Indoor smart farming by inducing artificial climate for high value-added crops in optimal duration

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Abstract: The global population is increasing rapidly as compared to food production; approximately three times more food would be required in 2050. Climate change affects crop production by causing sudden changes in weather conditions, including rain, storms, heat waves, doughiness, and water shortages. Farming with smart technology provides a productive solution. Smart farming is a productive solution that provides a great resource of income and improves the countries' economy by exporting consumable goods and preventing food security problems. Smart agriculture provides a combination of flexibility, remote access, and automation through the use of intelligent control technologies. Many countries are working towards smart and intelligent agriculture farming that analyzes crop, soil fertility, pests and weeds, and other problems caused by mismanagement and incompetence. However, smart agricultural farming is less widely adopted in agriculture as a result of high costs and little understanding of technology. In this study, An artificial climate control chamber (ACCC) was designed for cultivating plants by controlling the optimal parameters, especially the light spectrum. In ACCC, influential plant factors such as light, moisture, humidity, and fertilizer concentration have been controlled intelligently. Light spectrum was controlled by time periods in the previous system, while in the system proposed in this study, the light was controlled by image processing. In an artificial control chamber, the plant growth stages have been determined through image processing techniques. Datasets of image images have been used to organize specific intensities of the light spectrum. This intelligent system provides aid in the speed breeding procedure through variant spectrums of light and fertilizers combinations. In the research study, the yield and quality of intelligent farming are enhanced.

Keywords: indoor smart farming, artificial climate, high value-added crops, optimal duration, light spectrum, image processing
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1 Introduction

In Asian countries, especially southern Asian countries (Pakistan, India, Bangladesh, Sri Lanka, Afghanistan, Nepal, Maldives, and Bhutan), smart agriculture is not adoptable due to some sustainable factors controlling intelligent farming. In the coming years, food deficiency is the most critical problem due to climate change and disasters (heavy rain, flooding, sandstorms, heat waves, and droughts), and electricity consumption. Every year, the Pakistan population increases at the rate of 2.00% and the total Middle East population increases at the rate of 1.07%. Still, food production decreases day by day due to soil fertility deficiency, management, and climate change. Now novel technologies with innovation, such as the Internet of Things (IoTs) and computer sciences should be induced to help agricultural technology development[1].

In Pakistan, smart farming is not adoptable due to unsatisfied factory control of various factors such as temperature, moisture, sunlight, humidity, and climate change[2]. Especially in summer greenhouse farming temperatures, moisture is directly proportional to the feeling effects of temperature. Unnecessary sunlight radiations cause many harmful effects on plants in the greenhouse climate[3]. For example, sunlight produces diffraction of light by PVC sheets; this diffraction of light causes greenhouse effects (increase heat and humidity) and unnecessary growth in plants which is the reason for crop maturity and crop yield[4]. Some plant hormones promote plant growth (auxins, cytokines, gibberellins, and abscisic acid) at the specific spectrum of light[5]. The control of hormones was achieved through the light spectrum. Light obtains various spectrums, Previous artificial light spectrum changes by the principal of the time period, so the optimal plant growth condition is not obtained by this method. we can control by regulating the

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indensity of the different light spectrums according to plants' stage of growth. The current conditions of spectrum requirement through AI and image processing techniques were introduced in this study. This research work has improved plant growth with better growth domination and generates optimal conditions for obtaining high crop potential[6]. This formation was achieved by controlling the spectrum of light with image processing and electronic control by automation[1]. Image processing justifies plant growth stages, such as the vegetative growth stage, flowering stage, and maturity stage. This methodology proceeds by, Raspberry Pi generating a protocol in the growth stage action; then, the potentiometer regulates artificial light spectrum intensity and combination of light (red, blue, green, yellow, and violet). Artificial light promotes hormones in plants. Plant hormones regulate transformation in plant growth. The second factor is electricity. Electricity is used for maintaining temperature, suitable climate, and artificial light of spectrums which are the reason (electric consumption) farmers do not adopt smart farming. The proposed solution to this problem is the usage of solar energy techniques through photoelectric cell (PEC) and insulating material. Insulation material prepares with thermo-pole and polycarbonate sheets. This type of material is used to save reservoirs such as thermal energy and extra radiation[3,7]. All of these functionality's control by inducing computer sciences technology and electronic technologies. Artificial Intelligent software, sensors, microcontrollers, and visualization analysis of plant agronomy without intelligent mechanism, was not possible[8,9]. In ACCC, image processing, and computer vision techniques were used with the help of advanced intelligent algorithms (ANN, swam artificial intelligence) for a better-visualized experience[10]. With IoT, meka it robustness in smart farming parameters can be monitored using sensors such as moisture sensors, temperature sensors, humidity sensors, and gas sensors[11,12]. IoT offers farmers great capabilities for remote access, and IoT devices are also capable of capturing and transmitting data to their controllers. Agrometnists assist in optimizing plant nutrition formulas and provide information about plant responses to these formulas. By analyzing data, the strain of plants can easily and flexibly be observed. In smart farming, the proposed study enhances yield and quality. This research product contributes to the growth of the economy. The farms are capable of growing high-value crops, such as saffron, ginseng, caraway seeds, wasabi, and other herbs. Sometimes tissue culture plants cannot survive in an open environment due to a lack of optimal growing environment for immature plants because of ACCC being used for nursery development.

