AN ANALYSIS OF WEIGHT LOSS OF STORED YAM (*Dioscorea* SPP.) TUBERS

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Received 10 January 1984, accepted 12 October 1984

Ezeike, Gabriel O. I. 1984. An analysis of weight loss of stored yam (*Dioscorea* spp.) tubers. Can. Agric. Eng. 26: 115–119.

This study was undertaken to obtain quantitative data on the weight loss (WL) of stored yam tubers (*Dioscorea rotundata*) as affected by air temperature (T), relative humidity (RH), length of storage, tuber weight (TWT) and geometry. That is, WL = f(T, RH, time, TWT, geometry index). A total of 2316 cases of each variable were used for the analysis. A step-wise regression analysis yielded a prediction equation for weight loss in terms of the independent variables. The multiple correlation coefficient was 0.876 and the standard error of estimate was 3.2% weight loss. The component of weight loss arising from metabolic activity at a storage temperature of approximately 25°C, was found to range from 13.2 to 33.4% of total weight loss in a storage period of 24 wk.

INTRODUCTION

Yams are members of the genus *Dioscorea*, which produce tubers and bulbils of economic importance. Taxonomically, the genus *Dioscorea* is sub-divided into the edible species notably *rotundata, alata* and *cayenensis* and the medicinal species such as *mexicana* and *composita* from which pharmaceuticals (diosgenin) are extracted on a commercial basis.

The structural and anatomical determinants of shape and size of the tubers are controlled by genetic and environmental factors (Coursey 1967a). Most yam tubers are approximately cylindrical in shape and are covered by an outer protective periderm tissue (Fig. 1). Details of this structure are given elsewhere (Ezeike 1981).

The chemical composition of yam is characterized by a high moisture content (55–75%, WB) and dry matter. The dry matter is composed mainly of carbohydrates (65–80%), protein (1–2%, fresh weight), vitamins (ascorbic acid, carotene and riboflavin), as well as sugars and minerals (calcium, iron, phosphorous and ash). A detailed compilation of the chemical composition of yams has been made (Eka 1983).

By far the largest proportion of yams produced annually is marketed as fresh tuber; only a small fraction is processed as yam flour, flakes and chips and even a smaller fraction is converted to industrial starch. The biochemical and processing characteristics of these products have been studied recently (Osuji 1983; Ige and Akintunde 1981).

Unfortunately, the storage of fresh yam tubers, either for direct consumption or for transformation into processed foods, has presented a major problem over the years. The factors that control yam tuber deterioration in storage are both environmental and product-dependent. Thus, there is a need to examine critically the cumulative effect of these factors on storage loss. This study was therefore undertaken to obtain quantitative data of weight loss as affected by air temperature, relative humidity, duration of storage, tuber weight and tuber geometry.

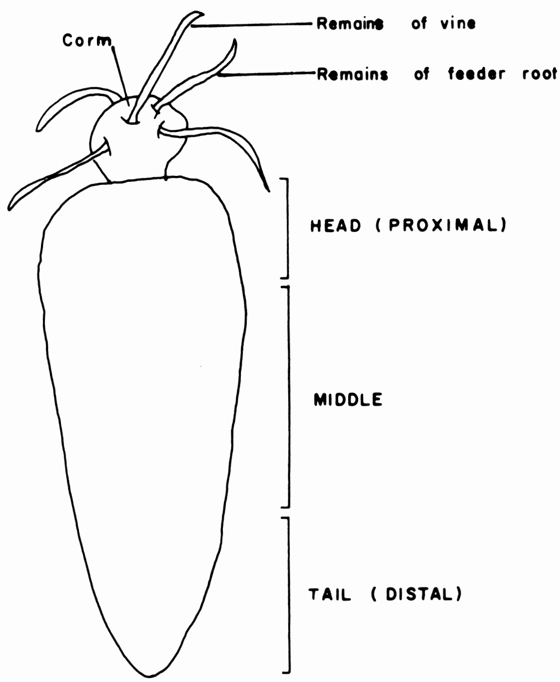

Figure 1. General morphology of yam tuber (*Dioscorea* spp.)

