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ORIGINAL ARTICLE

Investigation of the Potential to Introduce Internet of Things (Iot) Based Micro-Climate Controlling System for Salad Cucumber (Cucumis Sativus) in Conventional Protected Houses

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Abstract

Protected agriculture seeks to maximize productivity by manipulating climatic factors such as temperature to create the most favorable environmental conditions for the growth of animals and plants. This study aims to (a) identify the status of middle and small-scale protected house farmers using a questionnaire survey and (b) assess the impact of an IoT-based automation system to address identified issues of middle and small-scale protected house farmers. During the survey, the farmers revealed their inability to leave the polytunnel for at least one day without supervision and the higher labour cost as issues related to crop management. Decreased fruit quality and increased mite attacks, inability to achieve optimum crop yield were the main issues discovered which reduces the crop yield. The experiment was carried out in two protected houses where one house is under an IoT-based micro-climate controlling system and the conventional management in the other. Digital Temperature & Humidity Sensors (DHT21) were used to monitor relative humidity (RH) and temperature, and foggers and exhaust fans were used to control RH and temperature. Capacitance sensors were used to monitor substrate moisture, and a drip irrigation system was used to control it. Salad cucumber plants were grown in grow bags in each protected house. The inside day temperature was reduced by 1.55°C to 4.42°C in the IoT-based protected house and optimum inside day RH conditions were maintained. The maintained micro-climatic conditions showed a positive effect on yield and growth parameters of salad cucumber grown in IoT based protected house. In comparison to a conventional house, the IoT-based protected house had a 41.6% yield increment per vine.

Keywords: *Farmers' perception, Microclimate control, Protected agriculture, Smart agriculture, Yield increment*

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1. Introduction

"End all forms of hunger and malnutrition," says the second sustainable development goal, dubbed "zero hunger" (United Nations Development Programme 2022). According to current estimates, 8.9% (690 million) of the world's population is hungry, with the number expected to rise to over 840 million by 2030 (United Nations Sustainable Development 2022). To meet the challenge of ensuring an adequate food supply for the world's growing population by 2050, global food production must increase by 70% (Doering and Sorensen 2018) while putting the least amount of strain on the environment and biodiversity. To increase agriculture productivity sustainably, traditional farm management technologies must be replaced with smart technologies by re-engineering the agricultural production process. The Internet of Things (IoT) is a new Information communication technology (ICT) application in which a network of devices makes and implements decisions without the involvement of humans (Malavade and Akulwar 2016). Many agricultural processes, such as greenhouse management, livestock management, and the agri-food supply chain, have shown their potential benefits when using IoT technology (Shenoy and Pingle 2016).

Protected agriculture, also known as controllable agriculture, is a modern technique for modifying the microclimate conditions surrounding a crop to achieve optimal growth (Shi et al., 2019). It quickly gained popularity among farmers due to its increased productivity per unit area of land, efficient use of natural resources, and year-round production (Sabir and Singh 2013). IoT can be used to monitor and control environmental factors such as temperature, humidity, carbon dioxide concentration, substrate moisture, electrical conductivity (EC), pH, and illumination in real-time inside a protected house according to the condition of crop growth while reducing the amount of human labor required (Liu et al.,2018).

Protected agriculture, which was first introduced to Sri Lanka in 1987, has grown in importance in today's agricultural system because of its demonstrated advantages, which include increased profits, product quality, and year-round supply. To meet domestic and international market demand, Sri Lankan farmers primarily grow salad cucumber, bell pepper, chili, and lettuce (Kumara et al., 2015). Technical issues continue to impede the protected agriculture sector in Sri Lanka, preventing it from expanding and causing farmers to lose money (Premalatha et al., 2006). Emerging technologies, such as digitalization and automation, have the potential to transform the country's protected agriculture systems by enhancing the precise use of available resources (Development Asia, 2022). Few numbers of studies have been conducted to investigate the technical issues related to environment controlling in protected houses. Therefore, no recent literature is available regarding the technical issues of the protected agriculture sector of Southern province, Sri Lanka. The study's goals were to a) determine the current status of traditional middle and small-scale protected-house farmers in Sri Lanka's Southern province, and b) investigate the use of an IoT-based automation system to address the farmers' identified issues.

