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Development and Performance Evaluation of a Micro Controller Based Refrigeration Control System Using Fresh Fruits

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***Abstract**: This paper presents reports on the performance evaluation of a developed micro controller-based refrigeration control system (MCBRCS) using fresh fruits. The cooling system operating with R134a as working fluid consists of an evaporator, compressor, condenser, capillary tube and a temperature control device (TCD). The refrigerator system has capacity to accommodate about 0.02 metric tonnes (20kg) of any fresh fruits. The cooling system was validated on no load condition and was also used to preserve fresh fruits: pineapple (Ananas comosus) and cucumber (Cucumissativus L). The fresh fruits preservation spans over 14 days in two storage conditions, viz., ambient and MCBRCS storage. Study was conducted to check the freshness of the fruits and data were observed daily. The validation results of the attained cooling system revealed that the system performed well in terms of temperature and relative humidity regulation above freezing point. Physiological loss in weight (PLW) of the tested fruits samples was less under MCBRCS storage as compared to ambient storage. The needed optimum storage temperature for the preservation of the selected fresh fruits samples was achieved at 7°C - 10°C and the effects of excessive chilling/freezing injury commonly occurred in multipurpose VCRS is naturally eliminated. The organoleptic test results revealed that the developed MCBRCS performed up to expectation and could be used as a veritable tool to increase the shelf life of post harvesting perishable agricultural products.*

***Keywords:** Fresh fruits, micro controller-based refrigeration control system, ambient storage, temperature, relative humidity.*

1. INTRODUCTION

In order to protect quality and extend shelf life of fresh agricultural produce such as fruits and vegetables, they should always be cooled as soon as possible after harvest. This is due to the fact that once harvested, produce gains heat through respiration and conduction from the surrounding environment. Cooling involves heat transfer from produce to a cooling medium such as a source of refrigeration. The heat transfer processes involve during refrigeration process include conduction, convection, radiation and evaporation. Fresh fruits and vegetables are living tissues separated from the parent plant, which supplied them with water via transpiration. Fruits and vegetables are grown by subsistence farmers are stable foods for millions of people around the world, especially in Africa. Fruits and vegetables have been in the diet of Nigerian's for centuries and have gradually become a more important horticultural crop. Bates *et al* [1] in their study pointed out that fruits are non-staple foods which make-up about 39% of the food intake of persons living in developing countries of Africa. Findings from the studies of [2-13] reported that fruits contain high levels of bioactive and other phytochemicals such as antioxidants (e.g. polyphenols), solublefire (e.g. pectinandbeta-glucanase), prebiotics (e.g. inulin, fructan), vitamins (e.g. vitamins A, B group and C), flvone glycosides (e.g. hesperidin). They also contain organic acids: e.g. tartaric acid which, as functional food materials or nutraceuticals, provide specific health benefits such as prevention of diseases and growth of gut pathogens, enhancement of body immunity, protection against heart diseases, cancer, osteoporosis, hypertension, regulation of ageing, etc. Unfortunately, most of these beneficial compounds which are found in fresh fruits are lost when they are exposed to high temperatures during post-harvest and thus affect their quality, reduce their shelf life and marketing value. According to [14], fresh fruits and vegetables are living organism and continue to respire after harvest, this is obvious because fresh fruits and vegetables are living in nature, complete remaining life cycle after harvest, and then naturally spoil. This character puts fresh fruits and vegetables in the category of highly perishable commodities. According to [15], approximately one third of all fresh fruits and vegetables are lost before it reaches to the consumers. Findings from the study of [16] also revealed that 40–50 % of horticultural crops produced in developing countries are lost before they can be consumed, mainly because of high rates of bruising, water loss, and subsequent decay during postharvest handling. Thus, the decay of fresh fruits after harvest is an international issue commonly concerned.

It is interesting to highlight that, (i) preservation of perishable fruits and vegetables is vital and the loss due to lack of proper storage measures is often very high (ii) There are more and more requirements for freshness of fruits and vegetables as the demand for their supply is increasing every day. As a result, people put more and more focus towards the quality, safety, freshness, nutrition and environmental concerns on survival of fruits and vegetables. As pointed out in the study of [17], the quality and storage life of fruits and vegetables may be seriously altered within a few hours of harvest unless the crop has been precooled and properly stored in a well design storage facility to control deterioration. Padmini (2006). [18]. also point out that, terms like bacteria, yeast, moulds, enzymes, etc. growth decline as temperature fall and that growth becomes very slow at temperature below + 10°C This typical low temperature condition can only be achieved using refrigeration system. Refrigeration slows down the chemical and biological processes in foods and the accompanying deterioration and the loss of quality. Although, refrigeration is very popular but it has been observed that several fruits and vegetables cannot be stored in the multipurpose refrigerator for a long period as they are susceptible to chilling injury. According to [19], the major problem during storage is what happens to the quality parameters of these produce especially the physical characteristics such as; the color, texture, and freshness in which the price sometimes depends on. More so by preserving fruits in the existing multipurpose refrigeration system some undesirable physiological changes occur like tissue change known as chilling injuries, freezing injury which is characterize by rubbery texture, browning, bruising and drying due to rapid moisture loss. These factors, if not controlled properly, lead to postharvest losses on large scale.