PREVIOUS WORK

The techniques and structures adopted in yam tuber storage have been critically reviewed (Coursey 1967a, Ezeike 1984). These methods include storage in traditional barns, cribs and heaps, storage in ditches, cold storage, irradiation and use of sprout inhibitors.

Yam tubers are classified as perishable produce that can undergo a 5–60% food loss in developing countries (Ayernor 1981). Their bulky size, chemical composition and high moisture content make them vulnerable to degradation during long-term storage. The size of individual tubers may range from a few grams to over 20 kg and tuber lengths of about 2 m have been recorded (Coursey 1967a).

Published literature dealing with research on weight loss of yam tubers in storage has been scanty. Coursey (1967b) presented a survey of the causes and extent of weight loss of stored yam tubers. His work was primarily concerned with the determination of the range and distribution of tuber weight loss in the field and references to the causes of weight loss were qualitative. Olayide and Idusogie (1977) reported on the extent of post-harvest crop losses in Nigeria, and Passam et al. (1978) reported on the contribution of respiration to yam tuber storage losses. Recently, an attempt has been made (Osuji and Umezurike 1983) to find a biochemical basis for the deterioration of the yam tuber in storage.

It is therefore clear that no attempt has yet been made to determine the cumulative effects of temperature, relative humidity, tuber weight and geometry, or of length of storage, on weight loss of stored yam tubers.

The effect of airflow is limited by skin permeability (Burton 1963) and at low air velocities, the airflow becomes laminar resulting in a thick surface film which will limit the vapor pressure and heat transfer rates. In these experiments, air circulation was by natural ventilation at approximately 0.01 m·sec^{-1} and so air velocity was not included in our analysis.

EXPERIMENTAL WORK

Materials and Methods

The experimental facility used for this study was described in detail by Ezeike (1984). This consisted of an underground pit structure with a chimney and side ventilation ducts to facilitate cross and vertical airflow through the storage structure. The conventional yam barn was used as a control experiment.

A total of 100 tubers of *D. rotundata* were stored in the underground structure while 40 tubers were stored in the barn. The yam tubers were obtained about 4 days after harvest and were immediately put into storage after each tuber was weighed and identified. Tuber weights were obtained daily for the first 2 mo and subsequently on a weekly basis with a top loading balance sensitive to 1 g. The cumulative weight loss was based on the original weight of tuber. That is,

$$WL_n = ((W_o - W_n)/W_o) \times 100\% \qquad (1)$$

where WL_n = present magnitude of per cent weight loss; W_o = original fresh weight of tuber (kg); W_n = present weight of tuber (kg).

The three major diameters, that is, proximal, mid and distal as well as the length of each tuber (Fig. 1) were measured initially. These were used to determine the "surface factor," *SF*, of each tuber as follows;

$$SF = L/(D_1D_2D_3)^{1/3} \qquad (2)$$

where L = length of the long axis of tuber (m) and D_1, D_2, D_3 are the major diameters (m).

The surface factor is significant in relating the moisture loss from one tuber to that from another with different geometric characteristics. While volume increases with tuber weight, the surface area per unit volume or unit weight decreases with increasing tuber weight. Thus, the higher the value of *SF*, the greater the surface area available for the transfer of moisture and vice versa.

Daily readings of dry bulb temperature and air relative humidity were obtained with psychrometers installed in each storage structure. The tubers were inspected for rot development and sprouting during each visit. Some tubers were marked for moisture content determination and samples were taken every 2 wk for the duration of the experiment. Moisture content was determined by oven methods at 100°C for 24 h with chopped-up samples weighing about 100 g. The experimental conditions are shown in Table I. Also shown in Fig. 2 are the weekly average air temperatures in the two storage structures.

