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Development and Performance Evaluation of an Instrumented Hybrid Onion Storage Facility

Babatunde Oluwamayokun SOYOYE, Ademola Samuel OKUNJOYO, Adenike Mary ADEROTOYE

Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, Federal University of Technology Akure, Ondo State, NIGERIA
bosoyoye@futa.edu.ng/asokunjoyo@futa.edu.ng/amaderotoye@futa.edu.ng

Corresponding Author: bosoyoye@futa.edu.ng, +2348036577499
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Abstract: *Onion (Allium cepa L.) is one of the oldest bulb crops, known to mankind and consumed worldwide. It is valued for its distinct pungent flavour and is an essential ingredient for the cuisine of many regions of Africa especially Nigeria. This study aimed to develop and evaluate the performance of a refrigerated onion storage facility. The designed facility was simple, efficient, and cost-effective, with a focus on user-friendly operation and packaging of onions in zippered bags. The experiment involved slicing and dicing onions of equal size, which were then placed in zip bags and monitored over a week. The mass of the samples was measured daily to observe the changes. Additionally, laboratory analysis was conducted to assess the proximate composition, phytochemical contents, and heavy metal concentration of the onions. The results showed that the storage facility maintained a cooling rate of 0^{o}C and experienced fluctuations in temperature due to external weather conditions. The relative humidity ranged from 18% to 19%, indicating the coldness of the storage facility. The analysis of the onion samples revealed high moisture content, with values ranging from 80% to 90%. Other compositional parameters such as crude protein, CHO, crude fibre, fat content, and ash content were relatively low. In terms of phytochemical analysis, flavonoid content was found to be relatively high compared to saponin, alkaloid, and tannin contents. Flavonoid content was highest in the raw state of the onion. Heavy metal analysis showed significant differences in the concentrations of iron (Fe), manganese (Mn), and zinc (Zn), while copper (Cu) did not exhibit a significant effect. The developed refrigerated onion storage facility helps in maintaining a steady supply of onions throughout the year, reducing seasonal fluctuations and ensuring that processors have access to raw materials regardless of harvest times. The proximate composition analysis indicated that before and after storage of the onions, the moisture content and nutrients of onions was maintained. The phytochemical analysis revealed a significant presence of flavonoids, while heavy metal analysis showed varying concentrations of Fe, Mn, Zn, and Cu.*

Keywords: *Onion Storage, Hybrid, Proximate Composition, Phytochemical Analysis, Heavy Metal Analysis*

1. INTRODUCTION

Onion (*Allium cepa* L.) has been valued as a food and a medicinal plant since ancient times, it is a vegetable bulb crop that is known to most civilizations and is enjoyed all over the world. Its cultivation is second only to that of the tomato [1]. It is a short duration horticultural crop grown at low latitudes. Due to its highly regarded flavour, scent, and distinctive flavour as well as the therapeutic benefits of its flavour compounds, it is referred to as the "Queen of the Kitchen" [2]. Onion is used throughout the year, for example in curries, in the form of spices, in salads, as a condiment, or cooked with other vegetables, such as boiled or baked. It is also used in different forms of processed food, e.g. pickles, powder, paste, and flakes, and it is known for its medicinal values. George *et al.* [3] stated that onion is a biannual crop that grows from seeds to produce bulbs in the first season and flowers in the second season to produce seeds. According to Hussaini *et al.* [4] the crop ranks second in importance after tomatoes among the vegetables in Nigeria. Aliyu *et al*. [5] documented that it has been proven that this plant is mostly farmed for its bulbs, which are almost always used in homes. Worldwide demand exists for onions. It is a component of primary meals in Nigeria and is primarily used to season and flavour a wide range of dishes. It is also harvested in the green state and used as salads. Bulbs could be boiled, used in soups and stew, fried or eaten raw. As documented by USDA [6] and Patel and Rajput [7], including other vegetables, onions give the body a good number of minerals, vitamins including vitamin A and C, and other nutrients. Griffiths *et al*. [2] conducted a study on onions' health advantages and found that they had antithrombotic, anti-asthmatic, and antibacterial properties. In addition, Michael [8] uncovered that onions are one of the food plants with moderate levels of anticancer properties. Onion cultivation in Nigeria is confined to the Sudan Savanna zones especially Kano, Gombe, Sokoto, Kaduna, Plateau and Bornu States [9]. This research work was conducted in the quest for the uniform distribution of onion throughout the nation (Nigeria) and still preserve its nutritive values thereby reducing its post-harvest wastage.