2 Relative work

All over the world population increase with a rate of growth of approximately 1.07 annually. Only in South Asia, 24.00% population of the world and Pakistan's population reached 212.2 million with a 2.24% growth rate[13]. Most smart agriculture farming is not adoptable due to expensive implementation and high-tech control mechanisms. The second most common problem is design and climate effects on the structure of greenhouses or indoor shads. Mostly in European countries, design glass-made or PVC-made greenhouses for maximum sunlight[14,15]. Greenhouse shelters depend on weather and according to the area because of the locality of the sun's direction. Harsh arid locality countries have not adopted this type of greenhouse shelter. Especially south Asian countries require different shapes and materials (insulation and heat resistance with excellent holding strength)[16]. These types of sheets are made with polycarbonate and PVC materials.

2.1 Design

As shown in Figure 1, the shed's design also depends upon yield efficiency because sunlight radiation and wind direction damage the feasibility of plant growth[17]. Use a special design structure to prevent harmful factors such as (storms, rain, and other environmental effects). This structure is low-cost and highly reliable[18].

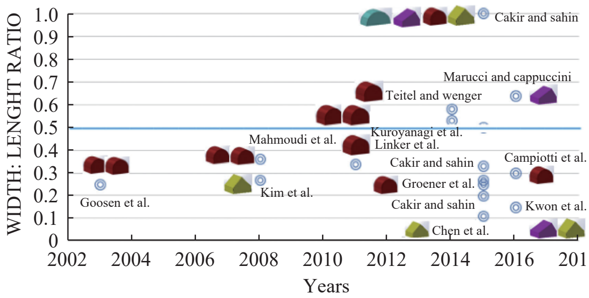

Figure 1 Various designs of greenhouse (area-wise)

2.2 Spectrum of light

The usage of light for the photosynthesis process at different stages of plant growth. Plants require different wavelengths of light[19]. Smart farming uses different types of lights (LED, fluorescent tubes, halogen tubes, and regular bulbs). Most smart greenhouses use LED lights because it is reliable and energy-efficient. LED lights provide different spectrums of light as the requirement of plants[5,20]. The spectrum of light plays the most important role in plant agronomy. Different light spectrum causes different effects on plant nourishment and growth. Plants require different light spectrums at different stages[21] such as the Germination phase (Seed dormancy), Embryogenesis phase (Fertilization of seed), Vegetative growth (Germination to adult), Reproductive development (Make flower), and Fruiting stage (After flowering maturity make fruits).

Every growing stage needs different spectrums of light as the requirement of the plant. Vegetative growth needs green and blue light spectrum and the fruiting stage need warm and yellow light spectrum. Different genetic plants need different types of the spectrum at different stages. The spectrum was controlled through the light duration in the previous system, not controlled as necessary for plants, such as the dark cycle and light cycle per hour[22].

2.3 Software and Algorithm design

Image processing dominant part of stabilizing this mechanism (spectrum control and nourishment)[23]. Image feature extraction algorithms are used for visualizing the plant's status. (ANN, SVM, and Swam intelligent) and SSD is used for feature extraction in response to plant growth. These Algorithms make it efficient for object observations (plant growth stages)[24]. The mobile application is used for remote monitoring and analysis of crops. Mobile applications store crop data for improvement of the crop in the next tenure of sowing and cultivation of crops through machine learning techniques[4].

3 Materials and methods

An artificial climate-controlled system (Figure 2) was used for plant growth and parameters were maintained. Artificially generating climate provided optimal surrounding state of the art in ACCC. Temperature, humidity, moisture, water drip irrigation, gasses concentration, and light are controlled inside the chamber by image processing, not with time duration. These factors were controlled by AI programs (machine learning) with the help of sensors and microcontrollers. Same as farmer brainstorming. The prototype was prepared for crops (wheat) farming or fruits and herbs. This prototype helped in developing a dataset and analysis of sensor data for designing protocols. According to plant growth, the protocols used to prepare artificial climate. The dataset was collated with runtime environmental data and set up environmental parameters through devices.

