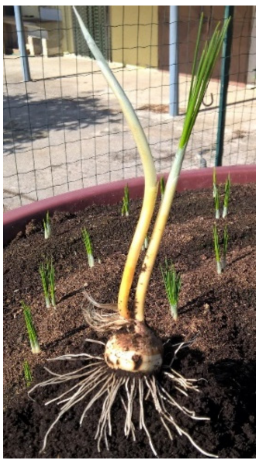


**Figure 4.** Infected corm lifted from sector 3 of the pot.

No weed control was carried out as it was not necessary, due to the quality of potting soil used.

During the 2015 flowering, the flowers from each sector were picked up delicately by hand, in the early hours of each day, put in four small wicker baskets and taken to the laboratory where stigmas were manually separated from the remaining part of the flower according to the stigma excision traditional method (TM). Then, stigmas were put in four small dark glass jars without caps and dried for 1 h in a yoghurt maker (Girmi) with a perforated lid on the top, at its working temperature of about 40 °C.

It was decided to use the yoghurt maker to test its performance in saffron drying also because of small daily stigma amounts. Then, dried stigmas from each sector were weighed before pooling in a single glass jar which was closed with its screw cap and stored at room temperature until the qualitative analysis was performed.

The method of saffron cultivation in large pots was also applied in the following two years using plastic pots a little smaller than the year before but very much more resistant for outdoor experiments. In detail, the pots used in 2016 and 2017 were about 29% smaller both in terms of volume and planting area than that used in 2015. The dimensional parameters of these new, large pots with a volume capacity equal to 250 L are as follows: A = 84 cm, B = 75 cm, C = 12 cm, D = 60 cm, H = 60 cm (see Figure 3a).

In detail, in 2016 the experimental test was carried out in the same field of Picerno. The trials were accomplished in duplicate. Indeed, corms with a 3.0–3.5 cm horizontal diameter from Spain, pretreated with the aforementioned fungicide aqueous solution, were sown in two large pots, 50 corms in each pot, at a distance of about 5 cm from each other. In 2017, the trial was carried out in the experimental field of Tricarico. In detail, corms (3.0–3.5 cm) from two different geographical origins (Spain and Holland), pre-treated with the same fungicide solution, were planted in pots with the same size as in 2016. The trials were accomplished in triplicate. Therefore, three pots were used for each provenience of corms and 61 corms were sown in each pot, at a distance of about 4 cm from each other.

The pots used in 2016 and in 2017 were filled as in 2015, but with a less deep layer of stones (10 cm).

No weed control was carried out in the 2016–2017 growing season since in this case it was also unnecessary. In contrast, in the 2017–2018 growth season, a weed control was necessary in the spring period probably because of the massive presence of weeds on the ground in the experimental field of Tricarico, compared to the cleaner area of Picerno. Perhaps, the conditions of the ground surrounding the pots facilitated the transport of the weed seeds into the pots with the wind. In any case, the corms were irrigated only during the sowing phase and never during the vegetative period.

Regarding the spice, during the flowering periods of the 2016 and 2017 years, flowers were picked delicately by hand in the early hours of each day, but unlike the previous year, they were put on a special tray, as drawn below. The flowers were taken to the laboratory where stigmas were quickly separated manually with the help of pliers and special funnel-shaped elements which housed the flowers on the tray. The number of daily harvested flowers from each pot was recorded. A new stigma-separating procedure, below described, was applied. The special tray and the funnel-shaped elements, kindly supplied by their designer, were designed to preserve tepal structure during both the harvesting, transporting and flower processing. The innovative device and the new method (NM) for stigma separating from the remaining flower part, shown in this report for the first time, were conceived to obtain both saffron flowers, dried in their original three-dimensional shape, and saffron of excellent quality. Stigmas separated daily from flowers from each pot were then dried at about 40 °C and stored in glass jars with screw cap as the previous year. The flowers without stamen and stigmas were transformed in 3D dried flowers according to the patented procedure (see Section 2.4).

At the end of the investigated cultivation cycles of each year, during the senescence phase (May), the corms from each sector or each pot were lifted from the soil, cleaned and the number of daughter corms per mother corm and their horizontal diameter were detected. Hence, the corm yield, expressed in terms of the initial corm multiplication index (ICMI), corresponding to the number of daughter corms per mother corm, was calculated for each growing season. Moreover, the number of daughter corms with a diameter less than 2.5 cm and with a diameter higher or equal to 2.5 cm from each mother corm were also recorded.

The descriptive features of the experimental tests are reported in synoptic Table 1 to highlight the differences.

**Table 1.** Descriptive features of the cultivation trials in large pots and methods for obtaining the spice.

| Experimental Trial | Experimental Site | Cultivation Period | Corm Origin | Corm Planting ($n$ pot$^{-1}$) | Pot Planting Surface (m$^2$) | Pot Height (cm) | Pot Volume (L) | Stigma Separating Method |
|---|---|---|---|---|---|---|---|---|
| P1 * | Picerno | 2015–2016 | Spain | 45 | 0.567 | 70 | 350 | TM |
| P2 ** | Picerno | 2016–2017 | Spain | 50 | 0.442 | 60 | 250 | NM |
| P3 *** | Tricarico | 2017–2018 | Spain | 61 | 0.442 | 60 | 250 | NM |
| P4 *** | Tricarico | 2017–2018 | Holland | 61 | 0.442 | 60 | 250 | NM |

Trial carried out in single *, duplicate ** and triplicate ***.

### 2.3. Spectrophotometric Analysis of Saffron Extract

To determine the saffron quality, samples of spice produced in 2016, 2017 and 2018 were analyzed using a UV–Vis spectrophotometer (Ultrospec 4000, Amersham Pharmacia Biotech, Milan, Italy) and quartz cuvettes with a path length of 1 cm according to the International Standardization Organization 3632 normative (ISO 3632-1010, 2011) [10]. Briefly, 500 mg of powdered samples were passed through a 0.5 mm sieve, transferred into a 1000 mL volumetric flask with 900 mL of distilled water (ultra plus distilled water purchased by Carlo Erba). The obtained aqueous solutions were stirred for 1 h in the dark and then brought to 1000 mL with distilled water. Extracts were diluted (1:10 $v/v$) with distilled water and filtrated with polytetrafluoroethylene (PTFE) filters (15 mm diameter and 0.45 µm pore size). The qualitative main characteristics of saffron samples were expressed as absorbance values at 257, 330 and 440 nm which correspond respectively to λmax of picrocrocin, safranal and crocins; representing, respectively, flavor strength, aroma strength, and coloring strength. Further details are reported in a previous paper [22].