2. Materials and Methods

An experiment and a survey were conducted during the study. The purpose of the survey was to identify issues related to protected house farming on a small or medium scale (section 2.1). The experiment took place in two protected houses built at the Faculty of Agriculture, University of Ruhuna. The experimental area is located in the WL_2B agro-climatic zone, which is a low-lying wet zone (section 2.2).

Survey on protected house farmers in Southern province

The survey was carried out among small and medium-scale farmers Galle, Matara, and Hambantota districts. A semi-structured questionnaire was used to conduct interviews with 30 protected house farmers. The farmers were chosen randomly from a list of participants obtained from the Department of Agriculture in Sri Lanka. The information was analyzed using IBM SPSS software.

Experimentation

Two double-roofed protected houses (92.88 m^2) were built with the same orientation and outside environmental conditions. The center height of the protected house was 5 m, and the gable height was 3 m. The top vents in both protected houses have been modified to allow air to escape. An insect screening net of 62000*38750 squares/m^2 was used to cover both protected houses. The top roofs of both tunnels were covered with 1000-gauge clear polyfilm. Two hundred and four salad cucumber plants (variety Efdal) were grown in grow bags with coir dust as the growth medium in each protected house. Salad cucumber was chosen to cultivate based on the results of the survey mentioned in section 2.2, as it was the most cultivated crop in the protected houses of the Southern province. There were only two treatments in the experiment, Treatment 01(T1)-IoT-based automated protected house and Treatment 02(T2)-Conventional protected house. According to the details given in Table 01, a protected house was developed with a microclimate monitoring and controlling system and a protected house without any microclimatic controlling mechanism was developed.

Mechanism used in IoT-based automated protected house (T1)

The microclimatic data collected by the sensors was sent to the gateway via a wired connection between the sensor nodes and the gateway. The growth media was fitted with nine capacitive moisture sensors. The sensors were buried 12.7 cm into the substrate, 6 cm away from the plant's root on the opposite side of the emitter. Five DHT 21 sensors, each with relative humidity and temperature sensors, were placed at four different heights from the protected house's floor level: 0.6, 1.5, 2.1 and 2.7 m. The gateway was linked to the internet via GPRS through a GSM module, and it collected real-time data every two minutes. In the gateway, a SIM card with the correct APN (Access Point Network) was inserted.

Table 1: Description of Treatment(T1) 01 and Treatment 02(T2)

Microclimatic conditions	Monitored by		Controlled by	
	T1	T2	T1	T2
Relative humidity	DHT21 temperature and humidity sensors	Wet and dry bulb thermometer	Three turbojet exhaust fans with 300 mm sweep and 1400 rpm speed & 21 four-way Mid pressure cross misting foggers type	No control
Temperature		Dry bulb thermometer		
Substrate moisture	Capacitance moisture sensor	No monitoring	Drip irrigation system	Applied by drip irrigation system the media get saturated before 8.00 am
Fertigation	No monitoring	No monitoring	The same dose was split & given 36 times a day starting from 6.00 am to 4.00 pm	The same dose was given in the morning before 8.00 am.

The gateway sent the sensor data to the IoT platform, where it was processed, and decisions were sent back to the gateway.

The IoT platform was the coded backend of the automation system that could make decisions after processing sensor data sent from the gateway without the need for human intervention. These decisions are made with the threshold values for each sensing parameter in mind. The microclimatic conditions were managed based on decisions made by the IoT platform. The farmer app interface was updated in two-minute intervals with real-time microclimatic data. The entire system was powered by 230V/13A. The gateway sent a signal to the relay module to turn on or off the actuators and the working time of the actuators to control the microclimatic conditions in the protected house, based on the decision made by the IoT platform in the server. The actuators can also be controlled manually by the appropriate switch on the main switchboard. Separate relays controlled the exhaust fans, water pump, foggers, and fertigation unit. The drip irrigation system, fogging system, and fertigation system were all controlled by separate solenoid valves. The solenoid valves were controlled by the signal from the relay.

Data collection and data analysis

Temperature and relative humidity were measured four times a day using wet and dry bulb thermometers in T2. Internodal length (cm), base thickness (cm), vine length (cm), SPAD value of 5th leaf & 14th leaf, number of nodes per vine, yield per vine per week (g), and number of aborted fruits were the growth and yield parameters measured during the research period. Data was analyzed using descriptive statistics like line charts and graphs and pooled t-test which was done using Minitab 17.

