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RESEARCH PAPER

Saffron corm sorting and rot treatment strategy for productivity enhancement for precision agriculture

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Abstract

One of the most economical and precious spices ever known is saffron. It has innumerable pharmaceutical applications, and its cultivation is limited to certain topographic regions throughout the world. Although efforts are continuously being made to increase productivity and increase the area under cultivation, there are multiple factors leading to its low production. Corm size is one of the major factors affecting the quality and production of saffron. The more the corm size for a plantation, the better the yield of the crop. This can pose a serious threat to saffron cultivators who are not able to get good quality corms and sort quality corms from infected ones. Additional factors affecting saffron cultivation include attack by fungus leading to corm rots and sclerotineal disease. In this paper, IoT (Internet of Things) has been used to provide an energy-efficient, ready-to-use, reliable, and user-friendly solution for corm sorting and treatment before sowing to promote quality, better yield and minimized wastage due to corm rots. After sorting the corms, they are treated with 0.2% of tiabendazole fungicide solution and dried, before sowing and for long-term storage. Firstly, sorting and treatment system for the saffron corms processing as per weight is proposed. First two-layer cleaning mechanism to remove foreign substances, then three-step treatment has been applied to remove microorganisms. An automated conveyor system equipped with IoT devices was used for sorting and treating saffron corms. Different energy efficient LPWA (Low Power Wide Area) and LTE (Long Term Evolution) technologies used in the framework, for communication are NB-IoT (Narrow Band IoT) and LoRa (Long Range Radio).

Keywords

Corm Rots, IoT, LoRa, NB-IoT, Precision Agriculture, Saffron

Introduction

Saffron or Red Gold known derived from stigma of Crocus Sativa, is known for its very high price value referred to as 'Golden Zest' in India. The lifecycle of the plant starts with the planting stage in June, with the flowering in mid - October and the leaves drying out in May. Saffron being a triploid perennial plant attains a maximum height of 25 to 40 cm. The conditions required for growth include soil with a pH value of 5.5 to 8.5, 100 mm water at the pre-flowering stage after every two weeks and always making sure that the crop is weed free.

Saffron crop can be subjected to a vast variety of fungal infections which include fungal infections like fusarium, violet root rot and Rhizoctonia Crocorum (Nekoei et al. 2021). The word 'saffron' finds its origin in Arabic, and has come from word "Zafaran" which means yellow. Saffron has great significance in different Indian rituals and is known by many names like 'Kesar', 'Kum-Kum' and 'Koung' in Kashmiri language. The estimated world production is around 200 tons annually (Ganaie and Singh 2019).The leading saffron producers of the world include Iran, Greece, Afghanistan, Italy and Turkey. Increase in saffron export can have a great impact on economy of a country. Herat, considered as the best quality saffron producing area has contributed to generating 2.6 billion U.S Dollars by exporting saffron. Various factors deciding the quality of this crop are based on the pigmentation of crocin, safranal and picrocrocin. As per the presence of these pigments, saffron is classified mainly into 3 categories, Grade 1, Grade 2 and Grade 3 in order of their quality (Rasooli et al. 2020). In India the cultivation is mostly in regions of Jammu and Kashmir. Saffron has a plethora of benefits ranging from culinary to cosmetics and textile dyeing to medicinal (anti-ulcer, anti-spasmodic, anti-cancer, anti-diabetic, depression and carminative properties) (Asiabani et al. 2020). It is one of the main spices for preparation of Kashmiri 'Kehwa'. Saffron has great significance in religious purposes. It is an important part of rituals as it is considered very pure by the Buddhist monks who have even adopted the saffron color for wearing. It can be of great value in acting as a home remedy for treating respiratory infections such as common colds, coughs, fever and bronchitis. The by-products are also widely used in cosmetics, perfumes and textile industry (Giupponi et al. 2019).

The production of saffron is declining in many countries of the world including India due to poor quality corms. Nutrient deficient soil having low traces of Phosphorous is also a reason for saffron decline. As per the research work (Kour et al. 2022b), the two major reasons for decline in yield and quality compromise are: non-availability of good quality corms and association of corm with various plant pathogenic microorganisms, bacteria, and soil-borne fungi which initiate corm rot. The corms available in the market are a combination of light and heavy weight. These corms are difficult to be sorted before sowing.

There is great need for a reliable and user-friendly solution which will help farmers with sorting of quality corms for sowing as corms having weight less than 8 gm will bear no flowers. The sorted corms also need to be treated for pest control. The known microorganism of corm rot like Fusarium oxysporum, Fusarium monliform, Fusarium solani, Bacillus croci etc. The death of foliage is characterized by yellowing, wilting and drooping of the shoots at the time of flowering period. Infected corms show small spots which have chlorotic holes later turning into dark powdery mass and decay. Therefore, it becomes necessary to treat saffron corms before preservation and plantation to have a high yield of saffron, the world's costliest condiment (Gupta et al. 2020; Gulzar et al. 2023; Ünal et al. 2024).

A good daughter corm is considered to have a weight above 8 grams. The corms having good weight and size produce the best quality of saffron and the daughter corms (Cardone et al. 2019). It is clear that saffron corm is very susceptible to soil-borne fungi, bacteria, and microorganism corms getting spoiled. Due to this factor, the supply of daughter corms decreases and reduces the overall cultivation area and hence the production. A mechanism for sorting and treatment of corms with fungicidal, anti-bacterial, and other chemical solutions is required to preserve the quality and yield (Bagherzade et al. 2017).