### 2.4. Optical Microscopy Observation

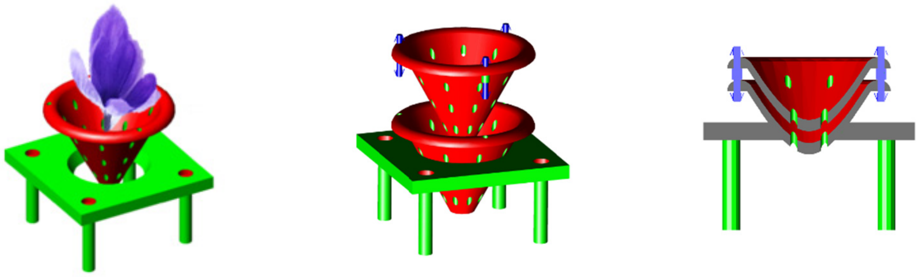
Observations by optical microscope (Zeiss Axiophot, Carl Zeiss S.p.A., Milano, Italy) were carried out on saffron samples, produced from the two different stigma separating methods (TM and NM) applied in this study. Microscopic analysis was performed, especially to assess pollen contamination according to the ISO 3632-2010, 2011 procedure [10].

Briefly, a test portion of the order 0.0002 to 0.0004 g was added to 10 µL of pure distilled water deposited on a slide. It was mixed with the water and after 5 min covered with a cover slide. The slide was placed under the microscope setting the magnification at 100 times. The elements observed were identified and counted on an observation of ten fields, setting the magnification at 400 times. The preparation of slide was carried out in duplicate.

### 2.5. Device and Processing Method to Obtain First Category Saffron and 3D Dried Flowers

The object of the invention was to maintain the chemical-physical structure of the bell-shaped flowers, just like the *Crocus sativus* L. flower calyx. Hence, the innovative device was designed to preserve both the three-dimensional structure of the flower and its nutraceutical properties as well as characteristic of edibility in an easy and inexpensive way. A further purpose of the invention was to further improve the saffron quality as much as possible.

The more significant parts of the device are illustrated below. Two funnel-shaped containers with filter surfaces were configured to house a flower with a three-dimensional structure calyx or bell-shaped with tepals directed towards the larger open top part with rounded edge. The housing device included spacers configured for removable coupling of the two funnel-shaped containers and to keep them a distance from each other, creating a cavity intended to be occupied by the tepal calyx of the flower (Figure 5).



(**a**) (**b**) (**c**)

**Figure 5.** First element of the funnel-shaped device with relative support base (**a**); two funnel-shaped elements in the phase of their coupling (**b**); longitudinal section of two funnel-shaped coupled containers (**c**).

During the harvesting phase in the flowering period of the years 2016 and 2017, the single flower was housed in the first funnel-shaped container used for preserving flower structure during the transport, processing and drying phases. This device was designed in such a way that it could be stacked on a special tray as individual elements of a tridimensional matrix ensuring the right distances between them in order to fill the smallest volume in the drying ovens (Figure 6).

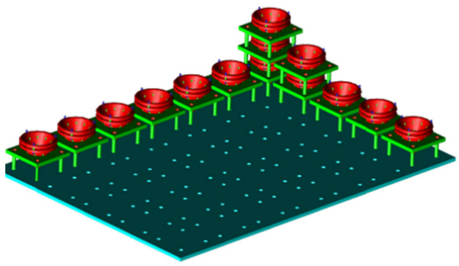


**Figure 6.** Tray for flower transporting and drying.

The first funnel-shaped container fulfilled expectations even during the stigma excision phase, avoiding direct contact of the flower with fingers.

In detail, each of the six tepals of the flower, already housed in the first funnel-shaped container, was opened up delicately and laid down on the cone's rounded edge with the help of suitable tweezers with rounded tips. The stamens were excised before stigmas. Optionally, a slight flow of inert gas (e.g., nitrogen) can be directed to the flower to eliminate possible pollen granules that may be present. Finally the stigmas were removed, collected and dried to obtain the spice which was stored until the time for analysis. Then, the funnel-shaped container containing the open saffron flower was coupled to the second similar element by means of spacers. Flowers, thus trapped, were dried in a ventilated oven at 80 °C until the weight was constant (about 3 h). For obvious reasons, the construction materials of the device are not specified although some options are indicated in the patent filing.

### *2.6. Statistical Analysis*

Data were analyzed with a one-way analysis of variance (ANOVA) ($p \leq 0.05$) by using Microsoft Office Excel professional plus 2016 software version 16.0.4266.1001.

## 3. Results

The results, shown below, were able to prove that the saffron cultivation system in large pots allowed us to overcome some difficulties and critical aspects of this crop, (e.g., improve the posture of workers during the planting, weeding and harvesting phases; hinder pests able to seriously damage the saffron crop) (Figure 7), without affecting the production of flowers and corms. In addition, this alternative cultivation method allowed us to recover more easily the most abundant by-product from saffron production (flower tepals), preserving its structural integrity and permitting us to enhance it by means of the device and the processing method, both patented.

(a) (b)

**Figure 7.** Some critical aspects of *Crocus sativus* L. crop: kneeling workers during harvest (**a**); residues of saffron corms eaten by voles in ground soil in a Tricarico open field (**b**).

The captured, detected and elaborated data, relative to the three trial years, concerned the meteorological parameters (maximum mean and minimum values of the daily temperature, daily rainfall) in the two experimental areas (Picerno and Tricarico), flower numbers, daughter corm numbers per mother corm and daughter corm numbers with a horizontal diameter less than 2.5 cm and higher than or equal to 2.5 cm. Moreover, the yield and quality of the spice were also determined. Finally, some parameters of the innovative device, designed obtain 3D dried flowers, were optimized to improve its performance.

### 3.1. Meteorological Data Elaboration

The mean values of monthly minimum, mean and maximum air temperature and rainfall, captured by the meteorological database of the Civil Protection of Basilicata region, were elaborated and averaged further to assess the mean meteorological conditions over the whole period of saffron growing, from the blooming (September–November) to the corm-development period (December–May), this latter corresponding to the vegetative stage (Table 2).

As far as the Picerno area is concerned, comparing the flowering period (Sep–Nov) of the first two growth seasons, a higher rainfall was recorded in 2016–2017. In contrast, a higher rainfall in the vegetative period (Dec–May) was recorded in 2015–2016. Nevertheless, the mean rainfall values for the whole plant cycle (Sep–May) were similar in both years in Picerno.

As regards the Tricarico area, during the 2017–2018 growing season, the mean values of rainfall in the flowering period and in the vegetative one were similar.

Comparing the rainfall data of the two experimental areas, lower rainfall in the flowering period was recorded in Tricarico while higher rainfall was also recorded in the vegetative period.

The temperature trend in the flowering and vegetative periods in the three growth seasons did not differ with the concordant tendency of the climatic seasons; in fact, the flowering period (Sep–Nov) in the three investigated growth seasons was warmer than the vegetative period (Dec–May).