2. MATERIALS AND METHODS

2.1 Machine Description and Working Principles

In the designing of the onion storage facility, the temperature sensor and relative humidity sensor are the main component of the design since they both serve as the nerves in the control box of the system. During the connections, the main plug-in wire of the refrigerator was detached and connected using a wire connector to the control box with both the temperature (T) sensor and the relative humidity (RH) sensor to the LCD display control box. The reason for this connection is to make the (T) and (RH) sensors send direct signal to the thermostat so that power can be cut off partially from the system when the set values of both the (T) and (RH) sensors have been attained for proper regulation of the refrigerator.

The solar powered system receives it current from the sunlight rays trapped by the solar panel which charges the battery directly with the help of the solar charger. For the solar charging device to work perfectively, an inverter system was introduced so that the D.C current from the battery can be converted to A.C current. The solar panel was connected to the display solar charger controller for monitoring the charge supplied to the solar. The inverter has two output, one which is plug directly to the alternating current supplied through the control box and the other which is from the refrigerator to the inverter which supply current to the refrigerator directly whenever there is shortage of power.

When using the refrigerator, lowering the air temperature of the onion storage slowly to 33°F (0.5°) is ensured. The onions must not be cooled too rapidly as this could result in damage to the onions from the low humidity and other stress damage. A guideline reduction of onion pile temperature at a rate of about 32°F (0.5°C) per day was taken into consideration. This helps to keep the onions in a refrigeration system down to a reasonable level. The refrigerator system size is 0.135 hp of compressor capacity per 6 zip locked pieces of onions which is cooled primarily by refrigerator. The design of the refrigeration system was made so that mixed refrigerated air passing through evaporator coils with recirculated warmer return air and the dehumidification of the refrigerator through the exhaust fans, so that the ventilated air will not be more than 28°F (-2°C) cooler than the coolest onions in the storage and in no case lower than 32°F (0°C) since the highest cooling point of the refrigerator used is 0^{o}C. The conceptual design of the developed hybrid instrumented onion storage facility is shown in Figure 1.