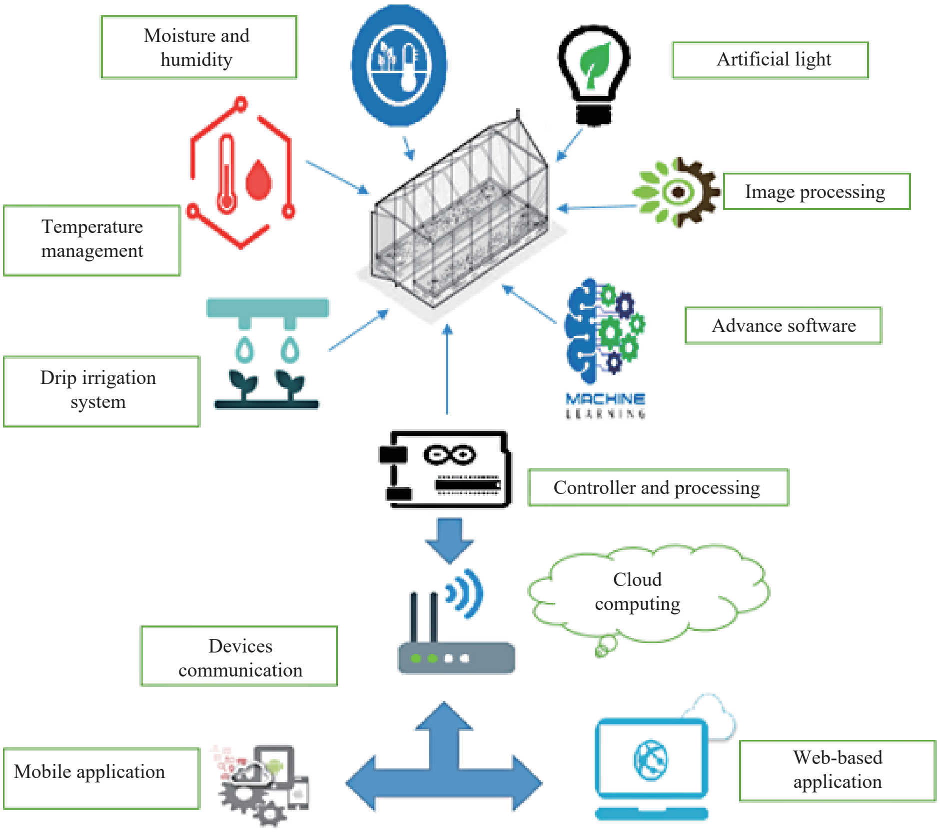

Figure 2 Process model used in experiments

3.1 Installing devices and controlling mechanism

Install the devices and sensors for data gathering from the artificially developed environment like moisture, temperature, humidity, and plant health factors. All these sensors were connected to the microcontroller. Microcontroller process data and regulate the artificial environment according to the crops. The special hardware was included for controlling the ratio of the light spectrum (Potentiometer). Potentiometers were used for digital auto-control of the intensity of light with the help of microcontrollers. Potentiometers worked at the rule of resistance of electricity point to point[25].

3.1.1 Image processing

Image processing was a significant part of this research devolvement work in which image processing was used for analysis and controlled plant factors like fertilizer ratio at different stages. The second factors were the adjusting phase through the spectrum of light at the germination phase, growing phase, vegetative growth phase, and crop maturity phase[26,27]. The camera captures images of the current condition of the plant and regulates nutrition values according to plant growth

3.1.2 Machine learning techniques

This study used machine learning algorithms (ANN, SVM, and SSD) to analyze crop health. Machine learning algorithms were used for better-visualized decisions and control in existing studies[10,28,29]. Feature extraction was used for controlling potentiometers by microcontrollers and for auto-fertilizing plants.

3.1.3 Remote access with mobile application

Remote access is an essential part of smart farming. The remote control system includes visualized analysis and includes records analysis of crop-by-crop data. Remote access reduces human interaction with crops. They can give people the advantage to reduce disease transformation into smart farms. This is possible with the help of IoT systems and smart devices[30].

The mobile application was used for the investigation of fieldwork and performance with remote access through IoT and mobile applications. This application shows that all environmental factors that produce an impact on a plant's health.

3.1.4 Cloud computing & web application

Cloud computing (optional) was used for online services through online database services and the use of online plate foam applications.

Web-based applications give us other features in which the application was used without mobile devices. All farm data access at the same spots. The web application is easy to access because that does not require specific operating system devices. This was optional.

3.2 Spectrum control mechanism through image processing

As shown in Figure 3, the spectrum control system works on computer vision in which the runtime camera visualizes the plant condition and analyzes health factors. Image processing processes the image and sends an impulsive message to the controller (Raspberry Pi). The controller changes the spectrum of artificial light and nutrition value according to the requirement of plants[2].