3. Results and discussion

The study included a survey and an experiment to achieve objectives 01 and 02, respectively. Section 3.1 discusses the survey results, while Section 3.2 discusses the results of the experiment conducted in the two protected houses.

Current status of conventional middle and small-scale protected house farmers in Southern province, Sri Lanka

The farmers who have protected house loor area of 464.51 m^2 were interviewed since they did not have the ability to afford high-cost technology solutions to automate their protected houses. The farmers who have a protected house floor area between 464. 51 m^2 and 278.70 m^2 were considered as middle scale farmers and the farmers with less than 278.70 m^2 protected house floor area were considered as small-scale farmers.

Crop management

Table 2. Microclimatic conditions of IoT-based protected house

Growth stage		**Nursery stage**		**Vegetative stage**	**Reproductive and maturity stage**
No. of days		1-4	5-8	9-28	29-120
Relative humidity (%)	6AM-6PM	80-90	65-70	65-75	55-65
	6PM-6AM	50	50	45-50	50-55

Table 3. Microclimatic conditions of the IoT-based protected house throughout the whole crop cycle

Condition	**Throughout the whole crop cycle**			
	9PM-6AM	6AM-9AM	9AM-5PM	5PM-9PM
Temperature (°C)	15	20	25	20
Substrate moisture	550%-600%(db) field capacity			

Tables 01 and 02 show the optimal conditions for Salad Cucumber growth that were attempted in the IoT-based automation system.

Twenty percent of those interviewed were under the age of 30, 20% were between the ages of 31 and 40, 40% were between the ages of 41 and 50, and 20% were over the age of 50. When the reasons for engaging in protected agriculture were explored, the majority (46.6%) responded that they began protected house farming due to its high profitability, 33.3% were influenced by other people who engaged in protected agriculture, and 20% became involved in protected agriculture due to interest generated by participating in protected agriculture workshops. According to the findings of the survey, all farmers interviewed preferred to engage in protected house farming because it provided them with more free time than routine jobs and was highly profitable. The farmers were hesitant to provide specific figures for their earnings, but they did state that protected house farming is profitable. Five-point Likert scaled statements were used to characterize the farmer's satisfaction with the profitability of engaging in protected agriculture. Seventy-seven percent of farmers were "very satisfied" with the profits from protected house farming, while 23% were "satisfied."

The interviewed farmers had an average protected house area of 285.67 m^2 with a minimum of 92.9 m^2. In terms of cultivated crops, 80% of respondents cultivated only salad cucumber in their protected houses, while 20% cultivated both salad cucumber and bell pepper in their protected houses. For each crop cycle, the average yield per plant of salad cucumber was 4 kg per plant and the average yield per plant of bell pepper was 1.5 kg per plant. The economic yield of the crop mainly depends on the expertise of the grower and the growing environment. An optimum yield of 15 kg is achievable from a salad cucumber plant under optimal growing conditions and industrially a plant yields around 7-12 kg (Badgery 2010). The optimum yield is not achievable under existing microclimate conditions in Sri Lanka. When it comes to crop management practices, 93% of protected house farmers only use family labour. For crop management in the protected house, only 7% of the target group used both hired and family labor.

Regarding the use of an automated microclimate monitoring and controlling system, all respondents were well aware of the system's importance in maintaining microclimatic conditions to obtain the best yield from the crop. Despite being aware of the importance of optimum microclimatic conditions for crop growth, 33.33% of farmers in the study did not use any microclimate monitoring and control systems. This group of farmers stated that they had been unable to find a dependable and cost-effective technical solution for microclimate monitoring and control for their protected houses. To monitor temperature, relative humidity, EC, and pH, most farmers (56.67%) used manual methods such as a thermometer, a relative humidity meter, an EC meter, and a pH meter.

Out of the 56.67% of farmers, 17.64 % sprayed water into the protected house roof with a hose, turned on foggers, or turned-on fans when the temperature is too high. To maintain optimum EC and pH conditions, 29.41 % monitored the pH and EC of the growth media and took necessary actions such as washing grow bags and adding buffers to the fertilizer solution. 17.64% of farmers did practice both the above-mentioned manual methods to monitor pH, EC of the growth media, and internal temperature. The remaining (35.29%), despite monitoring the microclimatic conditions, did not take any control measures. Farmers complained that these manual methods of microclimate control are time-consuming and require constant attention throughout the day.