On the other hand, the impacts of supply and the price differences of fruits and vegetables between boom and slack seasons are particularly large in the market. Thus, it is interesting to highlight that, there is a need for proper post-harvest handling and storage to reduce the incidence of loss in fresh weight, sprout and rot and to contribute to ensuring quality maintenance for perishable agricultural produce like fruits. As pointed out in the study of [20], the post-harvest losses encountered on agricultural produce could be reduced by improved threshing, drying and storage facilities at farm level. Findings from the studies of various researchers in the open literatures [21-25] revealed that the most effective storage condition required for most stored crops in a cooling compartment is the refrigerated space with sustainable low temperature above freezing point and high relative humidity. This is due to the fact that low temperature condition in a refrigerated space prolongs produce storage life by reducing respiration rate as well as reducing growth of spoilage microorganisms. Similarly, [26] in their study reported that most fruits and vegetables retain better quality at high relative humidity ranged from 85 to 90%. APHLIS [27] in their study also reported that, reducing post-harvest loss not only increases food availability, farmer income and consumer savings, but also reduces agro-related greenhouse gas emissions. Moreso, [28] in their study involved the effect of post-harvest treatments on quality of whole tomatoes, pointed out that consumer's increasing desire for high quality and nutritional foods has created a need for longer market season for both domestic as well as export markets. This objective could be achieved through development of a modern storage facilities for preservation of fresh agricultural produce like fresh fruits to meet their expected market demand during both boom and slack seasons is the major concern in this study. This study idea is found to agreeing with [29] who reported that, through the development of modern storage facilities, food crop preservation becomes easy and simple to follow.

Therefore, with a view to keeping the quality and shelf lives of fresh fruits and improve the economic effectiveness in favor of solving the farmer's income issues a micro controller-based refrigeration control system for preservation of fresh fruits is achieved in this study. The main purpose of the cooling system is to control the refrigerator temperature by using a temperature sensor known as temperature control device (TCD) This sensor monitors the temperature of the refrigerator for every few minutes; if the temperature of the refrigerator decreases below freezing point then it automatically turns OFF the device and thus maintain the expected required storage condition for the stored agricultural produce.

2. MATERIALS AND METHODS

2.1 Design Consideration

Most refrigerators use a liquefiable vapour as refrigerants. Based on the operation of the refrigerator, being a cyclic process, properties such as temperature (^{o}C), pressure (bar), specific enthalpy (kJ/kg), specific entropy (kJ/kg K), specific volume (m^3/kg) were put into the consideration to achieve a refrigeration system that can maintain a refrigerated space above freezing point to ease quality preservation of fresh fruits. This objective is achieved with the aid of incorporating a redesigned temperature control device (TDC) in the existing domestic refrigeration system. R134a was selected because it has zero ozone depletion potential and is widely used in most commercial refrigerators

2.2.1 Determination of Refrigerator's Capacity

This is estimated as the total heat gain for the cold storage (Q_{total}) plus the service factor (SF) which accounts for brief periods of unusually hot weather, i.e. loading rates that temporarily exceed those anticipated. Thus, the Refrigeration capacity (C_R) is given as follows:

$$C_R = SFQ_{total} \tag{1}$$

The Total Cooling Load (Q_{total}) is estimated taking into account the Transmission Load (TL), Product Load (PL) and Infiltration Load (IL) of the cooling system as follows:

$$Q_{total} = TL + PL + IL \tag{2}$$

Transmission load (TL)

The (TL) is calculated taking into consideration Eqns. (3) and (4)

$$Q = TL = UA(\Delta T) \tag{3}$$

where

$$U=\frac{1}{\frac{1}{h_o}+\frac{L_M}{K_M}+\frac{L_S}{K_S}+\frac{\mathrm{L}_G}{\mathrm{K}_G}+\frac{1}{h_i}} \tag{4}$$

Where subscript terms (M, S, and G) in Eq. (4) is given as Mild steel, Stainless steel and Glass fiber respectively.

Q is sensible heat gain (watts),

U is overall heat transfer coefficient (W/m ^{2} K),

A is the surface area of the cooled space (m^2), (1.5m ^{2})

ΔT is the overall change in temperature. Total surface area, A, is the wall area (1.5m ^{2} **);**

ΔT is calculated as Cooling load temperature difference (CLTD) (T $_O$ -T $_I$)^{o}C**;** T $_O$ is the outside or ambient temperature (30^{o}C)**;** T $_I$ is the inside temperature (7 ^{o}C to 10 ^{o}C);

h is the convective heat transfer obtained as h $_o$ is 11.6W/m ^{2} K**;** h $_i$ is 14.5 W/m ^{2} K as adopted from the study of [24];

L is the length of the materials obtained as: L$_M$ is 0.001 m; L$_S$ is 0.012 m; L$_G$ is 0.0006 m; k$_M$ is 46.5 W/m ^{2} K;

k is the material thermal conductivity obtained as k$_S$ is 0.046 W/m ^{2} K; k$_G$ is16.20 W/m ^{2} K; T $_O$ is 30 ^{o}C and T $_I$ is 7 ^{o}C to 10 ^{o}C;.

Thus, the sensible heat gain (TL) is estimated to be 72 kW using Eq. (3)

Product Load (PL)

The heat removed from the produce as they are cooled to refrigeration temperature and the heat released as the fresh fruits respire in the storage constitute the product load (PL) of the refrigeration system. This is obtained as summation of FH (Field Heat) and RL (Respiratory Load), this is the cooling necessary to reduce the product from harvest temperature down to the safe storage level.

The field heat load is estimated as follows:

$$Q_{FH} = mc\Delta T \tag{5}$$

Where,

Q_{FH} is field heat load, kW

m is the mass of product cooled per 24 hours, kg;

c is the specific heat of the considered fruit = 1.71kJ/kg ^{o}C (ASHRAE Handbook- Refrigeration)

ΔT (Temperature drop of product in 24 hours), ^{o}C

Mass of the propose agricultural produce (fruits) to be stored at a time is 20 kg

Q_{FH} = 20(1.71) (30-7) = 787W

Q_{FH} is thus obtained as 0.787 kW

The heat of respiration is the energy released by the product (Fruit) as it respires.

