DESIGN AND DEVELOPMENT OF A LOW-COST SOLAR POWERED STORAGE SYSTEM TO EXTEND THE SHELF LIFE OF LITCHI (*Litchi chinensis*) FRUITS

A THESIS

BY

MST. SHUMANA AKTER

Student No: 1707105

Session: 2022-2023

Thesis Semester: January-June/2024

MASTER OF SCIENCE

IN

FARM POWER AND MACHINERY

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200, BANGLADESH

JUNE-2024

DESIGN AND DEVELOPMENT OF A LOW-COST SOLAR POWERED STORAGE SYSTEM TO EXTEND THE SHELF LIFE OF LITCHI (*Litchi chinensis*) FRUITS

A THESIS

BY

MST. SHUMANA AKTER

Student No: 1707105

Session: 2022-2023

Thesis Semester: January-June/2024

Submitted to the

Department of Agricultural and Industrial Engineering

Hajee Mohammad Danesh Science and Technology University, Dinajpur in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

IN

FARM POWER AND MACHINERY

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200, BANGLADESH

JUNE-2024

DESIGN AND DEVELOPMENT OF A LOW-COST SOLAR POWERED STORAGE SYSTEM TO EXTEND THE SHELF LIFE OF LITCHI (*Litchi chinensis*) FRUITS

A THESIS

BY

MST. SHUMANA AKTER

Student No: 1707105

Session: 2022-2023

Thesis Semester: January-June/2024

Approved as to the style and content by

…………………………………………………….

Professor Dr. Md. Shaha Nur Kabir

(Supervisor)

…..………..……..……………………………

Milufarzana

Associate Professor

(Co-supervisor)

……………………………………………..

Chairman, Examination Committee

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200, BANGLADESH

JUNE-2024

Dedicated

To

My Beloved Parents

ACKNOWLEDGEMENT

All praises are due to "Almighty Allah" the beneficent, the merciful and the lord of the universe whose profound blessings and boundless peace's enabled us to complete the project report for the degree of Master of Science (M.S.) in Farm Power and Machinery at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur.

The author has the pleasure to express the heartfelt respect, deepest sense of gratitude, immense indebtedness and profound appreciation to her honorable supervisor, ***Dr. Md. Shaha Nur Kabir,*** *Professor, Department of Agricultural and Industrial Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur, for his scholastic guidance, constant inspiration, valuable advice and affectionate feeling for successful completion of this research work and preparation of the thesis paper.*

The author expresses her deepest sense of gratitude and heartfelt appreciation to her Co-Supervisor, **Milufarzana,** *Associate Professor, Department of Agricultural and Industrial Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur for her guidance, keen supervision, constructive criticism and valuable advice during every phase of this research work.*

The author also expresses deepest sense of respect & special sincere thanks to all the teachers of the Department of Agricultural Industrial Engineering, HSTU, Dinajpur for their valuable teaching, inspiration and encouragement during the whole course of this study.

The author expresses her special appreciation and indebtedness to her beloved parents, brother, and other relatives whose sacrifice and inspiration, encouragement, and continuous blessings paved the way for her higher education.

Finally, but not least, the author truly obliged to the above & to all those who have contributed to the completion of the research & improvements of this thesis.

June, 2024 *The Author*

ABSTRACT

Post-harvest losses of litchi in Bangladesh are significantly high, primarily due to improper handling, transportation, and storage conditions. This research aims to address these issues by designing and constructing a low-cost solar-powered storage structure specifically for the short-term storage of litchi fruits. The study also assesses the efficiency of this smart storage structure in reducing post-harvest losses and maintaining the quality of litchi fruits. A solar-powered evaporative cooling storage system was developed to prolong the shelf life of litchi fruits. The system comprises three main components: a storage unit, a cooling mechanism, and a controller unit. The cooling system uses a cooling pad, fan, pump, and water tank to maintain reduced temperature and humidity levels, while solar panels supply power. A microcontroller equipped with temperature, humidity, ethylene, and carbon dioxide sensors monitors storage conditions. The system's performance was evaluated against traditional storage methods, including open bamboo and plastic baskets, refrigeration in poly bags, and the developed storage unit, using 50 litchi samples for each method. The solar-powered storage system maintained a stable internal temperature of 27.42°C and relative humidity of 64.81%, compared to ambient conditions of 31.43°C and 75.13% humidity. The postharvest quality parameters of litchis stored in the developed system showed a physiological weight loss (PLW) of 19%, firmness between 10 N and 15 N, and total soluble solids (TSS) of 17%. The highest weight loss (28.37%) occurred in bamboo baskets, while the highest firmness (16.03 N) and TSS (17.95%) were recorded in plastic baskets and refrigerators, respectively. The evaporative cooling system effectively preserved the fruit's colorimetric properties (L* value of 27.39). The system demonstrated a benefit-cost ratio of 1.25, highlighting its economic feasibility for small-scale farmers. This study concludes that the solar-powered evaporative cooling storage system is a sustainable, low-cost solution for reducing litchi post-harvest losses, enhancing marketability, and improving profitability. Future research should focus on scaling the design for larger applications and integrating advanced preservation techniques to further extend the shelf life of litchi and other perishable fruits.

ABBREVIATION

CWN	Chitosan Water Nan composite
TSS	Total Soluble Solids
PH	Potential of Hydrogen
IDE	Integrated Development Environment
CO_2	Carbon Dioxide
C_2H_4	Ethylene

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER-I
INTRODUCTION

1.0 Background

Litchi (*Litchi chinensis*) is a seasonal fruit that is widely cultivated in tropical and subtropical regions around the world. This fruit tree, which thrives in specific climatic conditions, is therefore cultivated in a limited number of countries (Singh et al., 2023). Litchi is renowned for its high nutrient value, attractive color, and delicious taste. The fruit has an oblong shape, bright red skin, and sweet, juicy pulp.

Litchi is an excellent source of essential nutrients, including vitamins, minerals, and bioactive compounds such as phenolics and flavonoids, which possess natural antioxidant properties (Chadha, 2001; Luximon-Ramma et al., 2003). These bioactive components help to reduce scavenging reactive oxygen species and cholesterol levels, thereby lowering the risk of diseases such as cardiovascular disease, smallpox, and dyspepsia (Gao et al., 2017; Morton et al., 2000; Su et al., 2016). Wall (2006) suggests that consuming 14-17 litchis daily can fulfill an adult's daily requirement of vitamin C.

1.1 Litchi Production

Litchis originally came from southern China and were introduced to the Indian subcontinent by Myanmar, Taiwan, Thailand, Indonesia, Vietnam, India, Pakistan, and Bangladesh around the end of the 17th century. Today, China and India remain among the top regions for litchi cultivation. Litchi is believed to have been brought to Bangladesh from Myanmar (Belal, 2023). While litchi grows throughout Bangladesh, the primary cultivation areas include the districts of Dinajpur, Rajshahi, Rangpur, Khulna, Dhaka, Kushtia, Sylhet, and Chittagong.

According to data from the Bangladesh Bureau of Statistics (2022), litchi production in Bangladesh has shown significant growth over the past six years. In the 2017-2018 fiscal year, the production was 40,886 metric tons. Over the following two years, production increased to 92,958.42 metric tons. This data highlights the increasing importance of litchi cultivation in Bangladesh, as illustrated in Figure 1.1.

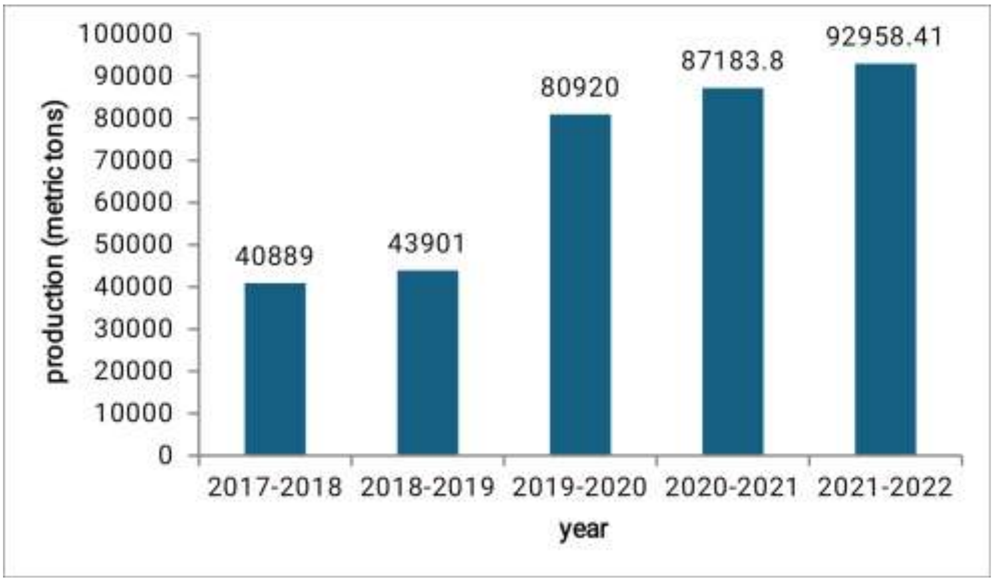


Figure 1.1: Annual litchi Production in Bangladesh (2017-2018 to 2021-2022)

(Source: Bangladesh Bureau of Statistics, 2022)

Dinajpur, located in the northern part of Bangladesh, covers an area of 3,437.98 km². This region is a significant producer of litchi due to its favorable geographical location, soil conditions, and rainfall patterns. The district has an average elevation of 37 meters above sea level, which further supports litchi cultivation.

Data indicates that litchi production in Dinajpur has gradually increased over the years. In the 2017-2018 fiscal year, the production was 3,097 metric tons. Over the next five years, this figure continued to rise, demonstrating the growing importance of litchi cultivation in the region. This trend is illustrated in (Figure 1.2)

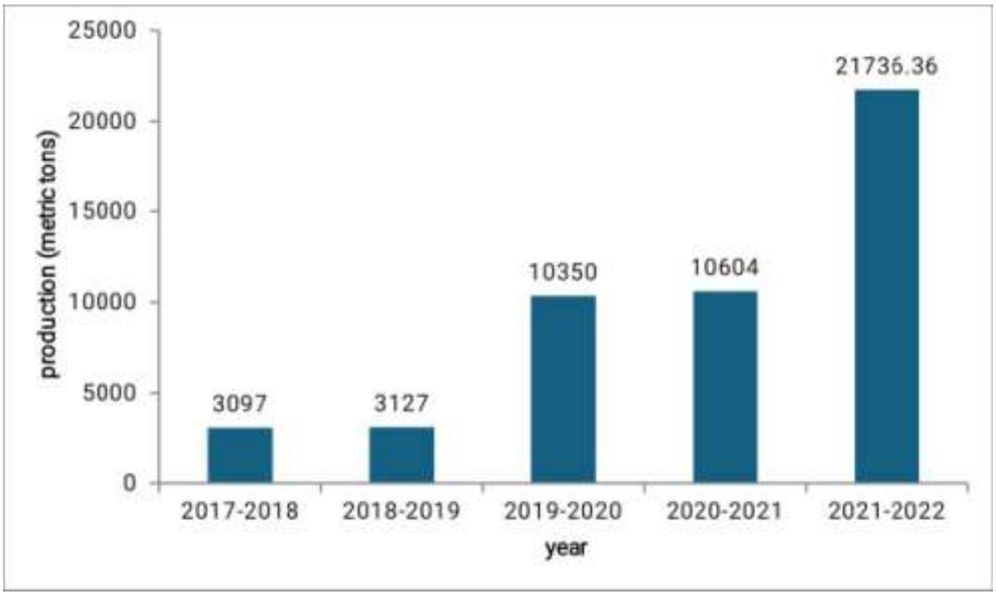


Figure 1.2: Annual litchi Production in Dinajpur (2017-2018 to 2021-2022)

(Source: Bangladesh Bureau of Statistics, 2022)

1.2 Post-harvest Losses of Litchi

In Bangladesh, post-harvest losses of litchis are estimated to be between 25-30% (TBS, 2023). These losses can occur due to various factors, including improper handling, transportation, storage, and environmental conditions.

Post-harvest losses often stem from physical damage during harvesting, inadequate packaging that leads to bruising and decay, temperature fluctuations that affect shelf life, and pest infestations. Mechanical injuries primarily happen during harvesting and transportation, processes that have not been adequately optimized. Litchi fruits, with their thin pericarp, delicate flesh, and high-water content, are prone to cell rupture, disruption, and separation due to collision and pressure (Chen et al., 2013).

Mechanical injury creates pathways for pathogenic bacteria to enter, accelerating fruit decay. Severely decayed litchi fruits lose their commercial value and must be discarded to prevent the spread of bacteria to other litchis. The impact of mechanical injury on the litchi pericarp has been extensively studied (Chen et al., 2013; 2013b). Apart from mechanical damage, litchi fruit decays very quickly after being harvested (Dharini et al., 2008). Despite advancements in preservation technologies that can partially slow the rate of decay (Khan et al., 2012) the rapid deterioration of litchi fruit after harvest continues to be a major challenger.

Improved living standards have increased demand for fresh food with extended storage times. Cold storage helps extend the shelf life of litchi fruit, resulting in less noticeable changes in its appearance, particularly during the early stages (Sai Xau et al., 2020).

Among the different pre-cooling techniques, evaporative cooling stands out as a straightforward, easy-to-use, and cost-effective method. This technique is affordable and can be easily implemented by farmers on their own farms. The aim of this study was to evaluate the effectiveness of evaporative cooling in reducing pericarp browning and preserving the postharvest quality of litchi fruits during storage (Shilpa et al., 2021).

A solar power storage system is a setup that stores the surplus energy generated by solar panels for later use. These systems are crucial for making solar energy available when the sun is not shining such as during the night or cloudy days.