**Table 2.** Mean values of monthly minimum, mean and maximum air temperature and rainfall in different periods in the three growing seasons 2015/2016 and 2016/2017 in Picerno and 2017–2018 in Tricarico.

| | Mean (Sep–May) | Mean (Sep–Nov) | Mean (Dec–May) |
|---|---|---|---|
| Picerno 2015–2016 | | | |
| T max (°C) | 16.8 | 20.2 | 15.0 |
| T min (°C) | 7.5 | 10.7 | 6.0 |
| T mean (°C) | 11.6 | 14.9 | 9.9 |
| Rainfall (mm) | 68.8 | 78.7 | 65.3 |
| Picerno 2016–2017 | | | |
| T max (°C) | 16.0 | 19.5 | 14.2 |
| T min (°C) | 6.6 | 10.4 | 4.7 |
| T mean (°C) | 10.8 | 14.3 | 9.0 |
| Rainfall (mm) | 66.7 | 106.2 | 46.9 |
| Tricarico 2017–2018 | | | |
| T max (°C) | 14.9 | 18.6 | 13.0 |
| T min (°C) | 7.9 | 10.8 | 6.4 |
| T mean (°C) | 10.9 | 14.0 | 9.4 |
| Rainfall (mm) | 73.0 | 72.3 | 73.3 |

### 3.2. Flower Yield

The planting date, flowering start date, days to flower, flowering interval, flower number per mother corm and flower number per square meter were annotated for each experimental trial over the three years (2015–2016–2017) and are reported in Table 3.

**Table 3.** Flowering difference between the trials carried out in large pots in the three consecutive *Crocus sativus* L. growth seasons.

| Trial in Pot | Planting Date | Flowering Start Date | Days to Flower (d) | Flowering Interval (dd) | Flowers ($n$ corm$^{-1}$) | Flowers ($n$ m$^{-2}$) |
|---|---|---|---|---|---|---|
| S1 | 17 September 2015 | 03 November 2015 | 47 | 11 | 2.45 | 190.5 |
| S2 | 17 September 2015 | 04 November 2015 | 48 | 10 | 2.45 | 190.5 |
| S3 | 17 September 2015 | 04 November 2015 | 48 | 9 | 2.54 | 197.5 |
| S4 | 17 September 2015 | 02 November 2015 | 46 | 11 | 2.63 | 204.6 |
| $P1 = \sum_{i=1}^{4} Si$ | 17 September 2015 | 02 November 2015 | 46 | 12 | 2.52 | 195.8 |
| P2 (I) | 18 September 2016 | 17 October 2016 | 29 | 36 | 2.86 | 323.5 |
| P2 (II) | 18 September 2016 | 17 October 2016 | 29 | 32 | 3.58 | 404.9 |
| P3 (I) | 09 September 2017 | 19 October 2017 | 40 | 26 | 1.36 | 187.8 |
| P3 (II) | 09 September 2017 | 15 October 2017 | 36 | 21 | 1.56 | 214.9 |
| P3 (III) | 09 September 2017 | 19 October 2017 | 40 | 20 | 1.07 | 147.1 |
| P4 (I) | 09 September 2017 | 29 October 2017 | 50 | 22 | 1.33 | 183.3 |
| P4 (II) | 09 September 2017 | 29 October 2017 | 50 | 22 | 1.20 | 165.2 |
| P4 (III) | 09 September 2017 | 29 October 2017 | 50 | 25 | 1.07 | 147.1 |

The 2015 flowering (P1) started later than 2016 (P2), specifically after sixteen days, although the respective planting dates differed only by one day. In contrast, the 2016 flowering (P2) started with a delay or advance of only two days compared to 2017 (P3) although there was a greater difference between the respective planting dates, nine days precisely. A noteworthy difference about the beginning of flowering was also found between the P3 and P4 trials, both carried out in the same site and in the same year but, using corms from different origins (Spain and Holland). In fact, corms from Spain (P3) bloomed about ten days earlier, with respect to the ones from Holland (P4), although both were planted on the same day in the Tricarico field (Table 3). Moreover, no significant difference was observed for the flowering start day within the repetitions of each test, including those relative to P3 and P4.

As regards the flowering interval, a shorter value was observed in 2015 than in 2017 and 2016, the flowering interval in the latter being the longest. No difference in this parameter was observed between the trials P3 and P4, although the corms were from two different geographical origins. In contrast, a difference between flowering intervals was observed when comparing the same geographical origin over the three different years. In particular, a flowering interval longer than twenty days was observed between P2 and P1 and a difference of about ten days was observed between P1 and P3 as well as P2 and P3.

Regarding the flower numbers per corm and the flower yield per surface unit, the best outcomes were obtained in the 2016–2017 growth season with an average value equal to 3.22 flowers per corm and about 364 flowers per square meter (Table 3). Most likely, this result depends on the higher corm density in P2, due to both greater corm numbers planted and the smaller planting area than in P1. In contrast, whereas the highest density of corms was used in P3 and P4 trials, the flower numbers from P3 and P4, similar to each other, were lower than both the P1 and P2 ones. This could be dependent on other factors, including the meteorological conditions. In particular, the rainfall in October 2017 was lower than that of the previous years and may have led to an increase in temperature in the pot, causing the reduction in blooming.

### *3.3. Yield of Stigma and Spice Quality*

The average yields of dried stigmas from the single experimental trials (P1, P2, P3, P4) over the three years were different. In detail, about 0.6 g were obtained from the first trial where 44 corms from Spain were planted in a single large pot. Instead, about 0.89 g were obtained from the second trial in duplicate where 50 corms from Spain were planted in each pot. Finally, about 0.45 and 0.44 g of spice were produced from the third trial in triplicate where 61 corms from Spain or Holland were planted for each pot, respectively. The results showed that the better spice yield was obtained during the 2016–2017 growth season. This result can only be correlated to the relatively higher flower production since the average weight of stigmas obtained from the Spanish corms was similar over the three years and equal to $0.00184 \pm 2.77 \times 10^{-5}$ g (mean $\pm$ standard deviation). In contrast, a significant difference in stigma yield was found between those of Spanish provenience and those from Holland, although there was no significant difference between the respective flower numbers. This result was due to the different average weights of the stigmas from the two origins. In fact, the flowers, as well as the stigmas, obtained from Spanish corms were smaller in term of length than those from Holland (Figure 8).

**Figure 8.** Flowers from corms from Holland were longer than flowers from Spanish corms.

Nevertheless, the smaller size of the flowers from Spain allowed us to get more graceful and beautiful dried flowers in 3D for food decoration purposes.

Regarding the qualitative analysis, the moisture and volatile matter content and the main characteristics of each saffron sample, named with the same acronym of the experimental trials, are determined and reported in Table 4.

**Table 4.** Qualitative analysis of the saffron investigated.

| Sample | Moisture and Volatile Matter Content [1] | Picrocrocin [2] | Safranal [3] | Crocins [4] |
|---|---|---|---|---|
| 2015–2016 [P1] | 10.08 | 95.41 | 26.47 | 241.3 |
| 2016–2017 [P2(I) + (II)] | 10.34 | 98.48 | 31.50 | 230.9 |
| 2017–2018 [P3(I) + (II) + (III)] | 9.57 | 115.27 | 24.66 | 284.67 |
| 2017–2018 [P4(I) + (II) + (III)] | 9.63 | 92.29 | 28.77 | 244.30 |