The respiration load Q_{RH} is calculated as follows:

$$Q_{RH} = MK \tag{6}$$

where,

Q_{RH} is respiration heat load, W, M is the mass of product cooled per 24hours and K is the rate of respiratory heat production, kW/ton.day. Using the equation proposed by [24], K is obtained as 1.064 kW/ton. day

Thus, by using Eq. (6), Q_{RH} is estimated as 0.8866 kW
The PL is thus obtained by summation of the estimated values of Q_{FH} and Q_{RH} as follows:

$$PL = Q_{FH} + Q_{RH} \tag{7}$$

By using Eq. (7) the PL is obtained as 1.67 kW

2.2.2 Determination of the system Infiltration Load (IL)

The heat gains due to the surrounding warm air entering into the refrigerated space through the cracks and the open doors constitute the infiltration load of the refrigeration system. The infiltration load changes with time. Thus, in this study maximum value of infiltration load is considered to properly size the refrigeration system.
For the infiltration load (IL), equation considered in the study of [30] is adopted in this study as follows:

$$IL = q_d \rho h \tag{8}$$

where,
q_d is the door infiltration (m^3/min) = (door openings /hr × safety factor)/60
q_d = 0.33 m^3/min $\approx$0.0056 m^3/sec
ρ is the density of air and h is the enthalpy of air = (c_{pa} t)
Assuming the door opens 10 times per hour and a factor of a light door is 2.0 per selected agricultural products, the infiltration load using Eq. (8) is estimated to be 0.00384 kW.
For better efficiency of the system, factor of safety between 5% and 10% is taking into consideration in this study, being an allowable safety factor range considered in the study according to [30]. Thus, the service factor (SF) is obtained as 1.1.
Hence, the total estimated capacity of the refrigeration system is obtained using Eq. (1) as follows:
Refrigeration capacity = $(TL + PL + IL)(SF)$ (9)
Implementing Eq. (9), the system capacity is obtained as 81.04 kW
Thus, the micro controller-based refrigeration control system (MCBRCS) developed in this study is realized based on the estimated designed value obtained using Eq. (9).

2.3 Design of Temperature Control Device (TCD) for the MCBRCS

Taking into account the aforementioned design parameters and conditions for the MCBRCS, a new Temperature Control Device (TCD) is constructed in this study.

2.3.1 The Circuit Diagram for the Temperature Control Device

Shown in Figure1 is the circuit diagram of the TCD. The Temperature Control Device (TCD) consists of a micro-controller, LCD, optocoupler, temperature sensor ADC, Voltage Regulator, Capacitor and Diode. The microcontroller port is connected to the data pins of LCD. Likewise port three of the microcontroller is connected to the data pins of the ADC. The Pins through which the LCD and ADC components of the TCD are connected to perform their expected functions though not shown in Figure1 have the following roles to perform: Pins P2.0 through P2.2, are connected to the LCD. Pins P2.3 through P2.5 are connected to the INTR, WR AND RD pins of ADC respectively. Pin P2.6 of the port 2 is used to generate control signal to actuate the compressor. It is obtained using PWM. This pin is connected to the input pin of the optocoupler, the optocoupler is driving the switch to turn the compressor on and off. The temperature control device designed in this study is a thermocouple type, Figure 2 presents the assembly of developed TCD. The algorithm of the thermocouple software is written with C++ programming language and the hardware is made of different components like: Thermocouple, Thermocouple amplifier, Switch circuit, Relay, Display unit, Storing device, Cable, USB cable, Socket, Panel, Arduino Micro-controller, and Casin. The TCD designed in this study can maintain a refrigerated space above freezing point a condition that is suitable for the preservation of fresh fruits over a long period of time without any chilling injury effect that is usually observed with the thermostats, a temperature control devised used in the existing multipurpose refrigeration system.

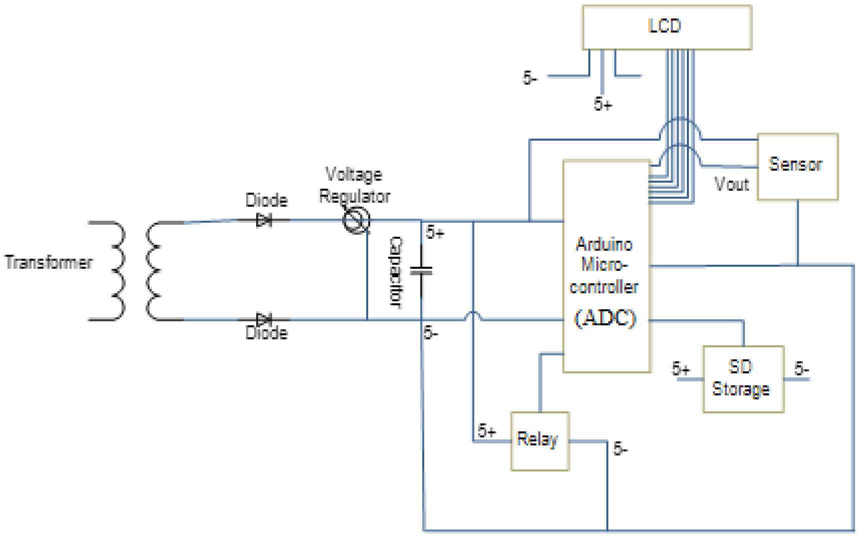

Figure 1: Circuit diagram for TCD.