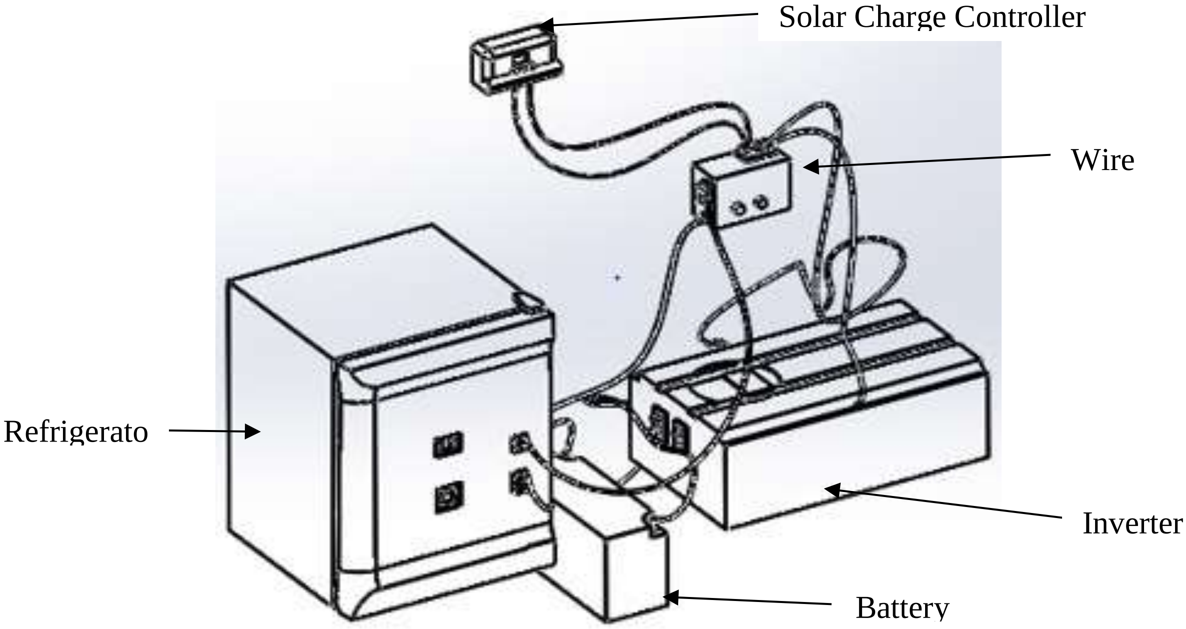

Figure 1: Conceptual design of the developed hybrid instrumented onion storage facility

2.2 Design Consideration

The design was targeted towards achieving a high efficiency, preferable low construction cost and the ease of maintaining the system with adjustable temperature and relative humidity sensors together with the transmission of exact power from either of the source and large compartment space for storage of onions.

2.3 Fabrication Parts of the Storage Facility

The principal operation that was involved in the construction of this project were: Connection of relative humidity sensor (RH), temperature sensor, inverter, solar charger controller, exhaust fans, LCD display reading system, control box, battery and solar panel (Figures 3 to 7).

S/N	COMPONENTS
1	SOLAR CHARGER CONTROLLER
2	CONTROL BOX
3	INVERTER
4	SOLAR BATTERY
5	MINI FRIDGE
6	EXHAUST FANS
7	WIRE CONNECTOR
8	SOLAR PANEL
9	TRANSPARENT DOUBLED LAYER PLASTIC COVER

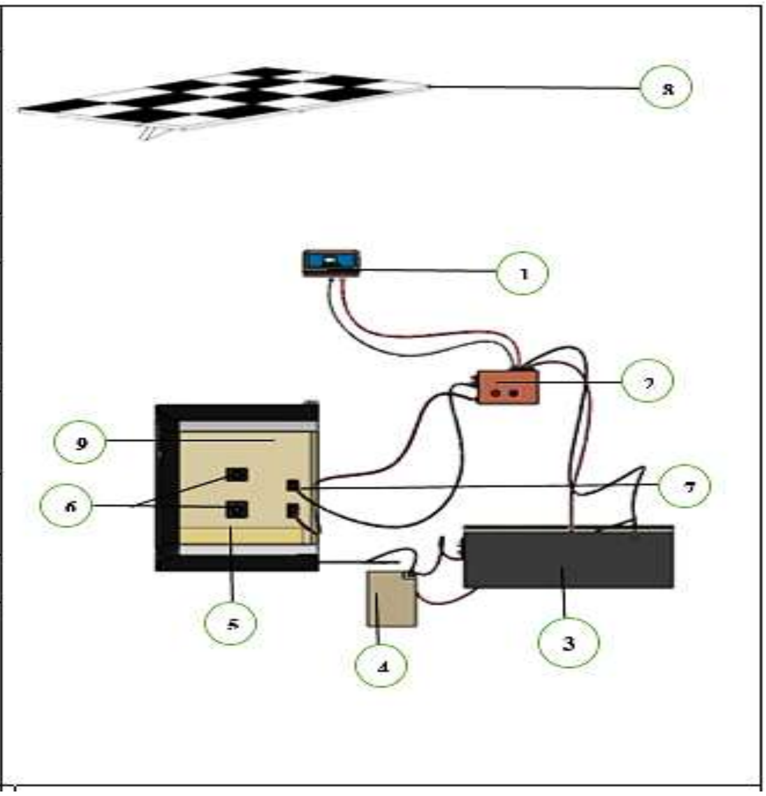

Figure 2: A labelled diagram view of the developed hybrid instrumented onion storage facility