Solar or photovoltaic (PV) cells generate electricity by directly converting sunlight. They can harness both direct and scattered solar radiation to produce electrical energy (Koberle et al., 2015). The process of converting solar energy into electricity through photovoltaic (PV) cells operate with efficiency ratings that range from 7% to 40% depending largely on the semiconductor material used in the cell construction (Makki et al., 2015). When sunlight strikes the cell, the energy causes electrons to be freed from their atoms, enabling them to flow through the material. This generate direct current (DC) electricity which is then converted into alternating current (AC) electricity by a power inverter, the from typically used for supplying power to supply line (Piciu et al., 2014)

Currently, two conventional methods are used for litchi quality detection: the sensory detection method (Alves et al., 2011) and the physicochemical detection method (Huang et al., 2016). The sensory detection method relies on human senses to evaluate qualities like pericarp color, flavor, and fragrance. In contrast, the physicochemical detection method measures the total soluble solid content, titratable acidity, and weight through chemical analysis or physical measurements. While the sensory detection method provides direct evaluations by humans, it is time-consuming, labor-intensive, and prone to human error. The physicochemical detection method, though objective and precise, is destructive, complex, and time-consuming. As a result, these traditional methods are inadequate for the evolving litchi industry.

Despite advances in machine vision (Xiong et al., 2011) and spectrum technologies (Xiong et al., 2018) that enable quick and intelligent detection of various agricultural products, they are ineffective in detecting the quality of stored litchi due to overlapping fruit during storage.

Indeed, the pericarp (outer layer) of litchi fruit is exceptionally delicate and highly perishable. Its shelf life under ambient conditions typically lasts no more than 24 to 72 hours, posing a challenge for storage and transportation. This necessitates the use of rapid cooling and specialized storage methods to maintain its quality and extend its shelf life (Kumar, 2000).

Litchi fruit cannot be kept for more than a few days at room temperature after harvest. One traditional technique for short-term storage is to place them in perforated plastic bags or containers and store them in a cool, dry place such as a refrigerator. This helps maintain their freshness and prolong their shelf life for a few days. Additionally, wrapping individual litchis in paper can help prevent bruising and spoilage.

Short-term storage of litchi is crucial for maintaining its freshness, flavor, and nutritional value. Proper short-term storage helps preserve freshness, retain flavor and texture, minimize post-harvest losses, maintain nutritional value, and extend market availability.

1.3 Research Objectives:

- To design and construct a low-cost solar-powered storage structure specifically for short-term storage of litchi fruits, focusing on enhancing their post-harvest shelf life and maintaining their quality.
- To assess the efficiency of the smart storage structure in reducing post-harvest losses of litchi fruits across various storage durations.

Chapter-II

REVIEW OF LITERATURE

Kaur et al. (2013) investigated the effects of ambient temperature and cold storage conditions on the size, weight, and volume of litchi fruits using eight different treatments. The treatments included Chitosan (1%), Ascorbic Acid (5% and 10%), Citric Acid (10% and 15%), and Oxalic Acid (5% and 10%). The study evaluated changes in fruit size, weight, volume, and chemical properties on the 1st, 3rd, 5th, and 7th days at room temperature. After seven days, untreated fruits spoiled, while the 1% chitosan treatment was most effective in slowing the decrease in fruit size, weight, and volume. Additionally, fruits treated with 5% oxalic acid had the highest total soluble solids (TSS), and those treated with 10% oxalic acid had the highest total sugar content. These findings suggest that 1% chitosan treatment could be a viable method to extend the shelf life of litchi fruits.

Kumar et al. (2017) focused on the issues related to the dryness and cracking of the outer layer of litchi fruits due to poor post-harvest handling practices. Cracking, which can occur before and during fruit growth, allows harmful microorganisms to enter the fruit during storage and transportation, especially at low temperatures. They highlighted that the drying and browning of the outer skin affect both the appearance and taste of the fruit. To mitigate these issues, they suggested the use of sulfur dioxide (SO2) during storage and transportation to maintain fruit quality and prevent browning.

Reshi et al. (2013) examined the impact of different post-harvest treatments on the quality of litchi fruits, focusing on water loss, browning, and the role of calcium in fruit aging. Storage experiments at (32 ± 3) °C over ten days revealed a steady decline in weight loss, acidity, and ascorbic acid, with an initial increase followed by a decrease in total soluble solids. Specifically, weight loss decreased from 1.33% to 5.08%, acidity from 0.41% to 0.22%, and ascorbic acid from 42.64 to 25.71 mg/100mL over ten days. Total soluble solids initially increased from 20.17 Brix to 26.64 Brix (up to six days) before decreasing to 17.06 Brix (up to ten days). The study also found that calcium treatments helped to prolong shelf life by preserving fruit firmness and reducing respiration rate, tissue breakdown, and disease occurrence, while sulfur treatments helped maintain overall fruit quality.

Sharmin et al. (2020) investigated the shelf life and quality of litchi fruits using various treatments, including calcium chloride, oxalic acid (2mM) + bavistin (0.05%) + ice, ice treatment alone, ice + oxalic acid (2mM), clean water wash, and a control group (no treatment). Treated litchi fruits showed significant improvements in delaying spoilage, extending shelf life, maintaining firmness, reducing pericarp browning, and preserving TSS, titratable acidity, vitamin E content, and pit quality compared to the control group. Notably, the combination of oxalic acid (2mM) + bavistin (0.05%) treatment, along with low-density polyethylene (LDPE) packaging at ambient temperature, exhibited the lowest rate of weight loss and disease incidence. These chemical treatments effectively extended the shelf life of litchi fruits while maintaining their nutritional quality.

Mahmood et al. (2017) investigated the effects of different storage conditions on litchie fruits. Fruits stored in open conditions rapidly lost weight and became unmarketable within three days due to pericarp browning. In contrast, those stored in polyethylene bags experienced reduced weight loss and retained their pericarp color better. However, decay symptoms appeared in fruits stored at ambient temperatures, regardless of being in polyethylene bags or bamboo baskets lined with litchi leaves. No decay symptoms were observed in fruits stored at 5°C, highlighting the importance of low-temperature storage.

Kumar et al. (2020) explored the use of a Chitosan: Pullulan blend antimicrobial edible coating to improve the storage life and quality of litchi fruits. This coating regulated total soluble solids (TSS) and total acidity (TA), decreased pH, phenolic content, flavonoid content, and antioxidant activity, thus extending the shelf life of the fruits. The application of this edible coating showed potential commercial applications for the primary and minimal processing of fruits and vegetables, maintaining their quality during storage.

Kaushik et al. (2014) studied the impact of high-pressure processing on the 'Bombai' variety of litchi fruits during refrigerated storage. This method increased color difference and soluble solids, decreased pH, reduced microbial counts, and extended the shelf life up to 32 days, compared to 12 days for untreated fruits stored at 5°C. This suggests that high-pressure processing can effectively prolong the shelf life of litchi fruits.

Deng et al. (2018) evaluated changes in phenolic profiles and antioxidant activity of litchi pericarp during storage at 4°C for seven days and at room temperature for 72 hours. The results indicated that storage at 4°C preserved more phenolics and retained higher antioxidant activity compared to room temperature storage, making it a more effective method for maintaining litchi pericarp quality.

Devi (2018) found that a treatment involving a 10-minute dip in HNO3 (1.5%) followed by a 15-minute dip in $CaCl_2$ (2%) resulted in the highest sensory scores and successfully increased the shelf life of litchi fruits. This treatment was effective in preserving the sensory qualities and extending the fruit's shelf life.

Talukder et al. (2020) compared treated and untreated litchi fruits and found that storing litchie in 75 µm polypropylene bags at 4°C provided the best storage performance. Fruits stored under these conditions had the longest shelf life (23.67 days), significantly outperforming untreated fruits, which lasted only three days. This study concluded that using 75 µm polypropylene bags at low temperatures is the best approach for extending litchi shelf life without compromising fruit quality.

Mphahlele et al. (2020) discovered that litchi fruits could be effectively maintained for up to nine days without decay in non-perforated and 1.1 mm perforated clamshell trays. The study involved storing Mauritius litchi fruits in clamshell trays with various perforation sizes at 1°C for 15 days, followed by two days at 12°C for shelf study. This storage method proved effective in preserving fruit quality.

Shen et al. (2024) reported that applying alginate oligosaccharides to litchi fruits resulted in improved color retention, reduced water loss, maintained hardness, and lower rates of mold infection compared to untreated fruits. This treatment shows promise for enhancing the post-harvest quality of litchi fruits. Kumar et al. (2024) found that a combination of methionine (0.1%), cysteine (0.1%), EDTA (0.1%), oxaloacetic acid (1%), ascorbic acid (1%), citric acid (1%), and potassium metabisulfide (0.5%) effectively reduced weight loss and preserved sensory attributes in litchie fruits. This combination of treatments offers a comprehensive approach to maintaining fruit quality during storage.

Javed et al. (2023) demonstrated that litchi fruits treated with VTSB exhibited lower levels of browning degree (BD), browning index (BI), weight loss, soluble quinone (SQ), relative electrolyte leakage (REL), and malondialdehyde (MDA) compared to untreated control fruits. These findings suggest that VTSB treatment can significantly enhance the post-harvest quality of litchi fruits. Khanal et al. (2023) investigated the effects of different concentrations of potassium metabisulfite and Bavistin on litchi fruits stored at ambient conditions. They found that specific concentrations resulted in minimal decay loss, lowest physiological weight loss (PLW), highest total soluble solids (TSS), and maximum ascorbic acid levels, indicating these treatments' effectiveness in maintaining litchi quality during storage.

Hayat et al. (2024) studied the effects of different acid treatments on litchi fruits. They found that a treatment with 1.5% nitric acid, 3% oxalic acid, and 3% ascorbic acid, followed by storage at 4±1°C for 12 days, significantly reduced pericarp browning and increased antioxidant activity. This treatment also enhanced catalase and superoxide dismutase activities, indicating improved preservation of fruit quality. Fang et al. (2024) examined the effects of treating litchi fruits with WSP. The treatment resulted in higher L value, increased total anthocyanin content, greater pericarp water content, and a thicker pericarp. It effectively suppressed electrolyte leakage and maintained higher ascorbic acid content in the aril. Additionally, WSP treatment reduced the activity and expression of browning-related genes, suggesting it as an effective method to delay pericarp browning and maintain litchi fruit quality.

Kapilan et al. (2023) provided a comprehensive review of evaporative cooling systems, examining their design, operation, and application. They highlighted the significance of evaporative cooling in preserving perishable products, including fruits like litchi (Figure 2.1)

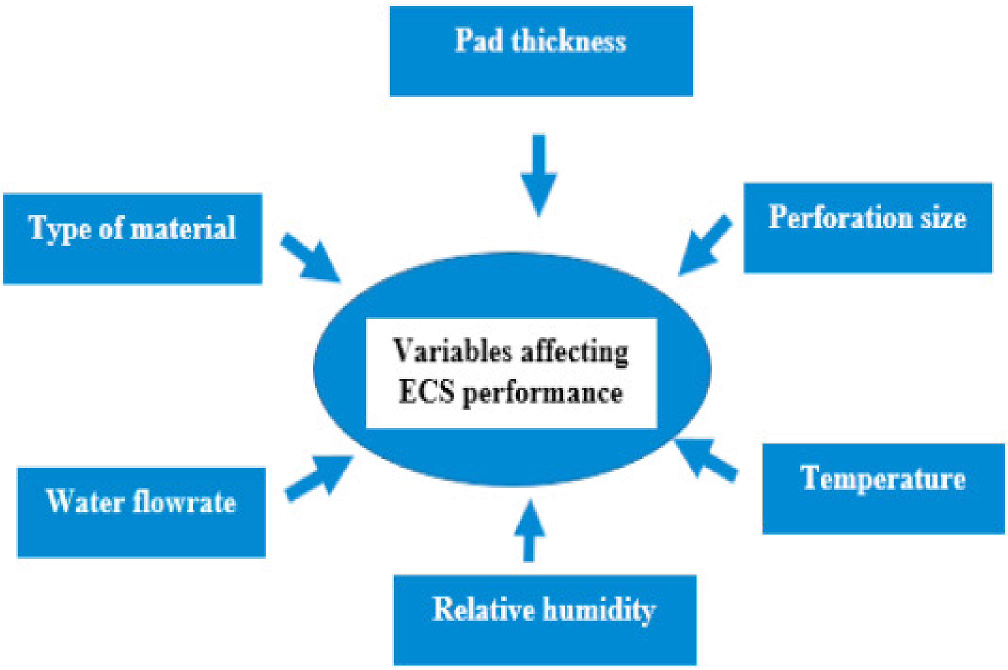


Figure 2.1: Important variables affecting ECS performance (Adapted from Kaplilan, 2023).

Shilpa et al. (2021) investigated the effects of evaporative cooling (EC) on litchi fruits. Storing litchi fruits in corrugated fiberboard boxes at 2-3°C and 90-95% humidity, along with a 6-hour EC treatment, significantly reduced weight loss and maintained higher levels of firmness, total soluble solids (TSS), acidity, anthocyanins, and total phenols over a four-week period. EC exposure effectively minimized fruit browning for up to 14 days and decreased enzyme activities (PPO and POD), extending the storage life of litchi fruits compared to untreated ones.

Huang et al. (2023) developed and tested a new spray hydrocooler with thermal energy storage (TES). They employed a mathematical model to determine TES capacity and hydrocooler parameters, and then proceeded with structural design and testing. Results demonstrated rapid precooling of litchis within 15 minutes, handling of 299 kg of litchis with one-third TES storage, and effective TES capacity with an energy efficiency ratio of 2. Optimal performance was achieved with specific litchi load and spray flow rate.

Figure 2.2: Spray hydrocooler (Reprinted from Huang, 2023)

Fukuyama et al. (2023) investigated the optimal concentration of chitosan-water nanocomposite (CWN) for preserving litchi fruits. Treatments with 9% and 18% CWN significantly reduced weight loss compared to the control group while maintaining quality parameters such as L* value, pH, and total soluble solids (TSS%).