Figure 2 Assembly of developed TCD

2.3.2 Working Principle of Temperature Control Device

Shown in Figure 3 is the algorithm / working principle of the designed TCD. The main purpose of a temperature control device, is to monitor and control the refrigerator temperature by using a temperature sensor. This sensor monitors the temperature of the refrigerator for every minutes, if the temperature of the refrigerator decreases below expected limit i.e (Freezing point) then it automatically turns off the compressor of the refrigeration system and vice versa when the temperature of the refrigerator increase beyond expected limit the sensor actuates the compressor. The temperature is read by the Analog to Digital Converter (ADC) module of the microcontroller unit. This ADC data is processed and converted into the actual temperature reading by the microcontroller. The processed data is sent to the LCD for user display

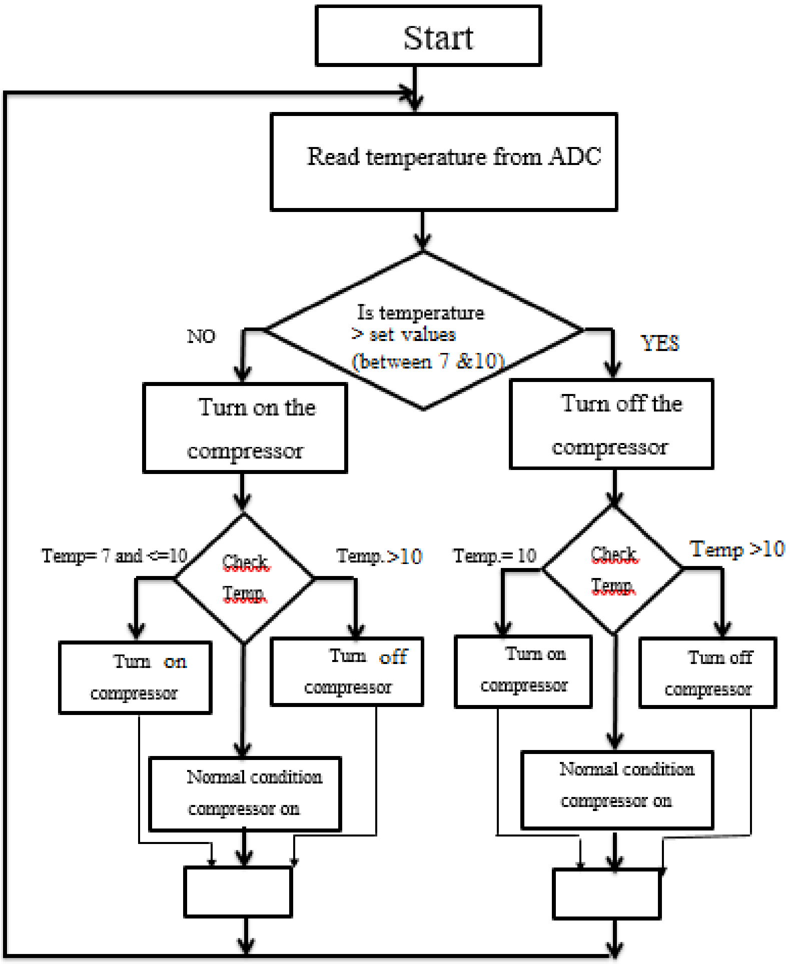

Figure 3 The algorithm/ working principle of the designed Temperature Control Device.

2.4 Apparatus and experimental Set-Up

With the view to evaluate the function ability of the developed MCBRCS in this study, performance evaluation of the cooling system is carried out as follows.

Figure 4 presents the attained MCBRCS where the temperature and relative humidity measurements were performed. The ambient and the cabinet temperature were measured by using digital thermometer and the newly designed TCD respectively. Both the ambient and the cabinet relative humidity of the developed MCBRCS were also measured simultaneously during the test by using a digital humidity –temperature meter. The experiment was carried out using the developed MCBRCS on no load condition for 5 days. The system was also used on loaded conditions to preserve fresh fruits (Pineapple and Cucumber) for the other 14 days. During the testing period on no load condition as shown in Figure 4, the refrigeration system was connected to the outlet source of the temperature control device (TCD) and the (TCD) was plug directly to the power source, a digital thermometer was suspended in the refrigerator cabinet to measure the cabinet cold region temperature in comparison to the temperature control device set temperature. Also on load condition in using the system to preserve the selected fruits (Pineapple and Cucumber) as shown in Figure 5, the digital thermometer was suspended in the chamber through a small hole in the cabinet to ascertain the variation of temperature in the refrigerated space, while a control sample of fresh fruits (Pineapple and Cucumber) presented in Figure 6 were expose to the open air. With the view to evaluate the performance of the developed cooling system, used on load condition (preserved fruits) in comparism to the control sample (unpreserved fruits), the weight of the tested fruits samples considered in this study was measured before and after the experimental test by using a digital weight balance.

Figure 4. Developed MCBRCS Tested on No - Load Condition

Figure 5: Performance evaluation of the developed MCBRCS with fresh Pineapple and Cucumber

