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Development and Evaluation of a Composite Storage Structure for Perishable Agriculture Produce in the Absence of Electricity

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ABSTRACT :*A composite storage structure for fruits and vegetables was designed, constructed and evaluated to determine its performance and ease the challenges and problems associated with the storage of perishable farm produce. It has the inner/outer length, breadth and height of 76.2cm/96.52cm, 45.72cm/66.04cm and 30.48cm/40.64cm respectively. The structure is a wall in wall mortar structures with a layer of wet sand of 7.5cm thickness in-between the walls. Tomatoes, chili pepper and okra were used in the evaluation. Temperature and relative humidity of both the system and general environment for control were considered during the experiments. The result from the evaluations showed that environmental factors ranged from 23.9^{0}C to 29.9^{0}C and 78% to 91% for temperature and relative humidity throughout the experimental period. Efficiencies with respect to tomatoes, chili pepper and okra after six days of storage were found to be 53.75%, 59.4% and 70% respectively. The percentage variations in the storage efficiencies to the advantages of the storage system over the control environment are 12% for chili pepper, 21.25% for tomatoes and 40% okra. It was found that the overall efficiency of the storage structure is 59.54 %.*

KEYWORDS: *composite storage structure, environmental factors, farm produce, fruits, relative humidity, temperature, vegetables*

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I. INTRODUCTION

Storage can be considered as one of the crucial operations in salvaging agricultural produce from deteriorations and losses after harvesting. Postharvest loss occurs as the degradation in both quantity and quality of a food production from harvest to consumption. Higher percentage of quantity losses are submitted to characterize developing countries (ACF, 2010). According to the statistics carried out by (FAO, 2000), it was discovered that in the tropics, 40 % of agriculture produced are lost to deterioration due to poor storage facility. The storage facility minimizes deteriorative reactions in fruit and vegetables and enhances their shelf lives, so that the produce will be available for longer periods; this would reduce fluctuation in market supply and prices (Dzivama, 2000). In Nigeria, research showed that at the national level, 24.8 % of children lower than 5 suffered from subclinical vitamin A deficiency while 4.7 % were vitamin A deficient, making a total of 29.5 % who suffered from clinically deficiency and this is due to inadequate storage facility (IITA, 2004). All biological processes was recorded to show direct proportionality in between temperature and the rate of degradation, in that, the higher the temperature the faster the occurrence of natural degradation processes which inevitably leads to loss of color, flavor, nutrients and texture changes (PEF, 2013). The use of cold handling and storage systems to prevent perishable food losses has been extensively embraced and appreciated long time ago in the developed countries, while the developing ones are still struggling to find a place for their feet in the area as a result of erratic power supply, inadequacy of relevant infrastructures and poor disposition on the side of the government towards local farmers who are the major player.

Therefore, various researchers in developing countries have presented alternative measures in different capacity and functionality to reduce these losses that are pertinent to perishable agricultural produce. Vakis (2001) used local grass to develop a cheap cool store in Kenya for storing vegetables by keeping the roof and walls wet through dripping of water from the top of the roof. Evaporative coolers, which rely on wind pressures to force air through wet pads, have also been designed and constructed, especially in some developing countries like India, China and Nigeria (FAO, 2006). Rusten (2005), did an extensive research in the construction of different evaporative cooling systems using locally available absorbent materials such as canvas, jute curtains, etc. Mechanical fans were used in some of the designs which drew air through a continuously wetted pad. Alebiowu, (2005) worked on the development of hexagonal wooden evaporative cooling systems and the system could be sub-divided into three parts head tank and pipelines work ,the through and the frame work made of woods and its ad-joints. The pipe line works at the top of the hexagonal frame supplied water constantly to wet the pad which is made of jute fibre. Wind pressure forced the air through the wetted jute pad. Limitation of this design is that the sufficiency of the evaporative cooler depends on wind velocity (FAO/SIDA, 2006).

Roy and Khurdiy (2006) constructed an evaporative cooled structure for storage of fruits and vegetables with a double wall made of baked bricks and the top of the storage space covered with khaskhas/gunny cloth in a bamboo framed structure. Abdalla and Abdalla (2005) worked on the development of a fan driven evaporative cooler. The research was study the suitability of using palm leaves as a wetted medium. This research was made possible due to the availability of palm leaves in Saudi Arabia. According to the research it was claimed that palm leaves could be used as the wetted media which is locally available to the masses.