The remaining farmers (10%) used various types of automation systems to monitor and control the microclimatic conditions in their protected houses. Out of the 10% of farmers, 66.66% used timer-based drip irrigation systems and 33.33% used an automated microclimate monitoring and control system including exhaust fans and drip irrigation systems with relevant sensors and actuators There was no way to remotely monitor and control the protected house conditions in that automation system.

The farmers' willingness to adopt a mobile app-based microclimate controlling and monitoring system was investigated by interviewing them about their knowledge and frequency of mobile app usage. Seventy-eight percent of those interviewed had used internet services, including mobile apps, daily. Nineteen percent of the interviewed group rarely used internet services, and 3% of farmers did not know how to use internet services. An open-ended question was asked from each respondent to identify the problems they face related to the microclimatic conditions of the protected house. The farmers stated that they were unable to leave their protected house without their supervision at least for one day since daily watering, fertilization, temperature, and relative humidity control are essential. High temperatures inside the protected house for an extended period reduce fruit quality, increase fruit abortion, and promote mite attacks (SenzAgro 2022). The farmers also had an issue in monitoring and controlling EC and pH as they only started treating extremes of EC and pH once the symptoms were shown in plants.

Investigation of the use of IoT-based automation system to address identified issues of the middle-scale and small-scale protected house farmers

To achieve objective 02; the effectiveness of the automation system was evaluated by measuring microclimatic data, yield, and growth data relative to the conventional protected house management

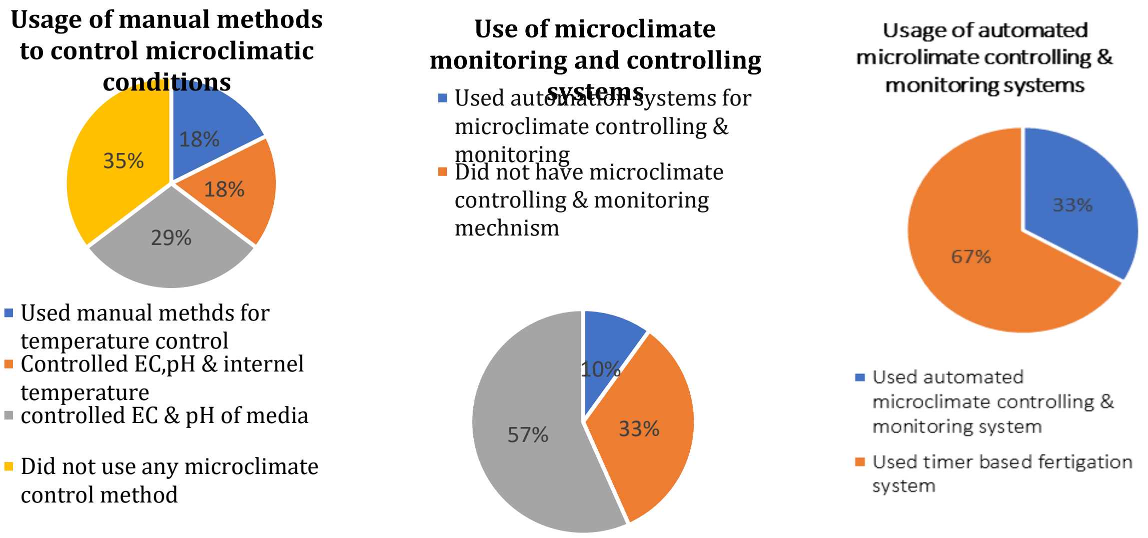
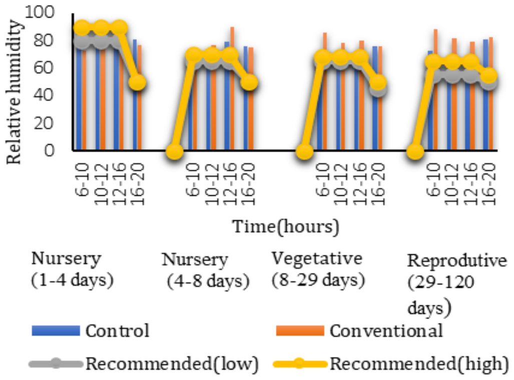