The model presented in this paper aims to address the above limitations and drawbacks and provides a sustainable solution with a simple, easy to operate, cost-efficient, less time-consuming, automated solution for sorting healthy saffron corms and preparing them for storage. In the last decade, the IoT has been one of the most amateur technologies, which has changed the facade of human life. With its rapid development, the paradigm of IoT is changing the face of agriculture world, with increase in qualitative crop yield. There is need for naive technology like IoT to overcome the cultivation hurdles. Although IoT provides smart solutions for different sectors but there are challenges like energy consumption. In order to address these issues, it is best to use NB-IoT, LTE, LoRa and LPWA for data communication and control. As the number of devices are also increasing every day, energy dissipation at large needs to be taken care of. This issue can be addressed by using low energy consuming devices with minimum energy required for operation. LoRa and NB-IoT offer energy-efficient access networks for communication. NB-IoT is a communication technology for M2M and device communication in IoT environment. It has very low cost and uses less power. LTE based on the Global System for Mobile Communication (GSM) / EDGE is a standard for wireless communication for mobile devices and data terminals. It leads to improvement in the capacity and speed by altering radio interface and core network improvements. LoRa includes a long-range, low-power wireless communication platform essential to the IoT (Khanna and Kaur 2019).

IoT is an impeccable solution for such agricultural issues related to saffron cultivation. Numerous challenges like adulteration, transportation and efficient utilization of by products can also be improved by using IoT with other technologies like block chain, supply chain etc., (Khanna and Kaur 2019). IoT also suffers from issues of energy usage and efficiency, which can be overcome by using solar energy for sustainability.

The approach is novel as it is the first designed system for sorting of corms in saffron. Availability of good quality corms is a challenge for farmers which can be achieved by using this framework. This paper provides the following contributions:

- A simple energy-efficient, automated three-layer mechanism for sorting quality and fertile corms for sowing.
- An automated novel, user-friendly and reliable strategy for preparing corms for long term storage without decaying.

- An automated three step process for treatment of corm rots and to kill soil-borne fungi, bacteria, and microorganisms for production of good quality daughter corms.

The structuring of the paper is as follows: Section 2 presents the literature survey related to various approaches from present state of art, used for saffron corm sorting and treatment. Section 3 discusses the problem statement and the proposed solutions and the complete working of designed system. Section 4 illustrates the detailed methodology in designing the framework and three stage mechanisms with hardware specifications. Section 5 is related to the discussion and important equations related to corm size and quality. Section 6 deals with the results and outcome of important parameters affecting corm size. Section 7 concludes the paper and discusses the future scope of the developed corm sorting.

Literature survey

The cultivation of saffron presents numerous challenges for farmers, which have been extensively examined in the literature. Predictions indicate a significant growth trajectory in the saffron market over the forthcoming years. Researchers have identified key areas for investigation, encompassing various aspects related to saffron cultivation. Additionally, existing solutions for saffron corm sorting have been scrutinized, revealing existing shortcomings and opportunities for enhancement.

Anabat et al. (2020) proposed an agro-ecological model for saffron crop using GIS (Geographic Information System) spatial decision-making methods to study suitability of saffron cultivation in various other Iranian regions. The simulation used here is Monte Carlo simulation (MCS) in association with GSA (Global Sensitivity Analysis). The use of former stated models greatly improves precision by removing variance of data. Results obtained using GSA method allows to obtain the priority of criteria and identify the most important criteria and the variability of outputs under uncertainty conditions for model inputs.

Shokati and Feizizadeh (2019) also studied differentiation of saffron on the basis of geography by using Gas ChromatographyMass Spectrometry/ Flame Ionization Detector (GC–MS/FID) and chemometrics methods. About 247 saffron samples were collected from different countries like Iran, Italy, Greece, Spain. The differences in these samples were studied using techniques like flame ionization, spectrometry and gas chromatography with percentages of correct classification and validation more than 95 percent.

The study (Aktaş et al. 2022) deals with the classification of pistachios on the basis of open or closed using deep learning. The dataset used is collected from industries using AlexNet and Inception V3. The accuracy of the tests performed was 96.13% and 96.54%. The testing and training of the model was done by comparing desktop data and industrial data with AlexNet structures. When the network structure trained with the desktop dataset is fed test images from the industrial dataset, test accuracy achieved is 61.75%. Conversely, test accuracy is computed as 99.84% when the desktop data set is input into an Alexnet structure that has been trained using an industrial data set. This indicates unequivocally how well the industrial dataset functions in industrial classification applications and how poorly the desktop dataset works in industrial applications.

The highest dry weight of stigmas, stigma length, stamen was achieved by corms of D1 class and highest number of flowers was achieved by D2 class production (35.9 tons per hectare) was obtained when corms belonged to D3 class. The quality traits obtained as per International Standardization Organization (ISO 3632) for taste (116.2 A1% 1 cm 257 nm) and color (306.3 A1% 1 cm 440 nm) were obtained for D2 class. Hence, corm dimensions have great impact on yield and quality traits of saffron. However, the paper indicates the need for more studies to evaluate nutritional value. Exact methods to evaluate the quality of saffron have also not been discussed (Cardone et al. 2021). The major research challenges identified from the literature faced by researchers is unavailability of good quality corms.

Menia et al. (2018) studied the quality components of saffron like crocin, picrocrocin, safranal determining color, flavor and aroma strength. The main reasons responsible for decline were enlisted as: corm rotting, inadequate postharvest practices and adulteration. Such issues can be taken care of by using adequate proportions of fungicide and pesticide solutions. The authors suggest educating the farmers about this and developing an apparatus for proper corm selection and fungicidal treatment.

Gupta et al. (2021) also describes corm rot as one of the major reasons for reduction in saffron production. Other than yield reduction, it also effects the daughter corms. There is lack of efficient mechanism to deal with this issue and curb it properly. Advanced methods like tissue culture and molecular breeding for making resistant genotypes against common diseases like Fusarium oxysporum has also been discussed. Much emphasis has been laid on making the good quality corms available to the farmer. There is need for advanced cultural practices and standard procedures at farmer's disposal to put an end to such issues.