RESULTS AND DISCUSSIONS

General Pattern of Weight Loss

A plot of weight loss of tubers versus storage time indicated considerable individual variation in weight loss characteristics (Fig. 3). The variation spreads as storage time increases. Typically a tuber loses weight nonlinearly with time such that the curve approximates a second degree polynomial. Tubers in the pit structure sustained a lower rate of weight loss than those in the barn. In addition, the cumulative weight loss of tubers in the pit was considerably lower than that of the tubers stored in the barn. This resulted from the lower temperature and higher relative humidity, respectively, in the pit structure compared with the barn. In ad-

TABLE I. EXPERIMENTAL CONDITIONS

	Range of values	
Variable	Pit	Conventional barn
Ts (°C)	21 – 26	23 – 36
RH (%)	42 – 91	39 – 65
Ta (°C)	25 – 35	
Tuber weight (kg)	1.2 – 3.4	
Length diam. ratio	1.19 – 4.42	
Duration of storage (wk)	24 – 24	

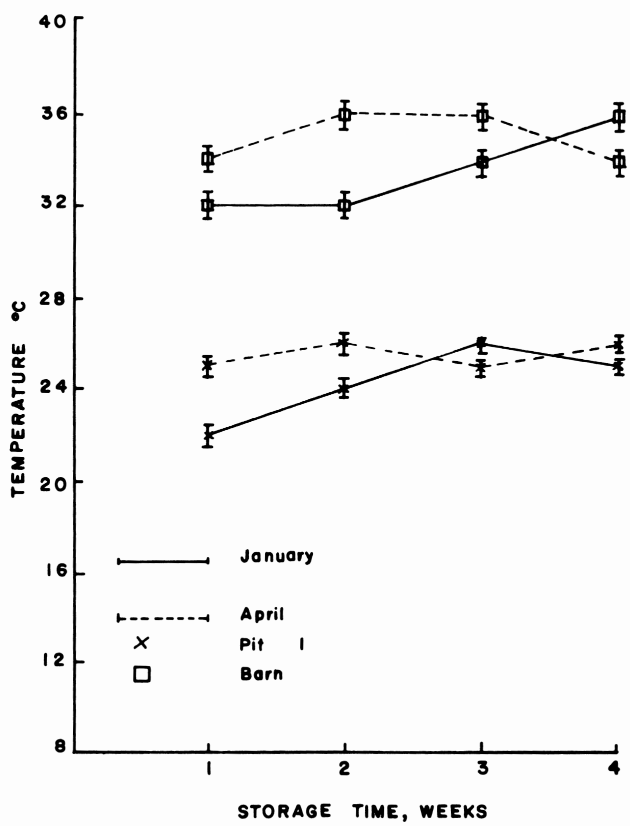

Figure 2. Weekly average air temperatures in the storage structures.

dition to higher rate of respiration at high temperatures, the combination of high temperature and low relative humidity in the barn caused a high vapor pressure transfer potential, resulting in increased water loss from the tubers due to transpiration.

As storage progressed, the tubers started sprouting during which time a rapid increase in weight loss occurred. This increase in weight loss was due partly to the relatively higher permeability of the sprouts compared to the periderm of the tuber, partly to the increased total surface area and partly to increased rate of conversion of dry matter into carbon dioxide and water. Working with potatoes, Silva and Andrew (1983) found that individual tubers exhibited different degrees of sprouting. It was postulated that the tubers may not be of the same physiological age, even though they were produced in the same season, harvested at the same time, and stored under similar conditions.

Development of the Prediction Equation

One of the requirements of a good storage environment is the maintenance of conditions that minimize tuber weight loss. The environmental control factors include temperature and relative humidity while the product-dependent factors are tuber age, weight and geometry.

