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Design, Construction and Testing of an Evaporative Cooling Barn for Storing Sweet Potatoes in the Tropics

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ABSTRACT

In this study, evaporative cooling barn was designed, constructed and tested using two varieties of sweet potato. The mean dry bulb temperature and relative humidity of the inside and outside air stream were 25°C and 90% and 31.5°C and 67.5%, respectively. The systems cooling efficiency was determined to be 127%. A test on the evaporative cooling barn using 18 mini sacks, each containing 14 tuberous roots with four replications for 12 weeks, revealed that moisture loss from the two varieties are approximately the same (13%). The moisture content of the root tubers decreased linearly from 68 to 59% and 60 to 52% (wb) over a storage time for TIS 2 and Ukerewe, respectively. Percentage weight loss increased linearly from 0 to 11.4 and 0 to 11.9% for TIS 2 and Ukerewe, respectively. The percentage wholesomeness decreased linearly with storage time from 100 to 76% and 100 to 60% for TIS 2 and Ukerewe, respectively. Percentage weevil damage increased non-linearly with storage time and started 6 and 10 weeks in storage for Ukerewe and TIS 2, respectively; percentage sprouting increased non-linearly with storage time and started 4 and 6 weeks for TIS 2 and Ukerewe, respectively. Percentage shrinkage increased linearly with increasing storage time from 0 to 3.6% and 0 to 4.6% for TIS 2 and Ukerewe, respectively. Percentage decay increased linearly with increasing storage time from 0 to 29% and 0 to 76% for TIS 2 and Ukerewe, respectively.

Key words: Evaporative cooling barn, cooling efficiency, TIS 2, Ukerewe, wholesomeness

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam) is a native of tropical America, which belongs to the family Convolvulaceae. It is sometimes classified as a tuberous root and also known as storage root. It is currently seen as a very important crop and is likely to increase its importance over the next 20 years (Scott *et al*., 2000). The crop is cultivated throughout tropical, subtropical and warm temperate regions where there is sufficient rainfall of 450 mm during the growing season (Onyekwere and Okafor, 1992) to support its growth. The crop does well in many farming conditions and has relatively few natural enemies. According to Ahn (1993), it grows well on light to medium drained textured soils with a pH range of 4.5 to 7.0. Mutandwa and Gadzirayi (2007) also observed that the crop does favorably well on a well drained ferratic, brown humic and calcimorphic soils. The crop is ranked seventh among the most important food crops worldwide (Scott, 1992) and fourth in China as a food crop after rice, wheat and maize (Li *et al*., 1992). In

Africa, sweet potato has recently gained importance because of its potential of alleviating poverty, reducing night blindness and improving the diet of the rural poor. In terms of area under cultivation, Nigeria is the leading producer in Africa followed by Uganda (FAO 2004a, b) although majority come from Southern and Eastern Africa (Root, 1994). In Sierra Leone sweet potato is the third most important staple after Cassava and Rice. Sweet potato yields recorded in Africa is between 41-21 t ha^{-1} in 140 days without fertilizer (IITA, 1985) while unimproved varieties average only 14 t ha^{-1} when harvested in 180-240 days after planting. In Ghana, sweet potato is grown by peasant and small-holder farmers scattered in Upper East and Central regions. These two regions in Ghana produce about 93603 metric tons (SRID, 2007). Yields of sweet potato recorded in Ghana at the subsistence level are quite low compared with the IITA varietal studies. Sweet potato production is a major income earner for small holder farmers in communities like Moree, Jukwa, Efutu, Ankaful and Koforidua in the Central region. Studies conducted to evaluate 19 sweet potato varieties for yield at Ohawu by Missah *et al.* (1991) revealed that an average yield of between 6-16 t ha^{-1} were recorded for improved varieties and 3.2- 10.8 t ha^{-1} for local varieties. However, there has been an improvement in yields due to the release of improved varieties and good agronomic practices.