Sumi et al. (2021) treated litchi fruits with various solutions and evaluated their quality during storage. Fruits treated with 1% calcium nitrate and stored at 4°C exhibited the highest levels of ascorbic acid, fruit firmness, and the lowest acidity. Meanwhile, fruits treated with 1% calcium chloride and stored at 4°C maintained high levels of total soluble solids, total sugar, and significant anthocyanin content in the peel even after 8 days of storage. These findings highlight the potential of calcium nitrate and calcium chloride treatments in preserving litchi fruit quality during storage.

Y. Xu et al. (2018) conducted research on a solar photovoltaic-powered ice storage air conditioning system. They tested two operational models through experiments. The results indicated that ice thermal storage could effectively replace a battery bank for storing solar energy in the field of distributed photovoltaic refrigeration. Key findings from the experiments include that, during sunny days, the ice could fully replace the battery bank in the energy storage process for ice-based air conditioning systems driven by distributed photovoltaic energy. Additionally, the average energy utilization efficiency of the ice thermal storage air conditioning system in working mode was 0.0525. Over three days of experiments, from 8 AM to 5 PM, the average ice production was 52.56 kg, and the average ice thickness formed on the evaporator was 51.17 mm. The system demonstrated average refrigeration efficiencies of 79% and 69%. During the night cooling supply (from 7:30 PM to 11:30 PM), the average cooling supply efficiency was 75%. In the second operational mode, which involved continuous testing for 2 days, the system's average energy utilization efficiency was 33.7%, which was 5.62 times higher than the efficiency observed in the first mode."

Chapter-III

MATERIALS AND METHODS

3.1. Concept of the Solar Powered Storage System

The overall concept of the solar-powered storage system is illustrated in Figure 3.1. Comprising three key units, namely a storage unit, a cooling system, and a controller unit, this system aims to provide an efficient solution for preserving litchi fruits post-harvest.

The cooling unit was assembled with components including a cooling pad, cooling fan, pump, and tank. In operation, hot air was drawn into the cooling pad while water from the tank was circulated via a pump, maintaining a cooler temperature within the unit. The cooling fan facilitated the conversion of hot air to cool air, which was then directed into the storage unit.

Solar panels integrated into the structure's roof served as the primary power source, harnessing solar energy to drive the system. To regulate and monitor the entire process, a controller unit equipped with sensors was employed. The dimensions of the complete storage structure were standardized to a length of 4 feet 6 inches, a height of 5 feet, and a width of 3 feet, ensuring practicality and scalability for implementation.

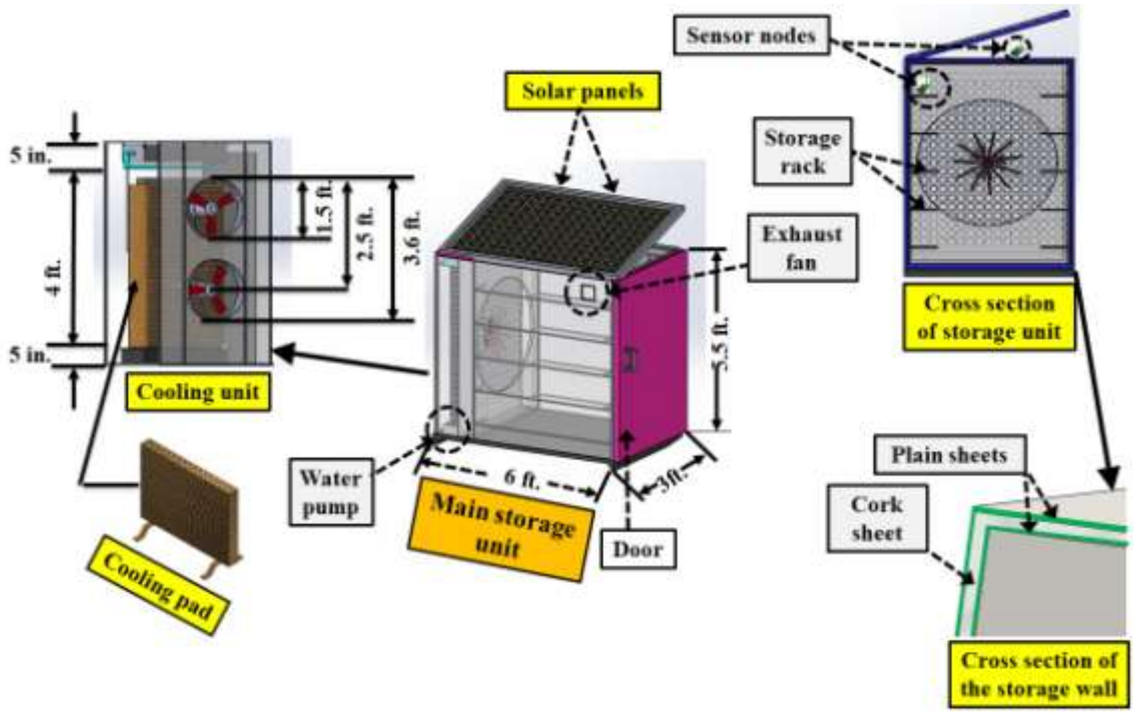


Figure 3.1: Design and overall concept of the proposed solar powered evaporative cooling storage system.

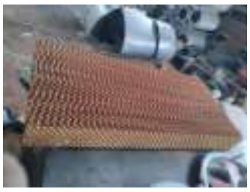
3.2. Materials Used in the Research

The design and construction of a solar-powered storage system necessitate a diverse array of materials to assemble various components, encompassing the solar power system, the cooling mechanism, and control features. For the fabrication of the cooling unit, essential components such as a cooling fan, cooling pad, and motor were utilized to ensure efficient heat dissipation and temperature regulation. Additionally, other materials essential for the assembly and operation of the cooling unit were carefully selected and procured.

Critical to the functionality of the system were the sensors employed for environmental monitoring within the storage unit. Temperature and humidity sensors were employed to track variations in environmental conditions, while an ethylene sensor was incorporated to detect ethylene gas levels, a vital indicator of fruit ripening and potential spoilage.

A comprehensive inventory detailing all materials utilized in the design and implementation of the solar-powered smart storage system was compiled. This inventory provides a transparent and systematic overview of the specifications and quantities of each component, facilitating replication and further research in this field.

Table 3.1. List of materials with specifications for the solar-powered storage system.

Sl no	Materials	Specifications	Figure
1.	Structural chassis	Length 4 feet 6-inch, Height 5 feet, width 3 feet	
2.	Cooling pad arrangement with upper container and lower container	Height 48-inch, length 34 inch, width 3 inch	
3.	Cooling fan	Size 18 inch	

4.	Exhaust fan	Model EX- 06, Input 220V, 50 Hz power : 28 W, size 6 inch	
5.	Solar panel	Model RS -M 150, Maximum power 150 W, Minimum power current 7.42 A	
6.	Pump	Voltage DC 12 V, Power 8W, H. Max 5m, Flow 10 L/min	
7.	C_2H_4 sensor	Model C_2H_4 - SM30, Measurement range: 0~10 ppm,0~100 ppm,0~1000 ppm, Accuracy: <+- 3% F. S	
8.	CO_2 sensor	Size (W) 40 mm× (H) 36 mm × (D) 11.7 mm, weight 12 g, Measuring range 0~ 3000/5000 ppm, Power input DC 5 V- 9V	
9.	Temperature and humidity sensor	Model AM2315C, living room temperature 15.6°C, Living Room humidity 63%	
10.	Microcontroller	Brand Raspberry pi, Model 3577	

11.	Wifi Module	Model ESP8266	
12.	Tank	Height 5 m, length 26 m, Width 7m	
13.	Shelf	length 3 feet, width 11 inch	
14.	Refractometer	Accuracy +- 0.5 %	
15.	Adapter	Model PA -1061-0, INPUT 100-240 V ~ 50 -60, OUTPUT:12V-5.0A	
16.	Penetrometer	Model EN ISO 14488	
17.	Basket	Width 11-inch, Length 15.5-inch, Height 7.5 inch	
18.	Weight Balance	MODEL - JJ3000A, Capacity 3000g	

19.	Battery	Horsepower Model -215, ECO power model-220	
20.	PH meter	Brand JENCO, Model-6177M	
21.	Slide Caliper	Wiika vernier caliper 150 mm (6 inch), WA-VC 1150 slide Caliper	
22.	Plane sheet	Length 4 feet 6-inch, width 5 feet, Height 3 feet	
23.	Solar charge controller	Model 2430 C Amp: 30 A Volt: 12 V/ 24 V	
24.	Jumper wire	Male to Male Jumper Wires 20 Pin 20 cm and Female to Female Jumper Wires 40 Pin 30 cm	
25.	Cork sheet	Length 4 feet 6-inch, width 5 feet, Height 3 feet	
26.	Bread board	Plastic Parts Materials ABS Distribution Holes. 200 and Terminal Holes 630	
27.	LCD Display	IC Chip PCF8574 Input Voltage Range (VDC) 5	

3.3 Construction of the Storage Structure

The storage structure was meticulously constructed within the engineering workshop located in Uttaron Engineering, Dinajpur, utilizing an iron frame for robustness and durability. It comprises three primary sections: the cooler unit, storage unit, and controller. The cooler unit was outfitted with two 18-inch cooling fans, a cooling pad, motor, and a water container to facilitate effective temperature regulation. Additionally, an exhaust fan was installed on the side of the unit to enhance airflow and ventilation.

Within the storage unit, an iron rack was incorporated to accommodate the litchi fruits, with plastic baskets installed within the rack. Each basket measured 15.5 inches in length, 7.5 inches in height, and 11 inches in width, with a total of 12 baskets distributed across six racks. With each basket capable of holding 150 litchis, the entire storage unit could accommodate a total of 1800 litchis.

The controller section of the structure was integrated with various sensors to monitor and maintain environmental conditions critical for preserving the quality of the stored litchi fruits. Illustrations detailing the construction of the storage structure are presented in Figures 3.2, 3.3, 3.4, and 3.5. The storage itself is covered by a plane sheet and three layers of plane sheet, with a cork sheet sandwiched between them to provide insulation and protection.

Figure 3.2: The structural chassis

Figure 3.3: The structure covered by plane sheet.

Moreover, the backside of the structure houses the cooler unit, ensuring efficient heat dissipation and temperature control. Two exhaust fans were used on both sides of the storage structure.

Figure 3.4: The inside part of the litchi storage structure

Figure 3.5: The back side of the structure

3.4 Solar Power System

Two solar panel was used, and the capacity of single solar panel was 150 W at 15 V. The system operated using two 12V batteries with the assistance of a solar charge inverter controller. 12V DC current was converted to 220V AC.

When the solar panel is exposed to sunlight, the photovoltaic (PV) cells within the panel absorb the solar energy. Subsequently, this absorbed energy induces the generation of electrical charges within the cells. These charges, in turn, respond to an internal electrical field within the cell, thereby facilitating the flow of electricity. Electrical load comprises all the electrical equipment used in the litchi storage facility, such as the refrigeration unit, lighting, and control unit.

Figure 3.6: Solar Power supply system.

3.5 Experimental Procedure

3.5.1. Sample collection

Fresh litchi fruits were procured from Mashimpur Farm located in Dinajpur Sadar. Upon collection, the fruits underwent pre-cooling under tree shade to mitigate post-harvest heat stress. Subsequently, the fruits were meticulously sorted and graded, with only mature and disease-free Bombai litchis being selected for storage.

3.5.2 Storage technique

The selected litchi samples were allocated to four distinct storage systems to evaluate their effectiveness in preserving fruit quality:

(a) Open bamboo basket: Litchis were stored in traditional bamboo baskets to represent a common storage method used in local practice and placed nearly the evaporative cooling storage (Figure 3.7).

Figure 3.7: Litchi stored in bamboo basket.

(b) Open plastic basket: Litchis were stored in open plastic baskets as an alternative storage approach and placed nearly the evaporative cooling storage. The air passed through the system (Figure 3.8).

Figure 3.8: Litchi stored in open plastic basket.

(c) Refrigeration poly bag: Litchis were stored in refrigeration poly bags to simulate controlled temperature storage conditions (Figure 3.9).

Figure 3.9: Litchi stored in refrigeration poly bag.

(d) Evaporative cooling storage system: Another batch of litchis was stored in the developed evaporative cooling storage system designed specifically for short-term storage. This system was situated at garden in the open environment, where the litchis were placed on the shelves within the structure (Figure 3.10). In evaporative cooling storage system was used 12 basket and single basket accommated 50 Litchis.

Each storage system accommodated 50 litchi samples, ensuring consistency and comparability across experimental conditions.

Figure 3.10: Litchi stored in developed storage structure.

3.6. Evaluation of the Storage Systems

The condition of the litchis in each storage system was systematically evaluated by monitoring various quality parameters and measuring losses over time.

3.6.1 Evaluation process

The assessment involved periodic evaluations at 2-day intervals to track changes and measure losses in the stored litchi samples. Data collection was conducted methodically to ensure comprehensive recording of the following quality parameters:

- Temperature: Recorded to monitor the thermal conditions affecting fruit storage.
- Humidity: Measured to assess moisture levels within the storage environment.
- Firmness: Evaluated as an indicator of fruit texture and structural integrity.
- pH: Analyzed to understand the acidity levels affecting fruit quality.
- Total Soluble Solids (TSS): Measured to determine the fruit's sugar content and sweetness.
- CO_2 and C_2H_4 Levels: Monitored to gauge respiratory activity and ethylene production, influencing fruit ripening and senescence.
- Physiological Loss in Weight (PLW): Quantified to assess the natural moisture loss of the fruits during storage.