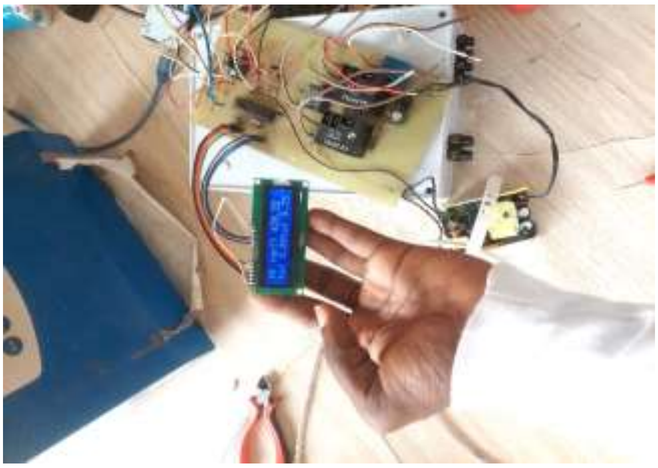

Figure 3: Configuration of LCD

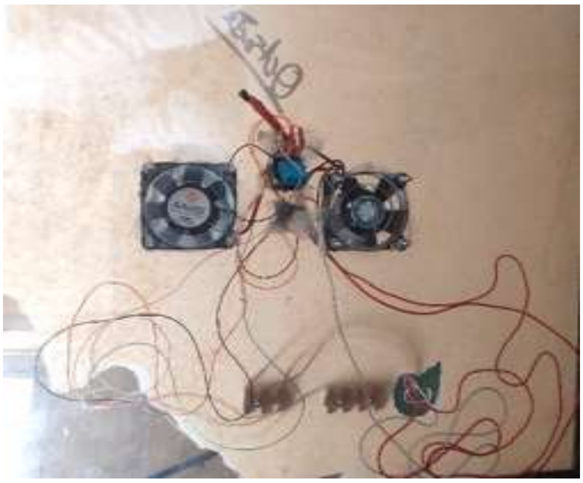

Figure 4: Exhaust fans with sensors

Figure 5: Solar charger controller

Figure 6: Control box

Figure 7: The developed hybrid instrumented onions storage facility

2.4 Sample collection and preparation

The experimental process of onions storage facility was carried out at the crop processing laboratory of the Agricultural and Environmental Engineering at the Federal University of Technology Akure, Nigeria. The onions were procured from Oja Oba Market in Akure, South-Western City of Nigeria. The onions were sorted and peeled and then cut into slices and diced forms of almost equal sizes. The onions were then enclosed in a zip bag and place in a tray to see the interaction between it and the open environment. At an interval of three days, a portion of the sample was taken for laboratory analysis. The zipped samples were labelled D1 (diced 1), S3 (sliced 1) and S4 (sliced 2). It was weighed every day and observed to see the changes that has taken place in the samples. Samples D1 and S3 was taken to the laboratory for quantitative analysis. Onions (Control) were cut in halves which is a very popular way of storing a part of used onions for later consumption. This was labelled S1, S2 and S3 after which it was placed in an open environment along sides with the sealed ones. At intervals of 30 minutes, the initial moisture content of newly acquired onions was assessed. Each experiment was run in triplicate sets. In the process of storing onions in the storage facility, onions were peeled, sliced and diced. The sliced and diced onions labelled F3 and F4 weighed 64.36g and 65.62g respectively was sealed inside zip bag and placed in the refrigerator for storage (Figure 8). The onions were stored in a cool, dry, and dark environment so as to eliminate direct moisture from the environment and bacteria activities. They were sliced in ring forms and diced shapes and were packaged in a zipper bag/ plastic wrap. The wrap serves a barrier between the onions and moist environment of the refrigerator. During the experimental processes and to ensure an interrupted experimentation, the onion storage facility was placed in a well-ventilated room. The solar panel was placed in an obstacle free environment so as to eliminate shadow cast. The refrigerator door was cut out by incorporating a suction fan which automatically rotates, open and closes to expel pressure out of the refrigerator when the pre-set relative humidity has been reached. Also, a hybrid change over switch was designed for the facility so it can automatically change when necessary. And, cooling points of (-0 ^{o}C) to (-2 ^{o}C) was pre-set to see if the onions life span will be maintained and to see if there's declination in the nutrition of the product. The samples were then taken to the laboratory for proximate and phytochemical analysis.