Nutritionally, the root is noted to contain 21-36 mg of calcium, 38-56 mg of phosphorus, 0.7-2.0 mg of iron, 10-36 mg of sodium, 210-304 mg of potassium, 35-5280 mg of beta-carotene and 24 g of magnesium per 100 g root (Duke, 1983; Walker *et al.*, 1984; Picha, 1985; Woolfe, 1992). Other minerals that are present in trace quantities are zinc, iodine, copper and manganese (Hug *et al.*, 1983). The vitamins present in the roots per 100 g of roots are thiamine 0.09-0.14 g, riboflavin 0.05-0.10 g, Vitamin C 16-22 mg, Niacin 0.6-0.7 mg and Ascorbic Acid 21-37 mg.

Though sweet potatoes have numerous benefits, storage in the tropics is still a challenge due to the high temperatures recorded throughout the year. Under the natural ambient environment the roots last only 1-2 weeks with no temperature control (Rees *et al.*, 2001) and not more than 5 weeks under ordinary storage conditions. However under controlled conditions, the roots can be stored for up to a year (Picha, 1986; Woolfe, 1992). The perishable nature of the crop is mainly due to its high moisture content, thin delicate skin, which encourages excessive respiration and easy damage during handling. On the other hand, the edible tuberous root sustains chilling injury when stored at a temperature below 8°C. More so, problems encountered with storage in the tropics include sprouting, shrinkage, decay, and weight loss. Other researchers (Birago, 2005; Golokumah, 2007) reported that sweet potato farmers in the Cape Coast Metropolis do not store their harvested sweet potato at all because of high deterioration in storage and inappropriate storage technology. Farmers therefore practice piece meal harvesting; that is they harvest in smaller bits and sell to consumers or retailers but this practice ties the land down to the crop, increases infestation of weevil (*Cylas* sp.) and roots become fibrous and renders the roots uncompetitive for the market. This situation drastically limits the potential income of the farmers and discourages large scale production. In addition, Duku (2005) reported that farmers use traditional methods of storage in the metropolis, which involves heaping the roots on the floors in airy dark rooms or under sheds, or on the corridors of homes but the roots store for 2-4 weeks with high losses as a result of rodent damage and domestic animal consumption. This study present the design, construction, and testing of an evaporative cooling barn for storing sweet potatoes in the tropics. Specifically, the study presents an affordable evaporative cooling barn capable of storing small to medium scale productions of the roots for at least three months.

MATERIALS AND METHODS

Study area: The research was carried out at the Technology village of the School of Agriculture, University of Cape Coast from January 2008 to January, 2010. The experimental area falls within the Coastal Savanna zone of Ghana. It is between latitude 05^0 03'N and 05^0 N and longitude 01^0 13'W and is characterized by annual rainfall of about 750 to 1200 mm (Boamah, 2008). There are two main seasons in the area; wet season and dry season. The wet season is divided into major and minor season. The major season start from May to July and peaks at June while the minor season begins from September to November and peaks at October. The main dry season in the area is from December to February. Temperatures throughout the year are usually high, with maximum usually between 30-36°C and minimum between 22-26°C (Ayittah, 1996). The relative humidity in the area ranges from 65 to 70% (Meteorological Station, 2002).

Design considerations and procedure: To design appropriate storage structure for a developing country like Ghana, the following design considerations for the materials were employed for the various component:

- Availability
- Affordability
- Workability
- Cultural acceptability
- Strength
- Suitability

The structure was designed using AutoCad. A site was selected for the construction of the evaporative cooling barn. A shady area was selected, cleared and leveled. Precaution was taken to avoid the trees from interfering with the prevailing air flow and also to prevent trees from falling on the structure during storms. The land had a good drainage and the door and window was oriented in south north direction to provide good ventilation during day and night, and to prevent direct sun rays from entering the structure. The materials used for the construction of the storage structure includes wood, bamboo, thatch (grass), jute sack, wire mesh, sack, concrete and blocks. The wood used was AVODIRE (*Turraeanthus africanus*). This was selected because it was readily available, cheap and had good mechanical properties. Bamboo was used for the rafters and water trough because it was readily available and relatively very cheap. It is also very strong and light weight thus imparts little on dead load. Spear grass was used as thatch roofing because it was available and free of charge on the site. Concrete block was chosen for the base of the wall because of its availability, strength, resistance to insect damage. The dimensions for the structure are as shown in Fig. 1.