Ghanatian et al. (2019) have proposed a saffron cultivation method and effect of rots on corms. The method is characterized by different steps from plantation to cultivation. The important factor in this paper is the significance of good quality corms. An apparatus has been designed which consists of a two conveyer belts, helping to sort corms based on different sizes. The procedure also involves treating of corms with carbendazim solution (50%) and drying before sowing. This is done to protect the corms from rots and fungus. The corm sorting is done efficiently by using two conveyer belts and a recycled bin however the system is not automated and is very clumsy. The solution is not sustainable and demands high power supply to work. This disease causes decay of saffron plants resulting in decline of yield. Corm rot is deadly as there is no detection in initial stages, due to which such seeds are sown and high labor is invested, resulting in wastage of time and effort as the seeds get decomposed to a fine powder over time (Mirghasempour et al. 2022b).

Materials and methods

The proposed solution provides an easy, energy-efficient and reliable solution for sorting of healthy and fertile corms on the basis of dimensions and weight. The power supply used for the device is solar which makes it energy efficient. The proposed system comprises of a different sorting mechanism explained in subsections below.

Working

A saffron processing system consists of a sorting mechanism, a vessel, a conveyor mechanism, a hopper, a load sensor and plurality of chambers. A sorting mechanism is configured with a plate comprising multiple holes coupled with a moving mechanism to oscillate in a horizontal plane to sort healthy saffron corms. The oscillations of the plate along with the length of the frame is achieved with a gear mechanism rotated by an electrical motor. The vessel is used to gather sorted saffron corms. The corms in vessel are sent for treatment with a plurality of water-soluble chemicals by the conveyer mechanism. The system has 0.2% tiabendazole chemical used for the treatment of the saffron corms against various diseases (Mirghasempour et al. 2022a). A conveyor mechanism coupled with a drive mechanism, a load sensor, and a hopper at the first end is used to deliver saffron corms one by one on a conveyor bed. The bed is equipped with a rotating door mechanism that passes saffron corms through a plurality of Ultra Voilet (UV) chambers having a lamp for treatment of the saffron corms, a load sensor configured with the conveyor, and two boom barriers each with an actuator unit to direct all saffron corms in a particular path. UV chamber consists of a power supply, shield from the operator, pulsed UV light, computer interface, and light source. A load cell works by converting mechanical force into measurable digital values that are processed by the microcontroller to classify into any of the three categories w1, w2, or w3 and take the required action. A plurality of containers is arranged at the second end to collect sorted saffron corms. A control unit comprising a processing unit, an ESP32 board, a switching unit, and an input-output unit is configured with the conveyer mechanism to execute and monitor one or more kinematic parameters of the conveyor. An external power source is used to receive packets of data transmitted by the sensors. The received packets are transmitted to a plurality of sensors and actuators coupled with the system to perform one of the functions. The two cores Protocol CPU (PRO_CPU) and Application CPU (APP_CPU).PRO_CPU processor of ESP32 handles the Wi-Fi, Bluetooth, and other internal peripherals while as the APP_CPU is used for the application coding. The system as shown in Fig. 1 provides an overview of the proposed system used, with an easy and reliable solution to sort corms and treat them for protection against rots and other diseases.

The communication between different IoT devices utilizes low power and energy by using Low Power Wide Area (LPWA) technologies.The software development framework for ESP32 is Espressif Internet Development Framework (ESP-IDF). ESP32 provides dual-mode wireless network connectivity which is communicatively

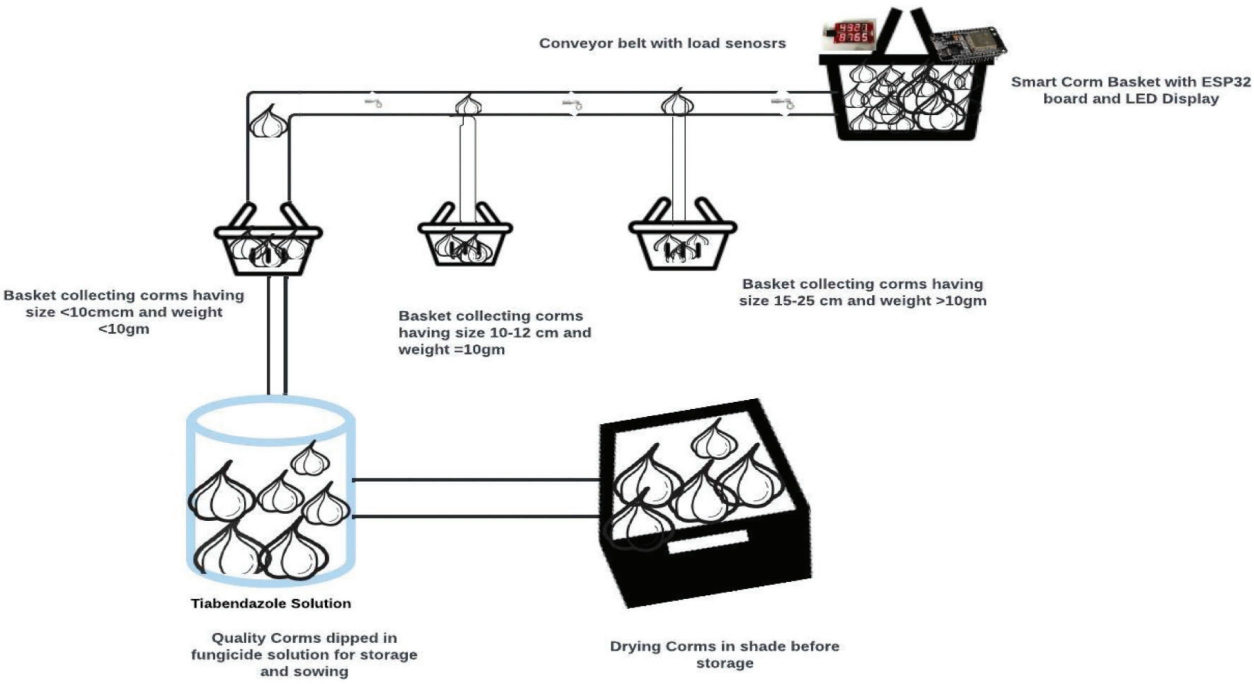

Figure 1. Saffron corm sorting and fungal treatment device.

