Development of an Arduino-based field heat regulator for fruit storage and transportation

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ABSTRACT

Fruit spoilage during transportation is a major problem that results in significant economic losses for fruit producers and distributors. One of the primary causes of fruit spoilage is heat buildup inside the storage container during transportation. Hence, this study was done to design and develop an Arduino-based field heat regulator for fruit storage and transportation, regulate field heat in terms of temperature and humidity monitoring; and assess its influence in terms of the skin color, firmness, and bruising of the fruit specimen. After the conduct of the study, it was found that the regulator underwent several iterations during product development and was tried out in an actual transportation procedure. The results revealed that during transportation the product was subjected to fluctuations in temperature and relative humidity, but the storage regulated heat by maintaining desired conditions. Additionally, there was a significant difference found in terms of the fruit's quality parameters when transported using the proposed storage and the traditional method. In conclusion, this storage has the potential to be used in fruit storage facilities, helping reduce post-harvest losses and decrease the chances of fruits being spoiled easily.

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1. INTRODUCTION

The transportation of fruits from the farm to the market is an essential aspect of the fruit industry and the agricultural field in the bigger scope. However, when transported, fruits can be exposed to extreme temperatures and humidity, which can cause them to spoil quickly [1]. Poor temperature and humidity management can lead to spoilage and loss of quality, resulting in substantial economic losses for farmers, shipping companies, and retailers [2]. According to the Food and Agriculture Organization [3], losses and waste in fruits and vegetables are the highest category of losses among all types of foods, with up to 60% of all fruits and vegetables making their way to landfills. Among them, most of the fruit waste is caused by the deterioration of fruit during storage and transportation. Spoiled fruit contains spoilage bacteria and foodborne pathogens that can cause discomfort and disease in humans when ingested [4].

Temperature is the primary factor influencing the quality of fruits; thus, they should be kept at optimal temperatures during transit and storage. Low heat content during transit and storage can change the color and texture of fruit, whereas higher temperatures can cause browning and softening [5]. Humidity, particularly relative humidity, on the other hand, is the measure of how much water vapor is in a water-air mixture compared to the maximum amount possible [6]. When the humidity is high, the fruit will ripen more quickly. High humidity also helps to keep the fruit's skin from drying out, which can cause it to crack or split. On the contrary, low humidity can cause fruits to dry out and become unripe or overripe [7]. A high relative humidity along with temperature fluctuations can lead to condensation of water. Yeast, mold, fungus, and bacteria can all thrive as a result of water condensation. Condensed water droplets may also obstruct perforated plastic containers, which would slow fruit respiration and hasten fruit deterioration. Additionally, it may also cause fog inside the package, which would impact the customer’s decision to buy the product due to an obscure vision of the product [8].

Field heat is the difference in temperature between the actual temperature of the crop that is being harvested, and the preferred optimal storage of the produce [9]. Field heat regulation is a critical first step in ensuring the freshest, longest-lasting produce while enhancing competitive positioning with downstream processors and markets. Regulation of field heat is the most important measure a farmer can take to protect harvest sellable weight, appearance, nutrition, and farm earnings for most farm commodities [10]. If the field heat is not regulated, it can accelerate the deterioration and senescence processes of the fruit [11].

Fruit spoilage is a severe issue that affects people all around the world. It refers to fruit deterioration, decay, or rotting caused by unfavorable conditions from harvesting to consumption [12]. It is estimated that about 20% of all fruits and vegetables produced are lost each year due to spoilage [13]. In the Philippines, fruit postharvest losses can reach up to 28% on average, with losses happening during harvest, packaging, transportation, exhibition, and even eating. Mishandling, poor storage, inefficiency in the distribution system, and pest and disease damage are all causes of postharvest losses [14].

To reduce fruit loss and wastage, proper storage and transportation is a must. Storing food correctly before transportation generally protects food from external elements and prevents organic decay [15]. Transportation facilitates the movement of products from their origin to ultimate consumers [16]. According to statistics, the transportation link accounts for 80% of fruit and vegetable loss [17]. Cold chain transportation is one of the most frequent transportation methods of food at a preset low temperature that guarantees the freshness of food during transportation to reduce food loss. However, a low-temperature environment is maintained through vast energy consumption, which means that cold-chain transportation consumes a large amount of energy. Thus, the delivery cost is greatly raised [18].

The problem of fruit spoilage during storage and transportation is a significant challenge faced by the fruit industry, hence the solid ground to conduct the study and innovate. While there have been several studies on the use of Arduino-based systems for temperature and humidity control, little to none have developed an Arduino-based field heat regulator specifically designed for fruit storage and transportation to maintain the best quality of a fruit and, possibly, other agricultural products vital to sustain the daily needs of the communities. As such, this study aims to answer the following research queries: i) How will the Arduino-based field heat regulator be designed and developed? ii) Will the product be able to regulate heat through temperature and humidity monitoring? iii) How will the use of the field heat regulator influence the skin color, firmness, and bruising of the fruit specimen?

2. METHOD

2.1. Research design

The research design utilized in this study was developmental research which was defined as a “systematic study of designing, developing, and evaluating instructional programs, processes, and products that must meet criteria of internal consistency and effectiveness” [19]. This means that in this type of research design, the product's design and development were analyzed and described. In addition to that, the final product was evaluated to determine whether the predefined research objectives were met.

