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Controlling Agronomic Variables of Saffron Crop Using IoT for Sustainable Agriculture

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Abstract: Saffron, also known as "the golden spice", is one of the most expensive crops in the world. The expensiveness of saffron comes from its rarity, the tedious harvesting process, and its nutritional and medicinal value. Different countries of the world are making great economic growth due to saffron export. In India, it is cultivated mostly in regions of Kashmir owing to its climate and soil composition. The economic value generated by saffron export can be increased manyfold by studying the agronomical factors of saffron and developing a model for artificial cultivation of saffron in any season and anywhere by monitoring and controlling the conditions of its growth. This paper presents a detailed study of all the agronomical variables of saffron that have a direct or indirect impact on its growth. It was found that, out of all the agronomical variables, the important ones having an impact on growth include corm size, temperature, water availability, and minerals. It was also observed that the use of IoT for the sustainable cultivation of saffron in smart cities has been discussed only by very few research papers. An IoT-based framework has also been proposed, which can be used for controlling and monitoring all the important growth parameters of saffron for its cultivation.

Keywords: IoT; saffron; agronomical variables; precision agriculture

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1. Introduction

The term Internet of Things (IoT), coined by Kevin Ashton in 1999, refers to the "things" or "devices" with unique addressing, inherent smartness, and ability to use communication protocols, form a secure network of devices, and interact with each other [1,2]. IoT comprises hardware devices, middleware, and end-user applications [2]. The number of devices connected to the IoT network is increasing day by day, predicted to rise by 500 billion by the year 2030. IoT has evolved the traditional agricultural practices to a great extent by the deployment of sensors in all domains of agriculture, as shown in Figure 1 [3,4].

Figure 1 clearly explains the use of different smart devices and sensors in vivid areas of agriculture, such as cultivation, irrigation, transportation, renewable energy production, livestock management, and other decisions related to the cultivation of crops. The data from the sensors are directly sent to the end-users, using fog layer devices and the internet to analyze and make correct decisions. The data are also continuously shared to the cloud for future use and predictive analysis. The use of IoT devices in the agricultural sector has started with the fourth industrial revolution with the involvement of technologies such as Blockchain, Artificial Intelligence, and Edge Computing [5–9].

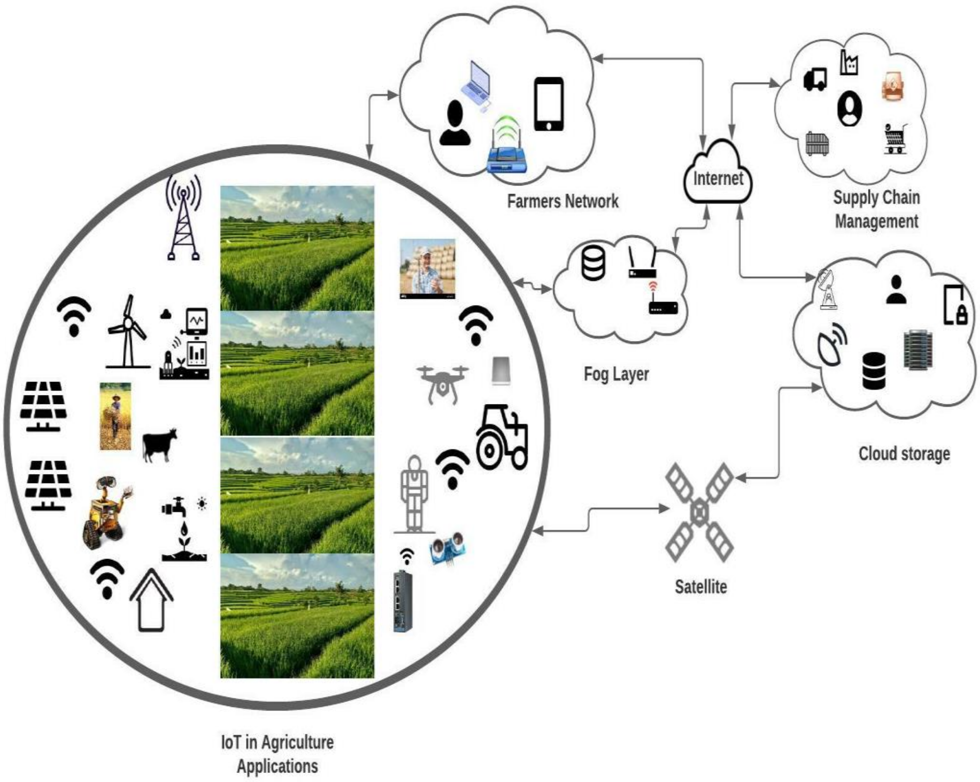

Figure 1. IoT application in agricultural sector.

The world population is increasing by 1.1 percent every year, resulting in a greater than ever increased demand for food. This rising demand can be met by using sustainable methods of crop cultivation, such as smart hydroponics. Using the latest trends in smart agriculture, food production is supposed to be increased by 70 percent by the year 2050 [6]. Smart agriculture refers to the system that involves monitoring, analysis, and control of data received from different agricultural sensors by the use of advanced technologies, such as IoT, fog computing, big data, and blockchain [6,7]. Using sustainable methods of agriculture with IoT will enhance agricultural output with water conservation, recycling, and renewable energy usage [7,8]. Smart agriculture can also be used for the sustainable cultivation of saffron. For creating a smart saffron cultivation model by using IoT, it is very important to study all the agronomical variables related to saffron. Agronomical variables may be defined as the important environmental and physiological factors affecting the yield and quality of a crop [9,10]. There is a lack of research for the identification of agronomical variables related to saffron and their optimal values. Also, much less research has been conducted for use of IoT in artificial saffron cultivation methods in smart cities [8,9].