Figure 8: Onions in refrigerator

2.5 Statistical Analysis

A one-way analysis of variance (ANOVA) test was used to establish the significant effect of length of the onion storage on the proximate and phytochemical properties of the stored onions. All the data analysis was carried out using Statistical Package for Social Sciences (SPSS) software (Version 25.0, SPSS Inc. Chicago, USA).

3. RESULTS AND DISCUSSION

3.1 Experimental Results

The experiment was conducted to check if all the requirements of the developed Instrumented hybrid onion storage facility could be achieved. Table 1 shows the overall performance of the storage facility based on its functionality requirements. These results indicated that the onion storage facility successfully achieved all the required objectives when tested. The Instrumented hybrid onion storage facility was able to do the following actions:

i. Displays the needed (T) and (RH) data of the facility on the LCD screen while working.
ii. Log the appropriate data's of (T) and (RH) on the SD Card for calculation.
iii. Automatic change over takes place between powers supplied and solar powered battery.
iv. Fans exhausts opens and closes (rotates) at pre-set relative humidity.
v. Solar panel charges the battery and the solar charger controller regulates the charge.
vi. The refrigerator cooling rate does exceed the pre–set temperature -0 ^{0}C / 32 ^{0}F to -2 ^{0}C / 28.4 ^{0}F.

Table 1: Functionality test of the storage facility

S/N	Goals	Results
1	System displays the accurate (T) and (RH) on the LCD screen	Successful
2	System logs accurate data of (T) and (RH) of the refrigerator	Successful
3	System changes automatically on varying power supplied	Successful
4	System fans operates on pre-set values of (T) and (RH)	Successful
5	System solar charger regulates the charge of battery	Successful
6	System cooling rate does not exceed the pre-set values	Successful

3.2 Temperature and Relative Humidity Analysis

The temperature gradient relationship and the relative humidity of the refrigerating system of the storage facility were monitored in the morning, afternoon and evening for a week and it was observed that the temperature of the storage facility maintains a cooling rate of -0 ^{o}C and fluctuates in instances when the surrounding weather of the storage facility was 37 ^{o}C high and the relative humidity tends to change from 18% to 19% respectively signifying the coldness of the onion storage facility. The highest temperature (41.67 ^{o}C) were logged in the afternoon period with a relative humidity of 19% while the lowest temperature (0 ^{o}C) was logged in the early morning and evenings with a relative humidity of 18%. The mass of the sliced onions was also monitored and recorded as well as that of the control (Tables 2 and 3). It was noted that the loss in mass of the slice onions was not significant (Table 2) compared to the control samples (Table 3). This was due to the pre-set conditions the storage facility was made to work upon. Rapid and maintained cooling range reduce the moisture migration in the onions which were deposited as a result of precipitation.

Table 2: Change in mass for 1-week

Days	S3	S4	D1 (grams)
1	41.96	47.54	51.90
2	41.69	47.28	51.61
3	41.23	46.94	50.43
4	40.66	46.52	50.13
5	40.13	45.81	49.98
6	39.94	45.10	49.92
7	39.66	44.69	49.66

Table 3: Weighed mass of Onions (Control)

Day	S1 (grams)	S2 (grams)	S3 (grams)
1	65.51	57.16	43.19
2	57.89	56.73	36.30
3	52.87	53.27	32.21
4	50.70	51.75	30.32
5	49.84	50.32	28.79
6	49.18	49.30	28.03
7	48.75	48.51	27.96