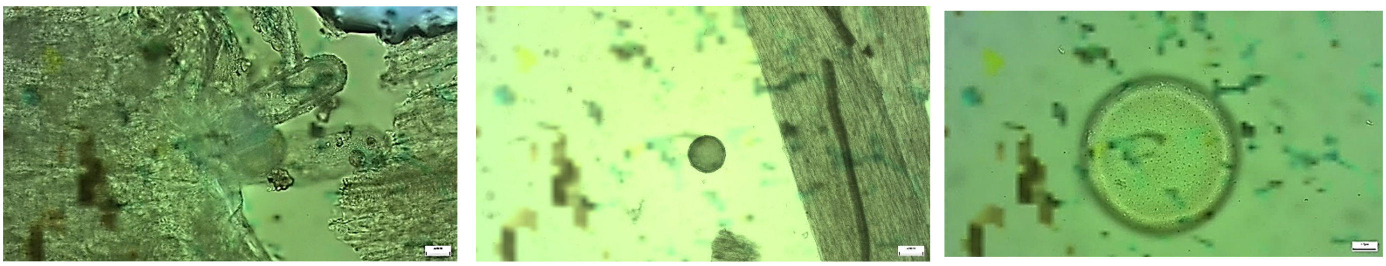
The ISO specifications 3632-1:2011 for the first qualitative category: [1]. Value for saffron in filaments and cut filaments (expressed as % max) ≤ 12; [2] flavor strength value (expressed as picrocrocin) $A_{1\,\mathrm{cm}}^{1\%}$(257 nm) ≥ 70; [3] aroma strength values [min-max] (expressed as safranal) $A_{1\,\mathrm{cm}}^{1\%}$(330 nm) 20–50; [4] coloring strength value (expressed as crocins) $A_{1\,\mathrm{cm}}^{1\%}$(440 nm) ≥ 200.

The results from the determination of the main characteristics of the investigated saffron sample showed that all samples belonged to the first qualitative category. P3 showed the highest values in both bittering power and coloring power, as well as the lowest value in aromatic power. P4 showed the lowest value of bittering power. The best result was observed in P2, showing a good bittering power, the highest aromatic power and a good coloring power.

### *3.4. Microscopic Analysis*

Microscopic observation was aimed only to determine the pollen grain percentage. The microscopic analysis highlighted the presence of pollen grains in the saffron from the P1 trial. Pollen grains can be associated with stigma as extraneous material but their amount must not exceed the maximum value of 0.5% of the total mass, expressed in grams, according the ISO 3632 normative which allows us to classify saffron belonging to the first category also on the basis of the presence of extraneous material. Such a limit was respected in the saffron sample from trial P1 (0.3%). As expected, the saffron from trials P2, P3 and P4 was free from pollen contamination.

Figure 9 shows some optical micrographs of the sample from trial P1 where the main anatomical structure of the stigma (papillae) and pollen grain were captured.



(**a**) (**b**) (**c**)

**Figure 9.** Epidermal cells with elongate papillae on edge of wall 100× (**a**); stigma structure and pollen grain 100× (**b**); pollen grain 400× (**c**).

### *3.5. 3D Dried Saffron Flower*

The new method of cultivation in large pots facilitated the harvesting procedure. Moreover, the innovative device preserved the integrity of flower tepals during harvesting, transporting and drying phases. Finally, the patented new method useful for both separating the stigmas from the remaining part of flower and flower drying, allowed us to realize a 3D dried flower without pollen granules. The absence of these latter was guaranteed also for stigmas which turned out to be of excellent quality. The hand process of flower transformation by the new method of stigma separating (Section 2.4) needs time and obviously it is more expensive than the traditional method. Nevertheless, only in this way is it possible to obtain 3D dried flowers (Figure 10).

(**a**) (**b**) (**c**)

**Figure 10.** Fresh flowers of *Crocus sativus* L. free of stamens and stigmas (**a**); flower dried in 3D configuration (**b**); 3D dried flower conserved in a glass jar (**c**).

Some parameters of the flower processing were optimized in the biochemistry laboratory of the Institute of Methodology for Environmental Analysis in Tito (Potenza), among them, the drying temperature and time. Suitable packaging enabled the dried flower to retain its bright colors for 5 months.

### 3.6. Daughter Corm Number and Diameter

Corms from Spain cultivated in the 2015–2016 and 2016–2017 growth seasons in Picerno were compared to each other and with those cultivated in the 2017–2018 growth season in Tricarico.

The results highlighted that the lowest number of daughter corms per mother corm was recorded in P1; on the hand, the highest numbers were found in P3 and P4 (Table 5). Nevertheless, the greatest number of daughter corms with a diameter equal to or greater than 2.5 cm was recorded in P1, although the number of mother corms planted was the lowest, both regarding the planted corm numbers per pot and the density. Moreover, the results showed that the daughter corm numbers per mother corm from the P2 trial were similar to those from P3. In turn, daughter corm numbers per mother corm in both the P2 and P3 trials were greater than those of P1, although this latter showed a higher number of daughter corms with a diameter greater than 2.5 cm. In detail, the daughter corm number with a diameter greater than 2.5 cm from P1 was about 68%, while the percentage in P2 and P3 was 22% and 31%, on average, respectively. The daughter corm number from P4 was similar to that of P3 and the relative daughter corm number with a diameter greater than 2.5 cm was about 27%.

**Table 5.** Difference between daughter corms (D corms) from the trials in pots over the three consecutive growth seasons (P1, P2 and P3) and from different geographical origin (P3, P4).

| Trial in Pot | Planted Corms ($n$ pot$^{-1}$) | Planting Density ($n$ m$^{-2}$) | D Corms ($n$ pot$^{-1}$) | D Corms < 2.5 cm ($n$ pot$^{-1}$) | D Corms $\geq$ 2.5 cm ($n$ pot$^{-1}$) | ICMI |
|---|---|---|---|---|---|---|
| $P1 = \sum_{i=1}^{4} Si$ | 44 | 77.6 | 154 | 49 | 105 | 3.5 |
| S1 | 11 | 77.6 | 42 | 16 | 26 | 3.8 |
| S2 | 11 | 77.6 | 39 | 12 | 27 | 3.5 |
| S3 | 11 | 77.6 | 37 | 10 | 27 | 3.4 |
| S4 | 11 | 77.6 | 36 | 11 | 25 | 3.3 |
| P2 (I) | 50 | 113.1 | 211 | 159 | 52 | 4.22 |
| P2 (II) | 50 | 113.1 | 217 | 178 | 39 | 4.34 |
| P3 (I) | 61 | 138.0 | 247 | 160 | 87 | 4.05 |
| P3 (II) | 61 | 138.0 | 277 | 180 | 97 | 4.54 |
| P3 (III) | 61 | 138.0 | 314 | 244 | 70 | 5.15 |
| P4 (I) | 61 | 138.0 | 255 | 168 | 87 | 4.18 |
| P4 (II) | 61 | 138.0 | 284 | 214 | 70 | 4.65 |
| P4 (III) | 61 | 138.0 | 334 | 263 | 71 | 5.47 |

In general, the mother corm progeny multiplication, in other words ICMI, evaluated over three years, was about 4.5 on average, which can be considered a good value because it guarantees the production of flowers in the next year and an excellent reproductive capacity. However, the best result was the reaching of the initial goal. Indeed, the results concerning mother corm and progeny corm proved that no damage from pests was incurred in Picerno and Tricarico fields in the three trials.