Another research design utilized in this study was the experimental research design. Experimental design is a framework of protocols and procedures created to conduct experimental research with a scientific approach using two sets of variables [20]. The use of an experimental design was required in this study to evaluate the proposed storage's effectiveness in regulating and maintaining the standard temperature and humidity ranges as well as the quality of fruits before and after transportation. Moreover, in this experimental design, the researchers specifically utilized a randomized controlled trial (RCT). A randomized controlled trial is a prospective, comparative, quantitative study/experiment performed under controlled conditions with random allocation of interventions to comparison groups [21].

2.2. Research setting

The study was conducted at Purok-1, Sto. Niño, Buara, Barangay Bayabas, Cagayan de Oro City, Misamis Oriental, Philippines. This area provided an adequate space for the researchers to conduct their study and develop their product. The setting offered the necessary materials required as well for the creation of the product. Moreover, to test the effectiveness of the product, the researchers traveled from Cagayan de Oro to a certain location, a vice versa, for a total travel time of about three hours.

2.3. Research materials

The researchers developed an Arduino-based field heat regulator storage for fruit transportation, utilizing a range of materials in order to make the product durable and effective in regulating heat. The materials used included a sheet metal, polyurethane foam, Arduino uno, DTH11 temperature, and humidity sensors, 20×4 LCD, DC fan, 9 V battery, battery snap connector, jumper wires and extra materials such as electrical tape, magnetic catch, stainless steel handles, and the fruit to be tested which was the Lakatan (*Musa acuminata*) bananas. The combination of these materials resulted in a durable and effective storage that assesses a consistent temperature and humidity level, ensuring that the fruit remains fresh during transportation.

2.4. Research procedures

The study followed a systematic research procedure that ensured that every step was followed accordingly. To achieve this, the research procedure followed a flowchart presented in Figure 1. The flowchart guided the researchers in conducting the study from finalizing its requirements, material procurement and gathering, product and system development, assembly of the components, testing procedure, data collection, and analysis to its conclusion and recommendations with the presentation of the results and discussions. This research procedure provided a systematic approach that ensured the development of a reliable and effective storage for fruit transportation.

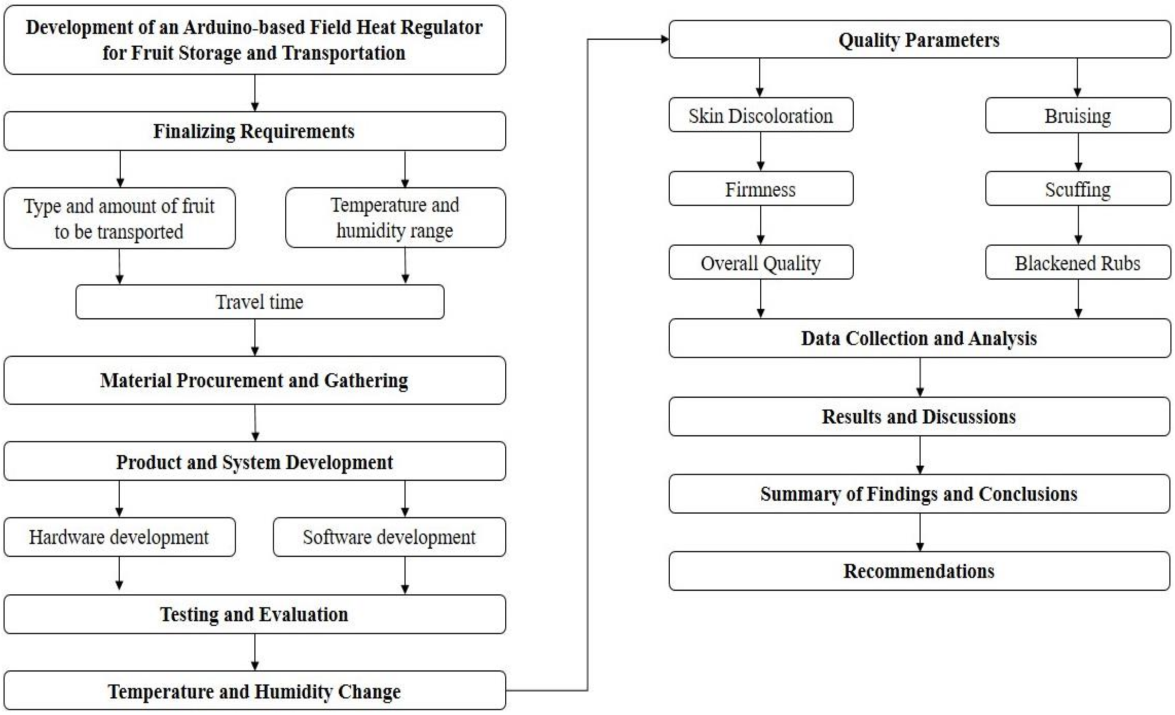

Figure 1. Flowchart providing a comprehensive overview of the research methodology

2.4.1. Blueprint overview

The blueprint of this prototype is shown in figure 2 illustrating the various features on the outside as well as the interior design and compartments. From the outside, handles are available to open the prototype. The exhaust fan is also noticeable on its top portion in order to regulate the temperature and humidity levels. The LCD display is also strategically located right in front for easy access of available information.

Aside from exhaust fan, the blueprint also highlights the use of foam inside the prototype. This is to further regulate the inside. It covers the entire corner inside the prototype before it is added with another layer of stainless steel. Inside the prototype, the temperature and humidity sensors are also placed that are directly linked to the LCD display for easy monitoring. Overall, the main material used in this prototype is stainless steel.