3.6.2 Data Collection

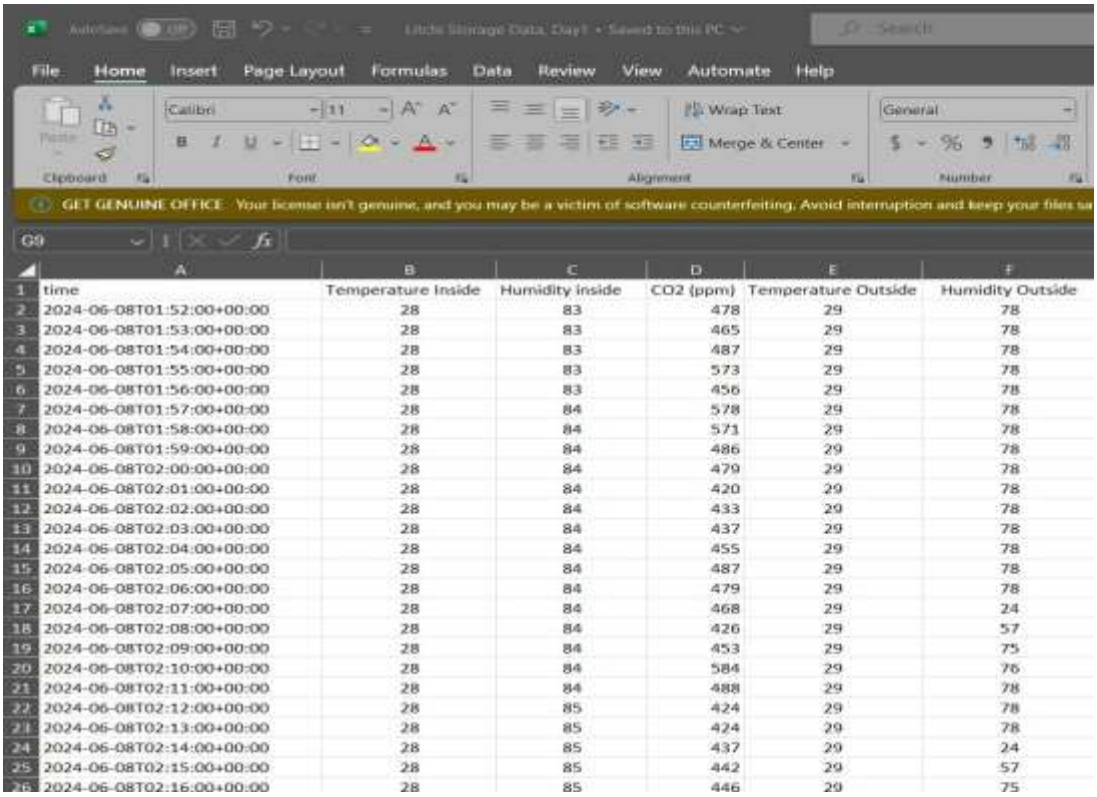
Data on these parameters was collected diligently at each interval to capture changes over the storage duration and to facilitate comparative analysis between different storage systems. This systematic approach ensured robust evaluation of the efficacy of each storage method in maintaining litchi quality and minimizing losses.

3.7 Monitoring of Ambient Conditions

3.7.1 Software setup

The software setup for monitoring the litchi storage conditions involved the use of specific applications and programming environments. Arduino IDE was installed for programming the microcontrollers (Arduino UNO R3) used in the sensor nodes. ThingSpeak Web Server was utilized for storing and analyzing the data collected from the sensors deployed in the litchi storage structure. ThingView App was used for real-time visualization of the litchi storage conditions, enabling remote monitoring.

Figure 3.10: Snapshot of the ThingSpeak webserver



	A	B	C	D	E	F
1	time	Temperature Inside	Humidity inside	CO2 (ppm)	Temperature Outside	Humidity Outside
2	2024-06-08T01:52:00+00:00	28	83	478	29	78
3	2024-06-08T01:53:00+00:00	28	83	465	29	78
4	2024-06-08T01:54:00+00:00	28	83	487	29	78
5	2024-06-08T01:55:00+00:00	28	83	573	29	78
6	2024-06-08T01:56:00+00:00	28	83	456	29	78
7	2024-06-08T01:57:00+00:00	28	84	578	29	78
8	2024-06-08T01:58:00+00:00	28	84	571	29	78
9	2024-06-08T01:59:00+00:00	28	84	486	29	78
10	2024-06-08T02:00:00+00:00	28	84	479	29	78
11	2024-06-08T02:01:00+00:00	28	84	420	29	78
12	2024-06-08T02:02:00+00:00	28	84	433	29	78
13	2024-06-08T02:03:00+00:00	28	84	437	29	78
14	2024-06-08T02:04:00+00:00	28	84	455	29	78
15	2024-06-08T02:05:00+00:00	28	84	487	29	78
16	2024-06-08T02:06:00+00:00	28	84	479	29	78
17	2024-06-08T02:07:00+00:00	28	84	468	29	24
18	2024-06-08T02:08:00+00:00	28	84	426	29	57
19	2024-06-08T02:09:00+00:00	28	84	453	29	75
20	2024-06-08T02:10:00+00:00	28	84	584	29	76
21	2024-06-08T02:11:00+00:00	28	84	488	29	78
22	2024-06-08T02:12:00+00:00	28	85	424	29	78
23	2024-06-08T02:13:00+00:00	28	85	424	29	78
24	2024-06-08T02:14:00+00:00	28	85	437	29	24
25	2024-06-08T02:15:00+00:00	28	85	442	29	57
26	2024-06-08T02:16:00+00:00	28	85	446	29	75

Figure 3.11: Snapshot of data process

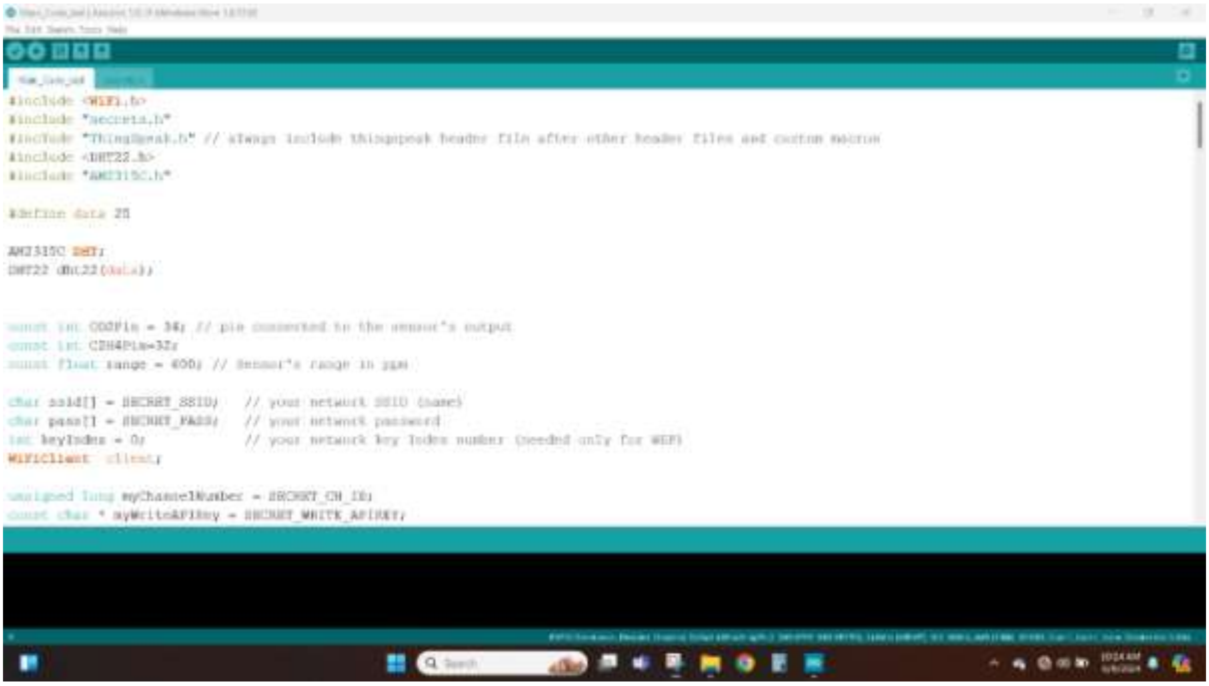


Figure 3.12: Snapshot of Arduino Program

3.7.2 Hardware setup

The hardware setup comprised sophisticated components to ensure accurate data acquisition and remote monitoring capabilities. Inside sensor node composed of micro controller: (Arduino Uno R3), sensors (DHT-22 (humidity and temperature), CO_2 sensor, C_2H_4 (ethylene) sensor), communication Modules (SX1278 LoRa module, ESP8266 Wi-Fi module), and Power Supply (9V battery). Outside sensor node composed of micro controller (Arduino Uno R3), sensors (DHT-22 (humidity and temperature), CO_2 sensor, communication Modules (SX1278 LoRa module) and power supply (9V battery).

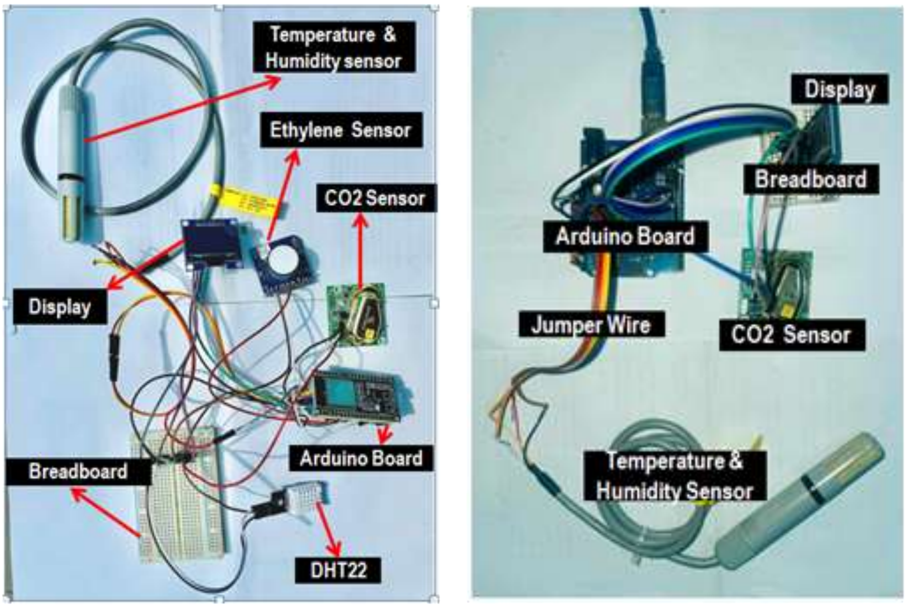


Figure 3.13: Hardware setup of real-time storage monitoring system.

3.8 Data Acquisition

The sensor nodes were strategically installed within the litchi storage structure to monitor critical environmental parameters essential for preserving fruit quality of temperature and humidity sensor was used for monitoring ambient conditions crucial for litchi storage. CO_2 sensor was used for monitoring carbon dioxide levels inside the storage conditions. C_2H_4 sensor was employed to detect the ethylene gas levels.

The data collected by the sensors were processed by the micro controllers (Arduino Uno R3) within each sensor node. The Arduino boards transmitted the collected data to the cloud storage via the ESP8266 Wi-Fi module. From the cloud storage, the data was accessible via the ThingSpeak application, allowing farmers to remotely monitor and manage their litchi storage conditions in real-time.

This setup not only facilitated effective monitoring of storage parameters but also provided insights to optimize storage conditions, thereby extending the shelf life of litchis and reducing postharvest losses. Figure 3.14 illustrates the comprehensive process of data acquisition and remote monitoring implemented in the proposed system.

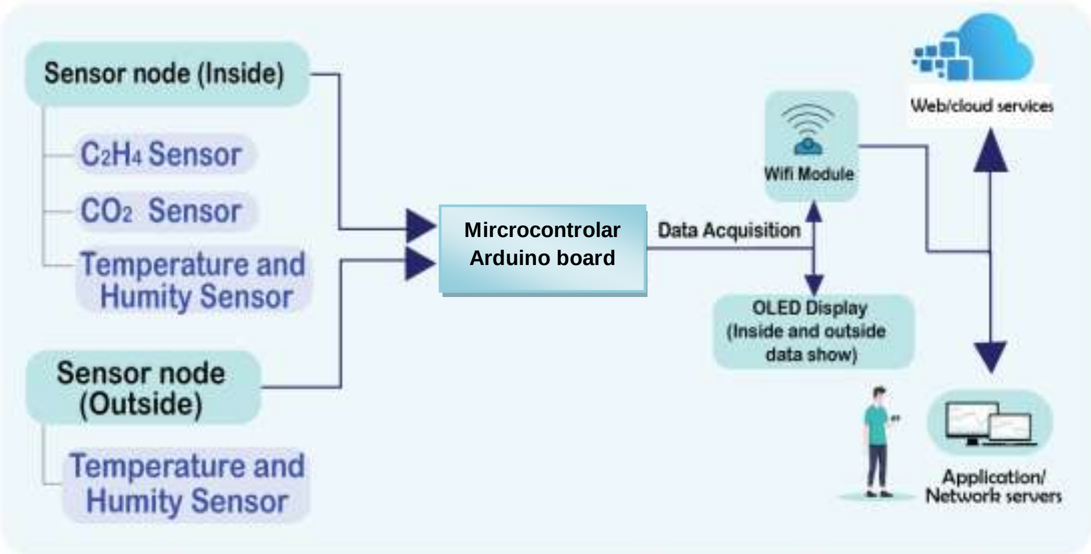


Figure 3.14: Block diagram of data acquisition

3.9 Evaluation of Post-Harvest Quality Parameters

In this study, several key parameters were assessed to evaluate the quality and physiological changes of litchi fruits during storage:

- Fruit size measurement: The diameter and height of each litchi fruit sample were measured using slide calipers. The fruit size was then calculated as the product of diameter and height.

Figure 3.15: Measurement of fruit size.

- Weight loss (%): Periodic measurements of litchi fruit weight, including any damaged fruits, were conducted using a digital electronic balance. Weight loss was calculated as a percentage of the original weight using the formula as described by Kuruba (2007).

$$\% \text{ Weight loss} = \frac{\text{Initial weight of fruit (g)} - \text{Final weight of fruit (g)}}{\text{Initial weight of fruit (g)}} \times 100$$

- Firmness (Kg/cm^2): The firmness of the fruit was assessed using a penetrometer (HANDPI, China), which measured the force required to penetrate the fruit's surface.