## 4. Discussion

The findings of this study, obtained by a multidisciplinary approach, showed different advantages from the alternative cultivation system proposed for the production of saffron (*Crocus sativus* L.). Moreover, the device and processing method for obtaining 3D dried flowers, in their turn, benefited from the advantages of the same cultivation method. The attention was focused on the implementation of the cultivation system which, relying on the use of large size pots (250–350 L), had to answer specific needs. In particular, this system had to be able to hinder the attack of pests, mainly moles and voles and to improve worker posture mainly during the 15–25 days of the harvesting phase [23]. At the same time, the potentiality and the efficiency in terms of yield and quality of both spice and propagation material, as well as weed control and management, were also assessed, not neglecting the meteorological variables during the three trial years. No trial in ground soil was carried out since it was considered to be a useless trial due to the presence of pests in both the experimental sites. In fact, this issue has deterred interest in the cultivation of this crop for some farmers in the experimental areas.

The results in the three trial years showed some differences in the parameters taken into account. In detail, as regards the flowering start date, the difference found could be due to the different meteorological conditions which can influence the temperature and humidity of soil and, consequently, the flowering start date in accordance with that reported by Aghhavani Shajari et al. (2022) [24]. Moreover, the results from all experimental trials showed that planting date did not influence the blooming start date, in accordance with Pirasteh et al. (2020) [25]. In contrast, the geographical origin (P3–P4) had an effect on the beginning of flowering in accordance with the previous results [22,26]. However, the differences between P3 and P4 could also depend on different corm storage temperatures in the different sites of provenience [27].

As regard to flowering interval, the differences observed in the three trial years, between the samples from the same origin, could be attributed to possible different humidity and temperatures of the soil [25], due to the different meteorological conditions in the flowering period (Sep–Nov) in which the 2016 rainfall was the most abundant (Figure 2, Table 2). In confirmation of the above mentioned, Aghhavani Shajari et al. (2022) reported that despite the low water requirement of saffron, the presence of soil moisture stimulated flowering [24]. Accordingly, it is believed that mainly rainfall may have influenced both flowering start date and flowering intervals. Nevertheless, Rezvani-Moghaddam (2020) reported that precipitation during flowering has a negative effect on the performance of the plant [5].

Regarding flower numbers per corm and the flower yield per surface unit, the differences, observed over the three years, depended on the different planting density. In fact, corm density can positively influence the flower numbers: as the density increases, so the flower numbers increase [6,12]. However, the number of flowers can also depend on the quality and storage conditions of the planting material [28], as well as on temperature. In fact, it is known that an inappropriate ambient temperature results in no flower initiation or flower abortion [27].

Summarizing, the best results were obtained in the P2 trial (2016–2017 growth season) mainly due to its higher planting density with respect to P1, thanks also to higher rainfall in the 2016 flowering period. However, all the results about the flower yield from the three trial years were promising, in line with the literature results obtained from traditional cultivation in open-field ground [22,29,30].

As regards the number and the size of the daughter corms, the results observed during the three trial years, also using corms from different provenience, demonstrated good efficiency of the alternative cultivation system proposed, although it was carried out without irrigation and nutrient management [24]. In accordance with data from the literature concerning planting material, it is believed that the differences between the parameters investigated could be ascribable to the different environmental conditions in the three trial years, as well as to planting density, corm storage temperature, without neglecting the different adaptation of corms in the two new environments of Picerno and Tricarico [12,27,29].

Thus, the experimental results obtained in this study of flowers and corms, obtained by cultivation in large pots, using corms from different origins, have shown that the proposed alternative saffron cultivation system is efficient. However, it is still perfectible through appropriate irrigation and nutrient management. Multiple scientific findings are reported in this regard [24,29,31,32].

Nevertheless, it should always to be kept in mind the criticality linked to the interaction between the optimized parameters and/or conditions for better management of saffron crop and the weather conditions. These latter, not controllable but only foreseeable, could affect, especially, traditional cultivation in ground soil. In other words, the meteorological parameters are those that can reserve the greatest surprises for farmers, even more so in recent periods as a result of climate change [33]. Currently, mainly the small farmers, in order to avoid water stagnation and to facilitate the removal of rainwater, prepare only appropriate beds on which they sow the corms [34]. The alternative cultivation system, relying on the use of large pots and on the functional layering of the filling materials (Section 2.2), thus ensuring excellent drainage, can represent a good adaptation to the system to reduce the revenue risk due to possible frequent and intense rainfall.

As regards the spice quality, the samples were evaluated following the ISO 3632-2010/2011 [10] normative which classified the saffron into the proper qualitative category to which it belonged. The differences encountered in this study, between the qualitative values, linkable to the content of the main biocomponent of the investigated samples, can depend on the different meteorological conditions in the three trial years, as well as on different provenience and corm storage conditions. It is known, in fact, that different accumulations of compounds in the plant parts, useful in medicinal, pharmaceutical, cosmetic and food fields, are generally affected by different factors such as the location of the growing place, altitude, soil type, climate, quality of the planting material, irrigation cycles and harvest time [35]. The differences between the main chemical characteristics of the samples investigated did not attract particular attention since all samples were classified in the first qualitative category, although the saffron from P2 gave the best results.

On the contrary, more particular attention was focused on evaluating the presence of extraneous material on the basis of the physical criteria of the ISO 3632 normative [10].

In fact, a disadvantage of the traditional separating method used to obtain the saffron is that, during the excision of stigmas, it is very likely that the spice is contaminated with pollen grains and any residues of tepals that may be cut during this manual operation. The contamination with pollen grains, mainly due to insect pollinators, is a great problem. Obviously, the contamination increases as the delay between the collection of the flowers being carried out and the moment at which the flowers begin to open increases [1]. Furthermore, the said contamination increases with the speed of the separating process. Generally, the speed of this operation is directly correlated to the quantity of flowers collected daily and inversely correlated to the number of skilled workers. Therefore, thanks to the cultivation system in large pots, using the innovative device and the new method of stigma separating, it was possible reduce or completely eliminate contamination from pollen grains and from other plant parts, thus obtaining excellent quality saffron.

Moreover, an important aspect to keep in mind is that saffron is identified as an occupational allergen as it may cause an acute allergic reaction in workers when exposed to pollen or stamen particles released during the traditional method of stigma excision from the saffron flowers. In fact, saffron contains a profilin-like protein which can be involved in immunologic IgE-mediated reaction or in cross-reactions causing allergic reactions in atopic subjects or sensitized individuals [36]. In accordance with the literature, it is very difficult to find first grade saffron on the market not only because of the presence of extraneous substances (adulteration by means of substitution with other plants) but also other parts of the plant itself (auto-adulteration by including styles, stamens, and petals) [37]. Hence, this cultivation system favors the obtaining of products that, being real unique products, could play a vital role in "niche product" marketing, also on-line [38], offering an economic advantage to producers.

