# Storage Stability of Selected Agricultural Grains

by

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## Abstract

Three grains maize, sorghum and millet were stored at different levels of moisture contents 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 % and 98 % wet basis in order to determine the optimum moisture content for maximum grain stability. The effects of moisture content levels on their quality at three different temperatures levels (20 °C, 25 °C and 40 °C) were evaluated. The Rockland (1969) concept of local isotherm was used to interpret the responses of the physical properties while the free energy equation was used to evaluate the energy levels of the grains at these moisture contents. This resulted in stability curves which showed that grains equilibrated by desorption (drying) have a two point minima levels (11.40 and 18.81 % at 20 °C, 12.75 and 18.84 % at 25 °C and 15.00 and 18.48 % at 40 °C for maize; 11.46 and 18.92 % at 20 °C, 11.36 and 18.92 % at 25 °C and 12.29 and 18.62 % at 40 °C for sorghum; 13.45 and 19.81 % at 20 °C, 14.79 and 21.20 % at 25 °C and 14.25 and 20.85 % at 40 °C for millet) that gives rise to a wider safe moisture range than by adsorption (humidification). The results further revealed that the three grains showed optimum moisture for stability above and below which deterioration takes place rapidly.

## Introduction

Moisture is an important and major constituent of all biological materials. It serves as a reactant, solvent and a vehicle for conveying other soluble constituents within the biomaterials. The control of moisture in storage and processing has been in practice for a long time. Moisture control measures such as salting, drying, sugaring and freezing is means of preserving food materials (Darby, 1976; Salaman, 1940; Tannahill, 1974) that dated back to early civilization period. These processes were adopted to control moisture availability with the ultimate aim of making biomaterials stable thus preventing physical degradation due to chemical and biological deterioration.

However, most of these control measures were not documented until late 1950's when Salwin (1957) and Scott (1957) came up with the concept of water activity (Aw), (defined as the ratio of vapour pressure of biomaterials to that of pure water at the same conditions). In those early days, maximum storage stability was associated with minimum moisture content. It was later demonstrated (Martnez and Labuza, 1968; Rockland, 1969) that a range of moisture contents exist below and above which food deterioration takes place rapidly. Thus the concept of defining minimum moisture content for food materials known as Local Isotherms (L.I.) was brought about. Rockland (1969), working on walnut, kernels reported on a safe range of moisture content and consequently divided moisture in biological products into three isotherm regions tagged local isotherms (L.I.) with differential stability coefficients. By this division, water activity (AW) below 0.138 was designated as L.I.1, AW between 0.138 and 0.264 was designated as L.I.2 while above this level is termed L.I.3. However, this range could only be a guide since biological materials vary widely in composition and cellular arrangement.

The objectives of the study reported in this paper were, (a) to evaluate the effects of moisture content and local isotherm regions on physical and physiological properties of grains and (b) the use of free energy concept to define optimum moisture content for maximum storage stability of grains.

## Theoretical Background

The moisture content of any hygroscopic material, including agricultural products, is a function of the properties of both the material and its environment. The affinity for water by any biological material varies with the inherent initial moisture content, the product composition, the water affinity (hydrophillicity or hydrophobicity), and the moisture availability in its environment (environmental relative humidity) Ajisegiri (2000). These three factors together determine the hygroscopicity of any biomaterial. All the three factors are related to energy balance since free energy is responsible for the transfer of water molecule first to the vapour state, and from the vapour state into or away from the absorbing surface. The energy balance could, in turn, be related to a typical heterogeneous chemical reaction rate that is dominated by resistance to diffusion between phases in which every slight increase in reaction rate is accompanied by rise in temperature.

The free energy involved in water transfer was reported by Igbeka (1987) to be:

$$\Delta F = \frac{RT}{18} \ln\left[\frac{P_0}{P}\right] \quad \text{.......................(1)}$$

Where, $\Delta F$ = Free energy change, R = gas constant, T = temperature, $P_0$ =vapour pressure of pure water, p = vapour pressure

This is free energy change during the transfer of 1 g of water in an isotherm process whose.

