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A Review: Intelligent Controllers for Tropical Food Storage System

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Abstract— Food security can be assured by improving on post harvest storage methods. Food stored under improper storage conditions are prone to increased respiration and transpiration processes which often result in depletion and weight loss of edible material. Storage temperature and relative humidity are major factors that ultimately determine product quality and quantity. This paper presents a survey on methods of post harvest storage systems. The indigenous methods of tropical food storage common to the West African region are discussed. The attendant problems associated with these methods are highlighted. Intelligent control methods are also discussed. A novel intelligent controller is proposed to sustain product quality and quantity by optimizing the storage process.

Keywords- intelligent control, food storage, yam tuber

I. INTRODUCTION

Harvested produce emit heat, moisture, carbon dioxide and ethylene gases due to physiological processes taking place within the body of the produce. Under storage, especially in confined spaces these emissions can be detrimental to the produce if not properly evacuated. Thus, a need for proper conditioning of the storage environment arises. The objectives of storage are sustenance of product quality and reduction in weight loss of the products under storage. Maintaining appropriate storage temperature and humidity levels play a major role in prolonging product shelf life.

A particularly economical method of storage employs air draught upwards through the produce pile thus conveying away the by-products. If conditions are suitable, ambient air is employed to optimise the operational cost. To optimise the storage process automatic control is employed. The thermodynamic process within the storage environment involves heat and mass exchange between the products and the environment (flowing air). As the air flows through the product pile its heat and moisture receiving capacities drop due to saturation effects. The resulting temperature and moisture gradients set up within the storage volume makes the storage process complex and nonlinear. In steady state, the temperature gradient with respect to product height within the storage volume remains relatively constant.

The remaining part of this paper is organized as follows. Section 2 deliberates on indigenous methods of yam storage common to West Africa. Section 3 discusses attempts by other researchers at improving on the indigenous methods. Section 4 reviews modern methods of food storage with emphasis on intelligent control systems. Section 5 discusses on the proposed intelligent controller for tropical food storage systems. Section 6 concludes the study by stressing the need to adopt modern methods of food storage systems in order to minimise losses prevalent with existing traditional approaches.

II. INDIGENOUS METHODS OF TROPICAL FOOD STORAGE

Of the three methods of food storage this study considers only two namely the indigenous and the intelligent-based control methods. The third is the model-based control method of food storage. This is illustrated in figure 1.

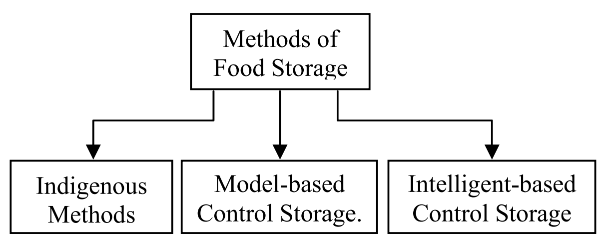

Fig 1. Indigenous and modern methods employed in the food storage process.

The indigenous method of food storage is commonly employed in West Africa. The model and intelligent based methods are the modern day methods employed in the food storage industry.

One of the most notable tropical foods is the yam tuber. It is the second most important tropical root crop in West Africa, after the cassava tuber (Opara, 1999). Unlike cassava, yam can be stored and eaten in tuber form long after harvest. The rise in export demand for yam tubers in recent times is another factor responsible for the choice of yam in this paper (Osunde and Orhevba, 2009).

Yam is the common name for some species in the genus Dioscorea (family Dioscoreaceae). Figure 2 shows typical yam tubers. These are perennial herbaceous vines cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America and Oceania. They are large plants with vines as long as 10 to 12 meters (35 to 40 feet). The tubers most often weigh about 2.5 to 5 kg (6 to 12 lbs) each but can weigh as much as 25 kg (60 lbs). After 7 to 12 months growth the tubers are harvested. In Africa most are pounded into a paste to make the traditional dish of "pounded yam" (Wiki 2010).