Construction: The Evaporative Cooling Barn had a concrete foundation, two layers of block wall at the base, and plastered with a 10 mm concrete plaster, making it a composite wall. It is then continued with wooden columns, beams and frames and walled with jute sack. The jute sack was fastened to the wooden columns and beams with thread and nails. In all, 46 jute sacks were used, each with an area of 0.9 m^2. There were two windows oriented in south-north direction in the opposite direction for better ventilation at day and night. The roof was double-pitched, covered with spear grass thatch with dropping eaves to reduce sun rays into the structure, and was sloped at 45^0

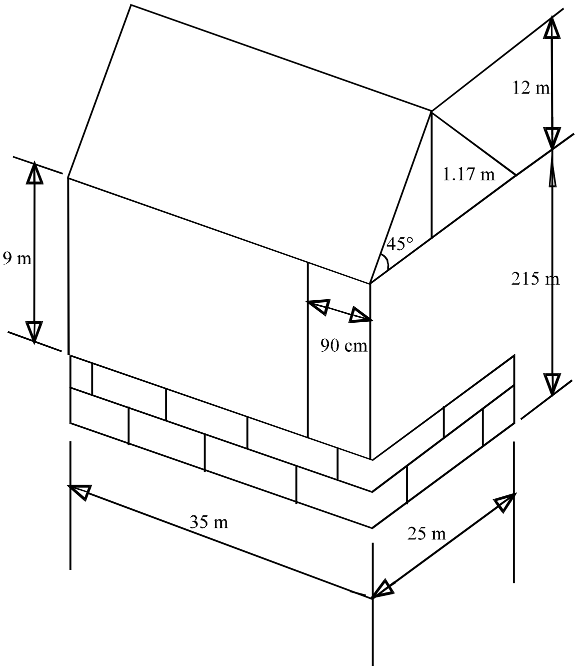

Fig. 1: 3D Design for the evaporative barn

to facilitate easy run-off when it rains and also to prevent leaking of the roof. A bamboo water trough was placed below and three inches PVC pipe was fixed above the structure to provide a wetting of jute sack when water is added manually to aid evaporative cooling. The floor was made of concrete grade C20 (nominal mix of 1:3:3) to 40 mm thick and allowed to cure for 7 days. The basement wall was also made of grade C15 (a nominal mix of 1:3:5) with 31 kg of water per bag of cement. The completed evaporative cooling barn is displayed in Fig. 2.

Testing: After the construction of the evaporative barn, two varieties of sweet potatoes namely TIS 2 and Ukerewe were cured and stored in the barn. Eighteen mini sacks, each containing 14 cured samples were placed in the shelves of the evaporative cooling barn using completely randomized design with four replications. The sacks in each shelf were sampled every two weeks for 3 months. During each sampling, one sack was randomly selected for destructive analysis. The daily temperature and relative humidity of the inside and outside air stream of the evaporative cooling barn were determined with a digital thermo-hydrograph. A Psychometric software (CYTPsyChart) was used to generate the other properties of the air streams. The cooling efficiency (η) of the storage structure was calculated from dry and wet bulb temperatures of the air stream inside and outside the barn using the formula:

$$\eta = \frac{Td - Tc}{Td - Tw} \times 100$$

where, η is the cooling efficiency, T_d and T_w are the dry and wet bulb temperatures of ambient air stream and T_c the dry bulb temperature of air stream inside the barn. Other researchers (Getinet *et al*., 2008) have used this equation to determine cooling efficiency of evaporative cooling unit.

Fig. 2: Completed evaporative cooling barn

After the cooling efficiency of the structure was determined, it was tested on the sweet potato tuberous root and parameters such as moisture content, weight loss, energy content, shrinkage, extent of weevil damage, rate of sprouting and wholesomeness of the stored roots were determined at each sampling period. The initial moisture content of the varieties was estimated using the oven dry method. Two sweet potatoes were selected at random from each mini sack and chopped into slices. Ten grams was taken and dried in an oven at 105°C until constant weight. The ratio of the difference between the initial weight and final weight to the initial weight was determined as the moisture content (Coskun *et al.*, 2006). Percentage moisture content of the roots, were determined at 2 weeks interval.