In addition to these advantages, the alternative system proposed for saffron cultivation was found to be very useful where there is the presence of pests (e.g., mole, voles and wild boars) as is the case in the experimental sites of the Picerno and Tricarico countryside. It is well known that these pests are economically very harmful to the saffron crop [16]. Moreover, Shuwen et al. (2019) reported that fungi of the genera Fusarium, Rhizoctonia, Penicillium, Aspergillus, Sclerotium, Phoma, Stromatinia, Cochliobolus, and Rhizopus were associated with saffron diseases [39]. The pathogen fungi survives in infected corms and in soil as mycelium, chlamydospores, macroconidia and microconidia which, by entering directly into the roots or through wounds in corms, can infect other plants [40]. Rot caused by Fusarium oxysporum is the most destructive disease in saffron field, causing severe corm losses [40]. In fact, the high contamination rate of saffron by these pathogens is a serious constraint on saffron production [39]. Therefore, the cultivation system in large pots can also offer the possibility of hindering the spread of possible fungal pathologies because it is a discontinuous cultivation system being delimited within the single pot.

In addition to hindering attacks from pests and the spread of possible pathogens, the method here proposed was able to improve weed control management. However, in some cases this critical issue was eliminated also thanks to the use of a good universal potting soil, allowed in organic farming. Generally, in traditional saffron cultivation, weeds need to be controlled from prior to flowering, when weeds are younger, until the vegetative phase closes. The number of laborers for weed control is estimated to be 80 per hectare in the traditional cultivation method; accordingly, the weeding phase is expensive [28]. Therefore, looked at from this point of view, the proposed cultivation system offers a considerable cost advantage not only when a good potting soil free of weed seeds is used but also when it is decided to use the ground of the same field to reduce the implementation costs of this alternative saffron cultivation system. In this case, the soil solarization method [41] was suggested to better control the possible weeds [28]. The solarization method, combined with other control measures for an integrated approach, can also be useful for soil disinfestation by reducing the pathogen contamination, thus improving its performance [42]. The application of this soil disinfection method can be applied more successfully to the cultivation system in large pots thanks to their geometric characteristics and since it can be directed only for the pots that need it for the presence of infected corms.

Another advantage of the system in a pot that should not be neglected is the improvement of the body position of the workers during possible weeding as well as during the sowing and harvesting phases. In this latter phase, the proposed saffron cultivation system also allowed us to pick the flower from its bottom part (stem), avoiding touching both the soil and tepals with the fingertips. In contrast, such a circumstance is very likely to happen when you are forced into an uncomfortable position, making it more difficult to preserve both food safety and the structural integrity of the flowers.

Structural integrity, the temperature and the time of dehydration of tepals are fundamental parameters to ensure optimal performance of the innovative device, described in Section 2.4, by which dried flowers in their original tridimensional conformation were obtained, also thanks to the application of the new method of processing saffron flowers.

As regards the advantages of both the device and the innovative method of flower transformation, it can be asserted that it is possible to further valorize a by-product of saffron production [14], thus making it an important raw material, respecting the concept of the circle economy [43].

Tepals, the most conspicuous part of the floral biomass are considered currently a by-product or waste material of saffron production [4]. During the traditional manual phase of flower "mondatura", preferably performed within the same day of the harvest, the original tridimensional shape and tissue system structure of the flowers are damaged or sometimes even destroyed. Indeed, traditionally, in order to intercept and take the stigmas, the flower can undergo an opening of the tepals that goes beyond the natural maximum opening of the flower. Hence the three-dimensional structure calyx or campanulate of the flower is almost always destroyed [11].

On the other hand, Mohammad Khajeh-Hosseini and Farnoush Fallahpour [16], in accordance with other authors, reported that the saffron tepals can be used as an alternative or supplementary medicine in the treatment of some diseases, highlighting the different pharmacological properties of the tepals, such as antibacterial, antispasmodic, immunomodulatory, antitussive, antidepressant, antinociceptive, hepatoprotective, renoprotective, antihypertensive, antidiabetic, and antioxidant; most of them are related to the presence of active components in saffron petals that mostly exhibit antioxidant activities [16,44,45].

Therefore, the growing consumer demand for healthier nutrition is leading the food industry to develop functional foods by including bioactive compounds in their formulations that provide health benefits beyond the nutritional properties of the food product it-self. Generally encapsulation and microencapsulation methods are used for the aim of reaching optimal results. Recently, micro-encapsulations of biocomponents also from saffron have been reported in the literature [15]. Diaz et al. (2013) reported both the approximate composition of each part of the saffron flower and their composition in minerals, anions, organic acids, dietary fiber and soluble sugar, concluding there was possible use of the whole flower from which to extract biocomponents [14]. Considering that the chemical composition of tepals is very similar to that of the stigma [46], the possibility of ingesting the nutraceutical biocomponents from *Crocus sativus* by eating the flowers directly should also be taken into account. Obviously, the absence of toxicity and contamination from extraneous and exogenous material is preparatory to the possible recovery of this biomass for food use.

Hence, the absence of stamens and pollen grains as well as the absence of microorganisms harmful to health assume a relevant importance when addressing the possibility of using a production by-product for food purposes.

For the above mentioned reasons, the saffron cultivation system in large pots can reduce the risk of microbial contamination due to pathogenic microorganisms from soil, a frequent source of contamination by enteric bacteria [47]. In addition, it allowed us to obtain very exciting and promising data on flower numbers, spice yield and quality, corm yield and daughter corm numbers with a large enough size to flower (horizontal diameter $\geq$ 2.5 cm corresponding to a weight higher or equal to 10 g). In fact, the results of this study were in line with those obtained from traditional cultivation methods, but additionally offering the interesting advantages discussed above.

Despite the numerous and huge advantages, the method proposed also showed two disadvantages; the first of which is represented by the higher initial implementation costs compared to those of the traditional method, while the second one is represented by the negative environmental impact due to the use of plastic pots. As regards the costs for implementation of the cultivation system in large pots, the feedback on investment was estimated to be two years more with respect to that estimated for the traditional method, without taking into account the economic advantages derived from the benefits for workers and the consequent economic savings for producers. Regarding the environment issue, it could be easily overcome by using more environmentally friendly materials, such as, e.g., tuff. This material can also offer the advantage of building up large pots on steep terrain with a high slope in marginal areas where, although the land is still fertile, it is very difficult to practice mechanized agriculture.

This alternative cultivation system, providing the above mentioned practical and economic benefits, could encourage investment by young entrepreneurs increasingly attentive to business risks. It could also encourage the establishment of an association of small saffron producers, interested in obtaining small quantities of the spice but of high quality, respecting the traditions of small and numerous territorial realities, such as those of the Basilicata region. Obviously, the production of a small amount of spice on each farm can guarantee the best results from every point of view, starting from the qualitative aspect all the way up to the management and economic ones.

Based on the results obtained, further investigations are underway to evaluate thoroughly the effect of the saffron cultivation system in large pots on some of the biodiversity characteristics (chemical and morphological traits) of *Crocus sativus* L. from different geographical origins. In particular, a study relying on the use of biostimulants which can promote sustainable growth and a greener and competitive economy by reducing chemical fertilizer use [3] is currently in progress by exploiting the advantages of this saffron cultivation method. Moreover, studies aimed at the automation of flower processing by using the patented device are also in progress.