A multiple regression analysis was performed on the experimental data to find the relationship between weight loss (WL) and the independent variables; namely, air temperature (TEMP), relative humidity (RH), length of storage (DAY), tuber weight (TWT), and tuber geometry (SF). A total of 2316 cases each of the dependent and independent variables were used in the analysis. A step-wise regression analysis was used to obtain the following prediction equation:

$$WL\ (\%) = a + b(TWT) + c(TEMP) + d(RH) + e(DAY) + f(SF) + g(RH)^2 + h(TWT)^2 + i(DAY)^2 + j(TEMP)^2 + K(SF)^2 \quad (3)$$

where

$a = -5.237$; $b = -2.375$; $c = 0.343$; $d = 0.164$; $e = 0.053$; $f = 0.145$; $g = -0.0022$; $h = 0.080$; $i = 0.0034$; $j = -0.0013$; $k = -0.0030$.

To obtain the final form of the equation, terms were added until the F-improvement became insignificant. A summary of the step-wise regression analysis is presented in Table II. The summary includes the multiple correlation coefficient, the standard error of the dependent variable (weight loss) and the F-value.

TABLE II. SUMMARY OF STEP-WISE REGRESSION ANALYSIS

Step no.	Variables included	R^2	Standard error of wt loss (%)	F
1.	DAY	0.741	4.2	2355.36
2.	DAY, RH^2	0.827	3.65	1940.40
3.	DAY, RH^2, DAY^2	0.841	3.56	1396.46
4.	DAY, RH^2, DAY^2, SF^2	0.841	3.57	1047.08
5.	DAY, RH^2, DAY^2, SF^2, TEMP^2	0.843	3.55	840.19
6.	DAY, RH^2, DAY^2, SF^2 TEMP^2, TWT^2	0.844	3.54	701.11
7.	DAY, RH^2, DAY^2, SF^2, TEMP^2, TWT^2, RH	0.846	3.52	608.37
8.	DAY, RH^2, DAY^2, SF^2, TEMP^2, TWT^2, RH, SF	0.846	3.52	532.21
9.	DAY, RH^2, DAY^2, SF^2, TEMP^2, TWT^2, RH, SF, TWT	0.864	3.41	520.43
10.	DAY, RH^2, DAY^2, SF^2, TEMP^2, TWT, RH, SF, TWT, TEMP.	0.876	3.22	512.19

Equation 3 may be used to predict the weight loss over the range of experimental conditions (Table I). As with most prediction equations, the accuracy is highest when values of the independent variables are chosen around the means of the experimental conditions. Near the means of the experimental conditions the standard error of tuber weight loss was approximately 1.6%. Also, results of this study showed that duration of storage followed by temperature, tuber weight and relative humidity were most highly correlated with tuber weight loss.