Figure 9: Onions in tray after one week

3.3 Laboratory Analysis

3.3.1 Proximate analysis

The proximate analysis was conducted on the samples to know the average compositions of the moisture content, fat content, ash content, crude fibre, crude protein, and CHO in the onion samples. The analysis of variance (ANOVA) table of the proximate analysis test is shown in Table 4, it was seen from the table that different storage period and method has a significant effect on the onions composition, such as moisture content, fat content, ash content, crude fibre, crude protein, and CHO. It was seen that the moisture content of the samples is very high compared to any every other parameters considered. The indication reveals that the moisture content in the sample D1 is the highest in percentage of 90% while the lowest moisture content was recorded for sample F3 which is 80% (Figure 10). The highest and lowest range result of the moisture content from the graph satisfies the moisture content test carried out in the laboratory using the laboratory dry oven in which the result is 85% moisture content. Given the other test results from the graph, crude protein is just below 10%, CHO is below 10%, crude fibre is below 5% while fat content and ash content are relatively low in the samples. Ash content is an indication of high inorganic mineral content [10]. This result indicates that there are few inorganic minerals in onions (*allium cepa*). The sample *Allium cepa* had protein concentration below 10 % [11]. The samples' moisture content indicates that they cannot be kept in storage for an extended period of time without microbiological and biochemical deterioration [10].

Table 4: The Proximate Analysis of the Onion Samples

Treatments		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Moisture content	Between Groups	119.868	5	23.974	57.799	.000
	Within Groups	2.489	6	.415		
	Total	122.356	11			
Fat content	Between Groups	.188	5	.038	4.908	.039
	Within Groups	.046	6	.008		
	Total	.234	11			
Ash content	Between Groups	.336	5	.067	9.138	.009
	Within Groups	.044	6	.007		
	Total	.380	11			
Crude fibre	Between Groups	1.222	5	.244	18.886	.001
	Within Groups	.078	6	.013		
	Total	1.300	11			
Crude protein	Between Groups	20.529	5	4.106	32.683	.000
	Within Groups	.754	6	.126		
	Total	21.282	11			
CHO	Between Groups	118.209	5	23.642	44.667	.000
	Within Groups	3.176	6	.529		
	Total	**121.385**	**11**			