Sanni (2009) did a research on the development of evaporative cooling system on the storage of vegetable crops. The major development was implemented by adding a regulated fan speed, water flow rate and wetted-thickness .This was possible as a result of varying temperature and relative humidity within the facility. Dzivama (2000) did a research on the performance evaluation of an active cooling system using the principles of evaporative cooling for the storage of fruits and vegetables. He developed mathematical models for the evaporative process at the pad-end and the storage chamber and a stem variety of sponge was considered to be the best pad material from the local materials tested as pad material.

Mordi and Olorunda (2003) in their study on storage of tomatoes in Evaporative cooler environment reported a drop of 8.2°c from ambient condition of 33°c while the relative humidity increased by 36.6% over an ambient 60.4%. They further reported storage life of unpacked fresh tomatoes in evaporative cooler environment as 11 days from the 4 days. Storage life under ambient conditions while in combination with sealed but perforated polyethylene bags; it was 18 days and 13 days respectively. Olosunde (2006) also did a research on the performance evaluation of absorbent, materials in evaporative cooling system for the storage of fruits and vegetables. Three materials were selected to be used as pad materials: jute, Hessian and cotton waste. The design implemented a centrifugal fan, high density polystyrene plastic, Plywood used as covering for the walls and basement and the top and the main body frame was made of thick wood. The performance criteria included the cooling efficiency, amount of heat load removed and the quality assessments of stored products. The result showed that the jute material had the overall advantage over the other materials. The cooling efficiency could be increased if two sides were padded.

Sushmita et al. (2008) did a research on comparative study on storage of fruits and vegetables in evaporative cool chamber and in ambient. An evaporative cool chamber was constructed with the help of baked bricks and riverbed sand. It was recorded that weight loss of fruits and vegetables kept inside the chamber was lower than those stored outside the chamber. The fruits and vegetables were fresh up to 3 to 5 days more inside the chamber than outside.

II. MATERIALS AND METHODS

In the development of the storage structure, two rectangular wooden formworks F_A and F_B was constructed in section and each form has double layers, one on the outside and one on the inside. In other that the form may be easily removed from the hardened concrete, it was coated with used motor oil which was applied with a brush. After the form was set in position it was braced to prevent bulging while the concrete is being spaded and tamped in place.

A 4 mm mesh sized wire gauze was passed through the form stud and tightened against wood spaces to hold the forms in position. A 5-gallon concrete paste was made using cement sharp sand and gravel. The concrete paste was immediately poured into the form work and left for some days to set so that the concrete will be strong enough to stand alone when the form is being removed. The larger form was filled with river sand which has been sieved with a 2mm mesh sized sieve to a height of 0.051m then the smaller form was placed into the larger one such that there exist a space of 0.051m (on all sides) between the larger and the smaller concrete form.

The space between the 2 forms was also filled with river sand sieved with 2mm mesh sized and thoroughly compacted. The storage structure was then placed under shade to protect the structure from direct sunlight thereby ensuring Moderate Corporation of moisture from the system. A 1.55m high, 1.25m long and 0.59m wide shed was made to protect the structure from rainfall. An aluminum foil was used to line the inside walls of the storage structure so as to avoid contact between the stored material and the storage structure thus preventing spoilage by contamination.

1. Design Calculations for Moulds

a. The volume of the inner mould is given as V_1 and is expressed as

$V_1 = L * B * H$

whereL = Length =762 mm

B = Breadth =457 mm

H= Height = 305 mm

$$V_1 = (762 * 457 * 305)mm^3$$

$V_1 = 0.106m^3$

b. The volume of the outer mould is given as V_2 and is expressed as

$$V_2 = L * B * H$$

Where L = Length =9652mm

B = Breadth =6605mm

H = Height = 4064mm

$$V_2 = (9652 * 6605 * 4064)mm^3$$

$V_2 = 0.259m^3$

2. Mortar Mix

Volume of water used = 5 gallons ($18.93m^3$)

Bag of cement = 1 bag (50kg)

Volume of sand = 5.66 cm^3

Volume of gravel = 8.50 cm^3

Mixing ratio of cement: sand: gravel is given as:

1 bag: 5.66 cm^3: 8.50 cm^3:

3. Reinforcement

For the reinforcement, a galvanize wire mesh was used with the following specifications

Thickness = 0.5 cm

Mesh size = 3 cm

4. Formwork

a. The volume of the inner formwork V_B is given as:

$V_B = L * B * H$

Where L = Length =7670.8mm

B = Breadth =4632.8mm

H = Height = 4098.8mm

$$V_B = (7670.8 * 4632.8 * 4098.8)mm^3$$

$V_B = 0.145m^3$

b. The volume of the outer formwork V_A is given as:

$$V_A = L * B * H$$

Where L = Length =9702.8mm

B = Breadth =6655.8mm

H = Height = 4114.8mm

$$V_A = (9702.8 * 6655.8 * 4114.8)mm^3$$

$V_A = 0.265m^3$

5. Lagging in-between Moulds

Mass of sand used to fill the concrete mould is calculated thus;

Mass of sand is given as $M_S = V_S * \rho_S$

whereρ_S = density of (packed)sand = 300kg/m^3

V_S = volume of sand = $V_2 - V_1$ = $(259.08 - 106.54)mm^3$

$= 0.152$

M_S = $(300 * 152.54)kg$

$= 45.6kg$

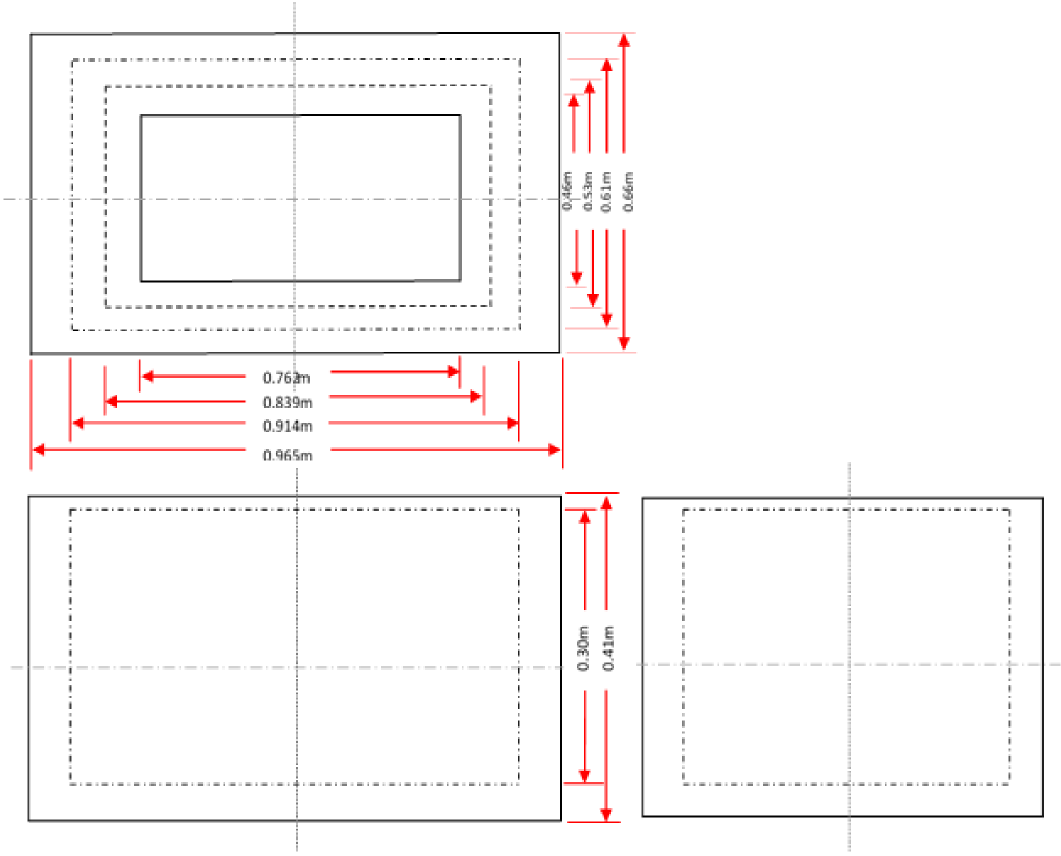

Fig.1: Isometric View of Composite Storage System

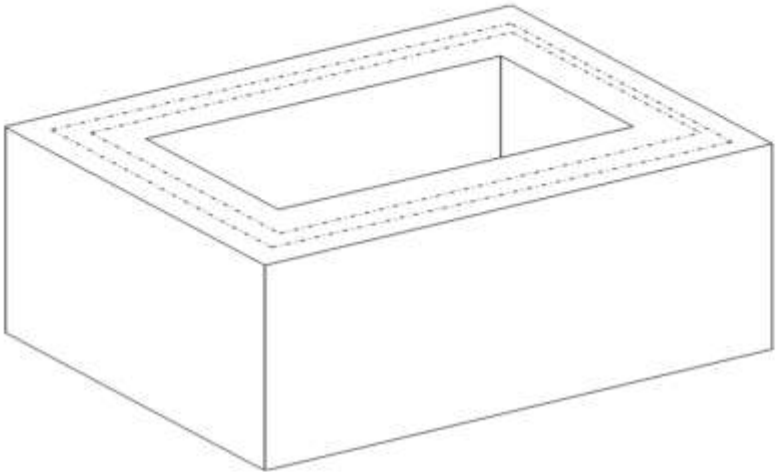

Fig.2: Orthographic View of Composite Storage System

6. Evaluation Method

i. The 0.075m space between the inner and the outer wall which was filled with sand was irrigated with water until it reached saturation using simple automated drip watering systems which consist of a 10cm^3 capacity plastic container fixed with a tap. The initial volume of water to saturate the soil was 36 cm^{3}at flow rate of 0.45 cm^3/minute to a final flow rate of 0.1125 cm3/minute.

ii. The storage structure was covered with a moist blanket and left to stay for 2 hours

iii. After 2 hours the temperature and relative humidity in the system was determined using a device called digital thermometer and the value was recorded.

iv. The temperature of the environment and the relative humidity of the surrounding was also determined and recorded.

v. To maintain a constant temperature and relative humidity in the system, the drip watering system was left open for the continuous flow of water at a flow rate of about 0.0125 cm^3 /min.
vi. A freshly harvested perishable agricultural produce was brought, washed, left to drain and weighed.
vii. A known quantity of the perishable agricultural produce was kept in the storage system while another known quantity was left in the open in container at the same general environment with the storage system as a control.
viii. The temperature and relative humidity of both the system and the surrounding was measured and recorded.