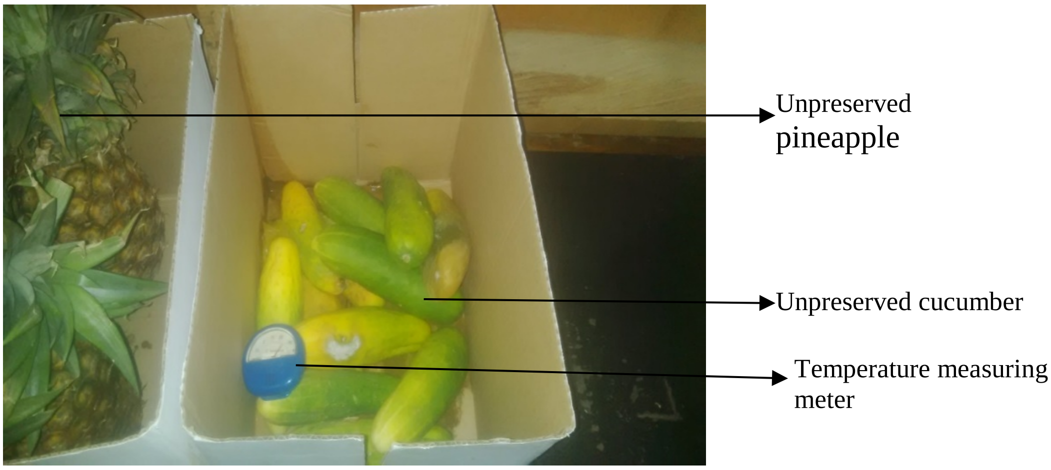

Figure 6: Fresh Cucumber and Pineapple used for the control experiment

3. RESULTS AND DISCUSSION

3.1 System Tested on No-Load

Presented in Figures 7. (a and b) are the analyses of the obtained experimental results from the developed MCBRCS on no load condition. Figures (a) and (b) represent validation of the cooling system showing variation of temperature and relative humidity against time respectively. The validation test of the attained micro controller based refrigeration control system was carried out in the Refrigeration and Air Conditioning Unit of the Department of Mechanical Engineering, Federal University of Technology Akure for 5 days between 16-09-2017 to 20-09-2017.

From Figure 7.a, the ambient temperature is observed to be increasing with the time changing as expected. The cabinet considered in this research experience drop in temperature for the first two hours of the test and thereafter maintained an appreciable constant low temperature between 7°C and 10°C for the rest hours of testing the cooling system. Ambient R.H of low value in the range between (62%-68%) is also observed with time changing during the test as presented in Figure 7.b. However, reverse is the case for the cabinet considered in this study where relative humidity of high value in the range between (83% - 95%) was observed. The validation results revealed that the system performed well in terms of temperature and relative humidity regulation above freezing point. This behaviour is due to the set point temperature observed with the newly designed and installed TCD in the refrigerating system. The observed condition of the refrigerating system attained in this study will be profitable for fresh fruits preservation as reported in the in previous study of [26] that most fruits and vegetables retain better quality at high relative humidity ranged from 85 to 90. The result also agreed with [24] who established that storage of farm produce is most effective at temperature just above the freezing point