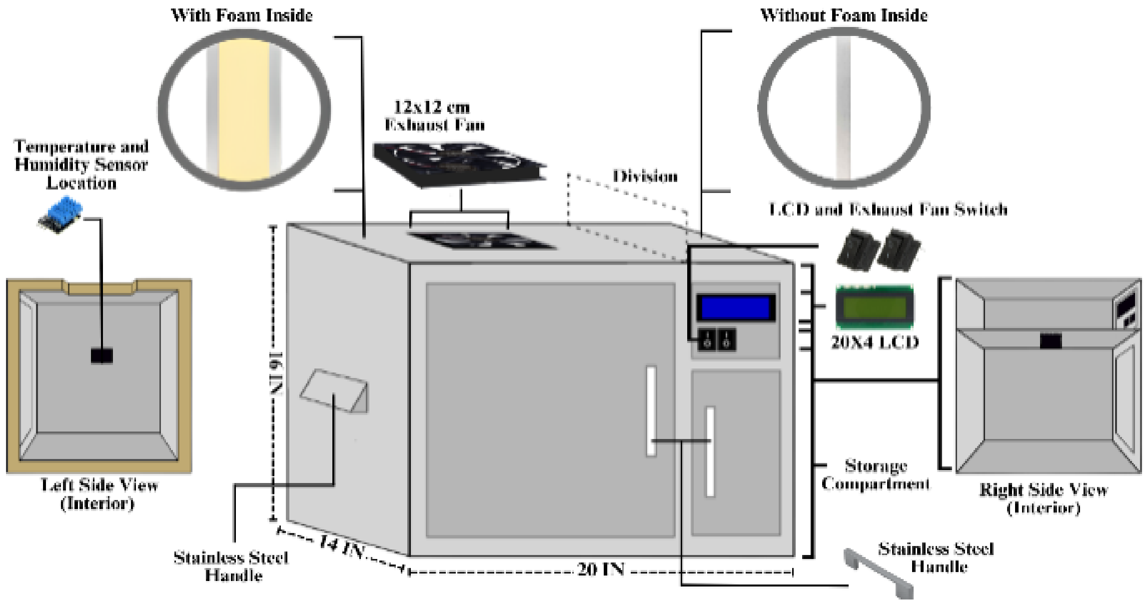

Figure 2. An overall overview of the conceptualized design and development of the product

2.5. Testing and evaluation

To evaluate and determine the effectiveness of the Arduino-based field heat regulator fruit storage, the researchers conducted visual and sensory evaluation tests of the certain quality parameters of the Lakatan (*Musa acuminata*) bananas. The researchers evaluated three main parameters including the color, firmness, and bruise levels, including superficial scuffing and blackened rubs as well as the overall quality in both the treatment group and the control group of fruit. The researchers would like to determine if the fruit, Lakatan (*Musa acuminata*) bananas, would remain in the same quality in an optimal ideal humidity and temperature set in the fruit storage before and after the transportation.

In all visual or sensory evaluation tests, the scores will be given by three trained panelists. The panelists were selected based on their educational background, research experience, and current work. The panelists were also selected based on their experience, and knowledge of with dealing things that involved food, and should be professionals who studied agriculture and other areas related to production and quality control in the food industry to ensure their ability to evaluate the fruit accurately.

2.6. Research instrument

The research instrument that was used in this study is a checklist designed to assess the certain quality parameters of the Lakatan *(Musa acuminata)* bananas before and after transportation. The researchers utilized an 8th and 5th grade scale to rate the color, firmness, and bruise level of the bananas, with the goal of determining how well the Arduino-based Field Heat Regulator Storage is able to maintain the standard range conditions during transportation. The checklist provided a structured approach to the data collection, allowing the researchers to systematically evaluate the fruit and ensure that all necessary criteria are being considered.

2.7. Data analysis

The evaluation's findings gathered by the researchers were utilized in the data analysis. The researchers interpreted the data collected from both the Arduino-based field heat regulator storage and the traditional method using modes of central tendency, specifically, the mean. To properly organize the data and determine the effectiveness of the Arduino-based field heat regulator storage, the researchers utilized tables and graphs to present the possible results.

2.7.1. Temperature and humidity range

The analysis of the data for the temperature and humidity levels was based on the established standard ranges of temperature and humidity that are necessary to avoid food spoilage. In a tropical country like the Philippines, where the temperature range is generally higher, the average temperature can range from 25 to 32 °C (78 to 90 °F), with an average annual humidity of around 77% throughout the year. With this climate, an ideal room temperature for fruit storage should be between 15 to 25 °C (59 to 77 °F), or up to 30 °C [22], [23]. In addition to temperature, humidity is also an important factor in fruit preservation. The ideal humidity range for fruits is between 70% to 80%, as maintaining this range can prevent moisture loss and deterioration of the fruit's texture and taste.

2.7.2. Quality parameter rating scales

The evaluation tests and analysis of the data for the certain quality parameters of the fruit were based on a rating scale. A rating scale is a closed-end survey question that is used to evaluate how survey responders feel about a particular product or statement. The rating scale is a variant of the well-known multiple-choice question [23]. In this study, the quality parameters used include skin color, firmness, bruising including scuffing and blackened rubs, and the fruit's overall quality.

The skin color of the Lakatan (*Musa acuminata*) bananas was evaluated visually. This visual evaluation is based on the 8-grade scale as shown in Table 1. Accordingly, an acceptance score of 6.5 was defined as the visual acceptability threshold [24].