3.2.1 Light frequency intensity ratio

Spectrum value was taken from experts in plant agronomies. The spectrum of light was divided into different phases in the

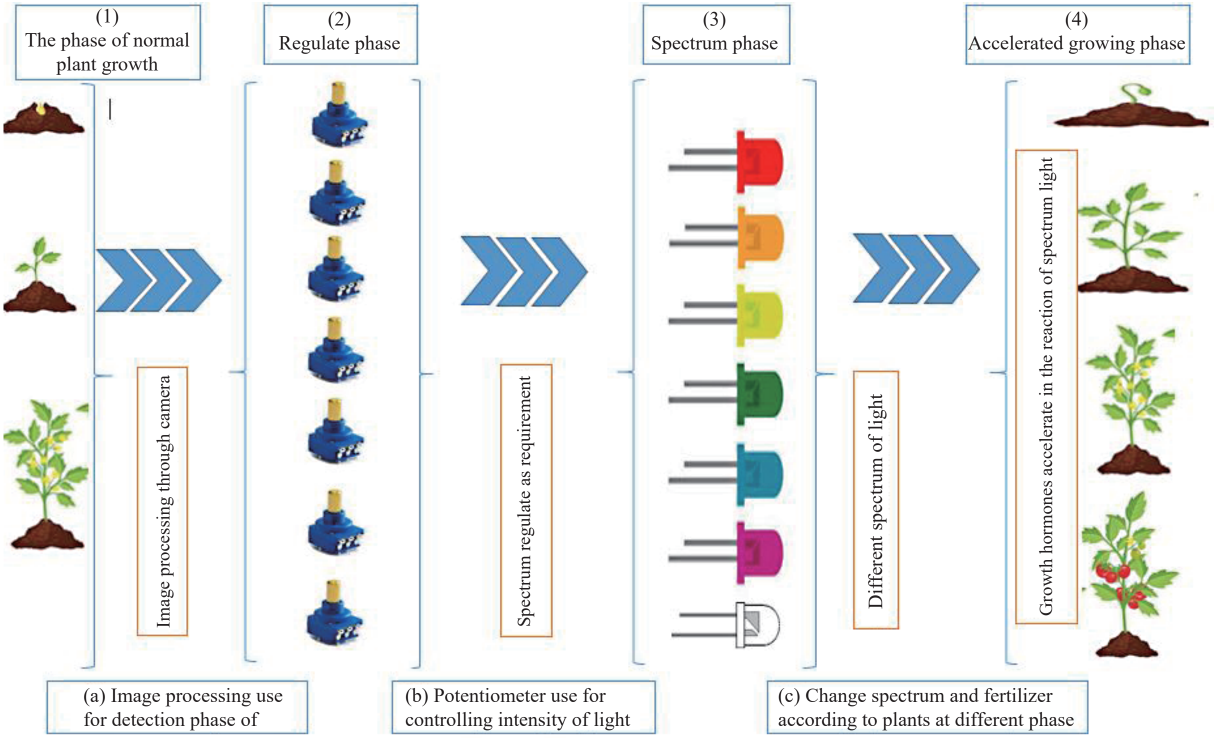

Figure 3 Spectrum-controlled mechanism

manner of different ratios of light wavelength intensity. Artificial light wavelength was divided into seven different spectrums[22,31]. This spectrum was visualized into seven colors (blue, yellow, golden, white, yellow warm, violet, green, and red) are shown in Figure 4[3].

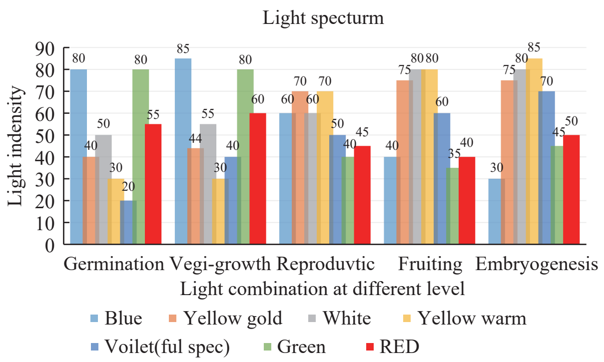

Figure 4 Ratios of light spectrums

3.2.2 Image processing for controlling the mechanism of spectrum

Image processing is a prominent feature of research in which machine learning techniques and advanced algorithms (Ann and intelligent swam algorithm, SSD, and SVM) were used for feature extraction with the help of Python programing language and Python libraries. Light spectrum intensity is controlled by a servo potentiometer as required of resistance of variables change.

3.3 Flow of processing of the proposed work

Electronic devices control all activities with the help of sensors and microcontrollers through advanced software. Sensors and cameras were sensing current values (temp, moisture, humidity, etc.) and plant conditions as a set of protocols and transmitted signals to controllers are shown in Figure 5. Controllers regulate the parameters. This circumstance manipulates the chamber's artificial environment atmosphere, again repeating this procedure for maintaining optimal surrounding for plants. The controller communicates with internet devices for remote access through mobile phones and mobile phone use for user interface connectivity.

3.4 Parameters of plants health

Plant health measures through chlorophyll color and formation. Plant leaf color also describes its health. In this work, some parameters were set by the rule of agronomists as listed in Table 1.

Table 1 Quality setting of variables in this study

Sr.	Color of Chlorophyll	Comment	Point out of 5	Weightage
1	Green	Good	*****	5
2	Light green	Fair	****	4
3	Light yellow	Bad	**	2
4	Yellow	Critical	*	1
5	Black/Brown	Die	--	0

4 Results and discussion

Wheat sowing observation describes a comparison study with different environments iterations with the health and growth of plants.