Figure 3.16: Measurement of firmness

- Total soluble solids (% Brix): The total soluble solids (TSS), an indicator of fruit sweetness, were determined using a digital refractometer (Hanna Instruments, Romania).

Figure 3.17: Measurement of Total soluble solid

- Color (L*, a*, and b*)

The color of litchie fruits was assessed using a Colorimeter (Konica Minolta, CM 250d, Japan). This method quantifies color in terms of three coordinates: L* (lightness), a* (red-green axis), and b* (yellow-blue axis). Lightness (L*) indicates how light or dark the fruit surface is, with higher values representing lighter colors. The a* value represents the red-green spectrum, where positive values indicate redness and negative values indicate greenness. Similarly, the b* value represents the yellow-blue spectrum, with positive values indicating yellowness and negative values indicating blueness.

Measurements were taken on both sides of the fruit in the equatorial zone, with each measurement repeated twice to ensure accuracy (Figures 3.18).

Figure 3.18: Measurement of color parameters

Respiration and ethylene production: The respiration rate of the stored litchi fruits, measured as the amount of CO_2 evolved, and ethylene production were monitored. This assessment was conducted under different storage treatments using a closed system approach, following the methodology outlined by Caleb et al. (2012).

Chapter-IV

Results and Discussion

4.1. Monitoring of environmental parameter

4.1.1. Temperature, humidity conditions, and carbon dioxide concentration

Temperature and humidity significantly impact the storage and shelf life of litchis. Elevated temperatures can increase the respiration rate of the litchis, causing them to decay and have a reduced shelf life. This study tracked environmental conditions in these storage methods (Figure 4.1). The highest inside humidity was 86.36%, outside humidity was 76.48%, inside temperature was 27.42°C, outside temperature was 31.48° C.

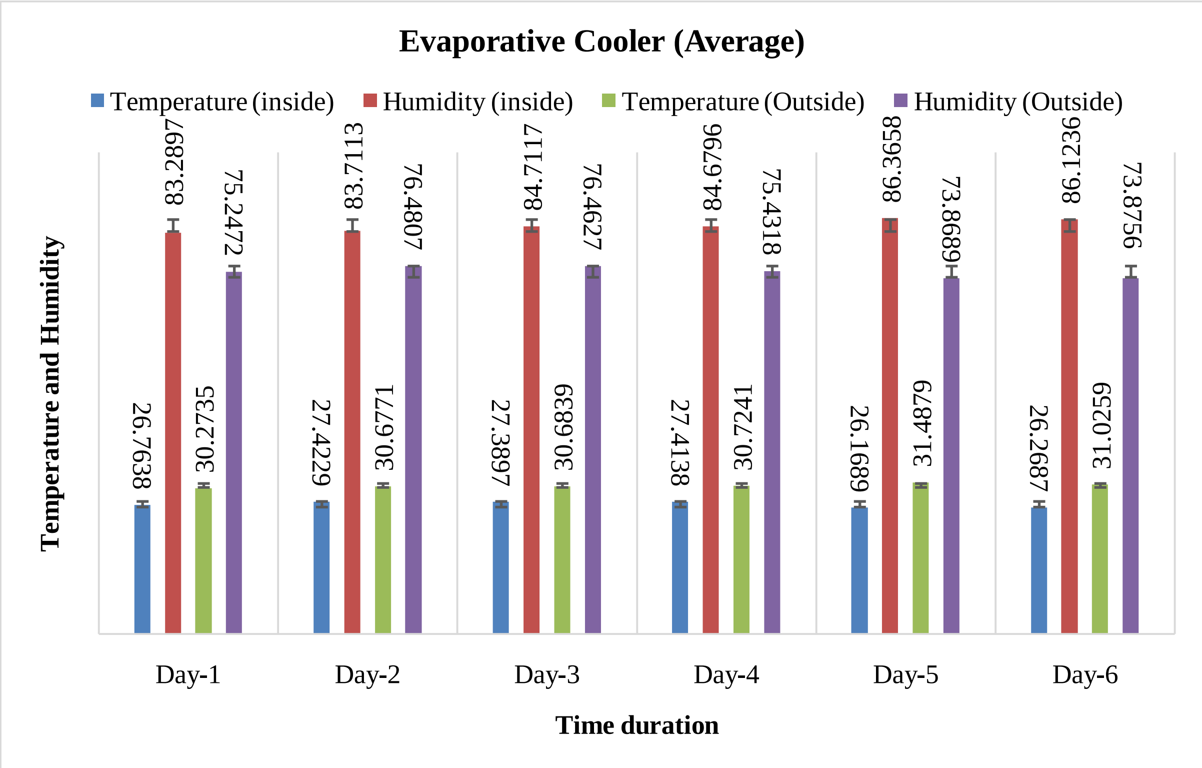


Figure 4.1: Changing in temperature and humidity with time.

4.1.2 C_2H_4 concentration in different storage condition

4.1.2.1 Open air (bamboo bin)

In the Bamboo Bin, there is a gradual increase in the concentration of C_2H_4. At certain points, the concentration experiences a decrease, while at other times it fluctuates randomly.

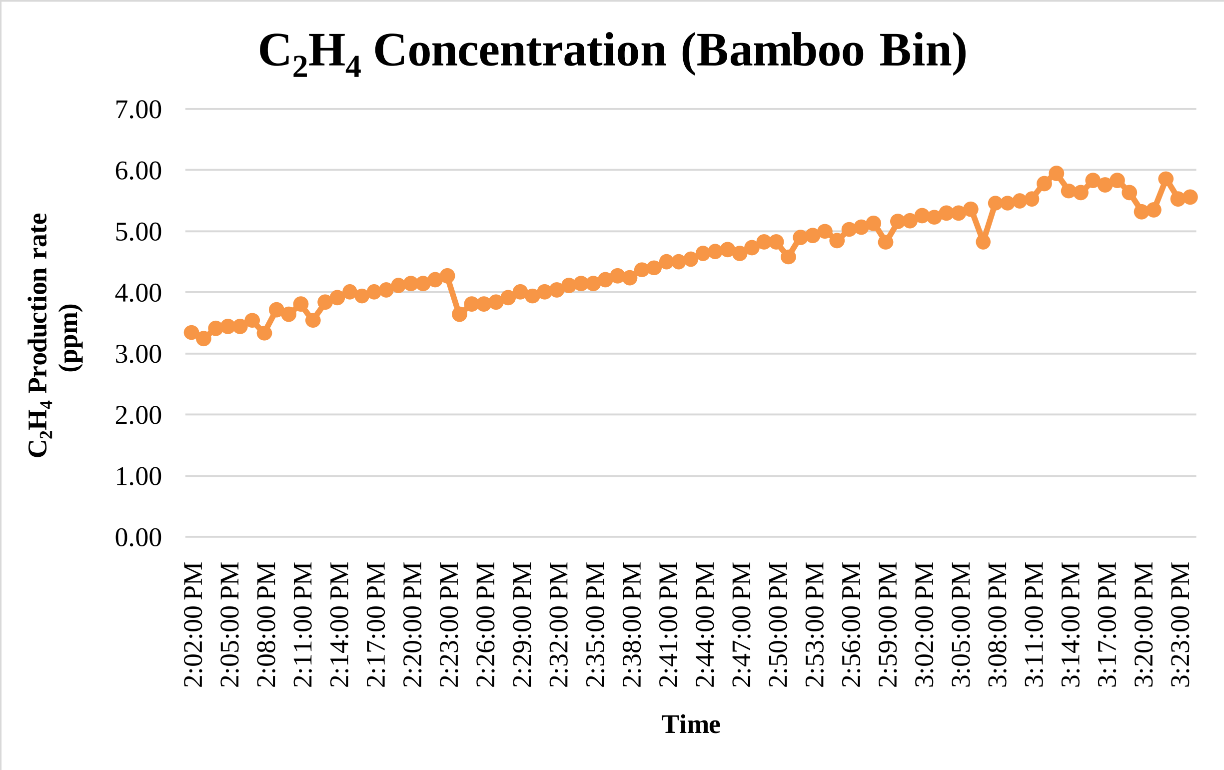


Figure 4.2: C_2H_4 Concentration (Bamboo Bin)

4.1.2 .1 Evaporative cooler

In the evaporative cooler, the C_2H_4 concentration gradually increases slightly. At some point, the concentration decreases, while at other times it remains constant.

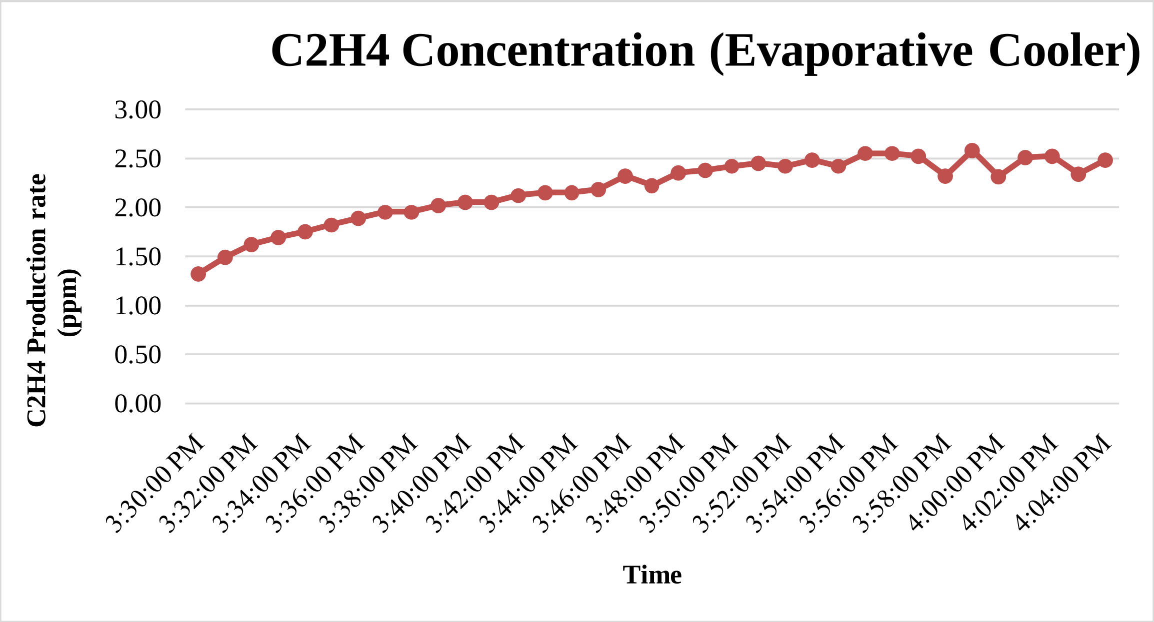


Figure 4.3: C_2H_4concentration (evaporative cooler)

4.1.2.1 Refrigeration

In the context of refrigeration, it is important to note that the concentration of C_2H_4 fluctuates within the range of 0.80 to 1.20 demonstrating a steady variance.

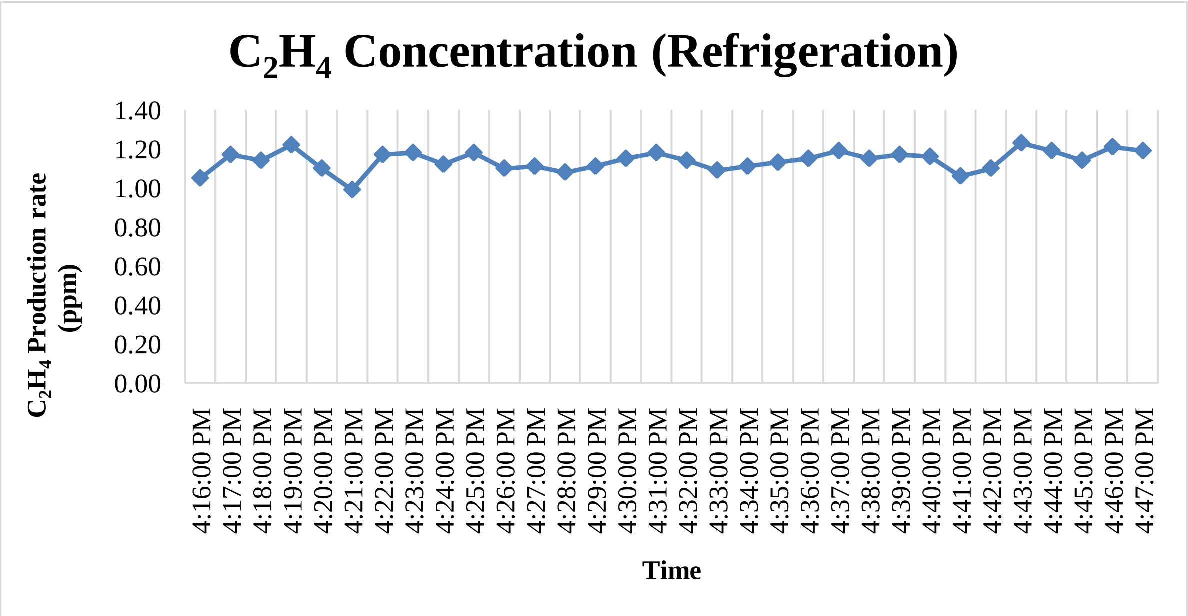


Figure 4.4: C_2H_4 concentration (refrigeration)

4.2 Post-harvest Quality Evaluation

Post-harvest quality parameters of litchi were evaluated from four storage conditions. Bombai litchi was evaluated with four storage system, each storage being composed of three litchis.

4.2.1 Physiological loss in Weight (PLW)

The percentage loss in weight (PLW) of litchi fruits increased as the storage period advanced. A statistically significant difference was noted among the various storage conditions. The highest PLW was observed in litchi fruits stored at ambient conditions, followed by those stored in open bamboo baskets. Water is the primary component of fruits and vegetables, so minimizing its loss is crucial for maintaining their postharvest quality attributes. Browning of the litchi fruit's pericarp is closely linked to dehydration (Molla 2017). The fruit stored at room temperature had lower relative humidity compared to those stored in refrigerators, resulting in a more noticeable increase in PLW rate and a rapid loss of the litchi fruit's bright red color. Therefore, storing litchi fruit at room temperature is not recommended due to the potential for excessive weight loss.