Table 1. The 8th grade rating scale for banana fruit skin color

Score	Class	Maturity Level
8	Brown	Overripe
7	Yellow flecked with brown	Ripe
6	Yellow	Ripe
5	Yellow with a green tip	Ripe
4	Greenish Yellow	Unripe
3	Beaker	Unripe
2	Light green	Raw
1	Dark Green	Raw

A sensory evaluation was conducted to determine the changes in the firmness of the chosen fruit, Lakatan (*Musa acuminata*) bananas. This evaluation will measure what is perceived about that product—not only in terms of its efficacy but also by the more subtle influences of touch. In a particular study, it was found that the rate of force applied in sensory testing is greater than that customarily used in tests with instruments [25].

The firmness of the Lakatan (*Musa acuminata*) bananas was evaluated by touching them. This evaluation was done following the 5-grade scale as shown in Table 2. An acceptance score of 3 (fairly firm) is considered as the lower limit of acceptability at the retail level.

Table 2. The 5th grade rating scale for banana fruit firmness

Score	Class	Description based on resistance to compression by fingers
5	Extremely firm	Fruit does not yield to considerable pressure
4	Firm	Fruit yields only slightly to considerable pressure
3	Fairly firm	Fruit yields slightly to moderate pressure
2	Soft	Fruit yields readily to slight pressure
1	Extremely soft	Fruit yields very readily to slight pressure

The bruising level of the Lakatan (*Musa acuminata*) bananas was evaluated visually. This visual evaluation followed the 5-grade scale as shown in Table 3. This scale is based on a book published where an acceptance score of 3 (moderate) is considered the lower limit of acceptability at the retail level [26].

Table 3. The 5th grade rating scale for banana fruit bruising

Score	Class	Percentage area	Description
4	Severe	5% to 10% or more surface	Extensive
3	Moderate	Up to 5% surface	Obvious
2	Slight	Up to 2% surface	Becoming obvious
1	Trace	Approximately 1% surface	Barely noticeable
0	None		

The superficial scuffing level of the Lakatan (*Musa acuminata*) bananas was evaluated visually. This visual evaluation followed the 5-grade scale as shown in Table 4. This scale is based on a book published where an acceptance score of 2 (slight) is considered the lower limit of acceptability at the retail level [26].

The blackened rubs of the Lakatan *(Musa acuminata)* bananas were evaluated visually. This visual evaluation followed the 5-grade scale as shown in Table 5. This scale is based on a book published where an acceptance score of 2 (slight) is considered the lower limit of acceptability at the retail level [26].

Table 4. The 5th grade rating scale for banana fruit bruising: superficial scuffing

Score	Class	Percentage area	Description based on Visual Evaluation	
4	Severe	20% or more surface	Extensive discoloration	Darkening to almost black
3	Moderate	Up to 15% surface	Obvious skin damage	Obvious
2	Slight	Up to 5% surface	Distinct rub mark	Becoming obvious
1	Trace	Approximately 1% surface	Light and/or localized	Barely noticeable
0	None			

Table 5. The 5th grade rating scale for banana fruit bruising: blackened rubs

Score	Class	Description based on Visual Evaluation
4	Severe	Very obvious damage potentially affecting saleability
3	Moderate	Obvious damage possibly with underlying flesh injury
2	Slight	Clear, noticeable damage to ridges
1	Trace	Barely noticeable, very little injury
0	None	

The overall quality of the Lakatan *(Musa acuminata)* bananas were evaluated visually. This visual evaluation followed the 5-grade scale as shown in Table 6. This scale is based on a book published where an acceptance score of 2.5 is considered the lower limit of acceptability at the retail level [26].

Table 6. The 5th grade rating scale for banana fruit overall quality

Score	Class	Percentage area	Description based on Visual Evaluation	
0	Very Poor	Very obvious damage	Not really edible	Definitely not saleable
1	Poor	Obvious damage	Unattractive with poor eating quality	Probably not saleable
2	OK	Noticeable defects	Not very attractive but eating quality is OK	Just saleable
3	Good	Skin with minor damage	Reasonable attractive with excellent eating quality	Definitely saleable
4	Excellent	Bright Skin	Little or no damage, no significant defects	Very saleable

2.8. Statistical treatment

A one-sample t-test using IBM SPSS Statistic Base was conducted to compare the mean difference and standard deviation in the chosen quality parameters between the group of fruits, Lakatan (*Musa acuminata*) bananas, transported using the Arduino-based field heat regulator fruit storage and the group transported using the traditional method. The one-sample t-test compares a sample mean to a hypothesized value for the population mean to determine whether the two means are significantly different [27]. The level of significance will be set at $\alpha = 0.05$, meaning that researchers will reject the null hypothesis if the p-value is less than 0.05. On the other hand, if the results of the t-test indicate a statistically significant difference in the mean temperature and humidity levels as well as the chosen quality parameters between the two groups, then the researchers can conclude that the developed product is effective in maintaining the required temperature and humidity levels during transportation.

3. RESULTS AND DISCUSSION

This section discusses how the Arduino-based field regulator was designed and developed. In this section, the gathered data is also presented in tabular form. This also includes the analysis and interpretation of findings based on the results of the statistical treatment applied.

3.1. Designing of the Arduino-based field heat regulator

For the designing phase of the Arduino-based field heat regulator, the product underwent several procedures. These procedures include material selection, foam selection, temperature and humidity sensor selection, shape and sizing, compartment design, and fruit selection. These are integral aspects of designing the product.

3.1.1. Material selection

In designing the product, the researchers decided to choose stainless steel for the development of the storage unit. This material is ideal for fruit storage as it does not absorb bacteria or chemicals that may harm the fruits [28]. It is also known for its resistance to rust and corrosion. Stainless steel is a commonly used material for food storage, appliances, and containers. Furthermore, it has chromium content which enables it to endure high temperatures often in the 750 to 1550 °F range 400 to 850 °C, making it an ideal material for the development of the fruit storage unit [29].