The energy content was calculated by using the equation:

$$E = -17.38M+1699$$

Where:

E = Energy in kJ per unit weight (100 g)
M = Moisture content (% wb)

Other researchers (Bradbury, 1986; Woolfe, 1992) have used this equation to determine energy content of sweet potato. Shrinkage of the roots was determined by measuring the diameter of the root with a caliper at the start of the research and also at every 2 weeks interval. The diameter measuring point at the start was marked with a permanent marker and this served as reference point for subsequent measurements. The differences in the initial and final diameter were used to calculate for shrinkage.

A tuberous root showing the presence of *Cylas* sp. or tunnels created by the weevils are recorded as damaged. Nicole (1997) used this approach to determine weevil damage in Sweet potatoes.

Rate of decay was assessed using the percentage surface of the roots deteriorated. The root becomes unmarketable when more than 10% of the surface shows visible decay. Roots showing extensive rotting (>50% surface) were removed from the sack The percentage severity was also recorded using a 1-5 scale depending on the percentage of the root surface showing decay (1: 0%, 2: 0-25%, 3: 25-50%, 4: 50-75, 5: 75-100%). Sweet potatoes that show at least 20%

deterioration are considered unwholesome. Other investigators (Rees *et al.*, 2003; Mutandwa and Gadzirayi, 2007) have used similar approach to assess root decay and percentage wholesomeness. The sprouting index was calculated using the ratio of the occurrence of sprouting to the total number of roots. The results were subjected to analysis of variance using GenStat statistical software to investigate significant differences in the parameters studied.

RESULTS AND DISCUSSION

The monthly mean temperature and relative humidity of air stream inside and outside the evaporative cooling barn for a period of 4 months is displayed in Fig. 3a and b. The mean temperature and relative humidity recorded over the period was 25 and 89.75% and 31.5 and 67.5% for the inside and outside air stream respectively this was similar to air properties reported by Teye (2010). The inside air condition is an improvement over 28.6 and 83% what was reported by Obetta *et al.* (2007) for ventilated underground storage structure. The relatively higher relative humidity and lower temperature value could be due to the constant wetting of the jute sack used as a wall pad for the evaporative cooling structure. The jute sack according to Faleh (2002) has the highest cooling efficiency. Under these properties of the inside and outside air stream, the wet bulb temperatures were 23.5 and 26.4 for the inside and outside air stream respectively. This gave the average cooling efficiency of the structure to be 127%. This was higher than 90-120% average cooling efficiency reported by El-Dessouky *et al.* (2004) in evaporative cooling of a combined system. The cooling efficiency of a combined the system may be greater than one. This is because the outside dry bulb temperature of the air stream can be lower than the inside wet bulb temperature.

The initial moisture content of the TIS 2 and Ukerewe sweet potatoes varieties were 68 and 60%, respectively. The moisture content was not different from Aidoo (2004). Figure 4 displays the

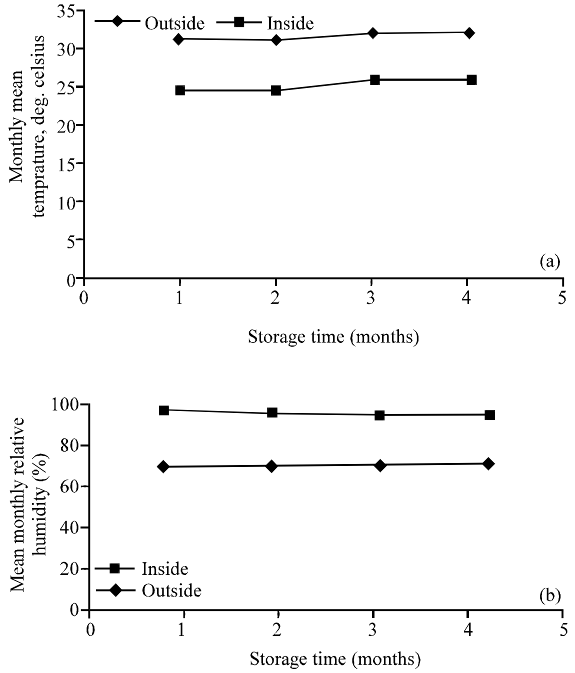

Fig. 3: Variation of (a) mean temperature and (b) relative humidity

variation of moisture content against storage time. Moisture content of the root for the two sweet potato varieties decreased linearly with storage time at rate ranging between 0.658 and 0.705% per week. The figure shows that moisture loss from both varieties after 12 weeks of storage are approximately the same and determined to be 13%. This relatively low value for the moisture loss indicates that the evaporative cooling barn is better than the traditional method of storing sweet potatoes.