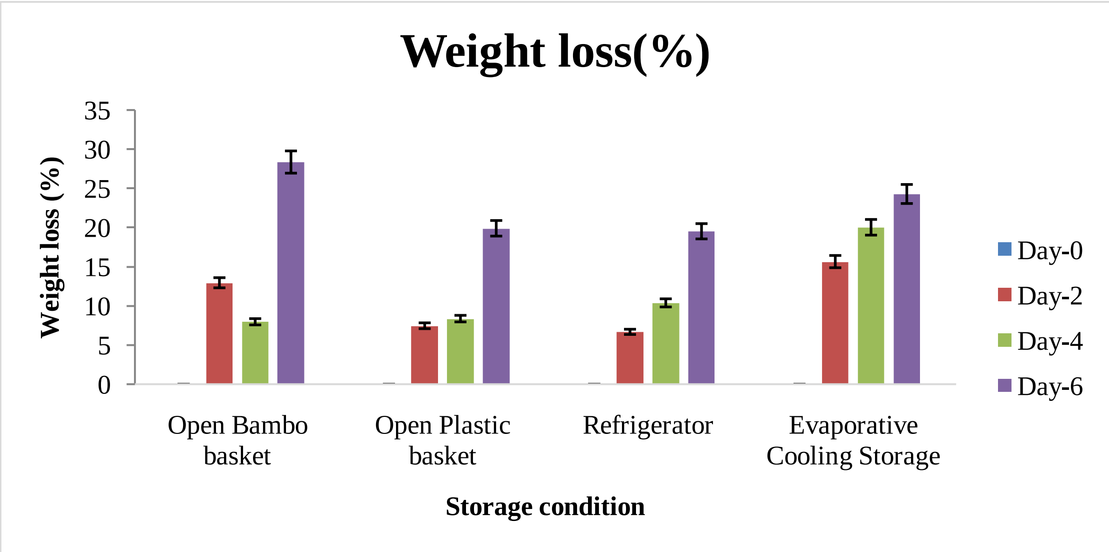


Figure 4.5: Weight loss (%) of Litchi

4.2.2 Firmness

The firmness range of evaporative cooling storage was 10 N to 15 N. The highest firmness value, 16.03 N was observed in the open plastic basket compared to other storage systems. Changing Firmness during storage period is shown in (Figure-4.6)

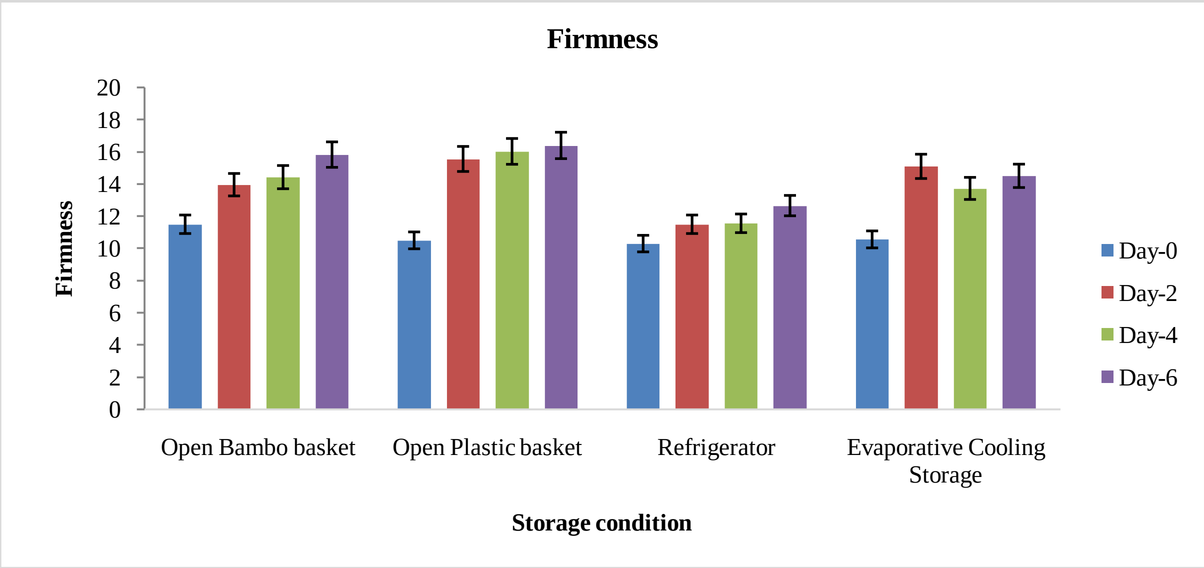


Figure 4.6: Firmness of Litchi

4.2.3. Total soluble solids (TSS)

The highest TSS value observed was 17.95% in the refrigerator-stored samples. The TSS value for the evaporative cooling storage was nearly the same, at 17%.Changing TSS during storage period is shown in (Figure 4.7)

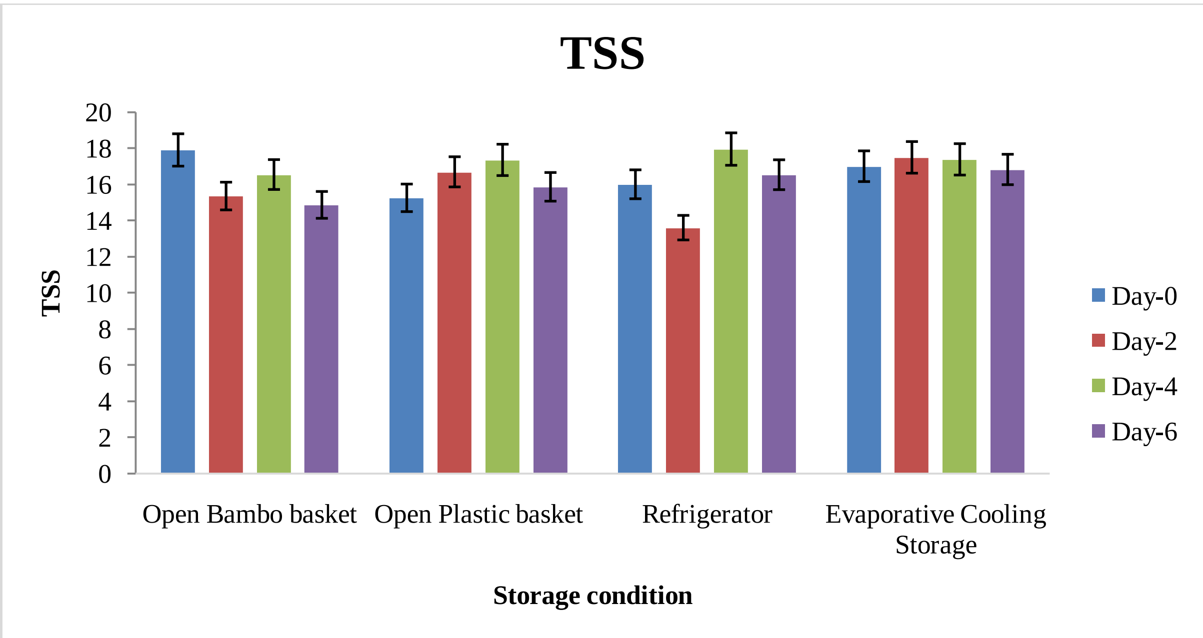


Figure: 4.7: Total Soluble Solids of Litchi

*4.2.4. Color (l*a*and b*)*

- Color (L*):

The highest lightness (L*) value recorded was 49, observed in the refrigerator storage method. This suggests that refrigeration effectively preserved the lightness of the litchi fruits, likely due to reduced enzymatic browning and slower degradation processes at lower temperatures.

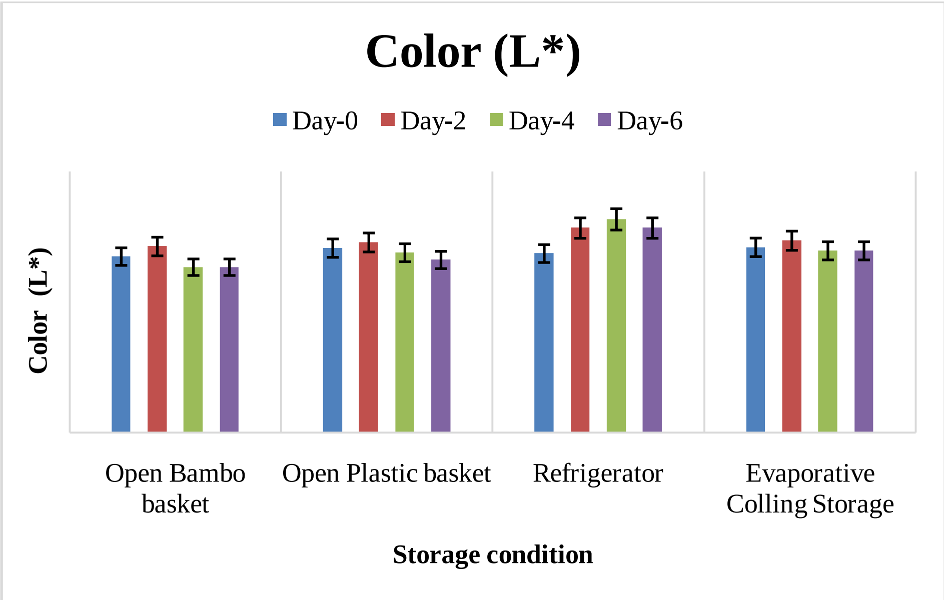


Figure 4.8: Color (L*) of Litchi

- Color (a*):

In terms of redness (a* value), the highest value recorded was 27.39 in the evaporative cooling storage method. This indicates that the evaporative cooling system was effective in maintaining the red pigmentation of the litchi fruits. The consistent high a* values suggest that the controlled environment of the evaporative cooling system mitigated the degradation of anthocyanins, which are responsible for the red color in litchis.

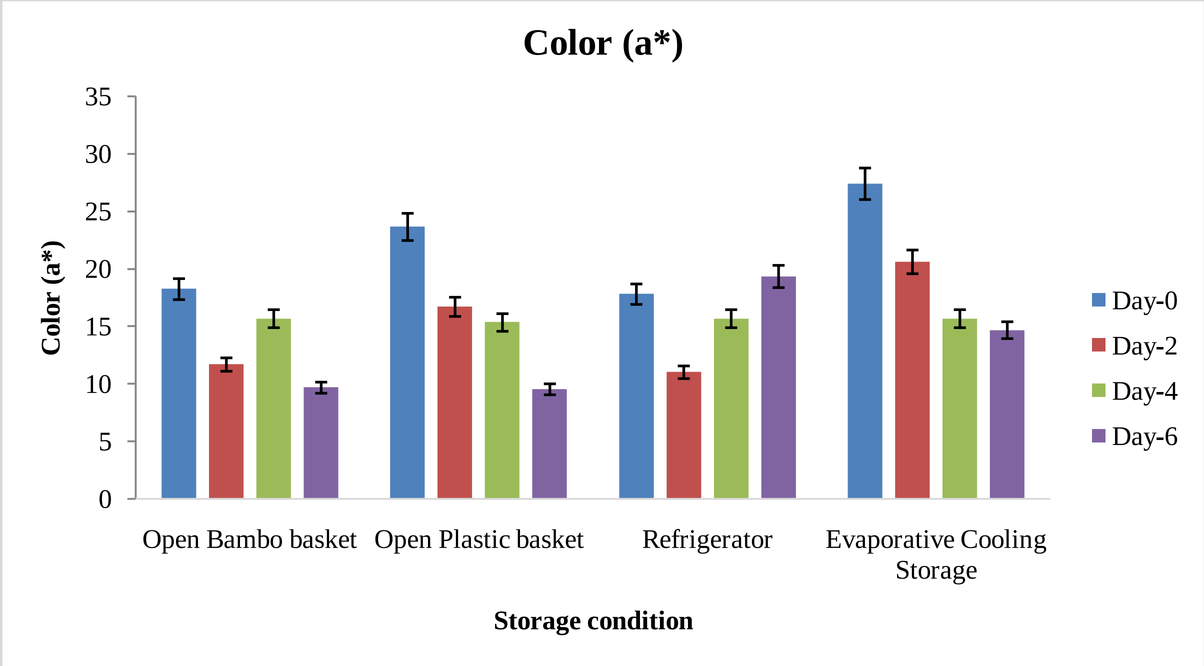


Figure 4.9: Color (a*) of Litchi

- Color (b*):

For the b* value, the highest recorded was 16.33, also observed in the refrigerator storage. This indicates a tendency towards a more yellow pigment in the refrigerated litchis, which could be attributed to the preservation of carotenoids and other yellow pigments.