Fig 2. A full (left) and a sliced tuber of yam (right). (3, 4)

A. Methods of yam storage

Yam tubers store relatively longer (about 6 months of storage are possible with indigenous methods) than most tropical fresh produce. The indigenous methods prevalent in West Africa coupled with the fluctuating environmental conditions often result in heavy losses of stored products. During storage, yam tubers must be kept cool and dry and away from sources of moisture. They should also be protected from the direct rays of the sun. Losses lead to shortages and increase in market prices during the products off season.

Causes of loss in yam tuber under storage include sprouting, transpiration, respiration, rot due to mould and bacterial attack, insect, nematode and rodent actions. Sprouting, transpiration and respiration are physiological processes which depend on the storage environment conditions (Passam, Read and Rickard, 1978). These physiological changes affect the internal composition of the tuber and result in destruction of edible material, which under normal storage conditions can often reach 10% after 3 months, and up to 25% after 5 months of storage (Passam, Read and Rickard, 1978).

Recorded weight losses are in the range of 10-20 % after about 3-months of storage and about 30-60 % after about six months of storage are possible (Booth, 1974).

B. Indigenous methods

Curing of tubers before the storage process is advised to heal the wounds incurred during harvest. The most common type of curing is the pit curing method and is widely used in parts of Nigeria. It consists of a pit, approximately 2.5 x 1.5 x 1 metre with the bottom lined with sawdust or dry grass. Yam tubers are placed on a lining and then covered with a thin layer of soil. The treatment takes about two weeks after which the tubers can be removed for storage. According to trials in Nigeria, yam tubers treated for two weeks by this method showed only 40% degradation after 4 months of storage, compared to 100% of untreated tubers (FAO, 1998).

Generally, yam tubers are stored based on their expected utilisation. Storage of yam is usually for either seed yam or for consumption. The various methods and their deficiencies are described below.

C. Hanging (stringing)

Seed yams are hung up to dry for about three months after harvest. They are later transferred to a sheltered shed and covered with a layer of plantain or other plant leaves. Fig 3. illustrates the hanging method of yam storage. The disadvantage is that storage of the yam seedlings may not exceed 3 months (Ofor, Oparaeke and Ibeawuchi, 2010).

Fig 3. A man inspecting tied yam tubers under storage

D. Trench Silos

A dug pit is lined with straws or similar material. Tubers are stored on a layer of straws positioned horizontally or on top and beside each other. The pit can be built underground or with a part of the store above the ground. Straws or similar material are used to cover the pit. Problems are lack of ventilation and direct contact between tubers. Contact promotes heating and thus formation of rot. The silos also offer good refuge for rodents. A typical trench silo is illustrated in fig 4.

E. Yams left in the ridges after maturity

This method demands the tubers be left in the ridges on the fields for up to about four months depending on the variety. The major disadvantages are termite, nematode, and rodent actions on the tubers, depending on the yam variety, the tubers cannot be left for more than 4 months. Another disadvantage is the non-availability of the land for farming purposes since it serves as storage.

F. Yam barns

Very common method of yam storage all over West Africa consisting of walls made of timber built on open ground as illustrated in fig. 5. The barns are covered with straws and are usually located in partial shade. Inside the barns tubers are tied such as to maximize air circulation.

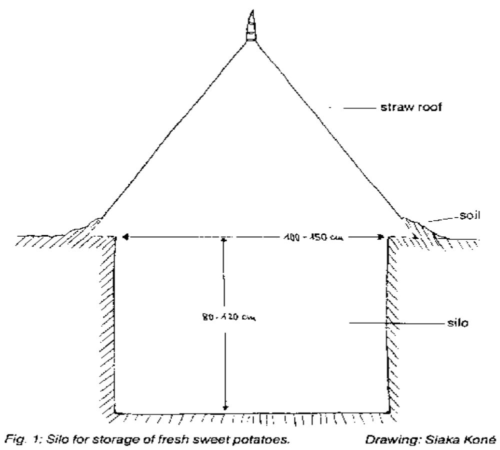

Fig 4. Trench silo method of yam storage (10).