Figure 1 Usage of microclimatic monitoring and controlling systems



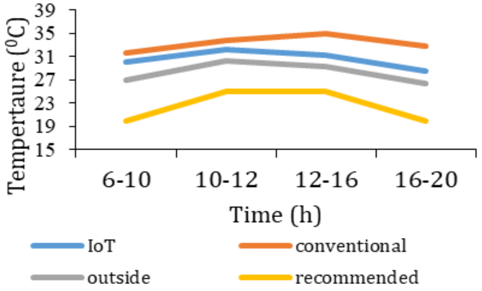


Figure 2: Relative humidity control

Figure 3: Temperature control

Figure 2 depicts the effectiveness of an IoT-based automation system in controlling relative humidity in the nursery stage (0-4 days), which was from seed sowing to germination, nursery stage (4-8 days), vegetative phase (8-20 days), and reproductive stage (28-120 days). From 06.00 to 16.00, the protected house was able to maintain the optimum RH. RH was unable to maintain optimum conditions from 16.00 to 20.00. In the protected house, 21 foggers and three exhaust fans were sufficient to maintain daytime optimum RH conditions, but three exhaust fans were insufficient to reduce the inside RH to the optimum level. Figure 3 illustrates the efficiency of the IoT-based automation system in controlling the temperature inside the protected house during the crop cycle. Using three exhaust fans and foggers, temperatures were reduced by 1.56 ±0.05°C, 1.55 ±0.105°C, 3.8 ±0.115°C, and 4.42 ±0.192°C from 6.00-10.00, 10.00-12.00, 12.00-16.00, and 16.00-20.00, respectively. The recommended temperature was not feasible under local conditions due to the high cost.

The vegetative and yield parameters of salad cucumber grown under T1 and T2 conditions were measured separately to assess the impact of an IoT-based automation system on crop growth.

T1's 5th, 14th, and 21st internode lengths were significantly shorter than T2's by 13.23%, 10.18%, and 15.98%, respectively (Figure 4). Every week after transplanting, the vine length of salad cucumber T1 was significantly greater than that of T2 (Figure 4). Vine length is determined by the internodal length and the number of nodes, and it is simply the sum of the plant's internodal lengths (Berghage 1998). The number of nodes per vine in T1 was significantly higher than in T2 (Figure 4), we can conclude that T1's significantly longer vine length was solely due to T1's significantly longer internodal length. The major factors influencing a plant's internodal length are heat, light levels, and the difference between day and night temperature (DIF) (Myster and Moe 1995). Heat causes a plant's intermodal length to increase as it attempts to cool itself by stretching upward (Rauscher 2022). The temperature was the only factor that affected internodal length because the light level was the same in both treatments.

The leaf unfolding rate, which indicates node number, is directly proportional to temperature within the optimum range (22°C – 30°C) and begins to decrease when the temperature is too high (Berghage 1998). Because the average day temperature in the conventional protected house was 34.29±0.105°C, this could explain why T2 had a significantly lower number of leaves. Eventhough T1's average temperature was 31.61±0.067°C which is lower than T2, the optimum temperature was not achieved with the tested structure.

The DIF of T1 was less than T2 due to the temperature control mechanism in the IoT-based automated protected house during the day, as the night temperature in both protected houses was nearly identica