4.1 Analysis progress

The proposed research showed the result of wheat varieties in different phases in different conditions. The effects of light and environmental changes were analyzed.

Figures 6 and 7 visualize the graph of the first experiment on wheat growth and health, which show the difference in plant growth as well as the progress rate of plant maturity based on various light conditions. This graph shows that improvement in maturity and plant health that is a concept of speed breeding through AI.

4.2 Discussion of different farming techniques

Simple farming crops grow in an open environment. In which no factor is controlled. Its performance is shown in Figures 6 and 7. In simple farming, plant growth ratio and health effect with resonance effect of climate require ideal factors. Crops grow in simple light (fluorescent bulbs). It's performed better than open-field farming but not efficient as compared to controlled climate farming. Its graphical presentation is shown in Figures 6 and 7. The orange color line presents simple light farming. Simple light has not the full spectrum of light. So fluorescent bulbs cannot produce

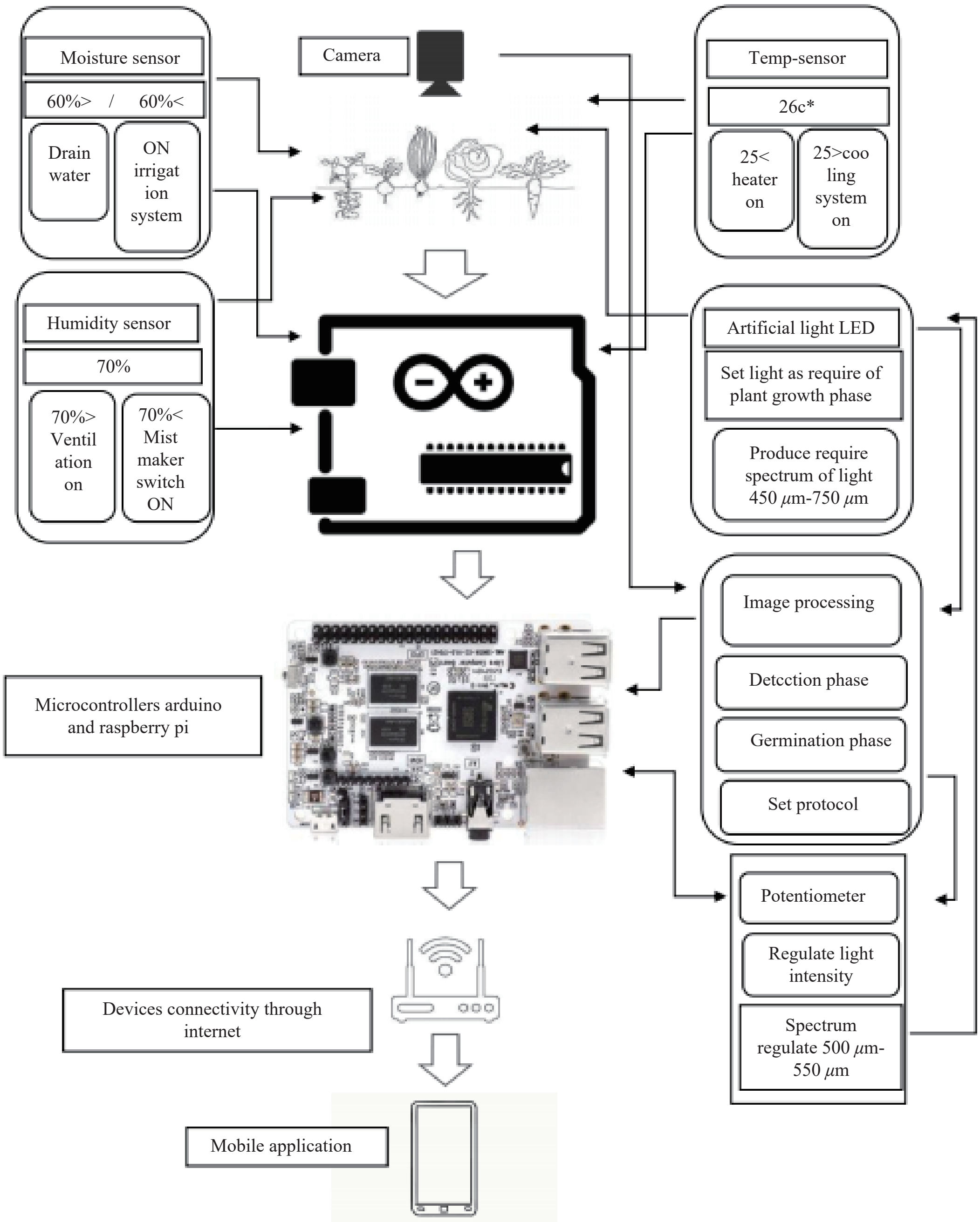

Figure 5 Schematic diagram of controlled mechanism used in this study

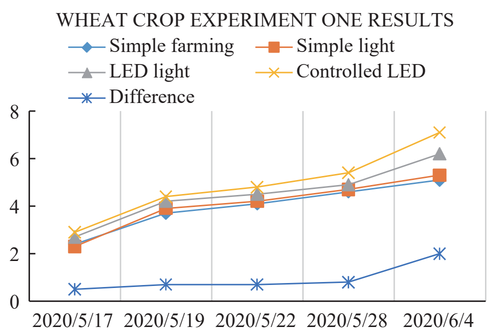

Figure 6 Wheat Crop Experiment 1

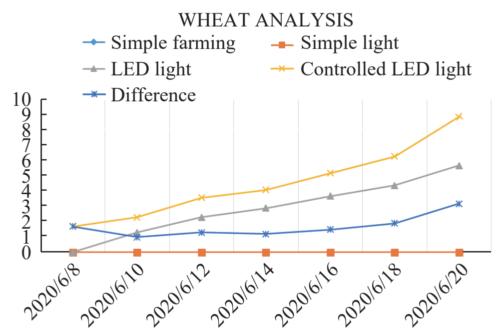

Figure 7 Wheat Crop Experiment 2

enough intensity and light nourish to plants.

LED light farming is better than the first two farming (simple farming and simple light farming). Temperature, moisture, and humidity were controlled artificially. Its performance is shown in Figures 6 and 7. LED light farming show with a gray line of graph line. ACL (artificial controlled light smart farming) was used by image processing and environment, which performs quite well in comparison to other approaches. The results of this farming can be found in Table 2. In the graph, the performance of controlled climate farming is depicted by a yellow line.

Table 2 Crop data of experiments

Parameters		Dates of sowing & analysis	Spl 1(O.F)	Spl 2(F.B)	Spl 3(LED.L)	Spl 4C.A.L	G.DSam1-sam4