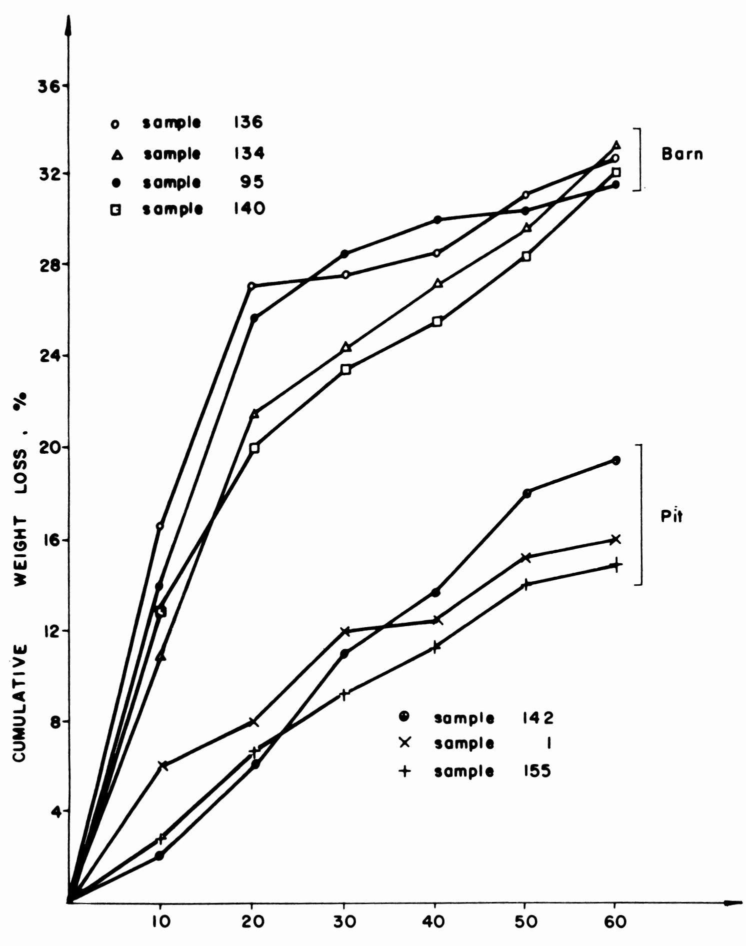

Figure 3. Cumulative weight loss versus time.

Contribution of Respiration to Tuber Weight Loss

The weight loss reported above was a composite weight loss which included the loss due to respiratory activity expressed by the well-known equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ H_2O + 6CO_2 + 2820\ \text{KJ/mole of starch} \quad (4)$$

Using the relative atomic masses, the weight loss due to respiration, WLR, may be determined from the expression;

$$WLR = RR \times TWT \times t \times 6.8 \times 10^{-4}\ (\text{g}) \quad (5)$$

where

RR = rate of respiration ($mg \cdot h^{-1} \cdot kg^{-1}$); TWT = weight of tuber (kg); and t = time (h).

The data of Coursey and Russel (1969) were reviewed and used to develop the following expressions for carbon dioxide output before and after sprouting. The data were accumulated for *D. rotundata* tubers stored at 25°C for over 24 wk. This was found suitable for the conditions in the pit structure, where the average temperature was approximately 25°C. Generally, the rate of respiration was relatively high at harvest, followed by a decrease in activity and a subsequent increase once sprouting of the tuber began. Tubers showing respiration rates of the order of 60 mg CO_2 per kg fresh weight per hour were associated with decay.

Before sprouting

$$RR = 23.61 - 0.3869\,\text{day} + 0.0055\,\text{day}^2 - 0.00003\,\text{day}^3 \quad (6)$$

where day = number of days of storage. The correlation coefficient was 0.874 and the standard error was 1.9 mg $kg^{-1} \cdot h^{-1}$