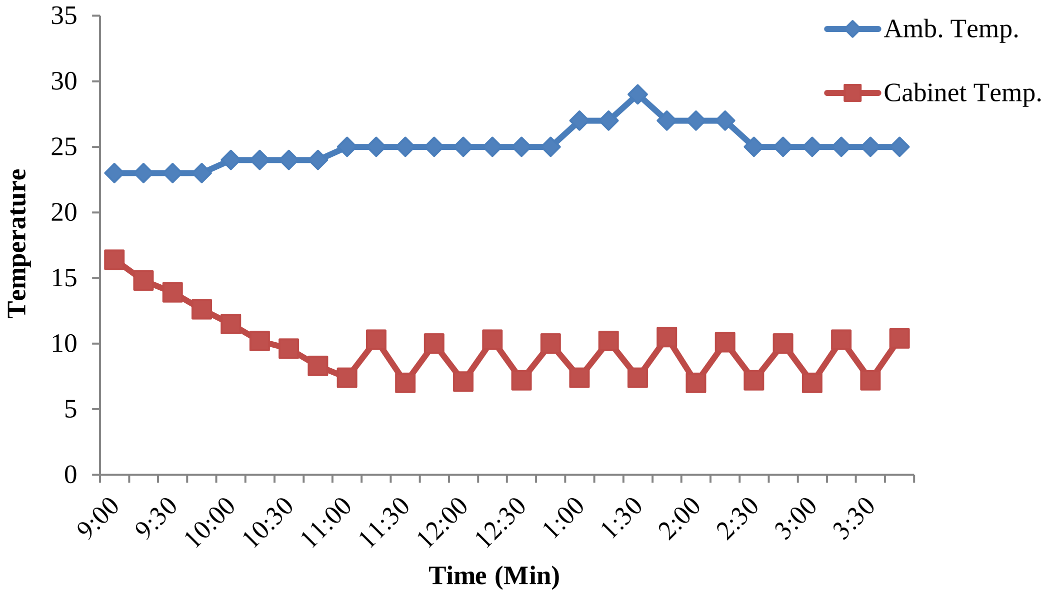

Figure 7.a: Variation of temperature against time on no-load condition

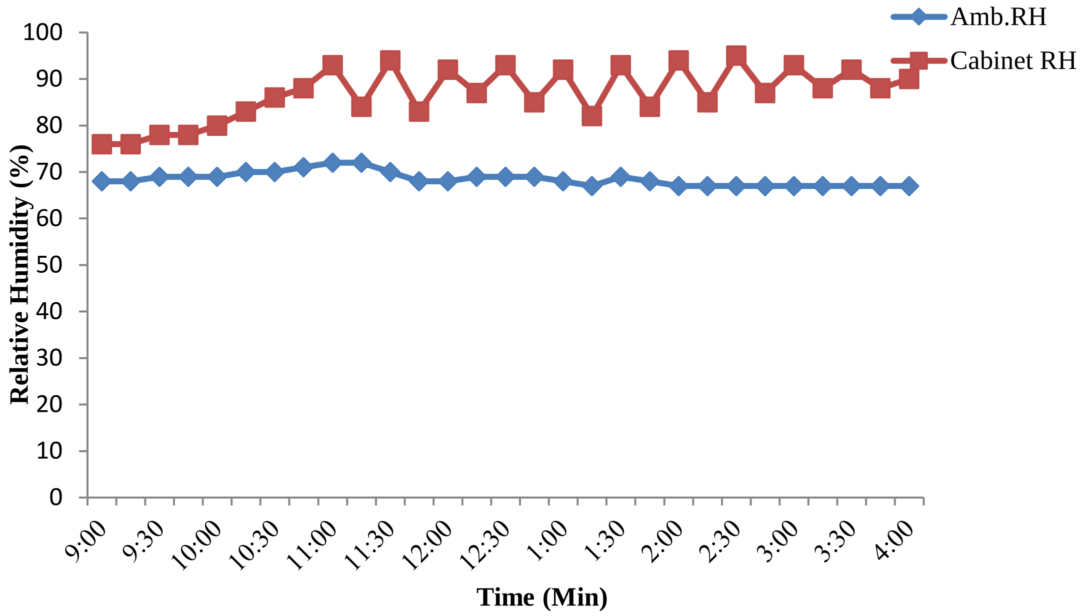

Figure 7.b: Variation of relative humidity against time on no-load condition

3.2 System Tested with Fruits Samples

Figures 8 (a and b) depict analysis of the obtained daily experimental result of the system in load condition using fresh fruits (cucumber and pineapple) considered in this study. As shown in Figure 8a, the samples inside the system experienced gradual drop in temperature and thereafter maintained an appreciable constant low temperature between (7°C-10°C) However, the control sample kept in the open air initially gained heat and latter maintained atmospheric temperature values of about 31°C. Similarly, the emission temperature result of the control sample kept in the open air recorded using a temperature measuring device as shown in Figure 6 revealed an increase in emitting heat by the fruits with time changing. This behavior encourages bacterial infestation on the fruits and thus reduces their quality. On the Physiological loss in weight (PLW), the control samples kept in the open air lost about 54% of its weight due to moisture lost after two weeks of preservation period, the weight reduced from 7kg to 3.2 kg and some of the products started decaying after 6 days. However, the preserved samples kept inside the developed MCBRCS lost about 13% of its weight, only for period of preservation, the weight reduced from 7kg to 6.1kg. Also, the physical appearance of the preserved products is attractive and marketable as shown in Figure 9. These result agreed with those observed in the study of [32] and it also correlate with that of [21]

The results from these figures generally revealed that the ambient temperature and the emission temperature ranged between 27 ^{o} C to 33 ^{o} C and 25 ^{o} C to 31 ^{o} C respectively throughout the testing period. These conditions aid bacterial infestation on the samples thus resulted in decaying and depreciation of the fruits quality as shown in Figure 10. However, the cabinet temperature is found to falls from 17 ^{o} C to 7 ^{o} C between the time frame of 2 hours i.e. (from 9am – 11 am) thereafter the cooling system is observed to maintain temperature range between 7 ^{o} C to 10 ^{o} C for the preserved sample. At 7 ^{o} C being the minimum set point temperature of the TCD used in this study, when the temperature falls below the 7 ^{o} C, the system compressor is observed to switch off for a period of 20 minutes and as the cabinet temperature rise to 10 ^{o} C being the maximum temperature set point of the TCD targeted in this study, the compressor actuate after the 20 minutes and the cabinet system maintain this mode of operation for the rest of the testing period. Additionally, considering the trend of the results displayed in Figure 8.b the ambient relative humidity is observed to fall from 68% to 45% and that of cabinet relative humidity increased from 65% -85% for a period of 2hours and 20 minutes and later maintains RH fluctuating between 85%-95%, for the rest of the testing period. These results confirmed and support previous report pointed out in the study of Wilson *et al*, 1995 that most storage fruits and vegetables crops require low temperature and high relative humidity.