Percentage weight loss of the roots against storage time is shown in Fig. 5. Percentage weight loss increased linearly with storage at a rate of 0.923 and 0.92% per week for TIS 2 and Ukerewe, respectively. At the end of the 12 weeks of storage time, percentage total weight loss ranged between 11.4 and 11.9% for the two varieties used. This is relatively lower than 11% recorded by Obetta *et al.* (2007) for 8-week storage of cocoyam. The lower percentage weight loss values recorded shows an improvement over the pit evaporative cooling barn designed by other researchers. The nature of the graph indicates that TIS 2 performed better in terms of percentage weight loss than Ukerewe. This might be attributable to the varietal differences existing between the two varieties. These results agree with those reported by Rees *et al.* (2003) and Duku (2005). The regression equations for moisture content and percentage weight loss as a function of storage time are displayed in Fig. 4 and 5. The values of coefficients of correlation were all higher than 0.93. This relatively high value of co-relation coefficient shows good fitness between predicted and observed values.

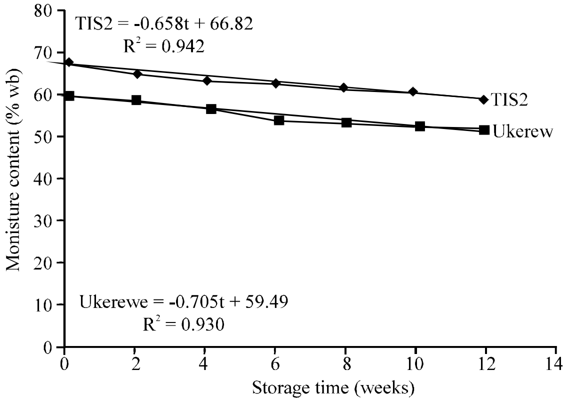

Fig. 4: Variation of moisture content versus storage time

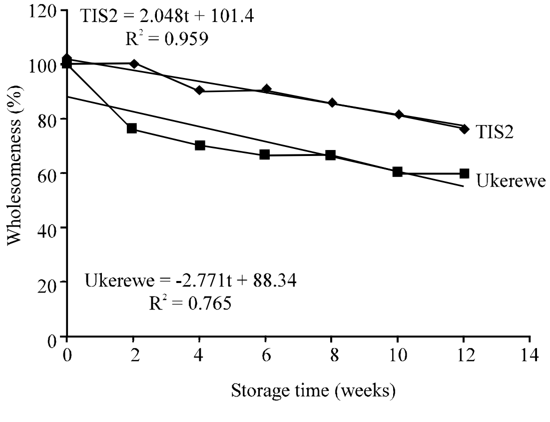

Fig. 5: Percentage weight loss against storage time

Figure 6 shows the percentage wholesomeness of the roots versus storage time. The percentage wholesomeness decreased linearly with storage time from 100 to76% and 100 to 60% at a rate 2.048 and 2.771% every week for 12 weeks in TIS 2 and Ukerewe, respectively. This relatively high decreased in wholesomeness compared with the rates recorded for percentage weight loss and moisture loss may be due to microbial infection from the field which rendered the roots unwholesome. It further supports the idea that pest infestation in stored food in the tropics is inevitable (Haines, 2000). Therefore protection from microbial infection may be necessary to enhance the rate at which the roots wholesomeness decreased. Figure 7 displays the percentage weevil damage against storage time. The figure indicates that weevil damage increased non-linearly with storage time and started 10 and 6 weeks in TIS 2 and Ukerewe, respectively. The difference might be due to different resistances to weevil attack of the two varieties.