coupled with the system using low energy dissipating protocols like LoRa, NB-IoT, a microprocessor, and an input-output unit to receive and transmit command signals. An external electrical source supplies electrical power to the system. Then they are taken to the treatment vessel in batches to treat with fungicides. The treated corms are dried and then taken to the hopper, and released on the conveyor system one by one with the help of a motion sensor and a door mechanism. The data is received by the control unit comprising of a processing unit, ESP32 board, and the switching unit to control the operation of the actuators and input-output device. The cloud server unit is connected to the conveyor system through the ESP 32 board making use of energy-efficient technologies like LoRa and NB-IoT. The data collected from the sensors is analyzed to take action by the system. This data is also sent to the cloud server for future prediction. Different data threats from damage and sensor failure pose cyber security issues to the evolving smart agriculture systems. Threats to data acquisition technologies like malicious attacks, unauthorized access, privacy issues, etc. are some of the major challenges to be addressed. However, an amalgamation of different technologies and measures like authentication control protocols, robust intrusion detection, cryptography, edge computing, and blockchain ledgers can be quite useful in addressing these challenges. covered in the future aspects of this study (Zahmati et al. 2018).The external power source is connected to units through a pair of electrical wires or solar grids for energy optimization. The flowchart in Fig. 2 explains the flow diagram of the system where in the first step, a batch of saffron corms irrespective of their weight are sorted with the first sorting mechanism and then taken to the vessel for their treatment with the fungicidal (Seyyedi et al. 2018; Gheshm and Brown 2021).

First sorting mechanism

In order to sort corms, three groups are used for classification. The first one is W1 where all corms have a weight between 8 gms to 12 gms, the second is W2 having weight between 12 gms to 16 gms, and the third is W3 for corm weight greater than 16 gm. The first sorting mechanism consists of a plate having multiple-sized holes to reject small-sized saffron corms not healthy for sowing. The diameter of the holes is kept between 2.0 cm to 2.25 cm so that almost all corms having a weight of 8 gms and above are not rejected as their diameter is generally 2.5 cm and above (Rezvani-Moghaddam 2020). If the weight of the corm is within W1, both arms will be up and the corm goes on the same track, if the weight of the corm is within W2, the first arm will not be lifted allowing the corm to change the track and go to the middle track whereas the second arm will be lifted to pass the corm further. If the weight of the corm is in the W3 group, both arms will not be lifted and the corm will be forced to move to the last track.

After drying the saffron corms, they are poured into the hopper and then into a chamber where they are treated with warm air ensuring no moisture is left inside the corms. The block diagram of the apparatus as shown in Fig. 3 consists of the first sorting unit used to filter all healthy corms weighing 8 gm and above.

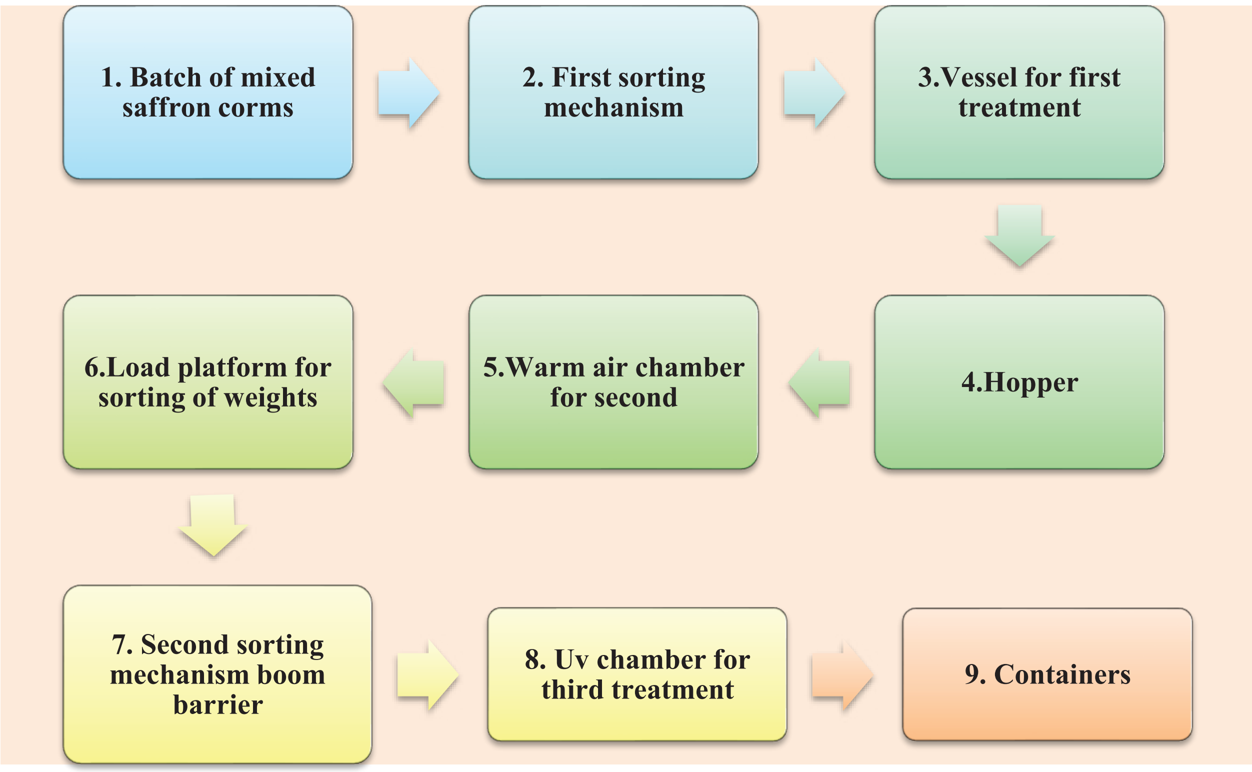

Figure 2. Step-wise Saffron Corm Sorting and Fungal Treatment Mechanism.