Experiment 1	Growth/Health		0 cm	0 cm	0 cm	0 cm	
	Height of plant	2020-05-14	0 cm	0 cm	0 cm	0 cm	0 cm
	Health of plant		Good	Good	Good	Good	Good
	Height of plant	2020-05-17	2.4 cm	2.3 cm	2.7 cm	2.9 cm	0.5 cm
	Health of plant		Good	Good	Good	Good	Good
	Height of plant	2020-05-19	3.7 cm	3.9 cm	4.2 cm	4.4 cm	0.7 cm
	Health of plant		Good	Good	Good	Good	Good
	Height of plant	2020-05-22	4.1 cm	4.2 cm	4.5 cm	4.8 cm	0.7 cm
	Health of plant		Good	Good	Fair	Good	Good
	Height of plant	2020-05-28	4.6 cm	4.7 cm	4.9 cm	5.4 cm	0.8 cm
	Health of plant		Good	Good	Fair	Good	Good
	Height of plant	2020-06-04	5.1 cm	5.3 cm	6.2 cm	7.1 cm	2 cm
	Health of plant		Good	Fair	Fair	Good	Good
Experiment 2	Height of plant	2020-06-08	0 cm	0 cm	0 cm	1.7 cm	1.7 cm
	Health of plant		Good	Good	Good	Good	Good
	Height of plant	2020-06-10	0 cm	0 cm	1.3 cm	2.3 cm	1.0 cm
	Health of plant		fair	fair	good	good	Good
	Height of plant	2020-06-12	0 cm	0 cm	2.3 cm	3.6 cm	1.3 cm
	Health of plant		fair	Fair	Good	Good	Good
	Height of plant	2020-06-14	0 cm	0 cm	2.9 cm	4.1 cm	1.2 cm
	Health of plant		Bad	Bad	Fair	Good	Good
	Height of plant	2020-06-16	0 cm	0 cm	3.7 cm	5.2 cm	1.5 cm
	Health of plant		Critical	Critical	Good	Good	Good
	Height of plant	2020-06-18	0 cm	0 cm	4.4 cm	6.3 cm	1.9 cm
	Health of plant		Critical	Critical	Good	Good	Good
	Height of plant	2020-06-20	0 cm	0 cm	5.7 cm	8.9 cm	3.2 cm
	Health of plant		Die	Die	Good	Good	Good

Note: O.F: Open Field; F.B: Florescent Bulb; LED.L: LED light; C.A.L: Control artificial light; G.D: Growth difference; SPL: Sample; pt: point; wtg: weightage.

4.3 Comparison study

All types of farming experiments perform in different parameters and stages. For instance, simple farming, fluorescent light farming, LED light farming, and controlled LED light farming, in which performance was analyzed under the plant nourish factors. In the previous system spectrum and nutrition set based on time period, this research is controlled through visualized conditions. In the comparison study chart, the early maturity factor is best in reserve order (Figure 8).