3.1.2 Foam selection

Knowing that stainless steel is a heat conductor, it is a big concern because temperature affects the quality of the fruits. With this concern, the researchers chose to use polyurethane foam (PU) because it has excellent thermal insulation and heat resistance, and it does not melt when exposed to high heat. A polyurethane foam is a good insulator that would absorb and reduce the thermal conductivity of the stainless steel, it retains heat perfectly [30].

3.1.3. Temperature and humidity sensor selection

The study aimed to identify the temperature and humidity levels required inside the storage. To accomplish this, the researchers have used a DHT11 humidity and temperature sensor. The DHT11 is a low-cost digital humidity and temperature sensor that is compact and has a high sampling rate. It is capable of measuring relative humidity in the range of 20% to 80% with an accuracy of 5% [31]. Since the temperature range that the researchers want to maintain is between 25 to 30 °C, the DHT11 sensor is an ideal tool for the job. The DHT11 sensor can measure temperature in the range of 0 to 50 °C, which falls within the required range [32].

To display the temperature and humidity readings, the researchers have used a 20×4 LCD with I2C as shown in Figure 3. The LCD screen displays the temperature and humidity levels, making it easy for the researchers to monitor the conditions inside the storage space. Both the DHT11 sensor and the LCD screen have been programmed using an Arduino Uno. This microcontroller is a popular choice for programming electronic devices and is ideal for this project.

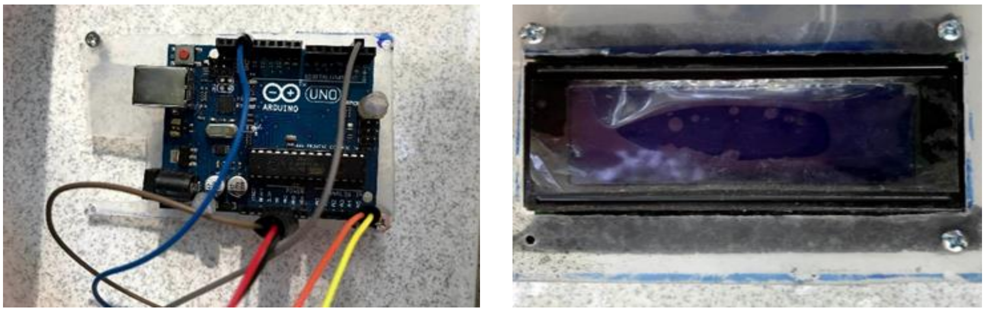

Figure 3. Arduino Uno and LCD screen

3.1.4. Shape and sizing

Shown in Figure 4 is the rectangular prism shape of the prototype with dimensions of 20 inches in width, 14 inches in depth, and 16 inches in height. The rectangular shape was chosen for several reasons. Firstly, the researchers needed a simple and efficient design that would allow for easy fabrication and assembly, and a rectangular shape fits that bill. Secondly, maximizing the use of available space in the field was a key concern, and a rectangular prism shape could be easily stacked and transported. Finally, the researchers required a stable and sturdy structure that could withstand the rigors of field use, and a rectangular shape provided the necessary stability and durability.

Figure 4. Prototype size

3.1.5. Compartment design

The researchers designed the Arduino-based field heat regulator storage with careful consideration of the specific requirements for transporting fruits. The storage features three compartments with different sizes and functions as shown in Figure 5. The main storage compartment, located on the left side, measures 14×14×16 inches, providing ample space for the fruits to be stored during transportation. The storage for programmed materials, located on the upper right side, measuring about 6×14×4 inches in height, is used to house the materials that power the temperature and humidity sensors used to monitor the storage conditions of the fruits. The additional storage compartment located on the lower right side below the programmed materials storage is used to store other items required during transportation, such as packaging materials, labels, or small tools.

Figure 5. Three compartments of the prototype

3.1.6. DC exhaust fan placement

To cool down the inside of the storage, the researchers utilized a DC exhaust fan to cool down and ventilate the heat inside the storage. The researchers initially planned to put the exhaust fan on the side to be more convenient. The researchers pointed the fan up into the case to help pull out hot air to the exhaust fan and be vented from the storage. Moreover, the DC exhaust fan as well as the LCD screen have their designated button for powering them on and off.

3.1.7. Fruit selection

In order to test the effectiveness of the field heat regulator storage in maintaining fruit quality, the researchers considered several factors when selecting the fruit for their experiment. The researchers decided to conduct a survey among fruit stand vendors at three different locations: Cogon Market, Divisoria, and Carmen Market, in Cagayan de Oro City. Since Bukidnon is the nearest region that supplies fruits to Cagayan de Oro City, the researchers conducted thorough research to identify the commonly transported fruits from Bukidnon to Cagayan de Oro. After careful analysis, they compiled a list of potential fruits, including bananas, watermelons, mangoes, lanzones, and pineapples.

To gather more specific data, the researchers divided the survey respondents into three groups based on the market locations, with three groups favoring bananas and one group favoring pineapples, the researchers decided to choose bananas as the fruit to determine the effectiveness of the storage. The researchers took into account the following aspects when selecting the specific type of banana to test. Among the different types, the researchers chose Lakatan *(Musa acuminata*) type of bananas, for its commonality, uniform size, and propensity for bruising and ripening when exposed to high temperatures.