ix. Observations and recordings were made on each day for six days, variations in temperature and relative humidity were noted alongside with changes in experimental samples and controls.
x. The weight variations of good quality produce were recorded and the values were used to calculate the percentage wastage.

7. Rate of Heat Transfer through the Composite Storage System (Unloaded)

The rate of heat transfer through the evaporative cooler is given as:

$$R = K \times A \frac{(T_1 - T_2)}{d}$$

where K = materials coefficient of heat transfer which is

$K_1 + K_2$

K_1 = concrete coefficient of heat transfer

K_2 = sand coefficient of heat transfer

K = 1.5 + 0.06 = 1.56

A = area = width x height

= 660.4 x 406.4

= 0.268 m^2

T_1 = Outside temperature =27.9^{0}C

T_2 = Inner temperature = 27.5^{0}C

d = thickness

d = thickness of outer mould + thickness of the compacted soil + thickness of inner mould

= 203.2 mm = 0.2032 m

$$R = \frac{1.56 \times 268.39 \times (27.942-27.510)}{0.2032}$$

= 0.890 J s^-

III. RESULTS AND DISCUSSIONS

3.1. **Combinations of Temperature and Relative Humidity for both Treatment and Control**

The results on temperature and relative humidity for both treatment and control experiment over the period of the evaluations (18 days) in three phases are showed in Table 1. Temperature (T) on the first day of evaluation in the composite storage system for the treatment sample (chilli pepper) was the highest throughout the evaluation period with the value of 29.70^{0}C contrary to temperature in the surrounding, which is 26.97^{0}C, second to the least temperature in all. Highest value of relative humidity (RH) was observed on the last day of the second phase of the composite storage evaluation with tomato (Table 1). In addition, the same day has the highest moisture gained cut across control and treatment experiments for all phases. Generally, calculated mean temperature and relative humidity through all phases showed that first phase in which chilli pepper was used has the maximum value of 27.67^{0}C and 87.33% respectively, while last phase in which okra was used has minimum values of 26.75^{0}C and 86.61% respectively as shown in Table 1.