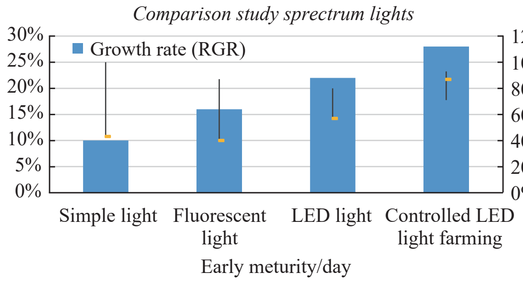

Figure 8 Comparison study of spectrum light

The qualitative variables were converted into quantitative variables because qualitative variables cannot be easy to estimate in a graphical presentation. The graph shows that wheat plant health is in a different situation. Which represents plant health by analyzing the color of plant chlorophyll, the strength of lounging and plant growth are shown in Figure 9.

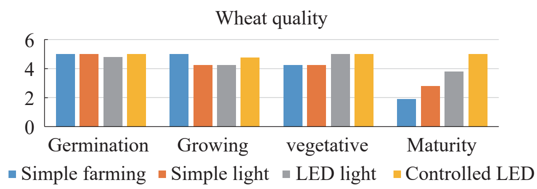

Figure 9 Wheat plant health and quality

5 Prototype

A prototype model was developed for experimental study on plants. Observation provides different results at different phases such as (Growth phase, Vegetative phase). All major factors were included, such as temperature through heaters and cooling systems, moisture through humidifiers or exhaust fans, light through artificial LED bulbs, nutrition value by fertilizers, soil moisture through the intelligent irrigation system, and soil replaces with coconut Piet. Frames prepare with anti-rust material (stainless steel) and acrylic UV sheets to preserve external light interference. The prototype's dimension was (3.048 m×1.820 m×1.820 m, as shown in Figure 10)

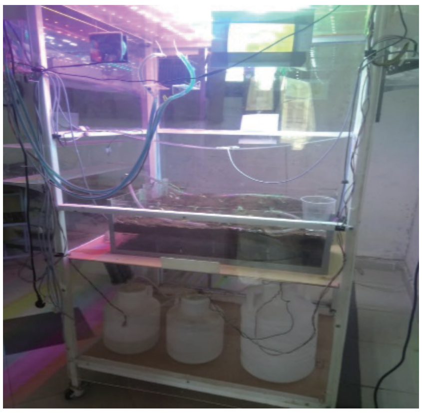

Figure 10 ACCC prototype used in this study

which installed two ports for the sowing of plants. Fertilizers and water were stored in lower-portion feed with bottles.

6 Conclusions

Climate change causes decreased yields, mainly in arid regions, as a result of inadequate factors of plant health and nutrition. The future of agriculture depends on smart farming. Some greenhouses are designed for specific areas according to weather and adaptability conditions. For summer farming, smart farming designs special structures with special isolation sheets. This structure is used for insulation and protection against the elements. Ventilation of sheets automates through smart devices and sensors. Smart shapes and devices for smart farming. Structure descriptions are dependent upon climatic change and the locality of formation. Smart agriculture farming is possible by inducing smart devices and sensors. Computer vision techniques provide machine-vision enhancement for developing intelligent systems. Smart farming will be able to produce consumable goods in people's kitchens and living rooms with the help of artificial intelligence and machine learning. ACCC system reduces approximately 13% (depending upon plant genetics) of maturity time compared to typical farming. With the use of this advanced technology, a vast amount of food can be produced in a short period of time, anywhere in the world, in a timely manner. The benefits of smart farming include the efficient use of resources and the provision of high-quality products.

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[References]

[1] Ali S, Liu Y, Ishaq M, Shah T, Abdullah, Ilyas A, et al. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. Foods, 2017; 6(6): 39.

[2] Farooq G M, Ofosu Y. Population, labour force and employment: concepts, trends and policy issues. International Labour Organization, 1992.

[3] Abbouda S K, Almuhanna E A, Al-Amri A M. Effect of using double layers of polyethylene cover with air gap on control environment inside greenhouses. Dallas: ASABE, 2012; 42044. doi: 10.13031/2013.42044.

[4] Baseca C C, Sendra S, Lloret J, Tomas J. A smart decision system for digital farming. Agronomy, 2019; 9(5): 216.

[5] Fukuda N. Plant growth and physiological responses to light conditions. In: Plant factory using artificial light, Elsevier, 2019; pp.71–77.

[6] Ghosh S, Watson Am Gonzalez-Navarro O E, Ramirez-Gonzalez R H, Yanes L, Mendoza-Suarez M, et al. Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. Nature Protocols, 2018; 13(12): 2944–2963.

[7] Mohammadi B, Ranjbar F, Ajabshirchi Y. Exergoeconomic analysis and multi-objective optimization of a semi-solar greenhouse with experimental validation. Applied Thermal Engineering, 2020; 164: 114563.

[8] Mukherji S V, Sinha R, Basak S, Kar S P. Smart Agriculture using Internet of Things and MQTT Protocol. In: 2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon), Faridabad: IEEE, 2019; pp.14–16. doi: 10.1109/COMITCon.2019.8862233.

[9] Ruan J H, Wang Y X, Chan F T S, Hu X P, Zhao M J, Zhu F W, et al. , A life cycle framework of green IoT-based agriculture and its finance, operation, and management issues. IEEE Communications Magazine, 2019; 57(3): 90–96.