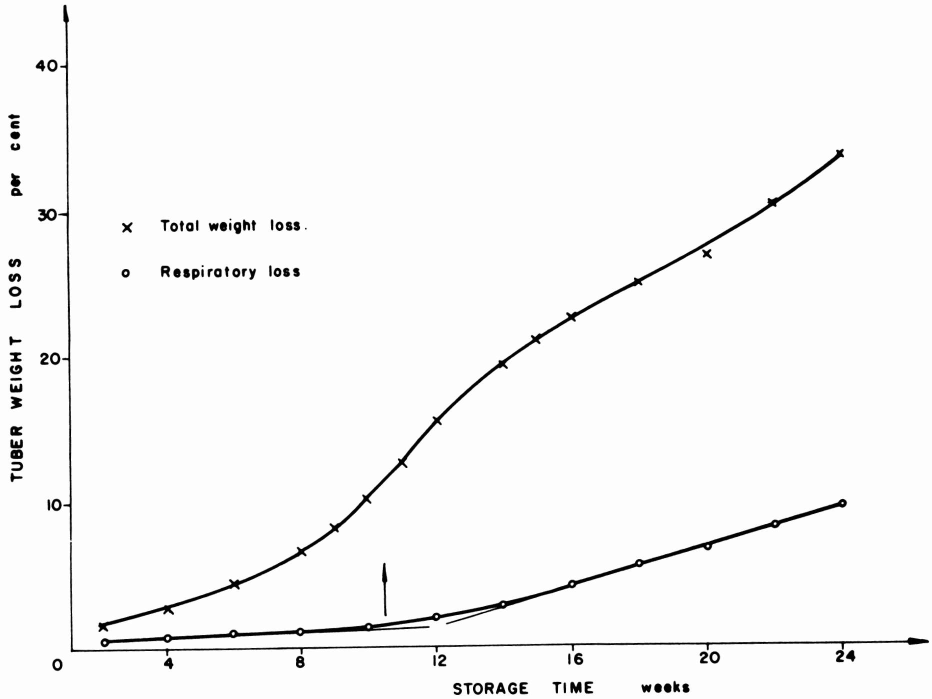

Figure 4. Tuber weight loss versus time (arrow indicates sprout emergence).

TABLE III. RELATIVE CONTRIBUTION OF RESPIRATION TO TOTAL WEIGHT LOSS OF YAM TUBERS DURING STORAGE

Condition of tuber	Daily wt loss due to respiration at 34°C (%)	Total daily weight loss (%)	
		Pit structure	Conventional barn
Harvest	0.076	0.25 ± 0.02	0.25 ± 0.02
Dormant	0.021	0.17 ± 0.03	0.27 ± 0.03
Sprouting	0.068	0.23 ± 0.02	0.35 ± 0.02

During sprouting

$$RR = 13.31 - 0.21139\,\text{day} + 0.0026\,\text{day}^2 - 0.0000021\,\text{day}^3 \quad (7)$$

The correlation coefficient was 0.912 and the standard error was about 1.1 $mg \cdot kg^{-1} \cdot h^{-1}$.

Also, the data of Passam et al. (1978) on respiratory rate of *D. rotundata* tubers stored at 35°C for over 28 wk were used to determine the rate of respiration of tubers stored in the barn where the average storage temperature was about 34°C.

Equation 5 was used to calculate the daily weight loss due to respiration in the barn at various physiological states of the tubers and the values shown in Table III are typical of the general pattern. Also, the daily weight loss of the 180 tubers in the storage structures was calculated from the experimental data; these values are shown in Table III. Tubers lost weight at rates which varied with time and physiological activity in storage; total weight loss varied between 0.17 and 0.25% at an average temperature of about 24.5°C and between 0.27 and 0.36% per day at an average temperature of 34°C.

Using equation 5, the contribution of respiration to yam tuber weight loss was calculated over a 6-mo storage period in the pit structure. Typical results are plotted in Fig. 4, on which the total weight losses have been superimposed. This shows a linear relationship between respiratory weight loss and storage time with a distinct discontinuity at sprout emergence. The percentage contribution of respiration to weight loss of healthy tubers ranged from 13.2 to 33.4% at a storage temperature of approximately 25°C. This shows that although destruction of dry matter occurs during storage through respiration, the major source of weight loss is due to tuber dehydration.

CONCLUSION

A total of 180 yam tubers (*D. rotundata*) stored under tropical conditions for over 6 mo were used to obtain quantitative data on tuber weight loss as affected by environmental factors such as temperature and relative humidity and product-dependent factors such as tuber weight, tuber age and geometry. A step-wise regression analysis was performed to give a prediction equation linking weight loss with the independent variables.

The prediction equation (R^2 = 0.876) was sufficiently accurate to estimate the total weight loss within the experimental conditions. Tubers lost weight at rates which depended on their physiological state, typically between 0.17 and 0.25% per day at about 24.5°C and between 0.27 and 0.36% per day at 34°C. The contribution of respiration to total weight loss was in the range of 13.2–33.4% at 25°C, during the storage period. This suggests that although destruction of dry matter does occur during storage, tuber dehydration is the main source of weight loss of healthy tubers.

ACKNOWLEDGMENT

The painstaking dedication of David O. Ajayi of the department of Agricultural Engineering, University of Nigeria, Nsukka, in collecting the experimental data is gratefully acknowledged.

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