The flow of data and information in an IoT-based smart agriculture environment has been explained in Figure 2. In Figure 2, data collected from different sensors attached to the crop are first sent to the fog nodes using data offloading, which gets shared with users on mobile devices in a very short time to take required actions that involve monitoring and controlling the parameters of growth [8–10]. These data are also stored in the cloud for storage and prediction-based analysis using different prediction and data-analysis algorithms. Besides the type of crop to be cultivated and the selection of energy-efficient protocols, the cost and the performance of sensors also matters a lot, as the agronomical variables for every crop are different [11].

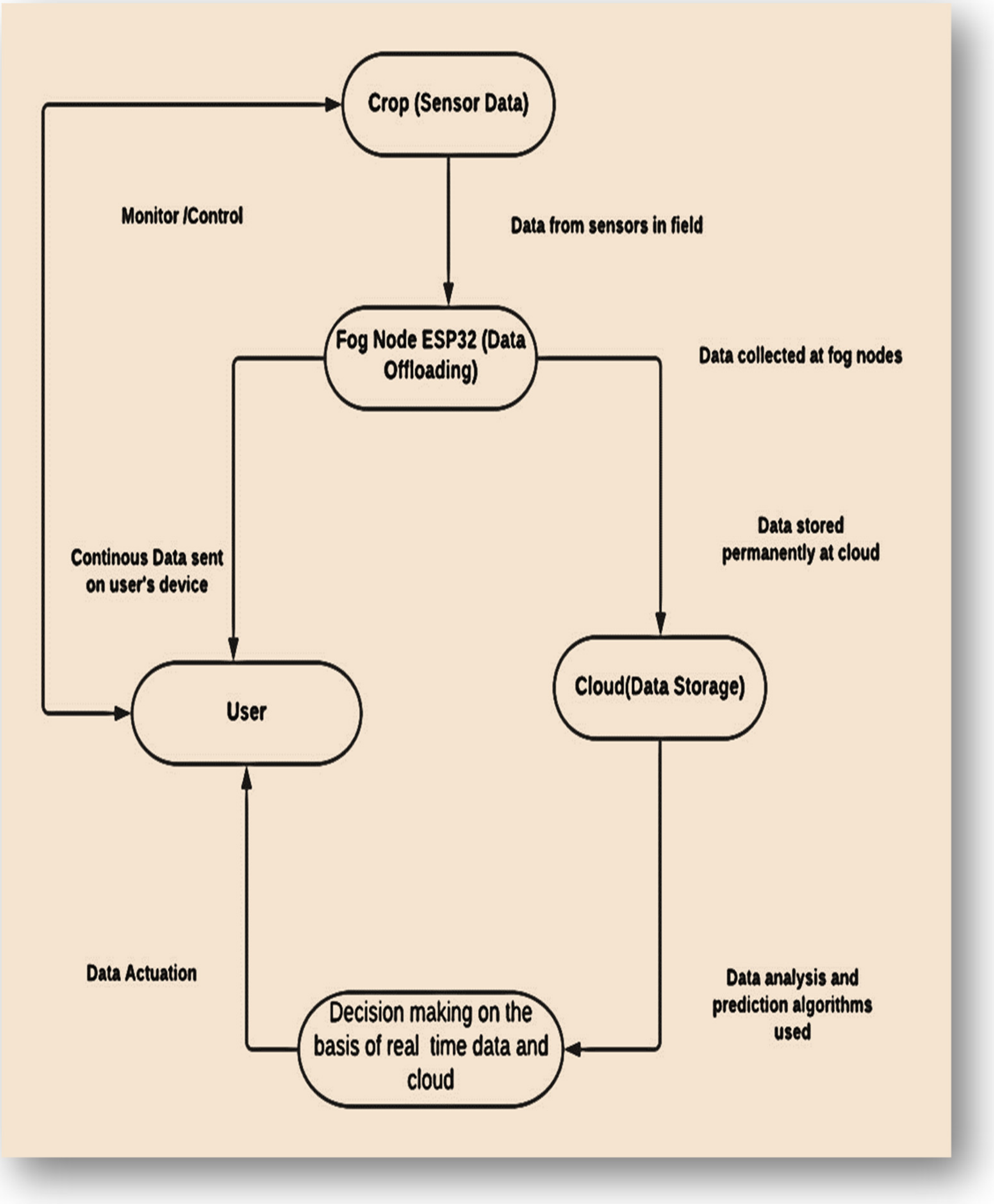

Figure 2. Data flow diagram of a smart agriculture system.

In an artificial cultivation environment, such as hydroponics, agronomical variables need to be monitored and controlled to develop an optimal IoT-based model for cultivating saffron with maximized production [10–12]. The major challenge for use of IoT in saffron cultivation is that there is much less literature related to the use of IoT in saffron cultivation. The research papers available on the use of IoT for crop cultivation focus on major crops of the world, such as wheat rice, etc., with much less focus on the economically valuable crops, such as saffron [12,13]. Research papers available on saffron focus mainly on areas such as reasons for the decline, adulteration, quality traits, distribution worldwide, applications of saffron, etc. [14–21]. Since the production of saffron is decreasing worldwide, various models for saffron cultivation using the greenhouse and hydroponic approaches have also been provided [22,23], but there is a lack of detailed analysis of all the agronomical variables of saffron to enhance yield and quality. This paper aims at studying all the agronomical variables important for saffron cultivation and determining their optimal values. The paper also provides an IoT-based system using renewable sources of energy for artificial saffron cultivation. The proposed system controls and monitors all the important agronomical variables for saffron cultivation.