## 5. Conclusions

The alternative saffron cultivation system, relying on the use of large pots, has al-lowed us to overcome several critical issues (pests, pathogen fungi, weeds) and some difficulties (e.g., the inevitable prolonged incorrect body posture which workers are forced to assume) typical of the saffron crop. However, the great advantage of the proposed cultivation system has been that of preserving the structural integrity of the flower tepals, a necessary condition to achieve good-looking, 3D dried flowers. Such a goal has been achieved by using, apart from the proposed saffron cultivation system, the innovative device and the new method for stigma separation. This combination has offered the possibility to eliminate or restrict as far as possible the presence of pollen grains. Accordingly, the recovery and the valorization of the main by-product of saffron production is better suited for food purposes. Moreover, excellent quality saffron has also been obtained.

## 6. Patent

The saffron cultivation method in large pots has allowed a high percentage of flowers (about 90%) to be obtained with their structural integrity preserved. This latter is a characteristic that is very important in order to produce good looking, 3D dried flowers, free from pollen contamination. Furthermore, the invention device allowed us, in turn, to obtain a saffron quality of the first category, suitable for everyone, but especially for allergy sufferers. The references of the patent are reported below:

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- Patent holders: TRIOLONE Nicola and CICCO Nunzia

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**Conflicts of Interest:** The author declares no conflict of interest. The author declares that she has a personal relationship with the designer of the innovative device, her husband. This personal circumstance has not influenced the representation or interpretation of the reported research results. The device designer had no role in the study relative to the alternative cultivation system in large pots; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## References

1. Rashed-Mohassel, M.-H. Chapter 4—Evolution and Botany of Saffron (*Crocus sativus* L.) and Allied Species. In *Saffron*; Koocheki, A., Khajeh-Hosseini, M., Eds.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Cambridge, UK, 2020; pp. 37–57, ISBN 978-0-12-818638-1.
2. Kumar, R.; Singh, V.; Devi, K.; Sharma, M.; Singh, M.K.; Ahuja, P.S. State of Art of Saffron (*Crocus sativus* L.) Agronomy: A Comprehensive Review. *Food Rev. Int.* **2008**, *25*, 44–85. [CrossRef]
3. Cardone, L.; Castronuovo, D.; Perniola, M.; Cicco, N.; Candido, V. Saffron (*Crocus sativus* L.), the King of Spices: An Overview. *Sci. Hortic.* **2020**, *272*, 109560. [CrossRef]
4. Shahi, T.; Assadpour, E.; Jafari, S.M. Main Chemical Compounds and Pharmacological Activities of Stigmas and Tepals of 'Red Gold'; Saffron. *Trends Food Sci. Technol.* **2016**, *58*, 69–78. [CrossRef]
5. Rezvani-Moghaddam, P. Chapter 8—Ecophysiology of Saffron. In *Saffron*; Koocheki, A., Khajeh-Hosseini, M., Eds.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Cambridge, UK, 2020; pp. 119–137, ISBN 978-0-12-818638-1.
6. Koocheki, A.; Seyyedi, S.-M. Saffron "Seed", the Corm. In *Saffron*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 93–118, ISBN 978-0-12-818638-1.
7. Ghaffari, S.; Roshanravan, N. Saffron; An Updated Review on Biological Properties with Special Focus on Cardiovascular Effects. *Biomed. Pharmacother.* **2019**, *109*, 21–27. [CrossRef] [PubMed]
8. Gohari, A.; Saeidnia, S.; Mahmoodabadi, M. An Overview on Saffron, Phytochemicals, and Medicinal Properties. *Pharmacogn. Rev.* **2013**, *7*, 61. [CrossRef]
9. Bolhassani, A. Bioactive Components of Saffron and Their Pharmacological Properties. In *Studies in Natural Products Chemistry*; Elsevier: Amsterdam, The Netherlands, 2018; Volume 58, pp. 289–311, ISBN 978-0-444-64056-7.
10. *ISO3632 ISO-3632-2-2010*; Part 1: Specification, Part 2: Test Methods. International Organisation for Standardization: Geneva, Switzerland, 2010.
11. Gracia, L.; Perez-Vidal, C.; Gracia-López, C. Automated Cutting System to Obtain the Stigmas of the Saffron Flower. *Biosyst. Eng.* **2009**, *104*, 8–17. [CrossRef]
12. Kothari, D.; Thakur, R.; Kumar, R. Saffron (*Crocus sativus* L.): Gold of the Spices—A Comprehensive Review. *Hortic. Environ. Biotechnol.* **2021**, *62*, 661–677. [CrossRef]
13. Serrano-Díaz, J.; Sánchez, A.M.; Alvarruiz, A.; Alonso, G.L. Preservation of Saffron Floral Bio-Residues by Hot Air Convection. *Food Chem.* **2013**, *141*, 1536–1543. [CrossRef]
14. Serrano-Díaz, J.; Sánchez, A.M.; Martínez-Tomé, M.; Winterhalter, P.; Alonso, G.L. A Contribution to Nutritional Studies on *Crocus sativus* Flowers and Their Value as Food. *J. Food Compos. Anal.* **2013**, *31*, 101–108. [CrossRef]
15. Bakshi, R.A.; Sodhi, N.S.; Wani, I.A.; Khan, Z.S.; Dhillon, B.; Gani, A. Bioactive Constituents of Saffron Plant: Extraction, Encapsulation and Their Food and Pharmaceutical Applications. *Appl. Food Res.* **2022**, *2*, 100076. [CrossRef]
16. Khajeh-Hosseini, M.; Fallahpour, F. Emerging Innovation in Saffron Production. In *Saffron*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 205–216, ISBN 978-0-12-818638-1.
17. Shahnoushi, N.; Abolhassani, L.; Kavakebi, V.; Reed, M.; Saghaian, S. Economic Analysis of Saffron Production. In *Saffron*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 337–356, ISBN 978-0-12-818638-1.
18. Kahriz, P.P. Saffron (*Crocus sativus* L.) Cultivation in Turkey. In *Saffron*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 33–43, ISBN 978-0-12-818462-2.
19. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Köppen-Geiger Climate Classification Updated. *metz* **2006**, *15*, 259–263. [CrossRef]
20. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated World Map of the Köppen-Geiger Climate Classification. *Hydrol. Earth Syst. Sci.* **2007**, *12*, 1633–1644. [CrossRef]
21. Samela, C.; Imbrenda, V.; Coluzzi, R.; Pace, L.; Simoniello, T.; Lanfredi, M. Multi-Decadal Assessment of Soil Loss in a Mediterranean Region Characterized by Contrasting Local Climates. *Land* **2022**, *11*, 1010. [CrossRef]
22. Cardone, L.; Castronuovo, D.; Perniola, M.; Cicco, N.; Molina, R.V.; Renau-Morata, B.; Nebauer, S.G.; Candido, V. *Crocus sativus* L. Ecotypes from Mediterranean Countries: Phenological, Morpho-Productive, Qualitative and Genetic Traits. *Agronomy* **2021**, *11*, 551. [CrossRef]
23. Cardone, L.; Candido, V.; Castronuovo, D.; Perniola, M.; Cicco, N. Comparing Annual and Biennial Crop Cycle on the Growth, Yield and Quality of Saffron Using Three Corm Dimensions. *Sci. Hortic.* **2021**, *288*, 110393. [CrossRef]
24. Shajari, M.A.; Moghaddam, P.R.; Ghorbani, R.; Koocheki, A. Does Nutrient and Irrigation Managements Alter the Quality and Yield of Saffron (*Crocus sativus* L.)? *Agric. Water Manag.* **2022**, *267*, 107629. [CrossRef]