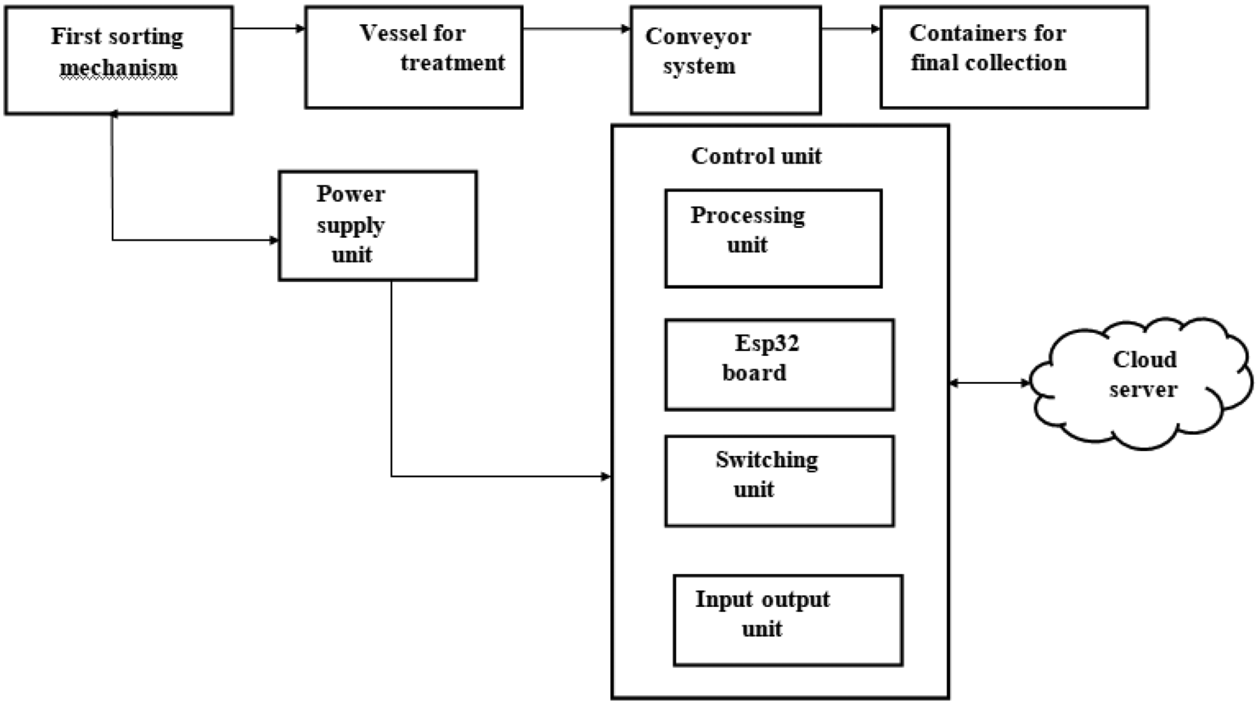

Figure 3. Block diagram of saffron corm sorting and fungal treatment apparatus.

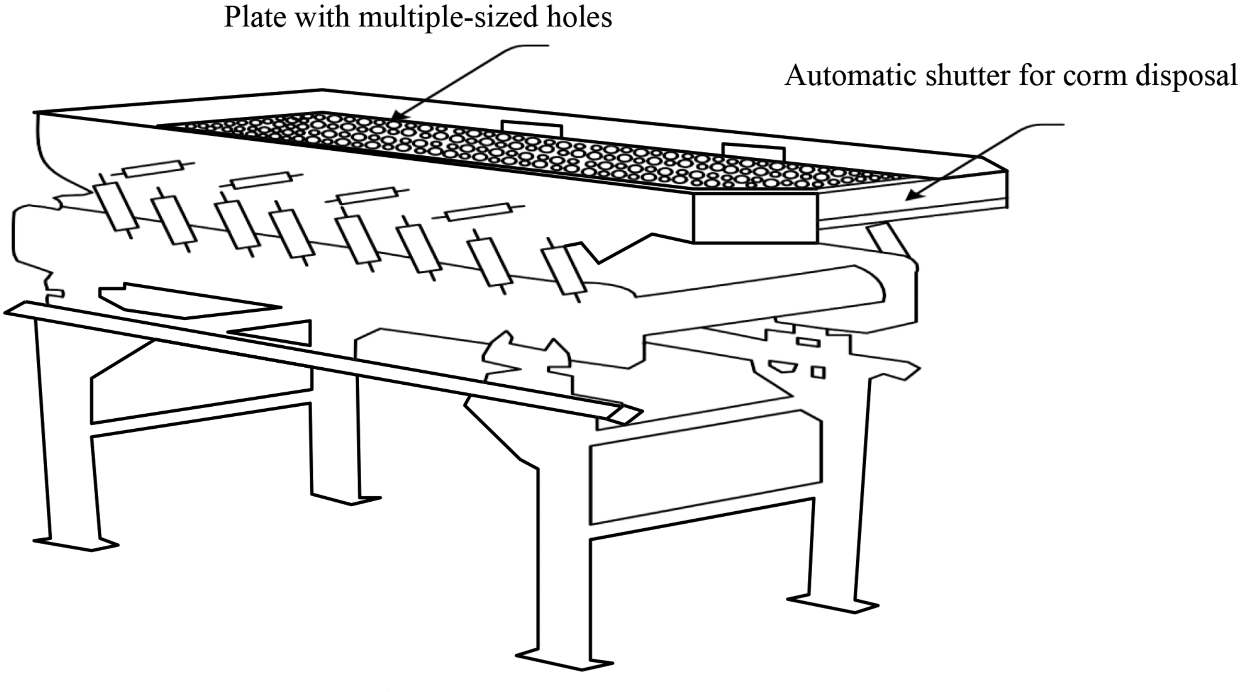

Figure 4. First sorting mechanism of designed apparatus.