Saffron (*Crocus sativus*), or the "Golden Spice", the most expensive spice known, can be grown only in some specific conditions of a particular region using corms. In India, saffron cultivation can mostly be seen in regions of Kashmir, where it was introduced from Iran around 750 A.D. before the reign of King Lalitaditya [24]. The vegetative cycle of plants starts in late summer, with active growth seen in autumn. The saffron is collected from the stigmas of the flower during late October and November. Attempts to cultivate saffron in other regions and using artificial methods have been made by many; however, the success obtained by using these methods is limited [25]. Agronomical variables, defined as the crucial factors which greatly influence the quality and yield of a crop, play a very important role in the artificial cultivation of saffron and need to be studied and analyzed in detail [26].

The major contributions of this paper are as follows:

- A detailed literature review for identifying all the important agronomical factors required for the cultivation of saffron.
- Identification of primary agronomical variables and the optimal values required for cultivation of saffron in an artificial environment.
- Designing an IoT-based model for monitoring and controlling agronomical variables of saffron.

The rest of the paper is structured as follows: Section 2 presents a detailed literature survey related to different agronomical factors in order of their value. The approach used for the selection of research subjects and different research questions is given in Section 3. Section 4 provides the solution to various research questions framed in Section 3. Section 5 illustrates an IoT-based model for monitoring and controlling the identified agronomical variables for saffron. Section 6 provides the conclusions from the research conducted, along with the future scope.

2. Literature Review

This section deals with the identification of all the important agronomical variables required for saffron cultivation. It was observed that the existing literature related to the agronomical variables does not clearly explain every variable required. Also, no information is present on the optimal values of these variables important for artificial saffron growth. The values considered in the literature so far are changing depending on the region of growth. The shortcomings in the literature considered can be summed up in Table 1 [27–32]. This section can be divided into different agronomical variables required for saffron cultivation, which can be explained in detail as:

Table 1. Comparison of agronomical variables of the saffron in existing literature.

Ref.	Agronomical Variables Considered	Values Obtained for Optimal Cultivation	Tools/Technology Used	Limitations
[27]	Temperature Water Altitude pH	5.9–18.6 °C 500 mm 1500–2800 m 6.8–7.8	Field Study	The results are based on only Talesh Region of Iran
[28]	Mycorrhizal fungi	NA	AMF	Experimental results only for Alpine areas.
[29]	Water	480–600 mm	Field Study	Time consuming (>3 years)

Table 1. *Cont.*

Ref.	Agronomical Variables Considered	Values Obtained for Optimal Cultivation	Tools/Technology Used	Limitations
[30]	Water	400–500 mm	Survey and crop coefficients (ET_c and ET_o)	Does not consider artificial environments.
[31]	Soil	Slity Loamy with 16.8% sand, 23.9% clay and 59.3% slit	Sampling & Regression Analysis	Climate, age of farm, corm density not considered
[32]	Temperature Water/Rainfall	<25 °C 400 mm	Sampling and Multivariate Regression Analysis	Model is based on data from previous years
[33]	Corm Genetics	Good quality corms	Field Study and Chromatography	Study does not specify the ideal parameters while choosing corms for plantation
[34]	Corm Size	>10 gm	Field Experiment	Results based on soil and climate of Iran
[35]	Corm	High quality corms with apocarotenoids	Field experiment and spectrophotometry	Three types of corms from Iran were considered
[36]	Corm	Heavy corms with favourable climate	Field Experiment and PCA	Identification of good corms was conducted irrespective of considering genetic difference between samples.
[37]	Corm Dimensions	Diameter 2.5–3.5 cm	Filed Experiment	No method to choose suitable corms has been provided
[38]	Corm distance Corm Size	10 cm 20–40 mm	Survey Based	Not implemented
[39]	Light Intensity	200 (3R2B)	Field Study	Does not focus on methods to control suitable light intensity
[40]	Corm	Increased Flavonoid contents	Field Study, HCA and PCA analysis	Lack of methods to measure flavonoid content
[41]	Water	3600 m^3 ha^{-1}	Field Experiment	Further studies are required to study agronomical factors
[42]	Water Salinity	100% WR 2–3 dS m^{-1}	Field Experiment	Further studies are required to study agronomical factors
[43]	K^+/Na^+ Planting Method	15.9% and 19.2% In-furrow	Field Experiment	Other important agronomical variables have not been considered
[44]	Soil Texture Water	Clayey and sandy soil 3000 m^3 ha^{-1}	Field Experiment	Use of low and moderate weight corms not considered for experiment
[45]	Temperature Water Nitrogen	30 °C–40 °C 200–600 mm 50 kg/ha	Survey	The optimal values given have not been implemented
[46]	Temperature Soil Type	12–28 °C Sandy Loam	Field Experiment	Variables have not been considered for different corm dimensions and water availability
[47]	Temperature Altitude	23 °C ~1250–~1400 m	Field Experiment	Environmental factors related to saffron for Iran were considered