Fig 5. A newly constructed yam barn on the (Left) (11). An old yam barn (right) (12).

The maximum storage life of yams in a barn is six months. Losses can be 10% to 15% during the first three months and up to 30% to 50% after six months (Ofor, Oparaeke and Ibeawuchi, 2010). Yam barns are not effective in the rainy season since the moist environment enhances the rotting of tubers.

G. Platform storage

Tubers are placed on raised platforms positioned on the fields or indoors. Rainy season adversely affects those on the fields. Fig 6 shows a typical indoor platform method of storage.

Fig 6. Yam tubers kept on platforms (13).

H. Conical protective roof

This type of storage is often erected under a shady evergreen. It consists of a conical protective roof. The shady tree makes temperature fluctuations throughout the day milder and the light protective roof allows sufficient ventilation. Aside from insect and rodent actions the tubers are piled on top of each other and the roof completely covers the tubers thus preventing regular visual checking of the stored produce (N'kpenu and Tougnon, 1991).

I. Heap storage

This method of storage can be erected with little cost. The presence of a shade for example by a tree somewhat balances out the temperatures occurring throughout the day. Disadvantages range from poor ventilation to insect and rodent activities (Nwankiti and Makurdi, 1989).

III. Methods of Improving Yam Storage

A. Tuber Irradiation

Sprouting accounts for a significant amount of loss in yam storage. Gamma irradiation is an effective method for discouraging sprouting of yam. Irradiation for a period of six months at specific doses offered a means of discouraging sprouting of yam tubers (Adesuyi and Mackenzie, 1973). Bansa and Appiah (1999) made comparisons between two forms of yam storage namely, barn and ground storage.

Though in both types, irradiated tubers experienced reduced sprouting there was less rotting action in the non-irradiated tubers stored on the ground. Studies by Vasudevan and Jos (1992) proved responses of tubers to gamma irradiation to be a function of tuber specie.

B. Application of chemical compounds

Application of chemical compounds such as Giberillic acid, chloroisopropyl phenylcarbamate and plant extracts have had profound effects in extending the shelf life of yam tubers. Application of Giberillic acid to D. rotundata and D. alata yam species often delays sprouting for almost three months and 3 1/2 months respectively (Gerardin et. al., 1998a and IITA, 2007). Reports have shown that immersion D. rotundata and D. esculenta in 1000 ppm of maleic hydrazide for ten hours reduces the rate of sprouting by 8% and 16% respectively (Ramanujam and Nair, 1982). Different species and cultivars have been known to respond differently to chemical treatments (Osagie, 1992. and Degrass, 1993).

C. Improving the storage structure

Many suggestions to improve on the storage structure have been proposed. Adejumo (1998) proposed a rectangular shaped barn with a raised cemented floor and a plastered concrete wall 1 meter in height. Prefabricated chicken mesh wall completed the rest of the wall. Raffia mats, grass or corrugated aluminium sheet is the employed material for the roof. Comparison was made between a yam barn, 2 pit structures one with a chimney and the other without. The results showed the pit with chimney having the highest humidity level while the barn had the lowest humidity level with corresponding average temperatures of 25^{o}C, 27^{o}C and 35^{o}C respectively (Ezeike, 1984). Reduced weight loss and delayed sprouting were most observant in the pit with chimney. The effects of improved ventilation using a standing fan on yam stored in a conventional barn was carried out by (Osunde and Orhevba, 2009). Results showed decayed tubers to be less than 2% for the barn with intermittent air flow while that of the barn with no airflow to be 12%.

D. Desprouting of tubers

Sprouting increases the transpiration rate of tubers which results in weight loss of the yam tubers. Weekly removal of the growing shoots resulted in reduced weight loss and increased shelf life (Martin, 1977). Another study carried out by Gerardin et. al. (1998b) proved that monthly removal of sprouts reduced weight loss during 5 months storage by 11% for cultivars of D. rotundata and D. alata tubers.

IV. INTELLIGENT-BASED CONTROL METHOD

Literature search has revealed quite a small amount of intelligent-based food storage systems in comparison to model-based ones. All the same intelligent controls of similar processes such as food drying and chemical processes are presented.