The variation of percentage sprouting against storage time is presented in Fig. 8. Percentage sprouting increases non-linearly with storage time. The figure shows that sprouting started 6 weeks after storage in Ukerewe but only 4 weeks in TIS 2. The values recorded are higher than 2 weeks recorded in storage of cocoyam (Obetta *et al*., 2007) using ventilated underground cooler and 1-3 weeks for storage of sweet potatoes traditionally. This might be due to the low temperatures which reduced the respiration rate of the root, thereby prolonging onset of sprouting.

Figure 9 displays the percentage shrinkage of the root versus storage time. Percentage shrinkage increased linearly with increasing storage time from 0 to 4.6% and 0 to 3.6% at a rate of 0.4 and 0.32% for Ukerewe and TIS 2, respectively. The low shrinkage rate might be due to the high relative humidity and low temperature recorded in the evaporative cooling barn.

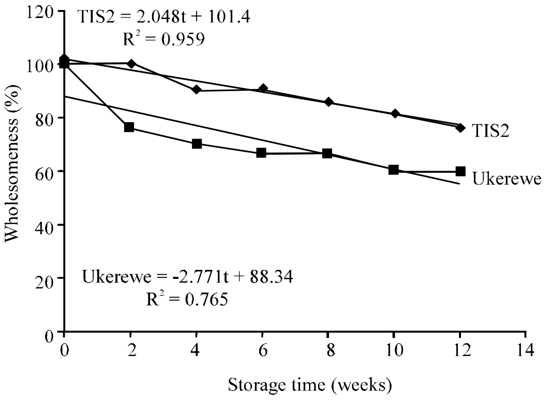

Fig. 6: Percentage wholesomeness against storage time

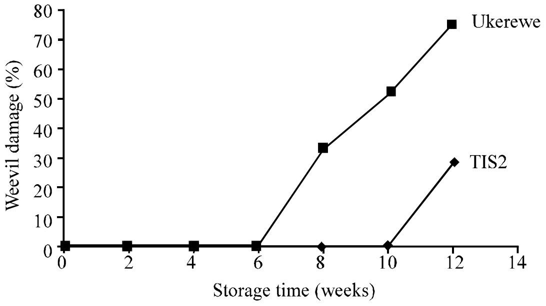

Fig. 7: Percentage weevil damage against storage time

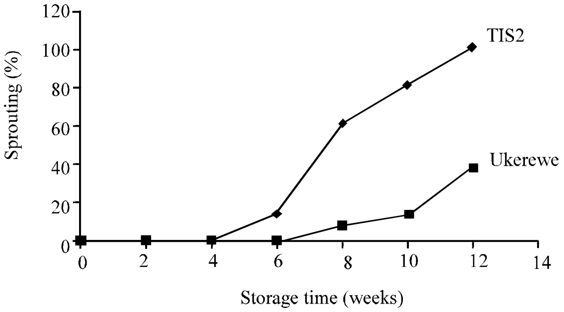

Fig. 8: Percentage sprouting against storage time

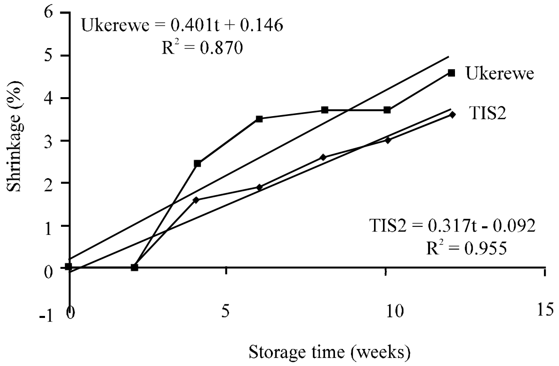

Fig. 9: Percentage shrinkage against storage time

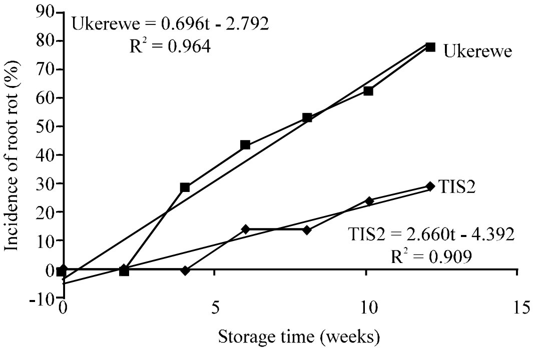

Fig. 10: Percentage incidence of decay against storage time

The percentage incidence and severity of decay of the tubers is presented in Fig. 10 and 11. Both the percentage incidence and severity of decay increased linearly with increasing storage time from 0 to 29% and 0 to 76%, 0 to 3% and 0 to 3.3% for TIS 2 and Ukerewe, respectively. The rates of incidence and severity were 2.6 and 6.7% and 0.21 and 0.27% for TIS 2 and Ukerewe, respectively. The values of coefficients of correlation were all higher than 0.91. This relatively high value of correlation coefficient again shows good fitness between predicted and observed values.