Table 1. *Cont.*

Ref.	Agronomical Variables Considered	Values Obtained for Optimal Cultivation	Tools/Technology Used	Limitations
[48]	Temperature Corm Distance Corm Weight Field Age	15 °C–20 °C 25–30 cm 7–10 gm 4 years	Survey	The optimal values given have not been implemented
[49]	Temperature	23 °C to 27 °C	Survey	Only environmental factors have been studied and optimal values for irrigation not provided
[50]	Fertilizer Corm Density	Vermicompost Phosphorous Nitrogen	Field Experiment	Methods to increase flowering have not been considered
[51]	Corm Density	Low	Field Experiment	Optimal values not derived
[52]	Mycorrhiza Vermicompost	10 g/(5 cm × 5 cm) 24,000 kg ha^{-1}	Field Experiment	Effect of inorganic and chemical fertilizers not studied
[53]	Minerals	N, P, K, Ca, and Mg	Greenhouse and ANOVA	Further experiments to be conducted to study impact of increase in concentration of minerals
[54]	Pathogens	Weeds	Survey	No officially registered herbicide for saffron crop
[55]	Moisture Content	<12%	HPLC-DAD	Increased Concentration of crocins and picrocrocin
[56]	Moisture Content	10–12%	Quality Analysis	Below 55 °C
[57]	Quality	Using biopolymers	Spectrometry	The use of biopolymers for coating saffron

2.1. Corm Size

Corm size is one of the most important agronomical variables affecting saffron yield and quality [33,34]. In [34], it was observed that the maximum flowering occurred in the corms having the highest weight at the time of plantation. In [35], the authors conducted a three-year field in nine different regions of Iran. The results of the study also establish a direct relationship between the corm properties and flower number and stigma yield. Cardone et al. [36] also conducted two-year research in southern Italy and observed that the best quality saffron was obtained by combining corm samples of Sardinia and Abruzzo. In [37], Loriana et al. classified corms into three categories based on their dimensions. The three categories (D1: 2.0–2.5 cm, D2: 2.6–3.5 cm, and D3: 3.6–4.5 cm) of corms were planted in the annual cycle and it was observed that the corms with the greatest diameter, i.e., D3, resulted on the best crop with a highest dry weight of stigmas and stigma lengths. In [38], Menia et al., in 2018, observed that the quality and size of corms were one of the most important factors that contributed to the production of the best quality saffron with increased yield. There is a direct relationship between the number of flowers and yield [39,40].

2.2. Water Availability

Koocheki et al. [30] studied the gap between the actual yield of saffron and its potential yield. It was observed that although the plant has a very low water requirement, the yield could be increased manyfold by improving the irrigation of fields in arid regions. In [41], it was observed that there was very little difference in root weight between all the nine dates, which means that saffron is resistant to drought stress except for severe water shortage.

Authors in [42,43] studied the effect of water scarcity and drought conditions on saffron plants. It was observed that water deficit can be compensated by using in-furrow planting methods as compared to basin planting methods. It was also observed that the saffron plant is more sensitive to water stress than salinity stress. Shajari et al. [44] also conducted a two-year experiment at the University of Birjand to study the effect of soil texture and irrigation on the saffron plant, and it was observed that shorter irrigation levels (equal to 30 cm) were the best for the cultivation of the saffron crop.

2.3. Temperature

Authors in [45] studied the growth of the saffron crop in modern sustainable agricultural systems. It was observed that the saffron crop is best cultivated in regions having warm dry summers and cold winters. It can tolerate frosts and can survive temperatures as low as −100 °C to −180 °C. Cicco et al. [46] also conducted a two-year experiment to study the impact of different factors on the cultivation of the saffron crop. It was observed that the crop is best cultivated under the temperature range of 12 °C–28 °C. Authors in [47] also conducted a two-year study and indicated that the optimum temperature required for growth is 23 °C–27 °C. In [48], it was found that the optimal temperature for flowering was found to be 15 °C–20 °C. Parviz et al. [49] also studied the impact of climatic conditions on saffron growth and observed that temperature is one of the main environmental factors regulating flowering in the saffron crop.

2.4. Planting Density

Various researchers have highlighted the importance of planting density during the first year of yield [41]. Seyyedi et al. in [50] conducted a three-year field experiment at Ferdowsi University of Iran to study the negative impact of higher planting density in daughter corms over the preceding years. It was observed that the weight and concentration of elements N and P were highest in daughter corms obtained from the corms having the lowest plantation densities. Gheshm et al. [51] also conducted a two-year experiment at the University of Rhode and observed that the planting density did not impact the yield during the first year; however, flowers from low-density plots generated heavier pistils.

2.5. Minerals

The studies conducted by researchers in [41], highlight the positive effect of minerals such as P and K on the yield of saffron. Authors in [50] conducted a three-year experiment and found that the application of minerals and vermicompost increased the size and quality of daughter corms produced. Authors in [52] also indicated the positive effect of minerals such as P, K, and N on different components of the yield of saffron, such as concentration of crocin, picrocrocin, leaf area, flower number, and dry weight. Salas et al. [53] conducted a trial for the application of different nutrients and minerals at Almeria University on 15 pots and observed that, by increasing the concentration of supplied mineral nutrients, a yield of three to five times more corms above 25 mm in diameter was obtained.

2.6. Pests and Diseases

In [38], authors have identified Furasium solani and nematodes on corms as the major reason for the decline in yield, generating about 50% of corms as diseased. Fungus infections, along with nematodes, lead to the lowest saffron yield. Authors in [54] have conducted a study aiming at the identification of various pathogens and weeds. The authors also highlight some major challenges for weed control, such as occupying land for several years, short and narrow shaped leaves for application of weedicides, no officially registered herbicide for the saffron crop, and costly manual weeding.

2.7. Storage Conditions

In [55], authors have studied the impact of storage conditions on the quality of saffron. It was observed that the samples dried in the oven had a higher concentration of crocin and picrocrocin as compared to the samples dried in shade. In [56,57], a qualitative analysis was conducted as per ISO 3632, in which 84 samples were collected for four years. Authors also suggested some practices to preserve the quality of the saffron, such as drying the stigmas carefully (moisture must be less than 12% according to ISO 3632) and at temperatures below 55 °C to avoid alteration, and storage of the spice in a cool, dark, and dry place inside a sterile airtight container to avoid change in its chemical nature.