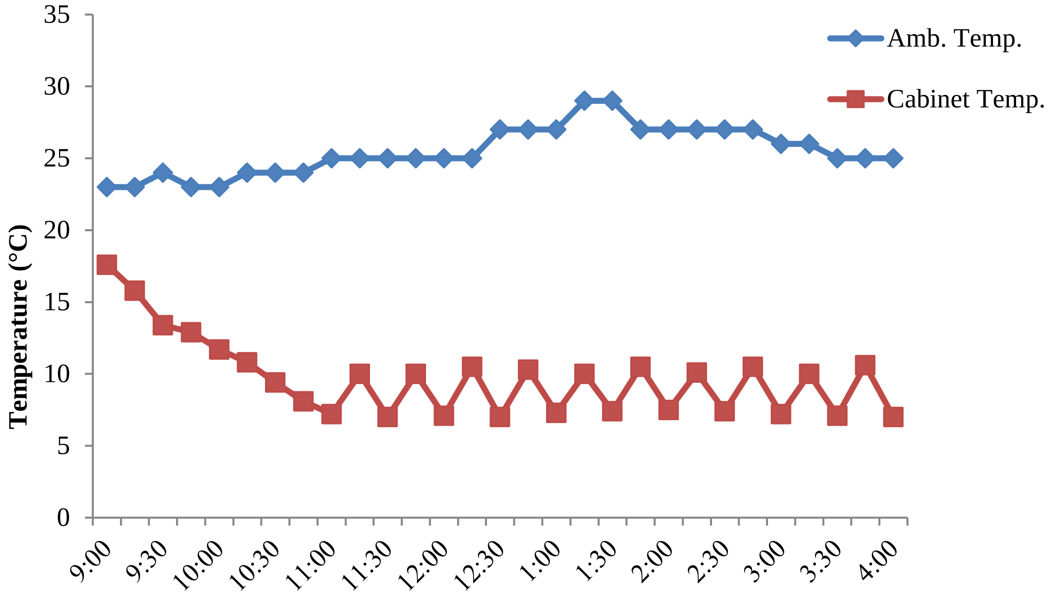

Figure. 8.a: Variation of temperature against time on no-load condition

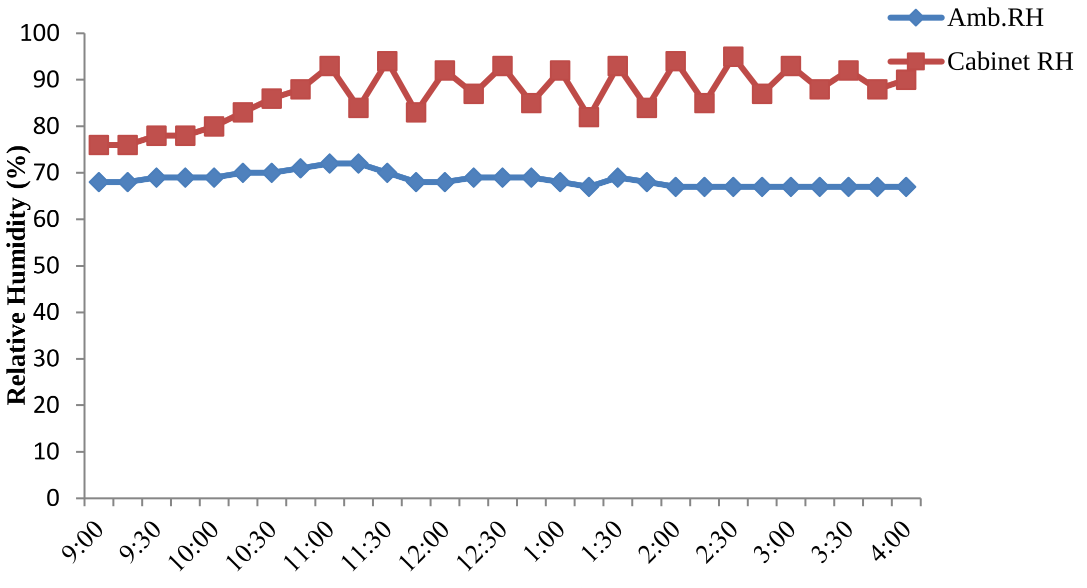

Figure. 8.b: Variation of relative humidity against time on no-load condition

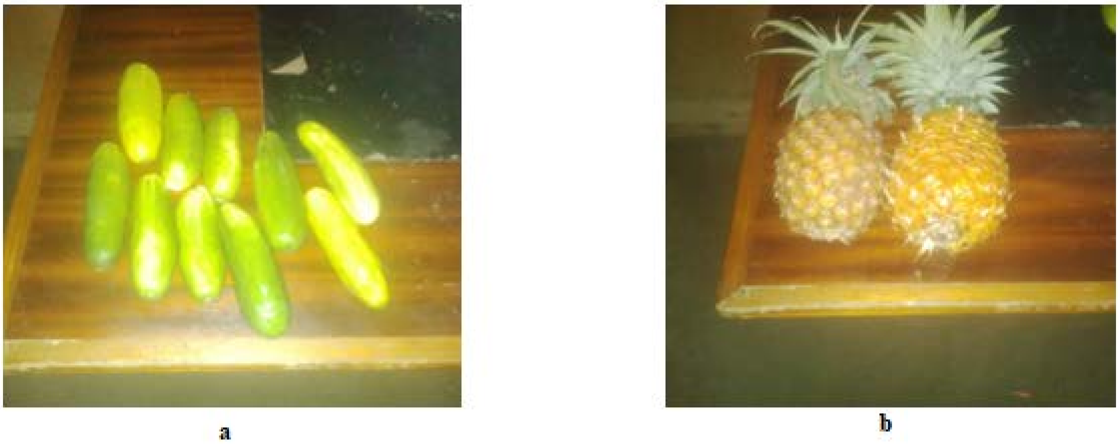

Figure 9: Preserved fruits samples inside the developed MCBRCS after 14 days: (a) cucumber and (b) pineapple

Figure 10: Tested fruits samples in ambient storage after 14 days: (a) cucumber and (b) pineapple

3.3 Organoleptic Test of the Tested Fruit Samples

In order to determine the quality of the preserved samples considered in this study, organoleptic test of the samples kept in the developed MCBRCS was carried out in the Department of Food Science and Technology, FUTA. The moisture, ash, crude fat, and crude fibre of the selected samples were determined in accordance with the standard methods of the association of official analytical chemists (AOAC, 1999). The nitrogen, crude protein and Carbohydrate contents were determined using the micro-kjeldahl method as propose by [33]. The mineral analysis of the tested fruits sample was also carried out using, atomic absorption sphectrophotometer (Buck scientific model 200A). The organoleptic test shows that the fruits samples kept inside the cabinet were found to be in good condition after 14 days of preservation (See Figure 9). On the other hand, the fruits sample spread in the open air were found to be in bad state after 14 days of ambient storage condition unlike for the fruits samples stored in the MCBRCS used in this study of which no visible shrinkage in size was observed and still give the same taste and smell as well of the case before the experimental test, the fruits samples kept under ambient storage present shrunk in size became discoloured, rotten and had a different smell from the original samples after 6days of the testing period (See Figure 10).

Proximate analysis of the tested fruits samples presented in Table 1 comparatively depicts high moisture content levels for the tested samples considered in this study. This indicates the reason why fruits are regard as good source of hydration for the body as well as possessing the ability to quench thirst. It is also revealed that decreased moisture content of the tested samples reduces their nutritive factors such as fat, protein and carbohydrate thereby reducing the energy value of the tested fruits. This behaviour is observed to be more pronounced for the unpreserved fruits samples but moderate for the preserved samples (fruits) obtained in this study. The observed low value nutritive factors such as fat, carbohydrate, crude fibre for the unpreserved sample indicate significant reduction of these nutritive factors in the sample. This result agreed with the report established in the study of [34]. However, significant presences of these nutritive factors were observed for the preserved fruits samples considered in this study. Additionally, the recorded value of carbohydrate ranged between (20.01% - 20.65% and 11.62% - 12.09%) observed for the preserved pineapple and cucumber respectively compared to the recorded value of carbohydrate ranged between (20.7% - 21.6% and 12.29% - 12.86%) analyzed for the fresh pineapple and cucumber respectively revealed that the preserved fruits samples still possess significant value of carbohydrate expected in fresh fruits compared to the unpreserved fruit obtained in this study. The observed proximate composition results indicate that the preserved fruits possess moderate source of sugar as pointed out in the previous studies of [35-36]. The proximate analysis result from this study show that the cooling storage system achieved in this study performed effectively.