[10] Patricio D I, Rieder R. Computer vision and artificial intelligence in precision agriculture for grain crops: A systematic review. Computers and Electronics in Agriculture, 2018; 153(1): 69–81.

[11] Shahzadi R<Ferzund J, Tausif M, Suryani M A, et al. Internet of things based expert system for smart agriculture. International Journal of Advanced Computer Science and Applications, 2016; 7(9): 070947.

[12] PPrathibha S R, Hongal A, Jyothi M P. IoT based monitoring system in smart agriculture. In: 2017 International Conference on Recent Advances in Electronics and Communication Technology (ICRAECT), Bangalore: IEEE, 2017; pp.81–84. doi: 10.1109/ICRAECT.2017.52.

[13] Worldometer. Available: https://www.worldometers.info/world-population/pakistan-population/. Accessed on [2020-07-23].

[14] Huang H K, Zhou Y J, Huang R D, Wu H J, Sun Y J, Huang G S, et al. Optimum insulation thicknesses and energy conservation of building thermal insulation materials in Chinese zone of humid subtropical climate. Sustainable Cities and Society, 2020; 52: 101840.

[15] Kim R-W, Lee I-B, Yeo U-H, Lee S-Y. Evaluation of various national greenhouse design standards for wind loading. Biosystems Engineering, 2019; 188: 136–154.

[16] Ghani S, Bakochristou F, Elbialy, E M A A, Gamaledin S M A, Rashwan M M, Abdelhalim A M, et al. Design challenges of agricultural greenhouses in hot and arid environments-A review. Engineering in Agriculture, Environment and Food, 2019; 12(1): 48–70.

[17] Esmaeli H, Roshandel R. Optimal design for solar greenhouses based on climate conditions. Renewable Energy, 2020; 145: 1255–1265.

[18] Rehman A U, Razzaq A, Rehman T U, Rehman A U, Farooq M, et al. Design and development of smart greenhouse for arid climate. in First iiScience International Conference, International Society for Optics and Photonics, 2020; 1156104. doi: 1156104/10.1117/12.2574354

[19] De Keyser E, Dhooghe E, Christiaens A, Van Labeke M-C. LED light quality intensifies leaf pigmentation in ornamental pot plants. Scientia Horticulturae, 2019; 253: 270–275.

[20] Kaiser E, Weerheim K, Schipper R, Dieleman J A. Partial replacement of red and blue by green light increases biomass and yield in tomato. Scientia Horticulturae, 2019; 249: 271–279.

[21] Ouzounis T, Rosenqvist E, Ottosen C-O. Spectral effects of artificial light on plant physiology and secondary metabolism: A review. HortScience, 2015; 50(8): 1128–1135.

[22] Yang Q R, Pan J Q, Shen G A, Guo B L. Yellow light promotes the growth and accumulation of bioactive flavonoids in *Epimedium pseudowushanense*. Journal of Photochemistry and Photobiology B:Biology, 2019; 197: 111550.

[23] Hatou K, Sugiyama T, Hashimoto Y, Matsuura H, et al. Range image analysis for the greenhouse automation in intelligent plant factory. IFAC Proceedings Volumes, 1996; 29(1): 962–967.

[24] Hber R, Bakker M, Balmann A, Berger T, Bithell M, et al. Representation of decision-making in European agricultural agent-based models. Agricultural Systems, 2018; 167: 143–160.

[25] Steven P. Potentiometers. [US1886439A], 1955.

[26] Harun A N, Mohamed N, Ahmad R, Rahim A R A, Ani N N, et al. Improved Internet of Things (IoT) monitoring system for growth optimization of *Brassica chinensis*. Computers and Electronics in Agriculture, 2019; 164: 104836.

[27] Poorter H, Niinemets U, Ntagkas N, Siebenkas A, Maenpaa M, Matsubara S, et al. A meta - analysis of plant responses to light intensity for 70 traits ranging from molecules to whole plant performance. New Phytologist Foundation, 2019; 223(3): 1073–1105.

[28] Praveen Kumar D, Amgoth T, Annavarapu C S R. Machine learning algorithms for wireless sensor networks: A survey. Information Fusion, 2019; 49: 1–25.

[29] Quy V K, Hau N V, Anh D V, Quy N M, Ban N T, Lanza S, et al. IoT-enabled smart agriculture: Architecture, applications, and challenges. Applied Sciences, 2022; 12(7): 3396.

[30] Modarelli G C, Paradiso R, Arena C, De Pascale S, Van Labeke M-C. High light intensity from blue-red LEDs enhance photosynthetic performance, plant growth, and optical properties of red lettuce in controlled environment. Horticulturae, 2022; 8(2): 114.

[31] Chiocchio I, Barbaresi A, Barbanti L, Mandrone M, Poli F, Torreggiani D, et al. Effects of LED supplemental lighting on the growth and metabolomic profile of *Taxus baccata* cultivated in a smart greenhouse. PLoS ONE, 2022; 17(7): e0266777.