3. Research Methodology

In this section, a systematic literature review (SLR) method for studying agronomical variables is provided. It was found that none of the research papers enlisted all the agronomical variables of saffron growth. Hence, a detailed literature study of all the parameters was considered. IoT was also considered for the monitoring and control of these variables. The following string query was used to determine important synonyms and keywords of the approaches:

"Saffron Cultivation" OR "Saffron" OR "Smart Saffron Cultivation" OR "Agronomical Variables" OR "Saffron agronomy" OR "Growth- parameters for saffron" OR "IoT and saffron cultivation"

We created some research questions (RQ) based on different agronomical variables used for saffron cultivation using the SLR method:

RQ1: What are the primary agronomical variables for the cultivation of saffron?
RQ2: What are the optimal values for the agronomical variables considered?
RQ3: What are the commonly used approaches for measuring the optimal values?
RQ4: Which of the agronomical variables can be controlled and monitored by using IoT?

To refine the string search, different strategies for paper selection were employed for the final selection of papers. Based on the tremendous potential, various reputed journals from Scopus, Web of Sciences, and IEEE Xplore with the peer-reviewed process were considered for this study. Some of the drawbacks in the papers studied were: 1. non-English research articles; 2. low-quality conferences with less than four pages; And 3. focus on studying only a few agronomical variables. Initially, 280 articles were studied and, out of these, 80 articles were finally chosen to find answers to our technical questions. In Figure 3, the number of articles published every year by IEEE, Elsevier, Springer, and Wiley related to agronomical variables of saffron are shown.

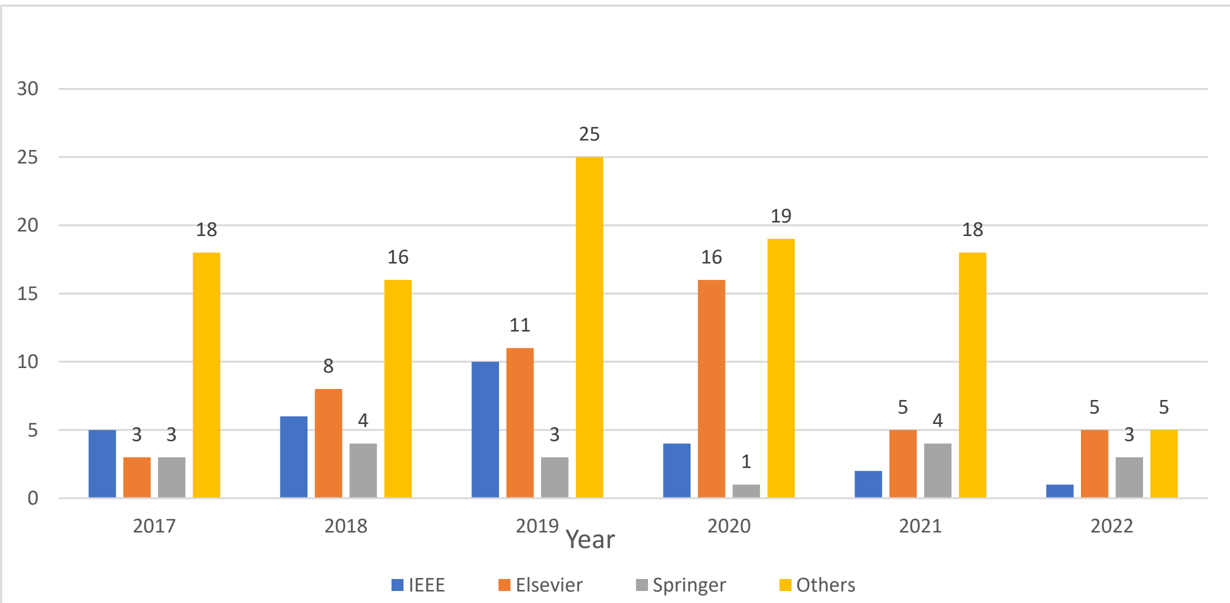

Figure 3. Year-wise research paper publications by publishers.

The addition and rejection process that followed for final paper selection is shown in Figure 4.