Pulaczewski and Wachowicz (1994) proposed the use of weather forecast and mathematical process model to minimize energy consumption during a potato storage process. They tackled the problem of parameter selection for the purpose of optimizing operational cost. Ventilation control was by FLC.

Gottschalk (1996) developed a one dimensional heat and mass transfer mathematical model which described air flow through a potato bulk. Though the model considered temperature and humidity, the developed FLC controlled only the storage temperature.

Gottschalk et al. (2003) improved the climate control for stored potato using a fuzzy controller supported by genetic algorithm (GA). Here the genetic algorithm was used to fit some parameters to the criteria to minimize the total storing cost. Temperature was the controlled storage parameter.

Morimoto, Suzuki and Hashimoto (1997) and Morimoto, Tu and Hashimoto. (1999) used fuzzy logic control aided by neural networks and genetic algorithms for the control of the storage process. In the former, Morimoto et al. optimised the storage process of oranges (Citrus iyokan) by using neural networks to identify the relationship between the relative humidity and ventilation and genetic algorithm to determine the membership functions and control rules efficiently during storage. In the later case two decision systems consisting of both neural networks and genetic algorithms were used to control the relative humidity of the storage environment for apples (Golden delicious) and oranges (Iyokan). The neural network identified the fruit responses as affected by the relative humidity and the genetic algorithm selected the optimal values of the membership functions and control rules. In both cases the controller adjusted only the storage relative humidity.

Jassar et. al. (2009) used an Adaptive Neuro-fuzzy inference system (ANFIS) model to estimate the average air temperature in multi zone heating system using 3 input parameters. The data consisted of a week's training data and 3 weeks test data. Simulation results obtained using the model were very close to experimental results. Worst case Root Mean Squared Error (RMSE) was 0.5782^{O}C.

Wang et. al. (2001) developed an intelligent control system for the wood drying processes. The intelligent adaptive controller consisted of an integrated, hierarchical control system comprising a knowledge-based, data processing level and a supervisory level and was compared with a conventional adaptive controller consisted of two sub-systems: the moisture adaptive control in the outer loop and the temperature adaptive control sub-system in the inner loop with pulse-width-modulated (PWM) heater control. Results showed savings of energy with the intelligent controller since required operating temperature was far less than that of the conventional adaptive control. The percentage duty cycle needed to bring down the moisture level to the final set point was also far less than that of the conventional adaptive controller.

A fuzzy logic controller was developed for drying tobacco leaves by Alvarez-López et. al. (2005). Expert advice was employed in developing the sugeno type fuzzy controller. The results showed that the fuzzy controller achieved considerable fuel savings in comparison with already established control algorithms.

Lakkhekar et. al. compared a hybrid fuzzy PID, and a fuzzy cascade controller with conventional feedback control and conventional cascade control for a continuous stirrer tank heater. The primary controller forming the outer loop consisted of a hybrid fuzzy PID subcontroller integrated with a conventional PID controller. The nearness of the process state to the set point determines which of the controllers takes over control. The inner loop made up of a secondary hybrid fuzzy cascade controller structure consisted of a fuzzy PI and PI controllers. The inputs to the fuzzy PI controller were error and change of error and its outputs were the proportional and integral gains to the PI controller in the form of scaling coefficients. Simulated results showed that the combination of fuzzy PID and fuzzy cascade controller had a better set point tracking performance than the classical control techniques.

Khiang et. al.(N.D.) developed a chilling and heating system based on fuzzy logic control and compared it with a PID control algorithm. A graphical user interphase in lab windows presenting the process variables was used to control the experimental set up. The mamdani type fuzzy logic controller had as inputs, error and change of error and output was change in control input signal. Results showed that the fuzzy logic controller performed better than the PID controller in the aspects of set point tracking, load disturbance rejection and noise reduction.