3.2. Development of the Arduino-based field heat regulator

For the development phase of the Arduino-based field heat regulator, the product underwent several procedures. These procedures include the integration of components, programming, and modifications which include repair of the lock, handles, and compartments as well as adjustments. These aspects are integral in the development of the product.

3.2.1. Integration of components

After the design phase, the development phase now commences. In developing an Arduino-based field heat regulator, one of the challenges that researchers encountered during the integration process was waste materials due to incompatibility between the different components. Prior to the development, the researchers purchased materials including a breadboard, an L298N motor driver, and a 16×2 LCD to use with an Arduino

Uno and DHT11 sensor. However, the researchers discovered that the 16×2 LCD had a missing piece and could not be used. The missing piece was not found in any market, and this resulted in the researchers having to find an alternative solution, which was to use a 20×4 LCD with I2C.

The researchers also encountered difficulties when using the breadboard to connect the jumper wires properly, and there was no specific coding for it. As a result, they decided to connect the 20×4 LCD and the L298N motor driver directly to the Arduino Uno using the digital input and output pins. Another challenge encountered was programming the DHT11 and L298N motor drivers together. The purpose of the L298N is to control the speed of the exhaust fan. The researchers tried to program the DHT11 and the L298N together, and it worked, but the problem was that when they tried to connect all three of them, the LCD would not display anything. The researchers tried to find a code that could be used by all three of them but did not find one. The researchers decided to separate the power by using a 9 V battery.

3.2.2. Programming

In order for the Arduino Uno, DHT11, and 20×4 LCD to work, the researchers downloaded Arduino IDE; this is where the specific codes is written for the devices as shown in Figure 6. The researchers searched for a specific library for DHT11 and a 20×4 LCD. After they found a library, the researchers tried to program the devices one by one; this was to ensure that the devices that we needed to use for this product were going to work. After that, the researchers connected both devices to the Arduino Uno and connected it to the laptop, where we downloaded the Arduino IDE. In order for the two of them to work together, the researchers combined the two codes that are used to test the device. The coding was successful, and the DHT11 can detect the humidity and temperature inside the storage. The DHT11 delivered a signal to pin 2, and the LCD will show the detected temperature and humidity.

```

#include <LiquidCrystal_I2C.h>
#include "DHT.h"
#define DHTPIN 2
#define DHTTYPE DHT11

LiquidCrystal_I2C lcd(0x27, 20, 4);  // I2C address 0x3F, 16 column and 2 rows
DHT dht(DHTPIN, DHTTYPE);

void setup()
{
  dht.begin();     // initialize the sensor
  lcd.init();      // initialize the lcd
  lcd.backlight(); // open the backlight
}

void loop()
{
  delay(2000); // wait a few seconds between measurements

  float humi  = dht.readHumidity();    // read humidity
  float tempC = dht.readTemperature(); // read temperature

  lcd.clear();
  // check if any reads failed
  if (isnan(humi) || isnan(tempC)) {
    lcd.setCursor(0, 0);
    lcd.print("Failed");
  } else {
    lcd.setCursor(0, 0);  // start to print at the first row
    lcd.print("Temp: ");
    lcd.print(tempC);     // print the temperature
    lcd.print((char)223); // print ° character
    lcd.print("C");

    lcd.setCursor(0, 1);  // start to print at the second row
    lcd.print("Humi: ");
    lcd.print(humi);      // print the humidity
    lcd.print("%");
  }
}
```

Figure 6. Arduino, DHT11 Sensor, and LCD code

3.2.3. Modifications

Shown in Figure 7 is the lock of the fruit storage which underwent modifications due to some defects that were found during meticulous checking by the researchers. Originally, a barrel lock was used, and this material was found to be susceptible to slipping, which would not guarantee the safety of the fruit during transportation, therefore the researchers replaced it with a magnetic lock. As for the door handle, it originally looked like a cabinet handle, which was not appropriate for a fruit storage unit. To rectify this, the researchers replaced it with a more suitable handle. The front handles of the storage were also modified to be more minimalist and visually pleasing.

Figure 7. Modified prototype design

3.3. Heat regulation through temperature and humidity monitoring

Table 7 represents the temperature and humidity change before and after 3 hours of travel. The target temperature and humidity range were set at 25 to 30 °C and 70% to 80%, respectively [22]. These values may be slightly higher than the standard for some fruits, but they were deemed effective in preventing fruit spoilage during transport under the given conditions. The data gathered during the test showed that the average temperature and humidity levels of the Arduino-based field heat regulator storage after three hours of transport were 30.5 °C and 74.00%, respectively.

Table 7. Temperature and humidity change before and after 3 hours of travel

Time	Temperature (°C)	Relative Humidity (%)
Before 3 hours	29.90 °C	78.00 %
After 1 hour	31.90 °C	72.00 %
After 2 hours	30.10 °C	74.00 %
After 3 hours	29.50 °C	76.00 %
Average (After 3 hours)	30.50 °C	74.00 %

These readings fall within the ideal temperature and humidity range for fruit storage and transportation in a tropical country like the Philippines. These suggest that the storage was effective in controlling the storage environment and preventing fruit spoilage. Additionally, the desired quality of the fruit was attained when heat was regulated as monitored in the temperature and relative humidity data.

3.4. Effect of the Arduino-based field heat regulator on the skin color, firmness, and bruising of the fruit specimen

In assessing the differences between the skin color, firmness, and bruising of Lakatan (*Musa acuminata*) bananas before and after 3 hours of travel, the researchers conducted three evaluation tests. Additionally, an overall quality evaluation test was also conducted to determine the impact of transportation on the overall quality of the bananas. To analyze the data, the researchers used one sample t-test.