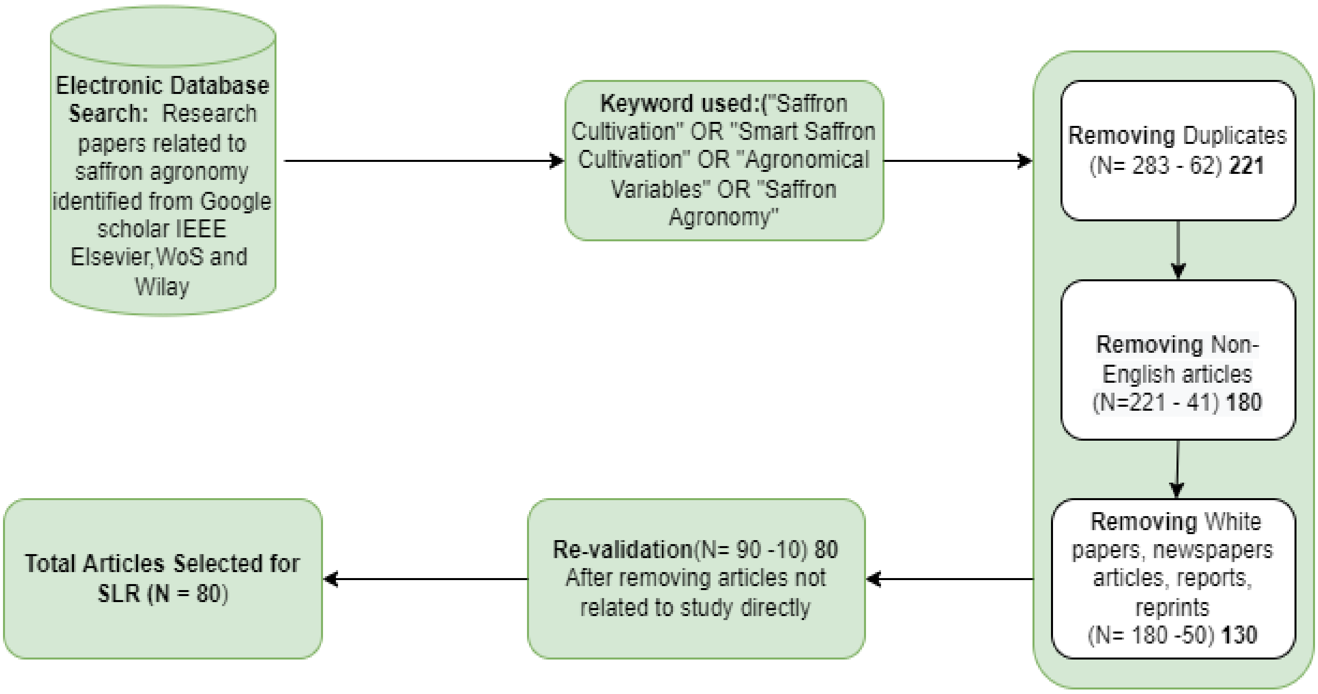

Figure 4. Paper selection procedure.

Based on the literature survey conducted, it was found that there was no single research paper that considered all the agronomical variables required for saffron cultivation in detail. Hence, different agronomical variables were identified. By studying the literature in detail, it was found that some variables had a more diverse effect on plant growth and were more important as compared to others. Agronomical variables having the greatest impact have been studied by researchers in the maximum number of publications. In Table 2, the agronomical variables of growth in decreasing order of importance are given; corm size holds the maximum priority, while pH and altitude matter the least.

Table 2. Agronomical variables of the saffron in order of priority for growth.

S No	Agronomical Variable	Paper References
1	Corm Size	[33–38,40,48,50,51]
2	Water Availability	[27,29,30,32,41,42,44,45]
3	Temperature	[27,32,45–49]
4	Planting Density	[43]
5	Minerals	[28,43,45,50–53]
6	Pest and Diseases	[54]
7	Storage Conditions	[55–57]
8	Altitude	[47,48]
9	pH	[39,48]

4. Discussion

This section discusses the research questions related to agronomical variables of saffron framed in Section 3. Various important factors, such as major agronomical variables affecting growth and their optimal values to be considered for artificial cultivation in a smart city, are discussed. The answers are based on the research papers studied and SLR presented in Section 2. The analytical examination and reports, based on the existing RQs in Section 3, can be given as:

RQ1:What are the primary agronomical variables for cultivation of saffron?

A study of various agronomical variables related to saffron is presented in Figure 5. After studying different research articles, we have identified agronomical variables required for the growth of saffron. After a detailed study, the primary agronomical variables identified for growth were found to be corm size, water availability, temperature, and minerals (K and P). Corm size has the highest impact on the growth of saffron based on the number of research articles referring to it. The percentage-wise priority of corm size as a variable is 34%, followed by water availability with 27%, and temperature and minerals with 24% and 17%.

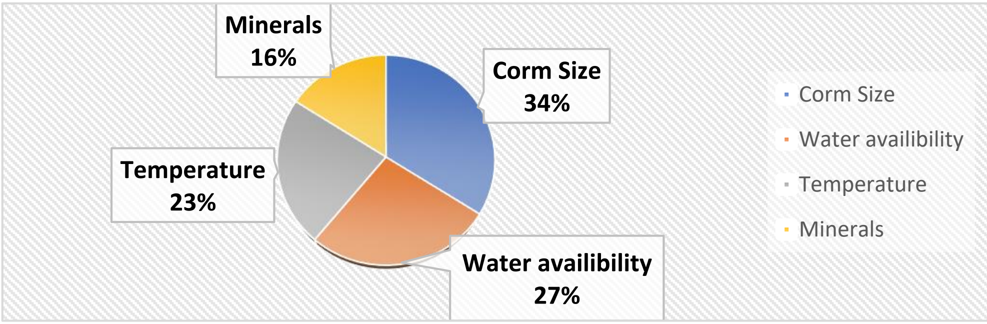

Figure 5. Priority percentage of primary agronomical variables for saffron.

RQ2:What are the optimal values for the agronomical variables considered?

In the literature studied, there are no common optimal values referred to for saffron cultivation. The values vary a lot based on geographical conditions and diverse physiological conditions. Based on the vast study of different research articles and the values considered optimal for artificial cultivation, the values given in Table 3 were identified. As per Table 3, 34% of the research papers have considered the values in the range of 9–10 g and 15–25 cm as optimal for corm size. The optimal value considered for water availability is 300–500 mm, considered by 27% of papers, whereas the best values considered for temperature are 20–300 °C. K, N, and P are the best-considered minerals for saffron cultivation, enlisted by 16% of papers.

Table 3. Optimal values for the agronomical variables considered.

Agronomical Variable	Optimal Value
Corm Size	9–10 gm. 15–25 cm
Water Availability	300–500 mm
Temperature	20–30 °C
Minerals	Phosphorous (P) and Potassium(K)

RQ3:What are the commonly used approaches for measuring the optimal values?