The first stage of sorting from Fig. 1 is shown in a detailed manner in Fig. 4. The platform is walled to avoid the falling of saffron corms. One of the walls of the sorting chamber is a movable door, opened for taking out sorted corms. To start the operation, a batch of mixed saffron corms is placed over the plate manually and the plate is made to oscillate in a horizontal plane along with the length of the frame, and the motion is achieved with a gear mechanism powered by an electrical motor. By opening the door, sorted corms are removed.

Treatment of corms

After this, all sorted corms are put in vessel in batches to first, wash them with clean water and then with different fungicide solutions. Various fungicide solutions include 0.2% water-based solution of tiabendazole, a 0.2% water-based solution of Bavistian, and 0.2% water based solution of captafol. All saffron corms are dipped in the solution at least for a period of 15 minutes to 20 minutes and then taken out from the vessel to dry in shade for a period of 20 to 30 minutes to drain out the solution. The dried corms are manually brought to the hopper configured with a door mechanism and a motion sensor at the first end to deliver saffron corms one by one at a pre-determined interval on one side of the conveyor bed operatively coupled with a drive mechanism. The moving door mechanism configured with the hopper is operable coupled with the control unit through the motion sensor. The moving conveyor bed passes saffron corms into the chamber where warm air with a temperature of 25°±5° circulates to remove leftover moisture from the saffron corms.

From the chamber, the saffron corm is passed on the load sensing platform to weigh and record all saffron corms one by one and to transmit weight information in packets of data to the control unit. As soon as a corm reaches the load platform, the conveyor bed stops for a pre-determined period upon receiving the signal from the position sensor to record the weight of the corm. At that moment, weight information is transmitted to the control unit, the control unit transmits the command signal to the motion sensor to move the conveyor bed. The detailed process of dipping quality corms in fungicidal solution is already shown in Fig. 1.

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Second stage of sorting

It comprises actuator units and a pair of arms and is placed obliquely over the conveyor bed that receives signals from the control unit to lift the arms. Their functions are like an operation of a boom barrier. This is to deflect saffron corms to be sorted in a particular path as per their weight groups. After the second stage of sorting, all corms are passed through a UV chamber for treatment. This process is used as the third stage for the treatment of saffron corms to eliminate the probability of contamination of corms during the journey from fungicidal treatment to the UV chamber. After passing through the UV chamber, all saffron corms are made to slide into respective containers arranged at the second end of the conveyor system from where they are collected manually for their preservation. A hopper is configured with the conveyor system, to manually collect saffron corms after the first treatment and drying, to supply them one by one on the moving conveyor bed. The timing that corresponds to the distance between the corms on the moving conveyor bed is controlled by the control unit through a motion sensor coupled with a door mechanism configured with the hopper. The released saffron corms then pass through a chamber where warm air with a temperature of 25°±5° has circulating movement to remove leftover moisture from the corms. The corm then moves to a load-sensing platform configured with a load sensor and a position sensor. The load cell used is an S-beam load cell, having a wide capacity range and high accuracy of up to ±0.02%. The operating voltage for the load cell and ultrasonic position sensor is 5V-12V.The position sensor used is an ultrasonic position sensor with an accuracy of ±0.144 inches. The position sensor transmits the corm location on the load platform to the control unit and upon receiving the signal, the control unit transmits a command to the conveyor motor to stop till weight is recorded by the load sensor. Once the weight is recorded, a signal is transmitted from the control unit to the conveyor motor to start. At the same time packets of signals are transmitted to the first actuator unit and to the second actuator unit to lift or not lift respective arms. The corms are sorted out into the respective weight group and the following different tracks are passed through the UV chamber for UV treatment, and the corms slide to the respective container configured as per the weight group. From the chamber, they move further to a load platform where the load information is transmitted to the control unit. Based on the information, the decision on lifting is made of the respective arms where the track of the corm is decided as per their weight. The weight-wise sorted corms are passed through the UV chamber for treatment. Finally, they slide down to their respective containers for their preservation. The bed is configured with multiple equidistant spaces, protruded lining along its length covering full width. To maintain the movement of the corms in the particular track on the conveyor bed unless forced to change the track. The third sorting mechanism from Fig. 1 can be shown , in detail as shown in Fig. 5.

The proposed solution has been tested on dataset related to yield, flowering, water productivity, emergence percentage given in Table 1, using Aqua Crop model and farm cultivation values obtained for consecutive years. The model predicts better results with high corm weight greater than or equal to 12 gm.

Performance metrics

The proposed model has been validated using dataset of three years from cultivation filed. The dataset was analysed using Aqua Crop simulator which predicts the values of growth, yield and other parameters given in Table 1, for different values of corm size. In order to increase the production and quality of saffron, saffron corm size and absence of corm rots are the most crucial factors. When the dataset for values of climate and soil conditions were used as input in Aqua Crop model, after running simulations, the relation between yield and corm size keeping other values same was obtained as shown in graph in Fig. 6. The relation between saffron corm and yield can be shown by plotting a graph between corm sizes and