Table 1: Combinations of Temperature and Relative Humidity for both Treatment and Control during Evaluation

	Chilli Pepper		Tomato		Okra	
DAYS	Tt/Tc (^{0}C)	RHt/RHc (%)	Tt/Tc (^{0}C)	RHt/RHc (%)	Tt/Tc(^{0}C)	RHt/RHc (%)
1	29.70/26.97	86.33/84.00	28.23/28.50	85.67/85.00	26.97/28.13	85.67/84.00
2	27.70/28.20	88.00/86.67	27.53/27.83	88.33/87.33	28.03/28.10	86.33/85.00
3	27.13/27.20	87.00.33/86	28.23/28.50	85.67/85.00	26.47/27.07	86.00/84.33
4	27.13/27.37	85.00/83.33	27.33/27.60	86.33/85.33	26.00/26.57	87.33/86.00
5	27.37/27.80	88.67/87.67	27.10/27.50	87.33/86.00	26.73/26.77	86.67/85.33
6	26.97/27.30	88.67/87.67	27.20/27.50	89.67/88.33	26.30/26.90	87.67/87.00
Minimum	26.97/26.97	85.00/83.33	27.10/27.50	85.67/85.00	26.00/26.57	85.67/84.00
Maximum	29.70/28.20	88.67/87.67	28.23/28.50	89.67/88.33	28.03/28.13	87.67/87.00
Mean	27.67/27.47	87.33/85.89	27.60/27.91	87.17/86.17	26.75/27.26	86.61/85.28

Tt = temperature for treatment, Tc =temperature for control, RHt = relative humidity for treatment, RHc = relative humidity for control

Effects of the Composite Storage System on Selected Agricultural Produce

The effect of the storage structure on the preservation of agricultural produce is as shown in Table 2. Equal quantityof 8kg were used for both control and treatment experiment for the selected produce (chilli pepper, tomato and okra). For all the produce used, those for treatment experiment are observed to retain higher quantity and quality compared to that of control experiment (Table 2). Table 2 showed that okra exhibited highest percentage gain of 70% for treatment experiment and at the same time the lowest percentage gain for control experiment. Percentage differences presented capability of the system, in that the storage system is capable of preventing 12.9%, 21.25% and 40% of chilli pepper, tomato and okra respectively from spoilage (Table 2).

Table 2: Percentage Difference of Treatment over Control

	Chilli Pepper		Tomato		Okra	
Variables	Treatment	Control	Treatment	Control	Treatment	Control
Iw (kg)	8	8	8	8	8	8
Fw (kg)	4.75	3.72	4.30	2.60	5.60	2.40
Percentage gain (%)	59.4	46.5	53.75	32.5	70.0	30.0
Percentage difference (%)	12.9		21.25		40	

Duration of Experiment = 6, Iw = initial weight, Fw = final weight

Rate of Heat Transfer in Composite Storage System

Fig. 3 showed the simple scattering plot and regression model for variations in the rate of heat transfer from the surrounding through to the storage system. From the resulton regression equations, it was shown that the rate of heat transfer may be dependent on the type of produce as well as intensity of the temperature. The equation with highest value of $R^2 = 0.2113$ corresponded to okra which was observed lowest heat transfer rate, while the lowest $R^2 = 0.0013$, yet highest heat transfer rate is relative to chilli pepper (Fig. 3). Tomato that has grand mean temperature and relative humidity with values in between chilli pepper and okra has regression equations and R^2 values of y= -0.3451To + 2.1909 and $R^2 = 0.1416$ respectively. It was observed that only regression equation for chilli pepper is positive (y = 0.0076Ch + 0.9564) as shown in Figure 3.