The data in Figure 6 depict that, out of all the approaches used for finding the optimal values of agronomical variables, field experiment is used by 58% of studies, followed by surveys with 21%, regression analysis and sampling with 14%, spectroscopy, and others with 7%. The methods considered so far for calculating optimal values are complex, time-consuming, and inappropriate to be considered for artificial saffron cultivation. The research articles using sensors for calculating optimal values are negligible.

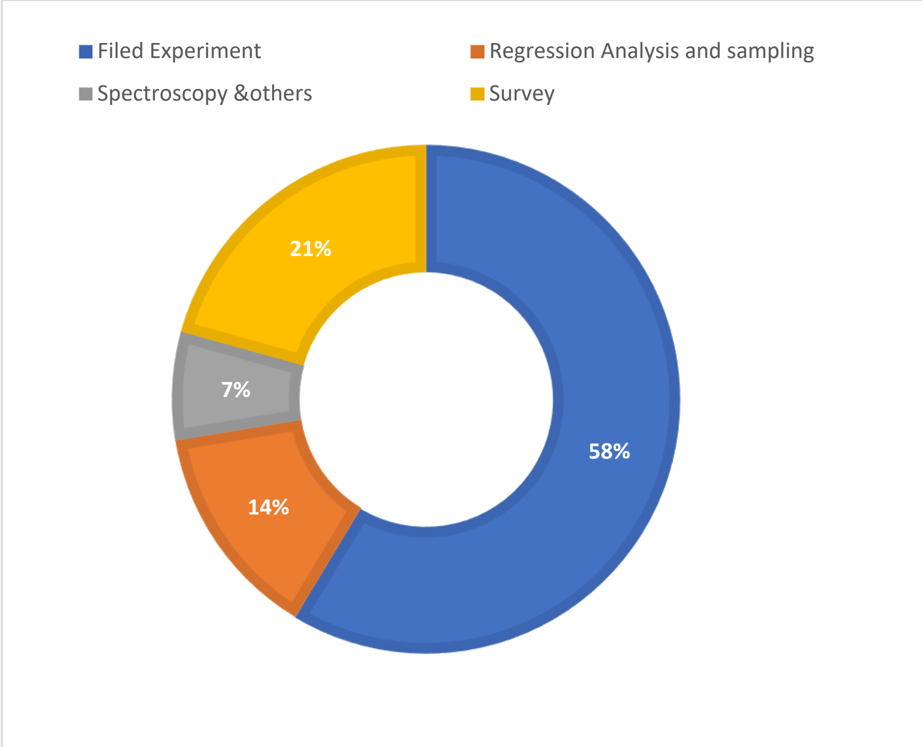

Figure 6. Commonly used approaches for measuring the optimal values.

RQ4:Which of the agronomical variables can be controlled and monitored by using IoT?

Agronomical variables can be controlled by using IoT and other technologies. Different sensors can be used to monitor and control temperature, water, mineral uptake, and the measurement of corm size. The number of research articles in which IoT sensors are used for measuring temperature, water availability, mineral uptake, and corm size are shown in Figure 7.

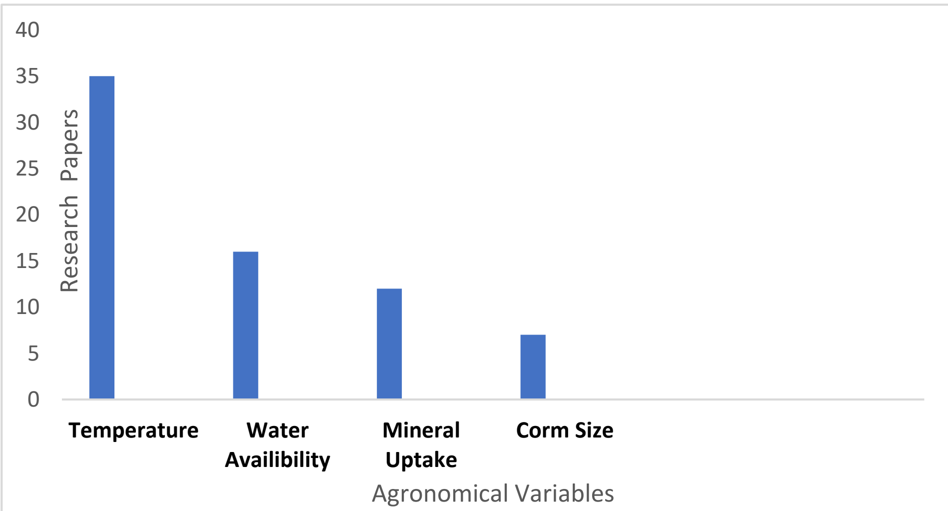

Figure 7. Agronomical variables controlled and monitored by IoT.

5. Automated System for Monitoring and Controlling Agronomical Variables

The production of saffron in the natural environment is declining day by day; hence, there is a great need for developing an artificial environment for cultivating saffron [58].

Different already existing models have been developed for artificial saffron cultivation. These models suffer from issues, such as latency issues, costs incurred due to electricity and costly devices, performance based only on simulation results, and systems not specifically designed for saffron, which demands different growth conditions as compared to other crops [59–67]. Keeping all these issues in mind, an automated system for monitoring and controlling agronomical variables has been given in Figure 8. As shown in the block diagram, the system works in two modes depending on availability, i.e., on renewable sources of energy, such as solar energy and water energy, or electricity. It stored the energy obtained from solar panels in the rechargeable battery and is supplied to the Arduino and Node MCU using an adapter.