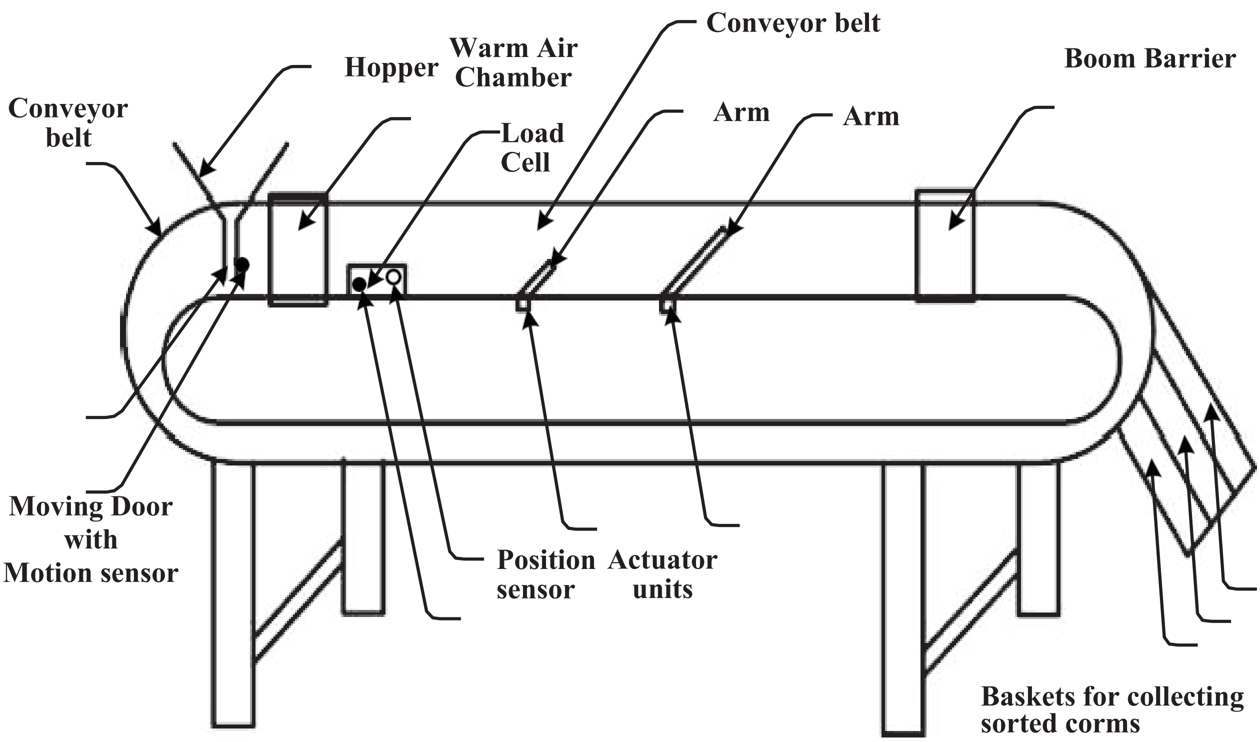

Figure 5. Second sorting stage and UV treatment in designed apparatus in designed apparatus.

yield, which increases with increase in saffron corm size (Jami-alahmadia et al. 2010; Ayoub et al. 2022, 2023; Kour et al. 2022a; Singh et al. 2023) as shown in Fig. 6.

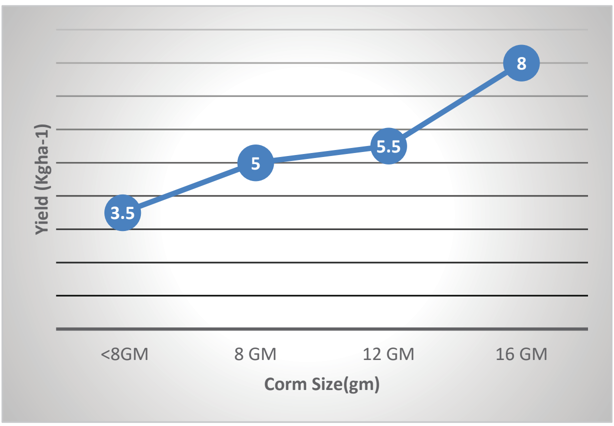

Figure 6. Relation between yield and corm size.

It was observed that with increased corm size, different parameters related to growth like number of flowers per unit area, emergence percentage, weight of flowers, yield and dry weight of saffron improved considerably. Reduction in flowering time and improvement in flowering days was also observed (Ghanbari et al. 2019).Corm rot and sclerotiorum disease also has a significant effect on yield and hence needs to be treated in time. Based on different researches and studies, it was observed that out of all the fungicides available, tiabendazole fungicide solution has a significant effect on corm rot reduction and decrease in loss due to fungal diseases. Tiabendazole fungicide solution curbs fungal growth by disturbing the energy production, blocking cell division, DNA and cell wall synthesis. As per reports, there is 88% corm rot and fungal decay reduction by using tiabendazole solution. In order to make the application of fungicidal solution to be more effective, it is used in combination with different bio agents to make it sustainable, energy efficient and environment friendly. Application of tiabendazole solution over mother corms and daughter corms was studied over different years, and as per the results from Aqua Crop model, it was reported that maximum suppression of disease-causing pathogens occurred in the first year as shown in Fig. 7, reportedly at 89%. The disease reduction percentage after the first year, kept on decreasing as shown below.

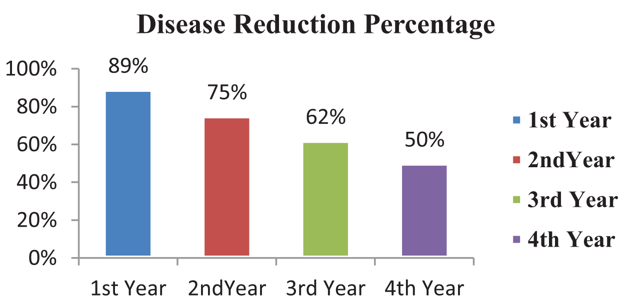

Figure 7. Disease reduction percentage over years by applying tiabendazole solution.

The reduction and treatment of fungus by using tiabendazole in corms is also linked to reducing the number of days taken to sprout and the emergence of flowering as compared to other solutions applied. There is also a need for making use of energy-efficient device components to save energy and offer sustainability. The system designed is user-friendly and reliable as compared to other systems designed, as it offers a ready-to-use solution for sorting saf-

Table 1. Traits of saffron under different corm size.