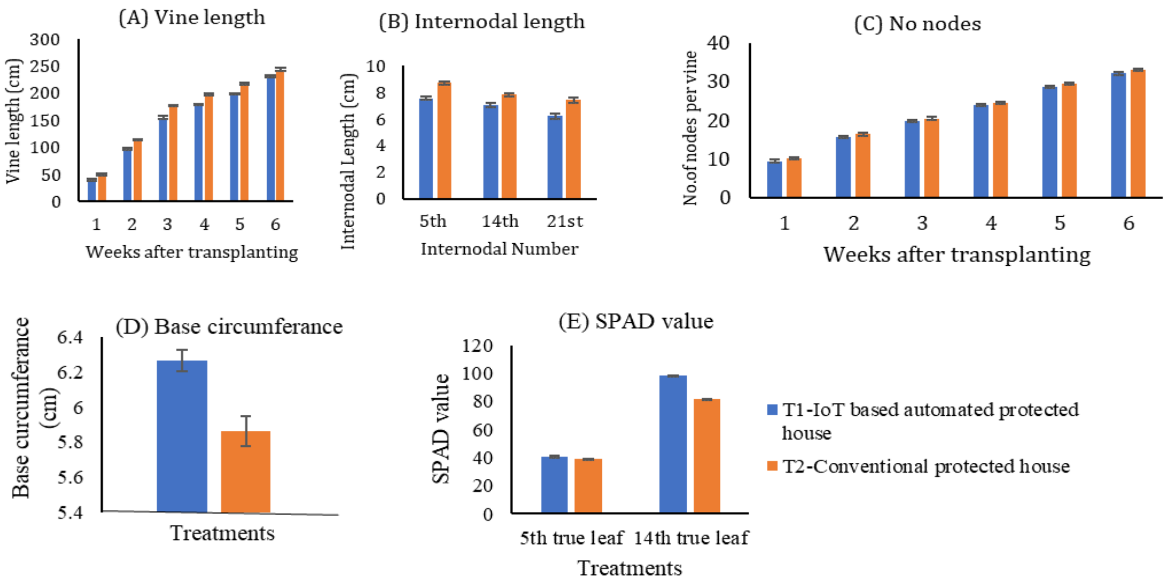
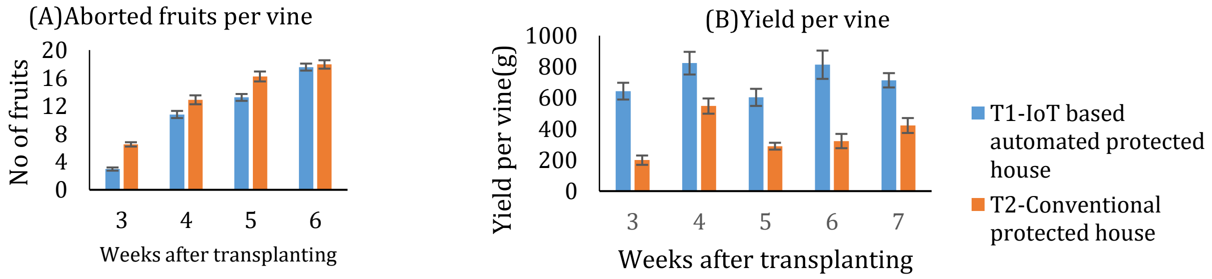


Figure 4: Growth parameters measured in the vegetative stage (95% confidence)

Error bars show the standard error. A=Vine length, B=Internodal length, C= No.of leaves per vine, D=Base circumference, E=SPAD value

Figure 5: Parameters measured in reproductive stage



Error bars show the standard error

A=Aborted fruits per vine, B=Yield per vine

The relatively higher day temperature reported in T2 was the primary cause of increased cell elongation in conventional protected houses, which eventually led to increased vine length. The same response was reported for many other ornamental and vegetable crops including Euphorbia pulcherrima (Berghage and Heins 1991), Nephrolepis exaltata (Erwin et al. 1993) and Cucumis sativus L. (Grimstad and Frimanslund 1993).

Due to more frequent training as a result of excessive stem elongation caused by high inside temperature, more labour hours are consumed (De Koning 1990). Because the temperature in the conventional protected house was higher in T2 than in T1, vine training was more frequent in T2. This made management practices more difficult. Controlling the inside day and night temperature in the protected house is a major way of controlling stem elongation and thus the rate and ratio of vegetative and reproductive growth in the crop (De Koning 1990, Erwin and Heins 1995) Controlling the day temperature is a commonly recommended practice in tropical climates for this purpose. Faster growth of salad cucumber plants, as evidenced by longer stems, has several negative consequences, including a shorter reproductive phase and overall life cycle due to excessive energy consumption in the vegetative phase, and lower yields (Hatfield and Prueger 2015). The significantly longer vine length indicates that the plant is developing faster, resulting in a longer vegetative period, a shorter reproductive period, and a shorter life span with low yields.

The excessive stem elongation and reduced crop water content (Sevanto 2003) resulted in stems with significantly lower (by 6.83%) base circumference in T2 compared to T1 (Figure 04). This makes the stems weaker and unable to bear large fruits (Maximum yield 2022). The relatively higher temperature in T2 increased the transpiration rate of the plant causing the plant to exhaust with the reduction of crop water content which ultimately reduce the base circumference of the plant. To compensate for the plant water loss by transpiration, the substrate moisture should be always higher than the critical point (Suraj et al. 2018). The reduced crop water content in T2 depicted the moisture stress undergone by plants due to insufficient moisture in the growing media. The plants in T2 showed temporary wilting in the afternoon around 12.00 pm to 2.00 pm because watering was only done in the morning. The plants in T1 did not face any moisture deficit because the substrate moisture was maintained within the container capacity level (Table 01).