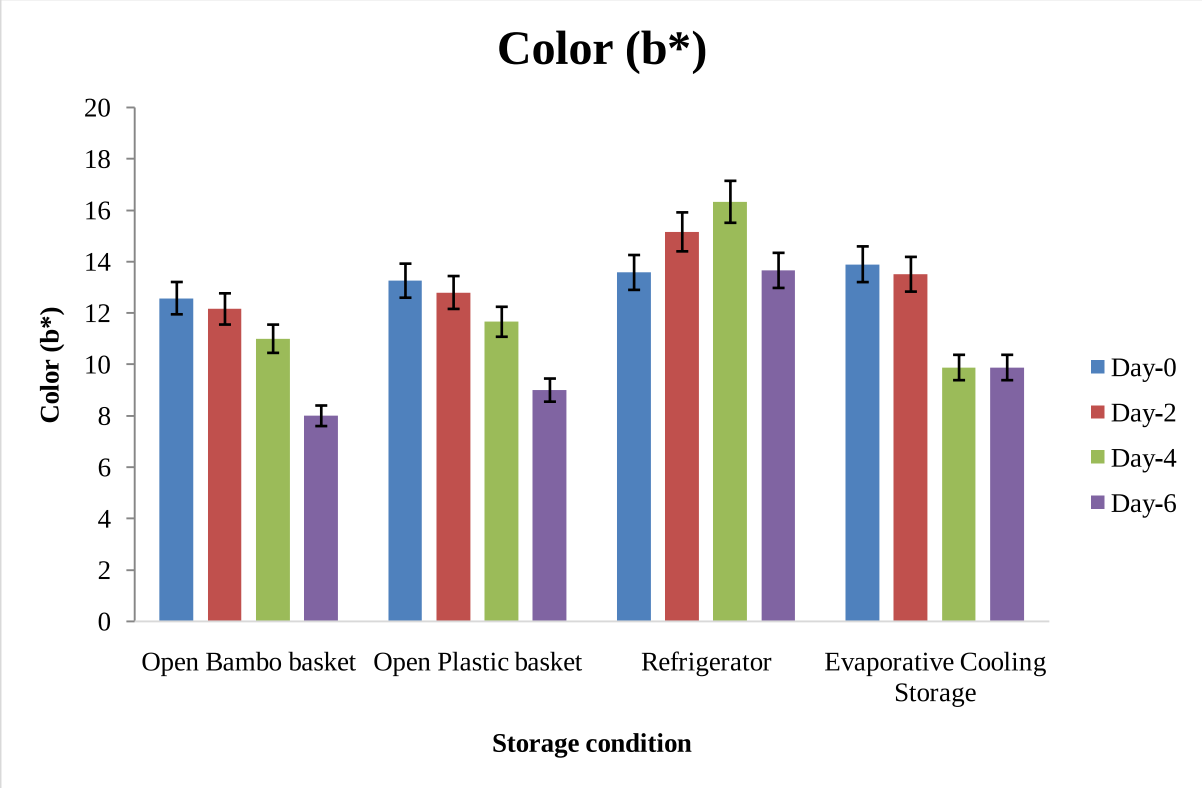


Figure 4.10: Color (b*) of Litchi

Comparative analysis of the color parameters across different storage methods shows distinct advantages for each method. Refrigerator storage effectively maintains lightness and yellowness, likely due to the stable low temperatures that slow down oxidative and enzymatic reactions. On the other hand, the evaporative cooling storage excels in preserving the red color, indicating a favorable environment for maintaining anthocyan in stability.

Overall, the evaporative cooling storage system demonstrates a significant potential for preserving the desirable color attributes of litchi fruits. By maintaining a stable and controlled environment, it effectively reduces the rate of color degradation compared to other storage methods.

4.3 Benefit Cost Ratio Analysis

The cost-benefit ratio analysis of the developed structure considering a total capacity 1800 litchi and a lifespan of 20 years is shown in table 4.1. The litchis were purchased at 350 Tk per 100 litchis after a 7 days storage period, the price increased to 450 Tk per 100 litchi. For the cost the benefit ratio (B:C) was observed to be 1.20 The highest cost-benefit ratio of 1.25 was observed over a period of up to 20 years without considering construction cost, indicating that the storage structure is economically feasible.

Table 4.1: Benefit cost ratio of the developed structure

Year	Input cost	Output Cost
1	350×1800+24000 = 654000	450×1750 = 787500
2	350×1800 = 630000	450×1750 = 787500
3	350×1800 = 630000	450×1750 = 787500
4	350×1800 = 630000	450×1750 = 787500
5	350×1800 = 630000	450×1750 = 787500
6	350×1800 = 630000	450×1750 = 787500
7	350×1800 = 630000	450×1750 = 787500
8	350×1800 = 630000	450×1750 = 787500
9	350×1800 = 630000	450×1750 = 787500
10	350×1800 = 630000	450×1750 = 787500
11	350×1800 = 630000	450×1750 = 787500
12	350×1800 = 630000	450×1750 = 787500
13	350×1800 = 630000	450×1750 = 787500
14	350×1800 = 630000	450×1750 = 787500
15	350×1800 = 630000	450×1750 = 787500
16	350×1800 = 630000	450×1750 = 787500
17	350×1800 = 630000	450×1750 = 787500
18	350×1800 = 630000	450×1750 = 787500
19	350×1800 = 630000	450×1750 = 787500
20	350×1800 = 630000	450×1750 = 787500
Total	12624000	15750000

Considering 50 litchi loss including weight loss, rotting

B_t = 15750000 (Benefit over time, t)

C_t = 12624000 (Benefit over time, t)

r = 16% (discount rate)

$$\text{BCR} = \frac{\sum_0^t \frac{B_t}{(1+r)^t}}{\sum_0^t \frac{C_t}{(1+r)^t}}$$

For the first year, the benefit cost ratio was calculated as follows:

$$\text{BCR} = \frac{\sum_0^{20} \frac{787500}{(1+0.16)^7}}{\sum_0^{20} \frac{654000}{(1+0.16)^7}}$$

$$= 1.20$$

Over a 20 years period, the benefit cost ratio was-

$$\text{BCR} = \frac{\sum_0^{20} \frac{15750000}{(1+0.16)^7}}{\sum_0^{20} \frac{12624000}{(1+0.16)^7}}$$

$$= 1.25$$

This analysis demonstrates the economic viability of the storage structure, offering a favorable return on investment both in the short term and over the long term. Notably, the cost-benefit ratio improves from 1.20 in the first year to 1.25 over a 20-year period, highlighting the substantial economic advantages and sustainability of the structure in the long run.

Chapter-V

Conclusions

5.0 Conclusion

A solar-powered evaporative cooling storage system was developed to extend the shelf life of litchi fruits. This system aims to address the significant post-harvest losses, improve the quality of stored litchis, and provide an eco-friendly and cost-effective solution for litchi preservation in Bangladesh.

The findings from this study demonstrated that the solar-powered storage system effectively maintained favorable conditions for litchi storage. The system successfully extended the shelf life of litchis by maintaining optimal temperature and humidity levels, thereby reducing physiological weight loss (PLW) and preserving firmness. The stored litchis retained their color, sweetness (TSS), and firmness significantly better than those stored under traditional methods, such as open bamboo or plastic baskets. The system managed ethylene concentrations effectively by value, which is crucial for slowing down the ripening process and preventing rapid spoilage. Furthermore, utilizing solar power made the system energy-efficient and environmentally friendly, offering a sustainable alternative for litchi farmers and traders. Overall, this solar-powered evaporative cooling system has shown to be an efficient method for short-term storage of litchi fruits, mitigating the challenges of rapid deterioration and improving marketability.

5.1 Future Research

To further enhance the performance and scalability of the solar-powered storage system, the following areas are recommended for future research:

- Investigation into alternative cooling methods or materials that could further enhance the efficiency of the evaporative cooling system.
- Exploration to scale up the storage system for larger quantities of litchis and other perishable fruits, ensuring practicality for commercial use.
- Implementation of advanced IoT technologies and automation will further streamline the monitoring and control of storage conditions, reducing the need for manual intervention.

- Research into complementary methods that can extend the storage duration beyond short-term solutions, such as integrating modified atmosphere packaging (MAP) with the existing system.
- Conduct a comprehensive cost-benefit analysis to evaluate the economic viability of widespread adoption of the solar-powered storage system among small-scale farmers.

By addressing these areas, future research can contribute to the development of more advanced, efficient, and sustainable storage solutions for litchi fruits, benefiting both producers and consumers.

This solar-powered evaporative cooling storage system offers a promising solution for improving the post-harvest management of litchi fruits. Continued research and innovation in this field can lead to more effective preservation techniques, reducing post-harvest losses, and enhancing the overall quality and availability of litchis in the market.

REFERENCES

Kaur, R., Singh, G., Saxena, D., and Singh, G. (2018). Effect of postharvest treatments for enhancing shelf life of ‘Litchi’ (Litchi chinensis Sonn.). International Journal of Current Microbiology and Applied Sciences, 7(8), 1040-1047.

Kumar, M., Teotia, P., Prasad, R., Varma, A., and Kumar, V. (2017). The litchie fruit: Postharvest handling techniques. In Varma, A. (Ed.), The Litchie Biotechnology, 193-211.

Pandey, N., Joshi, S.K., Singh, C.P., Kumar, S., Rajput, S., and Khandal, R.K. (2013). Enhancing shelf life of litchi (Litchi chinensis) fruit through integrated approach of surface coating and gamma irradiation. Radiation Physics and Chemistry, 88(5), 197-203.

Reshi, M.O.N.I.C.A., Kaul, R.K., Bhat, A.N.J.U., and Sharma, S.K. (2013). Response of postharvest treatments on nutritional characteristics and shelf life of litchi (cv. Dehradun). The Bioscan, 8(4), 1219-1222.

Deshi, V., Siddiqui, M.W., Homa, F., and Singh, J.P. (2020). Postharvest hydrogen sulfide infiltration modulates antioxidative metabolism and increases shelf life of litchi. Acta Physiologiae Plantarum, 42(2), 1-9.

Akter, M.S., Sarkar, M.R., Choudhury, S., Islam, N., and Uddain, J. (2020). Effect of postharvest treatments on shelf life and quality of litchi stored at ambient temperature. International Journal of Postharvest Technology and Innovation, 7(4), 319-334.

Phanumong, P., Rattanapanone, N., and Haewsungcharern, M. (2015). Quality and shelf-life of minimally-processed litchi fruit. Chiang Mai University Journal of Natural Science, 14(1), 1-8.

Talukder, F.U., Rahman, M.S., and Hassan, M.K. (2020). Effects of packaging and low temperature on shelf life and quality of Litchi. International Journal of Horticultural Science and Technology, 7(2), 103-118.

Kumar, N., Neeraj, Pratibha, and Singla, M. (2020). Enhancement of storage life and quality maintenance of litchi (Litchi chinensis Sonn.) fruit using chitosan: Pullulan blend antimicrobial edible coating. International Journal of Fruit Science, 20(Suppl. 3), S1662-S1680.

Sharma, S.K. (2020). High Density Planting of Subtropical Fruits-I Litchi An Introduction to Contemporary Orchard Management (Vol. 1). Nitya Publications.

Liu, H., Song, L., You, Y., Li, Y., Duan, X., Jiang, Y., Joyce, D.C., Ashraf, M., and Lu, W. (2011). Cold storage duration affects litchi fruit quality, membrane permeability, enzyme activities and energy charge during shelf time at ambient temperature. Postharvest Biology and Technology, 60(1), 24-30.

Kaushik, N., Kaur, B.P., and Rao, P.S. (2014). Application of high pressure processing for shelf life extension of litchi fruits (Litchi chinensis cv. Bombai) during refrigerated storage. Food Science and Technology International, 20(7), 527-541.

Ali, S., Khan, A.S., Malik, A.U., Anjum, M.A., Nawaz, A., and Shah, H.M.S. (2019). Modified atmosphere packaging delays enzymatic browning and maintains quality of harvested litchi fruit during low temperature storage. Scientia Horticulturae, 254, 14-20.

Singla, R., Kaur, B., and Goel, R. (2022). Controlled atmosphere and modified atmosphere storage for horticulture commodities: A review. Pharma Innov. J., 1581-1589.

Pérez-Lamela, C., Franco, I., and Falqué, E. (2021). Impact of high-pressure processing on antioxidant activity during storage of fruits and fruit products: A review. Molecules, 26(17), 5265.

Nhleko, Z.V. (2022). Effects of harvest stages, postharvest pre-treatments and storage duration on the quality and shelf life of minimally processed litchi. (Doctoral dissertation).

Phanumong, P., Sangsuwan, J., Kim, S.M., and Rattanapanone, N. (2016). The improvement of texture and quality of minimally processed litchi fruit using various calcium salts. Journal of Food Processing and Preservation, 40(6), 1297-1308.

Mphahlele, R.R., Caleb, O.J., and Ngcobo, M.E. (2020). Effects of packaging and duration on quality of minimally processed and unpitted litchi cv. ‘Mauritius’ under low storage temperature. Heliyon, 6(1).

Belal, M. (2023). Assessing the feasibility of diversifying litchi farming practices in Bangladesh. (Master's thesis, Eesti Maaülikool).

Shen, J., Wan, S., and Tan, H. (2024). Postharvest litchi (Litchi chinensis Sonn.) quality preservation by alginate oligosaccharides. arXiv preprint arXiv:2403.01383.

Kumar, P., Sethi, S., Nayak, S.L., Varghese, E., and Chand, G. (2024). Evaluation of physico-chemical, microbial and sensory attributes of minimally processed litchi (Litchi chinensis Sonn.) under low temperature storage. Journal of Horticulture and Postharvest Research, 1-14.

Javed, H.U., Liu, R., Li, C., Zhong, S., Lai, J., Hasan, M., Shu, X., and Zeng, L.Y. (2023). Preparation of Vanillin-Taurine Antioxidant Compound, Characterization, and Evaluation for Improving the Post-Harvest Quality of Litchi. Antioxidants, 12(3), 618.

Khanal, A., Baral, A., Timilsina, S., and Khanal, S. (2023). Effect of Different Concentrations of Potassium Metabisulphite and Bavistin on Postharvest Life of Litchi (Litchi chinensis Sonn var. Muzaffarpur). AgroEnvironmental Sustainability, 1(3), 257-264.

Chen, Y., Cai, W.A., Xiang, H.A., and Zou, X.A. (2013). A research on the respiration and peel shape of litchi in mechanical damage. Journal of Agricultural Mechanization Research, 3(5), 138-141.

Chen, Y., Xiang, H.P., Tan, J.H., Zou, X.J., Huang, G.G., and Bo, L.I. (2013). Effects of extrusion on mechanical damage and mechanical parameters of litchi. J. Hunan Agr. Univ., 3(9), 688-692.

Dharini, S., Eva, A., and Lise, K. (2008). Postharvest decay control and quality retention in litchi (cv. McLean’s Red) by combined application of modified atmosphere packaging and antimicrobial agents. Crop Prot., 2(7), 1208-1214.