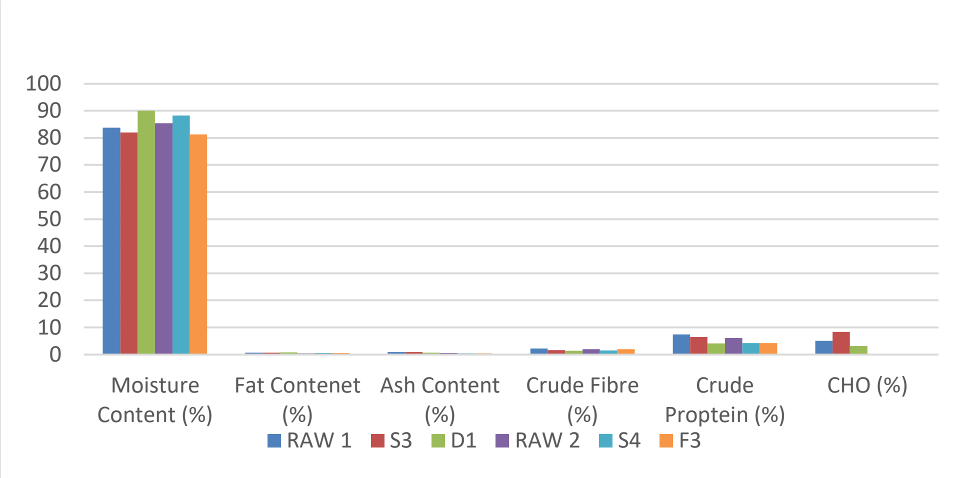

Figure 10: Graph of onion proximate analysis

3.3.2 Phytochemicals analysis

It was shown in Figure 11 that the Flavonoid composition of the samples is relatively high compared to Saponin, Alkaloid, and Tannin. In Flavonoid composition, the raw state of the onion (RAW 1) tends to have a higher flavonoid quantity followed by S3, RAW 2, F3, S4 and D1. The phytochemical present in spices is known to possess both physiological and medicinal activities. The analysis of variance (ANOVA) table (Table 5) shows that the sample has a significant effect on the flavonoid, saponin, alkanoid and tannin of the onion. And there are significant differences between the flavonoid, saponin, alkanoid and tannin because the P-value is less than the 0.05 alpha value ($P<0.05$). Tannins from *Allium cepa* skin have been reported to have antioxidant activity [12], and their presence may support the anti-inflammatory property of the plant and this may also explain its uses in the treatment of ulcer, earache and as antitussive as reported by [10]. Alkaloids are extremely helpful in medicine and are utilized to create a number of expensive medications [13]. The flavonoid profile affects the colour of onion bulbs, because red cultivars are richer in flavonols but also include anthocyanins, unlike white kinds, they often have higher total flavonoid content [10].

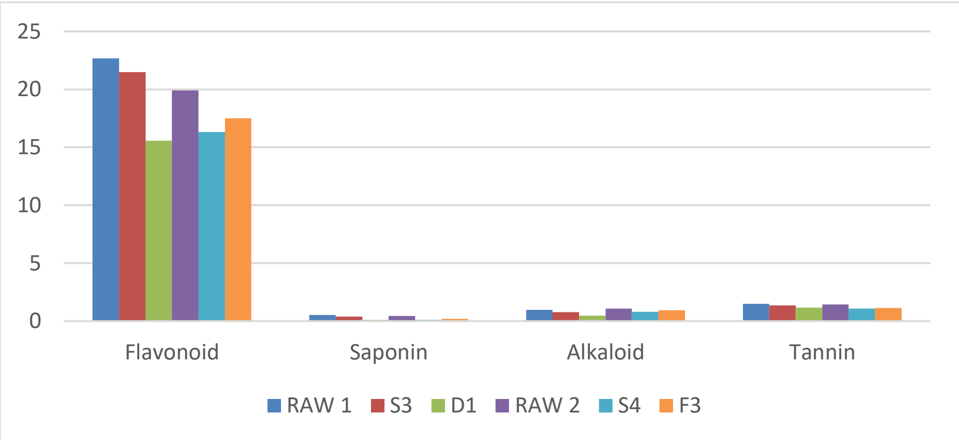

Figure 11: Graph of phytochemical analysis

3.3.3 Heavy metals analysis

Figure 12 shows the average compositions of Cu, Fe, Mn, and Zn in the onion samples. It was shown that the Zn composition of the samples is the highest and followed by the composition Fe when compared to Mn, and Cu. In Zn composition, the raw state of the onion (RAW 1) as the highest quantity followed by S4, F3, S3, RAW 1 and D1. The analysis of variance (ANOVA) shows that the sample has a significant effect on the Fe, Mn, and Zn compositions (Table 6). And there are significant differences between the Fe, Mn, and Zn because the P-value is less than the 0.05 alpha value ($P<0.05$). For the sample Cu it can also be seen that the sample has no significant effect because the P-value of Cu is greater than ($P>0.05$).Heavy metal toxicity may occur due to contamination of irrigation water, the application of fertilizer and metal-based pesticides, industrial emission, harvesting process, transportation, storage or sale. Crops cultivated in heavy metal-contaminated soils accumulate the pollutants more than those grown in uncontaminated soils [14]. Zinc is required for the growth and repair of body tissues, as well as an important element of ligaments and tendons. The heavy metal Zn values found in this study are comparable to those found in investigations that looked at Zn levels in different meals [15]. According to Rauf and Patel [16], Onions need a tiny quantity of copper for healthy development, and copper is a crucial micronutrient for plant growth. However, excessive amounts of copper can be toxic to plants and humans. Manganese is a crucial element for plant growth, and onions need a reasonable amount of manganese for healthy growth [17]. The vital role that iron plays in the human body includes transporting oxygen in the blood and bolstering the immune system [17]. However, excessive intake of iron can have negative effects on health, particularly for people with certain medical conditions.