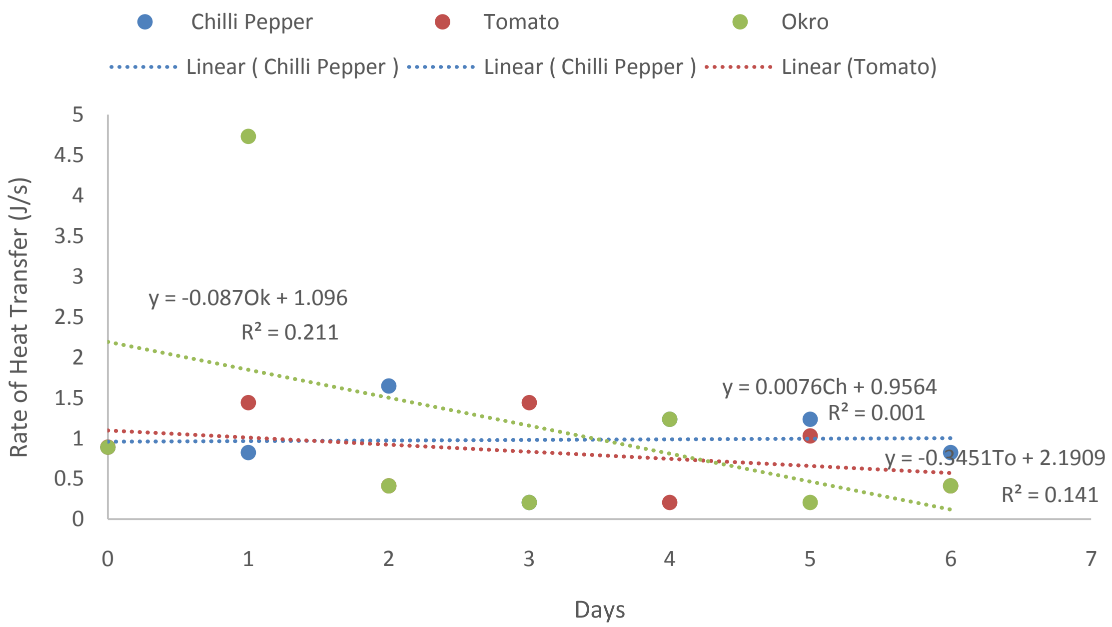

Fig.3: Variation in the Rate of Heat Transfer through Composite Storage System across each Crop for Six Days

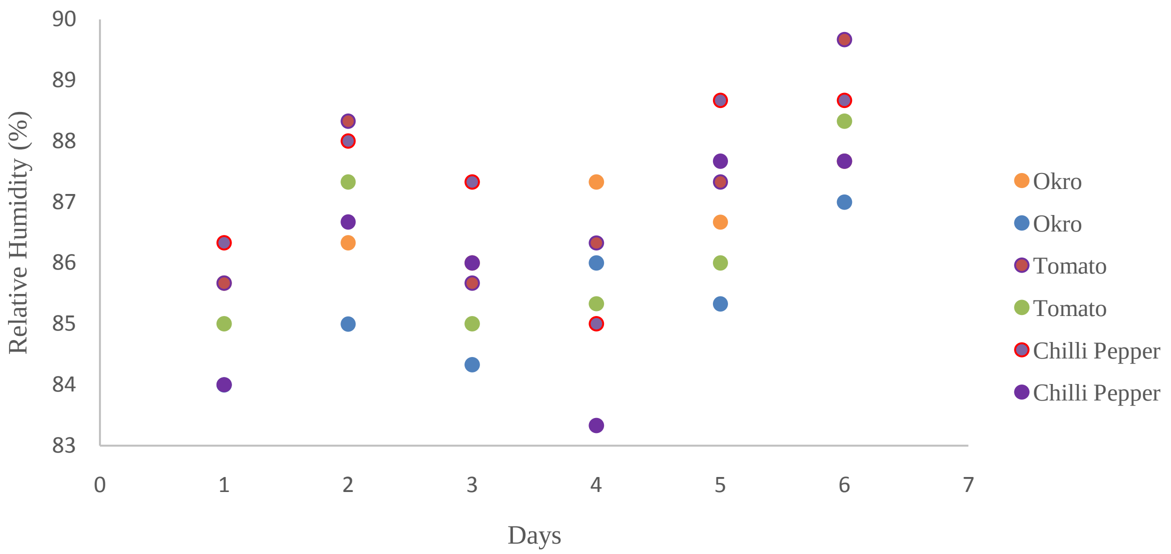

Fig.3: Variation in Relative Humidity in the Surrounding and in Composite Storage System across each Crop for Six Days

IV. CONCLUSION

There are many benefits to installing a monitoring system — some of which strongly interrelate with each other. A properly designed and installed monitoring system offers a deeper understanding of the operational parameters of the system. A close appraisal of the data generated by a monitoring system can reveal a variety of overt and subtle opportunities, including:

Environmental —better knowledge of how energy is used allows you to identify an array of prospects to improve efficiencyand reduce energy consumption.

Reliability — assessment of data from the monitoring system can reveal existing or imminent issues that can adversely affect the operation and product within a facility. Historical data from monitoring systems can help locate and correct both acute and chronic problems, resulting in increased productivity.

Maintenance — Data trends can forecast and notify the appropriate people when discrete equipment parameters may be exceeded, allowing you to plan ahead instead of facing an unscheduled shutdown.

Financial — each benefit discussed above either directly or indirectly influences a business's bottom line. In most cases, the monetary impact from even one or two benefits can quickly justify the purchase and installation of a monitoring system.

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