Alves, J.A., Lima, D.O.L., Nunes, C.A., Dias, D.R., and Schwan, R.F. (2011). Chemical, physical-chemical, and sensory characteristics of litchie (Litchi chinensis Sonn) wines. J. Food Sci., 7(6), S330-S336.

Huang, F., Guo, Y., Zhang, R., Zhang, M., Liu, Y., and Bai, Y. (2016). Comparison of physicochemical properties and antioxidant activity of polysaccharides from litchi pulp dried by different methods. J. Chin. Inst. Food Sci. Technol., 1(6), 212-218.

Xiong, J., Lin, R., Bu, R., Liu, Z., Yang, Z., and Yu, L. (2018). A micro-damage detection method of litchi fruit using hyperspectral imaging technology. Sensors, 18(8), 700

Xu, S., Huazhong,L., and Xiuxiu, S. (2020). Quality Detection of Postharvest Litchi Based on Electronic Nose: A Feasible Way for Litchi Fruit Supervision during Circulation Process. Journal of Food Science and Technology, 5(5), 476-482.

Appendices

Python code for sensor data acquisition:

```
h#include "AM2315C.h"
#include <SPI.h>
#include <SD.h>

AM2315C DHT;

const int CO2 Pin = A0; // pin connected to the sensor's output
const int chipSelect = 4;

float number2,number3,number4;

void setup() {
  Serial.begin(9600); // Start serial communication with Arduino IDE
  //Wire.begin();
  DHT.begin();
  pinMode(CO2Pin, INPUT);
  Serial.println("Wait 90s......");
  delay(90000);
/*
  Serial.print("Initializing SD card...");

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    while (1);
  }
  Serial.println("card initialized.");*/

}

void loop() {

  CO2 ppm();
  Temperature();
  Humidity();
/*String dataString= number2+","+number3+","number4;
 File dataFile = SD.open("datalog.txt", FILE_WRITE);
  // if the file is available, write to it:
  if (dataFile) {
    dataFile.println(dataString);
    dataFile.close();
    // print to the serial port too:
    Serial.println(dataString);
  }
  // if the file isn't open, pop up an error:
```

```
 else {
   Serial.println("error opening datalog.txt");
 }*/
 delay(2000);
}



float Temperature()
{
 int status = DHT.read();
 float T=DHT.getTemperature();
 Serial.print(" In Temperature=");
 Serial.print(T);
 return(T);
}

float Humidity()
{
  int status = DHT.read();
  float H=DHT.getHumidity();
  Serial.print(" In Humidity=");
  Serial.println(H);
  return(H);

}

//CO2 in ppm
float CO2 ppm()
{
    float voltage; // Variable to store the analog voltage value
    float CO2Concentration; // Variable to store the calculated CO2 concentration
    int analogValue = analogRead(CO2 Pin);

  // Convert the analog value to voltage (assuming a 3V reference)
  voltage = analogValue * (3.0 / 1023.0);

  // Use the map function to calculate CO2 concentration
  if (voltage <= 1.0)
  {
    CO2 Concentration = map(analog Value, 0, (int)(1.0 * 1023 / 3.0), 0, 1000);
  }

  else if (voltage <= 2.0)
  {
    CO2 Concentration = map(analog Value, (int)(1.0 * 1023 / 3.0), (int)(2.0 * 1023 / 3.0),
1000, 3000);
  }

  else
```

```
  {
    CO2 Concentration = map(analog Value, (int)(2.0 * 1023 / 3.0), 1023, 3000, 5000);
  }

  // Print the CO2 concentration value to the serial monitor
  Serial.print("CO2 Concentration: ");
  Serial.print(CO2 Concentration);
  Serial.print(" ppm");

  return(CO2 Concentration);
}

#include <WiFi.h>
#include "secrets.h"
#include "ThingSpeak.h" // always include ThingSpeak header file after other header files
and custom macros
#include <DHT22.h>
#include "AM2315C.h"

#define data 25

AM2315C DHT;
DHT22 dht22(data);


const int CO2 Pin = 34; // pin connected to the sensor's output
const int C2H4 Pin=32;
const float range = 600; // Sensor's range in ppm

char ssid[] = SECRET_SSID;   // your network SSID (name)
char pass[] = SECRET_PASS;   // your network password
int keyIndex = 0;            // your network key Index number (needed only for WEP)
WiFiClient  client;

unsigned long myChannelNumber = SECRET_CH_ID;
const char * myWriteAPIKey = SECRET_WRITE_APIKEY;

// Initialize our values
int number1 = 0;
int number2 = 0;
int number3 = 0;
int number4 = 0;
int number5 = 0;
int number6 = 0;

const float VOLTAGE_REF = 3.0;
const int ADC_MAX = 1023;

const float VOLTAGE_1 = 1.0;
const float VOLTAGE_2 = 2.0;
```

```
const float VOLTAGE_3 = 3.0;

const float CO2_CONC_1 = 1666.7;
const float CO2_CONC_2 = 3333.3;
const float CO2_CONC_3 = 5000.0;

String myStatus = "";

void setup() {
Serial.begin(115200);  //Initialize serial
Wire.begin();
DHT.begin();
pinMode(C2H4Pin, INPUT); // Set the PWM pin as an input
pinMode(CO2Pin, INPUT);

  while (!Serial) {
    ; // wait for serial port to connect. Needed for Leonardo native USB port only
  }

WiFi.mode(WIFI_STA);
ThingSpeak.begin(client);  // Initialize ThingSpeak

Serial.println("Wait 90s......");
delay(90000);
}

void loop() {

  // Connect or reconnect to WiFi
if(WiFi.status() != WL_CONNECTED){
Serial.print("Attempting to connect to SSID: ");
Serial.println(SECRET_SSID);
while(WiFi.status() != WL_CONNECTED){
WiFi.begin(ssid, pass);  // Connect to WPA/WPA2 network. Change this line if using open or
WEP network
Serial.print(".");
delay(5000);
    }
Serial.println("\nConnected.");
  }

  number1 =C2H4 ppm();
  number2 =CO2 ppm ();
  number3 =InTemperature();
  number4 =InHumidity();
  number5 =OutTemperature();
  number6 =OutHumidity();
```

```
  // set the fields with the values
ThingSpeak.setField(1, number1);
ThingSpeak.setField(2, number2);
ThingSpeak.setField(3, number3);
ThingSpeak.setField(4, number4);
ThingSpeak.setField(5, number3);
ThingSpeak.setField(6, number4);



  // write to the ThingSpeak channel
  int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
if(x == 200){
Serial.println("Channel update successful.");
  }
else{
Serial.println("Problem updating channel. HTTP error code " + String(x));
  }
delay(2000);
}

float C2H4 ppm()
{
  unsigned long durationHigh; // Duration of high pulse
  float C2H4Concentration; // Calculated CO2 concentration
    // Measure the duration of the high pulse
durationHigh = pulseIn(C2H4 Pin, HIGH);

  // Calculate the CO2 concentration using the provided formula
  C2H4Concentration = ((durationHigh - 2000.0) / 300000.0) * range;

  // Print the CO2 concentration value to the serial monitor
Serial.print("C2H4 Concentration: ");
Serial.print(C2H4 Concentration);
Serial.print(" ppm, ");

  return(C2H4Concentration);
}


// For Outside Himidity
float OutHumidity()
{

  float h = dht22.getHumidity();
Serial.print("Out Humidity=");
Serial.print(h);

  return(h);
}
```

```
//For Outside Temperature
float OutTemperature()
{
  float t = dht22.getTemperature();
Serial.print(" Out Temperature=");
Serial.print(t);
    return(t);
}

//Inside Temperature

float InTemperature()
{
 int status = DHT.read();
 float T=DHT.getTemperature();
Serial.print(" In Temperature=");
Serial.print(T);
 return(T);
}

float InHumidity()
{
  int status = DHT.read();
  float H=DHT.getHumidity();
Serial.print(" In Humidity=");
Serial.println(H);
  return(H);

}


//CO2 in ppm
float CO2 ppm()
{
     int analogValue = analogRead(CO2Pin);
  float CO2 Concentration = read CO2 Concentration (analog Value);

  // Print the CO2 concentration value to the serial monitor
Serial.print("CO2 Concentration: ");
Serial.print(CO2 Concentration);
Serial.println(" ppm");
  return(CO2 Concentration);
}


float read CO2 Concentration(int analogValue) {
  float voltage = analogValue * (VOLTAGE_REF / ADC_MAX);
  float CO2Concentration;
```

```
  if (voltage <= VOLTAGE_1) {
    CO2 Concentration = analogValue * (CO2_CONC_1 / (ADC_MAX * VOLTAGE_1 /
VOLTAGE_REF));
  }
  else if (voltage <= VOLTAGE_2) {
   CO2Concentration = CO2_CONC_1 + (analogValue - (VOLTAGE_1 * ADC_MAX /
VOLTAGE_REF)) *
                    ((CO2_CONC_2 - CO2_CONC_1) / (ADC_MAX * (VOLTAGE_2 -
VOLTAGE_1) / VOLTAGE_REF));
  }
  else if (voltage <= VOLTAGE_3) {
    co2Concentration = CO2_CONC_2 + (analogValue - (VOLTAGE_2 * ADC_MAX /
VOLTAGE_REF)) *
                    ((CO2_CONC_3 - CO2_CONC_2) / (ADC_MAX * (VOLTAGE_REF -
VOLTAGE_2) / VOLTAGE_REF));
  }
  else {
   CO2 Concentration = 0;
  }

  return CO2 Concentration;
}
```

Appednix-2

Table 1: Changing temperature, humidity, CO_2 and C_2H_4

Day	Temperature (inside)	Humidity (inside)	Temperature (Outside)	Humidity (Outside)	CO_2 (ppm)
Day-1	26.7638	83.2897	30.2735	75.2472	472.706
Day-2	27.4229	83.711	30.6771	76.4807	468.6016
Day-3	27.3897	84.7117	30.6839	76.4627	479.3681
Day-4	27.4138	84.6796	30.7241	75.4318	481.1683
Day-5	26.1689	86.3658	31.4879	73.3689	488.3625
Day-6	26.2687	86.1236	31.0259	73.8756	478.7639

Table 2: Changing ethylene concentration

C2H4 Concentration (Refridgeration)	
Timestamp	**PPM**
4:16:00 PM	1.05
4:17:00 PM	1.17
4:18:00 PM	1.14
4:19:00 PM	1.22
4:20:00 PM	1.10
4:21:00 PM	0.99
4:22:00 PM	1.17
4:23:00 PM	1.18
4:24:00 PM	1.12
4:25:00 PM	1.18
4:26:00 PM	1.10
4:27:00 PM	1.11
4:28:00 PM	1.08
4:29:00 PM	1.11
4:30:00 PM	1.15
4:31:00 PM	1.18
4:32:00 PM	1.14
4:33:00 PM	1.09
4:34:00 PM	1.11
4:35:00 PM	1.13
4:36:00 PM	1.15
4:37:00 PM	1.19
4:38:00 PM	1.15
4:39:00 PM	1.17
4:40:00 PM	1.16

C2H4 Concentration (Evaporative Cooler)	
Timestamp	**PPM**
3:30:00 PM	1.32
3:31:00 PM	1.49
3:32:00 PM	1.62
3:33:00 PM	1.69
3:34:00 PM	1.75
3:35:00 PM	1.82
3:36:00 PM	1.89
3:37:00 PM	1.95
3:38:00 PM	1.95
3:39:00 PM	2.02
3:40:00 PM	2.05
3:41:00 PM	2.05
3:42:00 PM	2.12
3:43:00 PM	2.15
3:44:00 PM	2.15
3:45:00 PM	2.18
3:46:00 PM	2.32
3:47:00 PM	2.22
3:48:00 PM	2.35
3:49:00 PM	2.38
3:50:00 PM	2.42
3:51:00 PM	2.45
3:52:00 PM	2.42
3:53:00 PM	2.48
3:54:00 PM	2.42

Table 3: Physiological loss in weight (%)

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	0	0	0	0
Day-2	12.96	7.47	6.69	15.66
Day-4	7.98	8.38	10.39	20.04
Day-6	28.37	19.91	19.53	24.29
Std dev	11.95310106	8.220685292	8.14567523	10.6009634

Table 4: Change in TSS during storage period

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	17.9	15.25	16	17
Day-2	15.35	16.69	13.6	17.49
Day-4	16.54	17.35	17.95	17.38
Day-6	14.86	15.86	16.53	16.82
std dev	1.356229455	0.921968004	1.81124267	0.315105802

Table 5: Change in Firmness during storage period

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	11.5	10.5	10.3	10.56
Day-2	13.96	15.56	11.5	15.1
Day-4	14.43	16.03	11.56	13.73
Day-6	15.83	16.4	12.66	14.51
std dev	1.804235757	2.769745777	0.96420952	2.0227127

Table 6: Change in color (*L) during storage period

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	40.44	42.39	41.14	42.57
Day-2	42.76	43.69	47	44.09
Day-4	38	41.33	49	41.77
Day-6	38	39.66	47	41.77
std dev	2.284089899	1.704550283	3.39679751	1.093739762

Table-07: Change in color (*a) during storage period

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	18.23	23.64	17.79	27.39
Day-2	11.67	16.69	11	20.6
Day-4	15.66	15.33	15.66	15.66
Day-6	9.66	9.52	19.33	14.66
std dev	3.862680416	5.800485612	3.62383315	5.819773048

Table-08: Change in color (*b) during storage period

Day	Open Bambo basket	Open Plastic basket	Refrigerator	Evaporative Cooling Storage
Day-0	12.58	13.26	13.58	13.9
Day-2	12.16	12.8	15.16	13.51
Day-4	11	11.66	16.33	9.88
Day-6	8	9	13.66	9.88
std dev	2.067615374	1.909066089	1.3169757	2.214096881

Table-09: Benefit cost ratio analysis

Sl No.	**Materials Name**	**Materials Cost**
01	Materials and technician cost	23500
02	Color	500
	Total	**24000**