25. Pirasteh-Anosheh, H.; Hashemi, S.E.; Del Borghi, A.; Spasiano, D.; Rad, M.; Race, M. Feasibility Study of Saffron Cultivation Using a Semi-Saline Water by Managing Planting Date, a New Statement. *Environ. Res.* **2022**, *203*, 111853. [CrossRef]
26. Renau-Morata, B.; Nebauer, S.G.; García-Carpintero, V.; Cañizares, J.; Gómez Minguet, E.; de los Mozos, M.; Molina, R.V. Flower Induction and Development in Saffron: Timing and Hormone Signalling Pathways. *Ind. Crops Prod.* **2021**, *164*, 113370. [CrossRef]
27. Wang, Z.; Li, X.; Xu, J.; Yang, Z.; Zhang, Y. Effects of Ambient Temperature on Flower Initiation and Flowering in Saffron (*Crocus sativus* L.). *Sci. Hortic.* **2021**, *279*, 109859. [CrossRef]
28. Bazoobandi, M.; Rahimi, H.; Karimi-Shahri, M.-R. Saffron Crop Protection. In *Saffron*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 169–185, ISBN 978-0-12-818638-1.
29. Aghhavani Shajari, M.; Rezvani Moghaddam, P.; Ghorbani, R.; Koocheki, A. The Possibility of Improving Saffron (*Crocus sativus* L.) Flower and Corm Yield through the Irrigation and Soil Texture Managements. *Sci. Hortic.* **2020**, *271*, 109485. [CrossRef]
30. De Juan, J.A.; López Córcoles, H.; Muñoz, R.M.; Picornell, M.R. Yield and Yield Components of Saffron under Different Cropping Systems. *Ind. Crops Prod.* **2009**, *30*, 212–219. [CrossRef]
31. Ghanbari, J.; Khajoei-Nejad, G. Integrated Nutrient Management to Improve Some Soil Characteristics and Biomass Production of Saffron. *Ind. Crops Prod.* **2021**, *166*, 113447. [CrossRef]
32. Esmaeilian, Y.; Amiri, M.B.; Tavassoli, A.; Caballero-Calvo, A.; Rodrigo-Comino, J. Replacing Chemical Fertilizers with Organic and Biological Ones in Transition to Organic Farming Systems in Saffron (*Crocus sativus*) Cultivation. *Chemosphere* **2022**, *307*, 135537. [CrossRef] [PubMed]
33. Dhakal, C.; Khadka, S.; Park, C.; Escalante, C.L. Climate Change Adaptation and Its Impacts on Farm Income and Downside Risk Exposure. *Resour. Environ. Sustain.* **2022**, *10*, 100082. [CrossRef]
34. Rather, A.M.; Rashid, S.; Sultan, R.; Nawchoo, I.A.; Wani, I.A.; Kamili, A.N. Hurdles and Clarifications for the Cultivation of Saffron in Jammu and Kashmir. *J. Agric. Food Res.* **2022**, *10*, 100344. [CrossRef]
35. Mykhailenko, O.; Desenko, V.; Ivanauskas, L.; Georgiyants, V. Standard Operating Procedure of Ukrainian Saffron Cultivation According with Good Agricultural and Collection Practices to Assure Quality and Traceability. *Ind. Crops Prod.* **2020**, *151*, 112376. [CrossRef]
36. Varasteh, A.-R.; Moghadam, M.; Vahedi, F.; Kermani, T.; Sankian, M. Cloning and Expression of the Allergen Cro s 2 Profilin from Saffron (*Crocus sativus*). *Allergol. Int.* **2009**, *58*, 429–435. [CrossRef]
37. Khilare, V.; Tiknaik, A.; Prakash, B.; Ughade, B.; Korhale, G.; Nalage, D.; Ahmed, N.; Khedkar, C.; Khedkar, G. Multiple Tests on Saffron Find New Adulterant Materials and Reveal That Ist Grade Saffron Is Rare in the Market. *Food Chem.* **2019**, *272*, 635–642. [CrossRef]
38. Phang, C.W.; Zhang, C.; Sutanto, J. The Influence of User Interaction and Participation in Social Media on the Consumption Intention of Niche Products. *Inf. Manag.* **2013**, *50*, 661–672. [CrossRef]
39. Shuwen, H.; Xi, Y.; Liqin, L.; Yumei, Y.; Guifen, Z.; Chong, Y.; Yan, D.; Xiaodong, Q. Limiting Factors of Saffron Corm Production from the Perspective of Microorganisms. *Sci. Hortic.* **2019**, *247*, 165–174. [CrossRef]
40. Palmero, D.; Rubio-Moraga, A.; Galvez-Patón, L.; Nogueras, J.; Abato, C.; Gómez-Gómez, L.; Ahrazem, O. Pathogenicity and Genetic Diversity of Fusarium Oxysporum Isolates from Corms of *Crocus sativus*. *Ind. Crops Prod.* **2014**, *61*, 186–192. [CrossRef]
41. Candido, V.; D'Addabbo, T.; Miccolis, V.; Castronuovo, D. Weed Control and Yield Response of Soil Solarization with Different Plastic Films in Lettuce. *Sci. Hortic.* **2011**, *130*, 491–497. [CrossRef]
42. Katan, J.; Gamliel, A. Plant Health Management: Soil Solarization. In *Encyclopedia of Agriculture and Food Systems*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 460–471, ISBN 978-0-08-093139-5.
43. Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; López-Felices, B.; Román-Sánchez, I.M. Circular Economy in Agriculture. An Analysis of the State of Research Based on the Life Cycle. *Sustain. Prod. Consum.* **2022**, *34*, 257–270. [CrossRef]
44. Lahmass, I.; Lamkami, T.; Delporte, C.; Sikdar, S.; Van Antwerpen, P.; Saalaoui, E.; Megalizzi, V. The Waste of Saffron Crop, a Cheap Source of Bioactive Compounds. *J. Funct. Foods* **2017**, *35*, 341–351. [CrossRef]
45. Tuberoso, C.I.G.; Rosa, A.; Montoro, P.; Fenu, M.A.; Pizza, C. Antioxidant Activity, Cytotoxic Activity and Metabolic Profiling of Juices Obtained from Saffron (*Crocus sativus* L.) Floral by-Products. *Food Chem.* **2016**, *199*, 18–27. [CrossRef] [PubMed]
46. Pandita, D. Chapter 14—Saffron (*Crocus sativus* L.): Phytochemistry, Therapeutic Significance and Omics-Based Biology. In *Medicinal and Aromatic Plants*; Academic Press: Cambridge, MA, USA, 2021; pp. 325–396.
47. Bauza, V.; Madadi, V.; Ocharo, R.; Nguyen, T.H.; Guest, J.S. Enteric Pathogens from Water, Hands, Surface, Soil, Drainage Ditch, and Stream Exposure Points in a Low-Income Neighborhood of Nairobi, Kenya. *Sci. Total Environ.* **2020**, *709*, 135344. [CrossRef]