The SPAD value is used to determine the nutritional status of crops in terms of nitrogen (Yang et al. 2014). In the conventional protected house, daily fertilizer dose was supplied at once in the morning. The SPAD value of the 5th true leaf of both treatments was not significantly different, but the chlorophyll content of the 14th leaf of T1 plants was 5.3% higher than that of T2, as shown in Figure 4. Plants in traditional protected houses received their daily fertilizer dose immediately after delivery, resulting in a nitrogen deficit during the day. The chlorophyll content of the 14th leaf of plants in the IoT-based protected house was 5.3% higher than in the traditional protected house. Because the fertilizer was applied slowly and consistently throughout the day, the T1 plants never had a shortage of nitrogen. Split root fertigation improved cucumber yield by 21% in ventilated and 17% in semi-closed greenhouse conditions, according to a study comparing the efficiency of split root fertigation and traditional fertigation (Jokinen et al. 2011). The plants in T2 may be suffering from a nitrogen deficit, which explains why their SPAD value in the 14th leaf is significantly lower than in T1.

Inadequate nutrition caused by a lack of fertilization, pests and diseases, a lack of plant regulators, and abnormal environmental factors such as low air humidity, high temperature, and dry winds are all factors that contribute to fruit abortion (Ersoy 2017). Inadequate nutrition, low humidity, and high temperature and moisture stress were identified as reasons for significantly higher fruit abortion in T2 plants compared to T1 plants during this study. Figure 05 demonstrates that plants grown in T1 had significantly fewer aborted fruits per vine than plants grown in T2. The source/sink ratio of a crop is a reflection of the crop's microclimatic conditions. CO2 concentration and the amount of light intercepted by the leaves are the two factors that influence a plant's source strength. Temperature and the number of sink organs in the plant have been identified as factors affecting the plant's sink strength. Abortion and organ formation in plants is caused by changes in the source/sink ratio (Marcelis et al. 2004). Minimizing daily temperature variations in salad cucumbers would result in balanced plant growth, regular fruit and flower production, and prevention of photosynthesis feedback inhibition (Marcelis et al. 2004 and Marcelis 1994). It was proved, a temperature control developed to lower the daily variation in the source/sink ratio of a cucumber crop was able to give a 5% yield increment on an annual basis by stabilizing and increasing the dry matter partitioning into fruits (Janse et al. 2006).

Figure 05 revealed that the yield per vine in T1 plants was significantly higher than those in T2. When the outside temperature in Sri Lanka's low country wet zone reaches around 26°C after sunset, the inside temperature of the protected house remains around 30°C for one to two hours without reaching equilibrium with the outside temperature. As the plants respire more and use stored carbohydrates due to the delayed equilibrium between inside and outside temperatures, yield losses occur (Whiting 2020). Due to the exhaust fans in T1, the inside temperature of the protected house made an early equilibrium with the outside temperature, decreasing yield losses in T1. Reduced carbohydrate consumption for respiration after sunset, significantly lower number of aborted fruits per vine, increased photosynthesis due to optimum RH and significantly higher number of leaves per vine, increased number of nodes per vine, consistent fertilizer supply by fertigation 36 times per day and optimum vegetative growth (Grimstad 1993) are the reasons for the significant increase in yield per 100 m2 in T1 relative to T2.

4. Conclusion

The problems reported from the survey were the inability to leave the polytunnel for at least a single day without supervision, reduced fruit quality and increased mite attacks, inability to obtain optimum crop yield and high labour cost. The growth parameters showed a positive effect on yield increment in IoT-based protected house when compared with the conventional protected house. There was an average 41.6% yield increment per vine in IoT protected house than that of conventional protected house. There was a 61.5% yield increment in the IoT-based protected house compared with the conventional protected house for 100 m^2.

5. Conflict of interest

This manuscript has not been published and is not under consideration for publication elsewhere. All authors have participated in the conception and design, or analysis and interpretation of the data, drafting of the article and approval of the final version. The authors declare that there is no conflict of interest.

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