The Lakatan (*Musa acuminata*) bananas in both the control and treatment groups were selected and placed in their respective storage set-ups. As shown in Figure 8, the fruit quality of the two samples before the three hours of travel portrayed similarity. Little to no differences were observed to guarantee parallel observation between the two.

Figure 8. The fruit quality before three hours of travel: control and treatment group (front view)

After three hours of travel, noticeable differences were observed in the two banana samples in the control group and experimental group. As shown in Figure 9, the banana sample in the control group portrayed noticeable discoloration, change in firmness, and bruising. These differences are further discussed in the following sections through the analysis of data collected during the conduct of the study.

Figure 9. The fruit quality after three hours of travel: control and treatment group (front view)

3.4.1. Skin color evaluation

Table 8 represents the banana skin color of the control group. The mean difference between before and after transportation was 7.66667, which is a considerable change in the skin color of Lakatan (*Musa acuminata*) bananas. The p-value of .002 and t-value of 23, with a degree of freedom (df) of 2, indicates that the difference between the two means is statistically significant. The statistical results indicate that there was a significant difference in the scores of the panels evaluating the banana skin color before and after three hours of transportation using the control group.

The statistical results indicate that there was no significant difference in the scores of the panels evaluating the banana skin color before and after three hours of transportation using the treatment group. The mean difference between before and after transportation was 0, indicating that there were no changes in the skin color of Lakatan (*Musa acuminata*) after three hours of being transported using the treatment group.

Table 8. Banana skin color evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	6.0000	.00000	7.6667	.57735	3	7.66667	.002	23	2	Significant difference
Treatment group	6.0000	.00000	6.0000	.00000	3	0				No significant difference

3.4.2. Firmness evaluation

Table 9 shows the banana firmness of the controlled group. The statistical results indicate that there was a significant difference in the scores of the panels evaluating the firmness of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the control group. The mean difference between before and after transportation was 1.33333, which was found to be statistically significant with a p-value of .057 and a t-value of 4. This suggests that the fruit became softer after three hours of transportation, as indicated by the change in the mean score from 4.0000 before transportation to 1.3333 after transportation.

The statistical results indicate that there was no significant difference in the scores of the panels evaluating the firmness of the Lakatan *(Musa acuminata)* bananas before and after three hours of transportation using the treatment group. The results showed a mean difference of 0, a p-value, and a t-value of 0. This suggests that the firmness of Lakatan *(Musa acuminata)* bananas was maintained after three hours of transportation using the treatment group, which is considered a positive outcome.

Table 9. Banana firmness evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	4.0000	.00000	1.3333	.57735	3	1.33333	.057	4	2	Significant difference
Treatment group	4.0000	.00000	3.0000	.00000	3	0				No significant difference

3.4.3. Bruising evaluation

Table 10 shows the banana bruising of the control group. The statistical results indicate that there was a significant difference in the scores of the panels evaluating the bruising of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the control group. The mean difference between before and after three hours of transportation using the control group was 3.66667. The p-value obtained was 0.008, which is statistically significant, indicating that there is a significant difference in the level of visible bruising before and after transportation using the control group. These results indicate that the transportation method used in the control group caused visible bruising on the Lakatan (*Musa acuminata*) bananas.

The statistical results indicate that there was no significant difference in the scores of the panels evaluating the bruising of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the treatment group. The mean difference between before and after transportation was 0, indicating no visible bruising on the peel after the fruit was transported using the treatment group. This data shows that there was barely noticeable bruising on the peel of Lakatan (*Musa acuminata*) bananas after three hours of being transported using the treatment group.

Table 10. Banana bruising evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	.0000	.00000	3.6667	.57735	3	3.66667	.008	11	2	Significant difference
Treatment group	.0000	.00000	1.0000	.00000	3	0				No significant difference

3.4.4. Bruising: superficial scuffing evaluation

Table 11 represents the banana bruising (superficial scuffing) in the control group. The statistical results indicate that there was a significant difference in the scores of the panels evaluating the bruising in terms of its superficial scuffing of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the control group. These findings suggest that the transportation process using the control group resulted in obvious skin damage on the peel of Lakatan (*Musa acuminata*) bananas.

The statistical results indicate that there was no significant difference in the scores of the panels evaluating the bruising in terms of superficial scuffing of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the treatment group. The mean difference between before and after three hours of transportation using the treatment group was 0, indicating no significant change in the level of superficial scuffing. These findings suggest that the treatment used in the transportation of Lakatan (*Musa acuminata*) bananas effectively prevented superficial scuffing, which is an essential aspect of maintaining the overall quality and appearance of the fruit during transportation.

Table 11. Banana superficial scuffing evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	.0000	.00000	3.3333	.57735	3	3.33333	.010	10	2	Significant difference
Treatment group	.0000	.00000	1.0000	.00000	3	0				No significant difference

3.4.5. Bruising: blackened rubs evaluation

Table 12 represents the banana bruising (blackened rubs) of the control group. The statistical results indicate that there was a significant difference in the scores of the panels evaluating the bruising in terms of the blackened rubs of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the control group. The statistical analysis showed that this difference was statistically significant, with a p-value of .008 and a t-value of 11, indicating a highly significant effect. These results suggest that there is obvious damage, possibly with underlying flesh injury, on the peel of Lakatan (*Musa acuminata*) bananas after three hours of being transported using the control group.