Simulations studies were carried out on the tuning of the output scaling factors which were a representative of the controller gains of a PI-like fuzzy logic controller by Pal and Mudi (2008). The self-tuning fuzzy PI-like controller performed better than the adaptive neuro-fuzzy and PID controllers in terms of peak overshoot and settling time.

A Labview based closed loop fuzzy controller developed by Wali et. al. (2009) was used to automatically and continuously adjust the applied power of a microwave biodiesel reactor under different perturbations. The inputs to the Mamdani type fuzzy logic controller were error and change of error of the temperature within the reactor system. The controller output was the microwave delivered power. The Fuzzy controller tracked the reactor desired temperature precisely with minimal overshoot and fast warm–up phase. The disturbance in the form of varying flow rate in the process input was well rejected by the controller.

Comparative studies on the drying of olive stones using a fuzzy controller and a neuro-fuzzy controller (ANFIS) was carried out by Kiralakis and Tsourveloudis (2005). Expert knowledge was used to develop the Mamdani-type fuzzy logic controller and it was compared with the Takaji-Sugeno type ANFIS controller developed using experimental data. Different initial olive stones moisture contents, cylinder temperature, material feed rate and membership functions shapes were considered. In terms of stability and set point tracking the ANFIS provided better results than the Fuzzy logic controller. At higher initial moisture content the fuzzy logic controller did better. The triangle shaped membership functions gave the best results.

Kanagaraj, Sivashanmugam and Paramasivam made comparisons of a hybrid fuzzy coordinated PI controller, conventional PI and PI-type fuzzy controllers. In the hybrid the supervising Mamdani-type fuzzy controller had error and controller output as inputs and modification of the proportional and integral controller gains for the PI controller through coefficient scaling as outputs. In terms of stability and set point tracking the hybrid fuzzy-coordinated PI controller performed better than the conventional PI and PI-type fuzzy logic controllers.

V. PROPOSED INTELLIGENT CONTROL FOR TROPICAL FOOD STORAGE SYSTEMS

As discussed earlier, the indigenous and attempted improvements on traditional yam storage structures have been identified. The open nature of the storage structures allows interference of the environment in the storage process.

A 4-compartment structure for multiple-storage is proposed with an intelligent controller set up.

The controller consists of a fuzzy logic and neural network systems. The objective is to control the storage temperature and relative humidity primarily, while monitoring the carbon dioxide build-up within the storage environment. The block diagram for the controller is shown in Fig. 7.

A mathematical model is also being developed to analyse the heat and mass transfer processes taking place within the storage environment during the storage process.

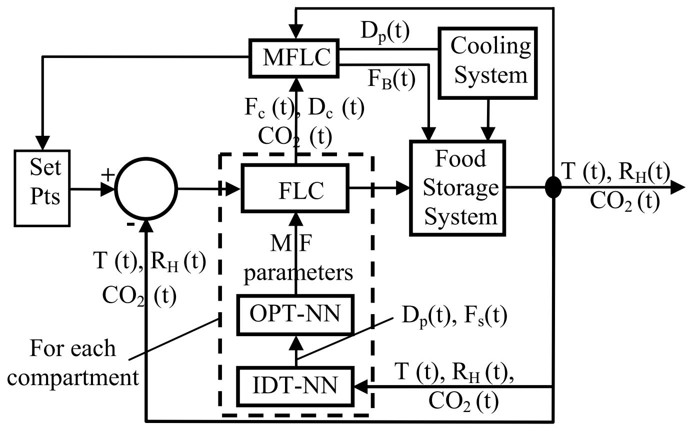

Fig. 7. Block diagram of the controlled storage system

VI. CONCLUSION

A detailed review of food storage has been done in the study. Emphasis on yam storage as a tropical food example was discussed. Existing methods of food storage can be grouped into three as shown in figure 1. It was observed that despite the importance of yam in West African countries, there exists little or no model or intelligent based methods of yam storage. The need for a more efficient method which employs automatic control of the storage process either through model based or intelligent controllers cannot be over emphasized. The intelligent method is the preferred method for the control of food storage systems for tropical harvested products due to its ability to handle complex and nonlinear problems.

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