The variation in energy content in the root tubers as a function of storage time is shown in Fig. 12. The root tuber energy content increased linearly from 656 to 795 kJ and 515 to 671kJ per 100 g for Ukerewe and TIS 2 cultivars, respectively. These results resemble those reported by Zhitian *et al.* (2002) where he observe an increase in sugars (Glucose and sucrose) early in storage. The rates of energy content increment were 12.25 and 11.44 kJ per week for Ukerewe and TIS 2.

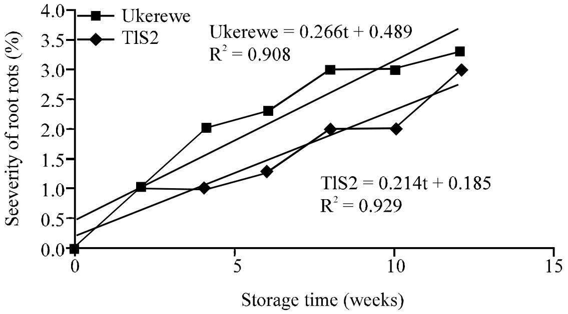

Fig. 11: Percentage severity of decay against storage time

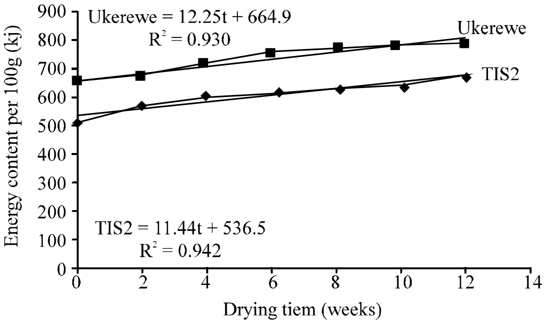

Fig. 12: Variation of energy content against storage time

The values of coefficients of correlation were all higher than 0.93. This relatively high value of co-relation coefficient shows good fitness between predicted and observed values. In addition, the energy content has a strong dependence on the root moisture content. The energy increased with decreasing moisture content of the root tubers.

CONCLUSIONS

The evaluation of an evaporative cooling barn storage structure for sweet potatoes revealed the following:

- The average cooling efficiency of the evaporative cooling barn was 127%
- There was no significant effect of storage time on weight loss, shrinkage, and energy content. However, there was significant effect on wholesomeness, sprouting, incidence of root rot
- The moisture content of the root tubers decreased with storage time from 68 to 59% (w b) at a rate of 0.658% per week
- Percentage total weight loss increased linearly from 0 to 11.9% at rate of 0.92% per week
- The percentage wholesomeness decreased linearly with storage time from 100 to 76% at a rate 2.048% every week
- Percentage weevil damage increased non-linearly with storage time and started between 6 and 10 weeks after storage
- Percentage sprouting increased non-linearly with storage time and started between 4 and 6 weeks after storage
- Percentage shrinkage increased linearly with increasing storage time from 0 to 4.6% at a rate of 0.4% per week

- Both the percentage incidence and severity of root rot increased linearly with increasing storage time from 0 to 29% and 0 to 3% respectively
- Root tuber energy content increased linearly from 656 to 795 kJ per 100 g

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