The statistical results indicate that there was no significant difference in the scores of the panels evaluating the bruising in terms of blackened rubs of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the treatment group. The results showed that the mean difference between before and after transportation was 0, indicating that there was no significant difference between the before and after transportation scores. The p-value of 0 and t-value of 0 with df = 0 further confirm this result, implying that there was no significant difference in the scores between the two groups. These results suggest that there was a trace of blackened rubs on the peel of Lakatan (*Musa acuminata*) bananas, but it is barely noticeable and there was little injury damage on the peel after three hours of being transported using the treatment group.

Table 12. Banana blackened rubs evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	1.0000	.00000	3.6667	.57735	3	3.66667	.008	11	2	Significant difference
Treatment group	1.0000	.00000	1.0000	.00000	3	0				No significant difference

3.4.6. Overall quality evaluation

Table 13 represents the banana overall quality of the control group. To further analyze and support the quality parameters being evaluated, another evaluation test was given out about the overall quality. The statistical results presented in Table 19 indicate that there was no significant difference in the scores of the panels evaluating the overall quality of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the control group. The p-value of .423 and t-value of 1.000 with a df of 2 further suggest that there is no significant difference in the overall appearance of Lakatan (*Musa acuminata*) bananas before and after transportation using the control group. This data shows that there is a decrease in the overall quality and noticeable defects of Lakatan (*Musa acuminata*) bananas after three hours of being transported using the control group.

The statistical results indicate that there were no significant differences in the scores of the panels evaluating the overall quality of the Lakatan (*Musa acuminata*) bananas before and after three hours of transportation using the treatment group. This is indicated by the mean difference of 0 as well as the p-value of 0, t-value, and degrees of freedom of 0, indicating that the difference is not statistically significant. This data shows that there are no major changes in the quality of Lakatan (*Musa acuminata*) bananas, there is little to no damage and no significant defects on Lakatan (*Musa acuminata*) bananas after three hours of being transported using the treatment group.

Table 13. Banana overall quality evaluation

Groups	Before		After		N	Mean Difference				Remarks
	M	SD	M	SD			p	t	df	
Control group	3.0000	.00000	.3333	.57735	3	.33333	.432	1	2	No significant difference
Treatment group	3.0000	.00000	3.0000	.00000	3	0				No significant difference

4. CONCLUSION

The researchers successfully designed and developed an Arduino-based field heat regulator for fruit storage that can maintain the quality of fruits during storage. The use of stainless steel for the storage unit and polyurethane foam as insulation helped prevent heat from passing through the inside of the storage, ensuring that the temperature and humidity levels were maintained at the required range. The use of a DHT11 temperature sensor and an LCD screen allowed the researchers to monitor the temperature and humidity levels inside the storage, while the exhaust fan helped cool down the inside of the storage. The testing of the device using bananas showed that the device was effective in maintaining the quality of the fruit during storage.

Based on the findings, it can be concluded that the product was subjected to fluctuations in temperature and relative humidity during transportation. The temperature increased by 2.90 °C in the first hour, but then gradually decreased to almost the previous state in the final three hours. Similarly, the relative humidity decreased by 5.00% in the first hour but then increased by 2.00% in the second hour and another 2.00% in the final three hours of travel. This shows that the temperature and relative humidity inside the storage changed during the travel time, but the storage could maintain the desired conditions. The average temperature and relative humidity during the entire travel time were 30.50 °C and 74.00%, respectively, which indicates that the storage was effective in protecting the stored items.

With this, it can be concluded that transport has a significant effect on the skin color, firmness, and bruising of Lakatan (*Musa acuminata*) bananas. However, the standard range of temperature and humidity may vary depending on the type and quality of fruit that is used in testing out the fruit storage and the results may vary depending on the extended time of transportation using the same fruit. Further research is needed to confirm these results and to determine the generalizability of the findings to other types of bananas and transport conditions.

5. RECOMMENDATIONS

Based on the findings and conclusion, these recommendations are presented to highly revolve around the major areas that this study focused on. Firstly, the future improvements that can be made in designing and developing the product. This is followed by suggestions on assessing temperature and humidity with the data vital for this research. Lastly, the type of fruit specimen that may be used in future research as well as the other quality parameters that may be considered.

5.1. Designing and developing of the Arduino-based field heat regulator storage

In designing and developing the storage, future researchers can conduct thorough research about other materials that have a high chromium content. Materials with high chromium content exhibit more durability, high resistance to heat, and are very resistant to corrosion and rusting. With this, the product could sustain transportation conditions for a much longer time.

To achieve more accurate measurements of temperature and humidity within the fruit storage, future researchers can utilize the DHT22 temperature and humidity sensor. This sensor offers improved accuracy and reliability compared to other sensors. Since the data from these parameters are vital, it is necessary to upgrade the sensors to be used depending on the type of environment in which this product may be utilized.

5.2. Temperature and humidity change assessment

While transporting the control and treatment group, future researchers may set up a data logging system to record temperature and humidity readings at regular intervals, such as every 15 minutes or hourly. This will provide a time-series dataset that can be analyzed to identify patterns and trends in temperature and humidity fluctuations. Since these parameters can influence the quality of fruit, monitoring it is much more accurate and easier when a data logging system is utilized in the future.

5.3. Fruit selection and fruit testing

In addition to Lakatan (*Musa acuminata*) bananas, the researchers may conduct testing on other fruits that are prone to discoloration, bruising, and ripening when exposed to high temperatures. This will provide a broader understanding of the storage's effectiveness in preserving different types of fruits with varying characteristics. Future research may also expand the type of parameters that may be considered in assessing fruit quality in terms of its sensory evaluation and others.

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