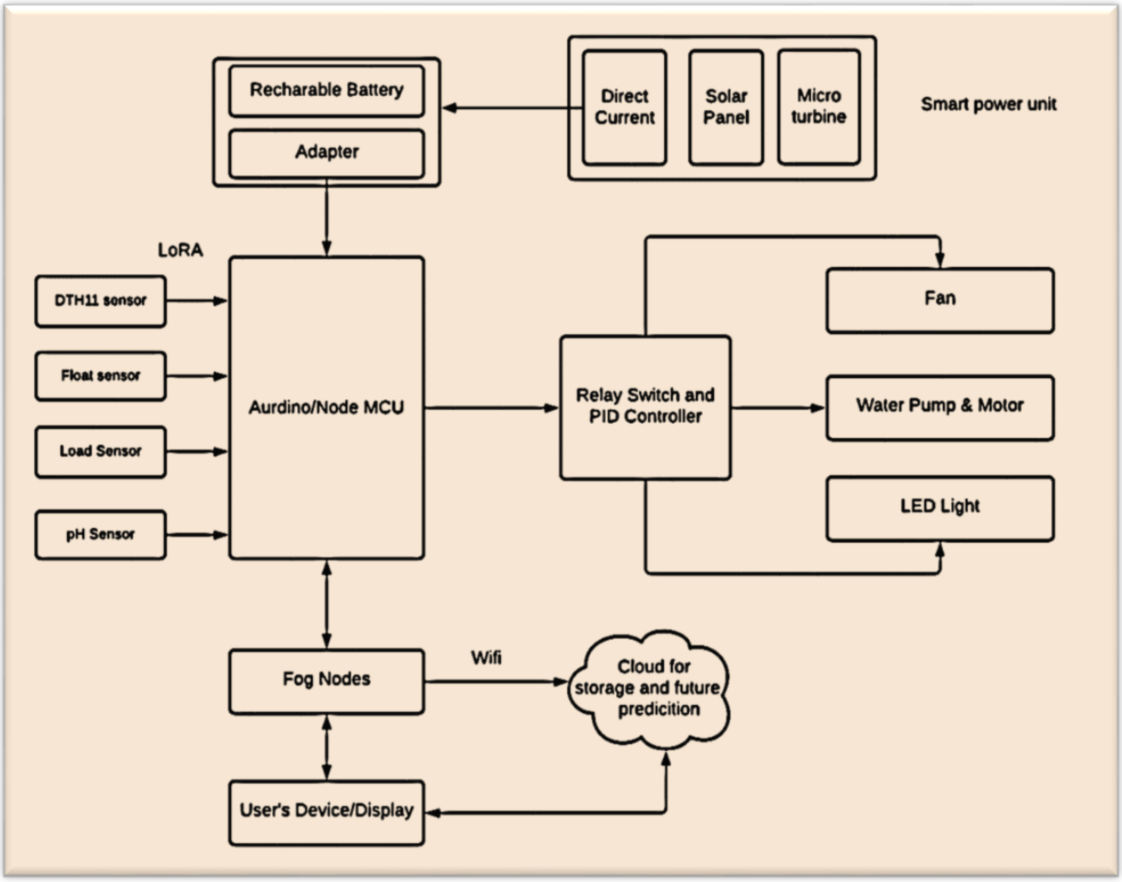

Figure 8. Automated system for monitoring and controlling agronomical variables.

The sensors are connected to Node MCU and Arduino on one end and the water pump, motor, fan, and LED on the other side, enabling the continuous monitoring and control of agronomical variables [68–71]. The proposed system uses DTH 11 sensors (for temperature and humidity), a float sensor for monitoring the water level, a pH sensor to monitor the pH of nutrient solution, and a load sensor to check the weight of corms before sowing [72,73].

The sensors are connected to the Node MCU and Arduino, in which the software is programed using Python and NB-IoTwith optimal values of temperature, humidity, and water level already provided [74]. As soon as the temperature and water level deviate from the threshold value already set, an email or message is sent to the user on his phone and the user can automate the operation of the pump, motors, and relays to control the agronomical variables, such as temperature, humidity, and water level. To ensure the proper monitoring and control of agronomical variables, the control board is also equipped with Proportional–Integral–Derivative (PID) Controller, which works by reading sensor data and calculating the corresponding output by using fuzzy logic functions and adjusting the derivative factors [74,75]. The data are first offloaded to the fog node (ESP32), which acts as a gateway and characterizes data into two categories: instant response required and data not required urgently [74]. Addressing the storage issue and the vast amount of data generated over time, the data required for future prediction is sent to the cloud for storage using Wi-Fi, while the repeated data are moved to make space for new data.

6. Conclusions and Future Research

The paper provides a detailed literature review of agronomical variables required for saffron cultivation. After discovering all the variables related to the cultivation of saffron, the important agronomical variables were identified based on the reference of each growth variable in the literature. It was also found that there are different challenges related to saffron cultivation, such as no standard optimal values of agronomical variables considered by all research articles, the studies based on different geographic regions involving different physiology and climate, and lack of knowledge related to the most important parameters to be considered for saffron cultivation. IoT for monitoring and controlling the major agronomical variables has not been considered by the majority of articles related to saffron. It was observed that the use of IoT for monitoring and controlling agronomical variables of saffron was presented in very few articles, i.e., out of 80 research papers selected for SLR, only 10 research articles were related to the use of IoT in saffron cultivation. Popular techniques used by other researchers were regression analysis, sampling, etc. Out of 283 research articles identified initially, the number of research articles related to saffron after eliminating the non-English, duplicates, and non-Scopus indexed journals was very low (N = 80); hence, there is much need for research in this area in collaboration with IoT and other new technologies. The future scope of this study involves the implementation of IoT in an artificial environment by using scientific methods, for saffron growth in a smart environment, and its performance evaluation.

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