Corm Weight	No. of flowers per unit area	Emergence Percentage (%)	Biomass (mg/m²)	Actual Yield (Stigmas) (mg/m²)	Time Period (First Flowering in days)	Duration of Flowering (days)
<8 gm	8.07	80.8	195	11.09	52	8
8 gm	10.02	91	240	14.02	48	9
12 gm	12.5	122	286	16.45	42	10
16 gm	42.66	149	370	46.33	35	16

fron corms. The system is automatic in nature due to the use of sensors and microcontrollers, operated by using switches, which can even be used by a layman not having much technical expertise. The system saves time, as compared to manual process which is inaccurate and time consuming.

Hence, as observed corm size and treatment with the best fungicidal solution is very crucial to optimized growth of the saffron plant. The yield and time taken for sprouting and flowering are directly impacted by the use of the right corms and proper drying and treatment with fungicidal solutions. There is also a need for making use of energy-efficient device components to save energy and offer sustainability. The system designed is user-friendly and reliable as compared to other systems designed, as it offers a ready-to-use solution for sorting saffron corms. The system is automatic in nature due to the use of sensors and microcontrollers, operated by using switches, which can even be used by a layman not having much technical expertise (Jami-alahmadia et al. 2010; Ünal and Aktaş 2023; Ünal 2024).The system saves time, as compared to manual process which is inaccurate and time consuming.

The values were analysed for different sizes of corms as shown in Table 1, and it was observed that the corms weighing 8 gm and more were ideal for sowing. Table 1 presents the values of quality parameters for four different categories of corm sizes.

The tiabendazole and other fungicidal solutions also effect the days taken for emergence of flowers The results indicate that tiabendazole solution is most effective in improving growth parameters including time taken to start flowering. Hence, as observed corm size and treatment with the best fungicidal solution is very crucial to optimized growth of the saffron plant. As per the results from Aqua Crop model, the yield and time taken for sprouting and flowering are directly impacted by the use of the right corms and proper drying and treatment with fungicidal solutions as shown in Fig. 8.

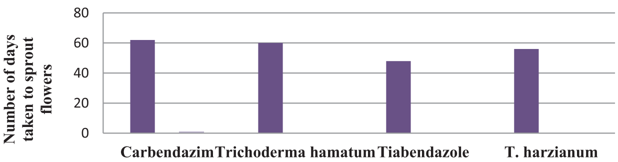

Figure 8. Effect of fungicides on the flowering period.

Corm density and porosity are important parameters for determining the quality of a good corm. These attributes can be determined by different equations with the help of a water filled cylindrical container. After weighing the corms, they are dropped into the container, and determining the weight of water displaced by the corms. The values of corms can be calculated by using Archimedes and Bernoulli's principle as given in eq. 1:

$$v_u = \frac{m_u}{\rho_u} \tag{1}$$

Where vu is the volume of water displaced by saffron corms in (gcm^{-3}), mu is the mass of water displaced and ρ_u is the density of water measured in (cm^{-3}). By using eq. 2, corm density can be directly calculated by the mass and volume values of the corms measured, given by eq. 2.

$$\rho_C = \frac{m_C}{v_u} \tag{2}$$

Where ρ_C is the corm density in (gcm^{-3}), m_C is the corm mass in grams. The bulk or volumetric density measured as the weight of corms in a container can be used to determine porosity which measures the aeration quality of corms, by using the relations given in eq. 3 as:

$$\varepsilon = \frac{\rho_C - \rho_v}{\rho_C} \times 100 \tag{3}$$

Where ε is the value for porosity in (%), ρ_C is the corm density in (gcm^{-3}) and ρ_v is the bulk density given in (gcm^{-3}).

Other properties of the corm like sphericity were measured by using arithmetic and mean diameter given by eq. 4.

$$\phi = \frac{D_1}{a} \tag{4}$$

Where D_1 is the geometric mean diameter, given by eq. 5.

$$D_1 = (lbh)^{0.333} \tag{5}$$

Where l, b and h are the values for length, breadth and height respectively.

Conclusion and future scope

The presented work relates to the field of precision agriculture and energy optimization in IoT. As per the literature, one of the most effective factors controlling saffron yield and quality is corm. The important parameters related to saffron corms which are of utmost importance include corm size and corm weight; treatment of corms before storage and sowing. It was observed that only the corms having a size greater than 8 gm were ideal for sowing and production of daughter corms.

The proposed system provides an easy, cost-effective, reliable two-stage sorting and a three-stage treatment system for the saffron corms processing and for preservation according to their weight. The healthy and fertile saffron corms are sorted from a group of mixed corms using three-layer mechanism out of which two-layer cleaning mechanism to remove dust, soil lumps, and weed and a three-step treatment to kill soil-borne fungi, bacteria, and microorganisms. It uses an automated conveyor system for final sorting and treating saffron corms. The system also addresses energy issues of IoT devices by making use of energy-efficient standards like LPWA.

The proposed method is expected to save time, manpower, and money to make the system more sustainable. Smart corm sorting apparatus is a reliable solution for grouping corms on the basis of dimensions and weight and treatment with tiabendazole and other solutions automatically to make them ideal for future storage and drying them at the ideal temperature before sowing. The device is compact, economical, and easy to be used by farmers. The efficacy of proposed model has been verified by using Aqua Crop model and comparing values of yield, disease reduction percentage, biomass, emergence percentage and others. The results obtained indicate better yield and productivity with increase in corm size and weight. The yield and the biomass values obtained with a corm size of 16 gm is 46 mg/m^2 and 370 mg/m^2 respectively which is almost 52% greater than the values obtained with corm size less than 8 gms.

The future scope of the apparatus involves the use of renewable sources of energy for sustainability and cost optimization. The use and effect of optimal weighing corms for sowing in the next season and the impact of daughter corms obtained in the previous year by the apparatus will be the future scope of this paper. The future scope of this study will be a detailed statistical analysis of data related to saffron corms using a large sample and protection of sensor data against cyber security attacks. The effect of rodents and treatment to save the corms from being eaten up will also be covered in the future scope of this study.

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Competing interests

The authors declare no conflict of interest.

Availability of data and materials

All data generated or analyzed during this study are included in this published article. Any data required can be made available on request.

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