Table 5: The Phytochemical analysis of the onion samples

Treatments		Sum of Squares	Df	Mean Square	F	Sig.
Flavonoid	Between Groups	83.705	5	16.741	23.376	.001
	Within Groups	4.297	6	.716		
	Total	88.002	11			
Saponin	Between Groups	.305	5	.061	22.131	.001
	Within Groups	.017	6	.003		
	Total	.322	11			
Alkaloid	Between Groups	.486	5	.097	30.252	.000
	Within Groups	.019	6	.003		
	Total	.505	11			
Tannin	Between Groups	.305	5	.061	4.827	.041
	Within Groups	.076	6	.013		
	Total	**.381**	**11**			

Table 6: The heavy metal analysis of the onion samples

Treatments		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	.000	5	.000	1.218	.402
	Within Groups	.000	6	.000		
	Total	.001	11			
Fe	Between Groups	.014	5	.003	20.031	.001
	Within Groups	.001	6	.000		
	Total	.015	11			
Mn	Between Groups	.005	5	.001	12.142	.004
	Within Groups	.000	6	.000		
	Total	.005	11			
Zn	Between Groups	.041	5	.008	1498.097	.000
	Within Groups	.000	6	.000		
	Total	**.041**	**11**			

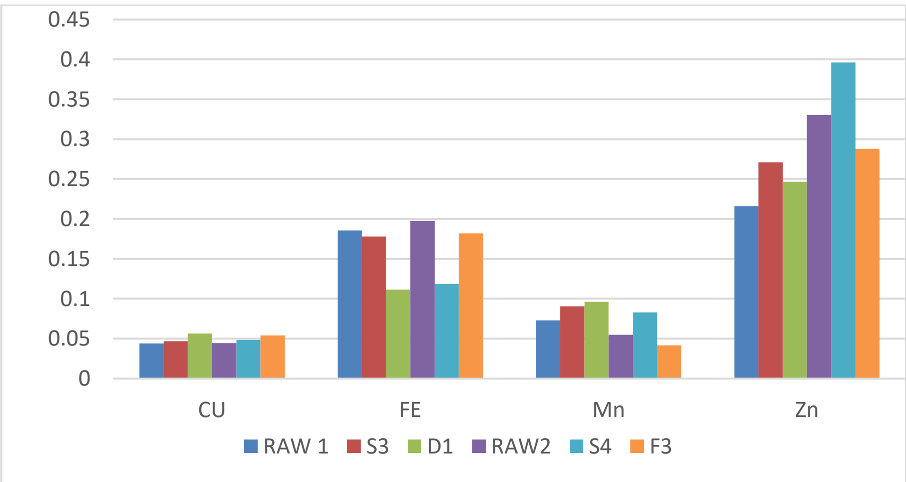

Figure 12: Graph of heavy metals analysis

3. CONCLUSION

This paper presented the design and evaluation of an instrumented hybrid onion storage facility. The facility utilized Arduino code for control response, enabling it to operate according to pre-set conditions. The experimental results demonstrated that the storage facility successfully met its defined requirements. These included the ability to open and close fans based on pre-set pressure, logging internal temperature and relative humidity, displaying real-time temperature and humidity information, seamlessly switching based on available power, and regulating and charging the battery using a solar charger. The performance evaluation of the onion storage facility led to several conclusions. Firstly, the facility effectively preserved the onion samples. Secondly, the temperature and relative humidity gradient within the storage facility remained unaffected by climatic factors and external forces, ensuring the onions were well-preserved. Lastly, the proximate analysis of the onions indicated that the moisture content was maintained at 88%, while other minerals such as CHO, crude protein, and crude fibre were also well-preserved showcasing the significance of the designed storage facility in the conservation of both the proximate and phytochemical properties at safe levels. Overall, this research demonstrates the successful design and implementation of an instrumented hybrid onion storage facility that meets its intended objectives. The facility provides effective preservation of onions, maintains appropriate temperature and humidity levels, and operates efficiently with both constant and standby power supply.

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