Table 1: Proximate Composition of the Tested Fruits Samples

Samples	**Moisture (%)**	**Ash (%)**	**Crude fibre (%)**	**Fat (%)**	**Protein (%)**	**CHO (%)**
Fresh Pineapple						
Test 1	79.02	0.056	2.76	0.74	1.76	20.7
Test 2	78.15	0.060	3.02	0.85	2.04	21.6
Fresh Cucumber						
Test 1	91.27	0.09	1.84	1.06	1.78	12.29
Test 2	92.20	0.06	2.06	1.23	1.81	12.86
Unpreserved Pineapple						
Test 1	82.22	0.43	1.87	0.14	1.61	13.73
Test 2	82.44	0.41	2.01	0.15	1.61	13.38
Unpreserved Cucumber						
Test 1	87.50	0.63	1.23	0.38	1.59	8.67
Test 2	86.53	0.64	1.28	0.37	1.61	9.57
Preserved Pineapple						
Test 1	84.92	0.22	2.37	0.73	1.71	20.01
Test 2	85.38	0.19	2.81	0.79	1.82	20.65
Preserved Cucumber						
Test 1	88.50	0.36	1.64	0.93	1.79	11.62
Test 2	88.20	0.49	1.59	0.94	1.75	12.09

Similarly, the result of the mineral composition of the test fruit samples presented in Table 2. revealed that the preserved fruits are of better quality as about 95% of the expected mineral content such as (K, Ca, Na and Vitamin C) in fresh fruits are yet maintained in the samples after two weeks of preservation using the developed MCBRCS in this study. This is not the case for the fruits samples kept under ambient storage where about 66% of the mineral content got loss due to the environment bacterial infestation during the testing period. It is also noticed that compared to the fresh fruit samples considered in the study, the unpreserved fruits had virtually loss about 95% of its vitamin C while the preserved fruits still maintain about 97% of these minerals. It is interesting to point out that according to [37] vitamin C is vital for absorption as well as the formation of intracellular protein collagen in the body system. Similarly, potassium content of fruit is for intracellular and extracellular cations formation in the body. Akpanyung [38] also pointed out that sodium content of the fruits involved in the regulation of plasma volume, acid base balance, nerve and muscle contraction in the body. Therefore, by achieving a significant quantity of these minerals in the preserved fruits samples obtained after two weeks of preservation using the developed MCBRCS signifies that the system performed satisfactorily and could be used as a veritable tool to increase the shelf life of post harvesting perishable agricultural products.

Table 2: Mineral Composition of the Tested Fruits Samples

Samples	**Calcium mg/100g**	**Iron mg/100g**	**Potassium mg/100g**	**Sodium mg/100g**	**Vitamin.C mg/100g**
Fresh Pineapple					
Test 1	11.18	0.56	10.01	3.21	28.22
Test 2	11.22	0.49	10.06	3.20	28.51
Fresh Cucumber					
Test 1	14.08	0.30	128.00	5.20	12.07
Test 2	14.04	0.32	124.00	5.16	12.04

Unpreserved Pineapple					
Test 1	5.88	0.21	3.49	1.08	1.52
Test 2	5.89	0.26	3.51	1.10	2.01
Unpreserved Cucumber					
Test 1	7.38	0.10	32.00	1.21	2.07
Test 2	6.34	0.09	34.00	1.16	2.04
Preserved Pineapple					
Test 1	10.48	0.51	9.51	3.10	27.42
Test 2	10.50	0.46	9.49	3.08	27.46
Preserved Cucumber					
Test 1	13.48	0.31	126.00	5.18	11.47
Test 2	13.44	0.28	120.00	5.10	11.44

4. CONCLUSSION

In this study, micro controller-based refrigeration control system for preservation of fresh agricultural produce (fruits) was developed and its performance evaluated. The cooling system was tested on no-load. It was thereafter used to preserve fresh fruits (Pineapple and Cucumber). The attained micro controller-based refrigeration control system performed up to expectation as tested samples maintained their fresh condition for the 14 days for which they were tested. The needed optimum storage temperature for the preservation of the selected fresh fruits samples was achieved at 7°C - 10°C. On quality of the stored fresh fruits products, the cooling system developed maintained expected better quality in comparison to the ambient storage samples as observed based on organoleptic test carried out in this study (See section 3.4). The effects of excessive chilling or freezing injury commonly observed with the multipurpose refrigerating system were naturally eliminated in using the developed micro controller-based refrigeration control system. This cooling system is attained by incorporating an existing domestic vapour compression refrigerator system with a redesigned temperature control device (TCD), a temperature monitor medium through which the stored products were only exposed to their required optimum storage temperature. With respect to the organoleptic test in terms of proximate and mineral composition analysis, the quality of the stored items (fruits samples) results obtained revealed that the preserved fruits using the developed MCBRCS are of better quality in comparison to the unpreserved fruits sample as about 95% of the expected mineral content such as (K, Ca, Na and Vitamin C) in fresh quality fruits are yet maintained in the preserved samples after two weeks of preservation while about 66% of the mineral content of the control sample got loss due to the environment bacterial infestation within 6 days of the testing period. This work has clarified means of preserving fresh fruits from waste, which if adopted will reduce postharvest losses, hence increase income generated from agricultural produce (fruits). The findings from this research would help innovative farmers who yearn for modern storage technology to expand and improve their storage methods by storing quality produce to enable them to have access to various market opportunities.

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