Integral is the form;

$$\Delta F = \frac{RT}{18} \int \frac{M}{RH} d(RH) \quad \text{.......................(2)}$$

Where, M = moisture, RH = relative humidity

The equation forms the basis of the formation of "stability isotherm" which has been successfully applied to some crops with accurate results (Rockland, 1969). Equation (1) is also similar to the differential coefficient of moisture with respect to relative humidity whose integral could be written as;

$$\frac{\Delta M}{\Delta RH} = \int_0^\infty \frac{M}{RH} dM \quad \text{.......................(3)}$$

Comparatively, Equation (2) is similar to (3), which is free energy change involved in a transfer of 1 g of water in an isothermal process expressed in terms of relative humidity (RH). In both equations, M is a function of relative humidity (RH) while in equation (2) RT/18 is a constant. Considering Equation (2) the integral function is minimised when M/RH is of minimum value. Consequently, free energy is also minimised at this point. That is the point where minimum slope occurs on the L.I. curve or where a minimum change occurs in M/RH with M. It could therefore be stated that maximum stability of biomaterial occurs at M/ERH coordinates where minimum change of moisture content takes place per change in equilibrium relative humidity. This concept was applied in this study to analyse the moisture data and to determine product stability of maize, sorghum and millet at 20 °C, 25 °C and 40 °C respectively.

## Experimentation

Maize, sorghum and millet, were obtained fresh from the National Cereals and Seed Service Federal Dept. of Agric. Ibadan, Nigeria with initial moisture content of 16.27 %, 16.01 % and 19.47 % (wet basis) for maize, sorghum and millet respectively. The grains were threshed by hand (to prevent mechanical damage) and dried to a moisture content of 4 % wet basis (4.2 % dry basis) to enable the determination of water

**Table 1** Grain surface texture

| Fresh | Region A (L.I.1) | Region B (L.I.2) | Region C (L.I.3) | Crop |
|---|---|---|---|---|
| Smooth surface, partially shiny | Smooth, partially shiny, shrunk grem, shrink appearance with powdery surface | Smooth, partially shiny with slightly shrunk grem appearance | Bloaty, cakey, black spots deposition on the surface (fungal growth) | Maize |
| Slightly rough | Slightly rough, sunken germ and protruded ends, partially shiny | Slightly rough surface | Brittle, round, shade bloaty appearance | Sorghum |
| Shiny, slippery and smooth | Shiny, slippery and smooth with brittle ends that easily break | Shiny, slippery and smooth | Dull looking, cakey with outer whitish deposit | Millet |

**Table 2** Grain colour variation

| Fresh | L.I.1 | L.I.2 | L.I.3 | Crop |
|---|---|---|---|---|
| Light to very deep yellow | Deep yellow | Light to deep yellow | Light yellow with black spots | Maize |
| Light to deep reddish brown | Very deep reddish brown | Light reddish brown | Very light red with whitish outer coat | Sorghum |
| Milky white | Light brown with deeper brown | Milky white with a shade of deep colour | Light colour with whitish deposits on outer surface | Millet |

activity at a relative humidity range of between 10 % and 98 %. The low moisture content was achieved by slowly drying a bulk sample of the products in a laboratory vacuum oven at a temperature not exceeding 5 °C. After drying, the grains were packed in sealed plastic bags and stored.

Ten grams (10 g) of each grain sample were placed in an equilibrium chamber containing saturated salt solution that develops known equilibrium relative humidity at specific temperature, as described by Greenspan (1977), Bosin and Easthouse (1970) and Igbeka et al. (1975) and modified by Ajisegiri and Igbeka (1986) and re-modified by Ajisegiri (1987). When the samples reached constant weight, equilibrium moisture content was determine by drying in an air oven for 12 hours at 103 °C (± 2 °C).

The equilibration time varied between forty-eight and ninety-eight hours but the experiments were continued after these periods for 1680 hours (about 10 weeks) to monitor physical changes such as weight gain/loss and germination and proliferation of microbiological organisms. The germination or viability tests were conducted by planting some seeds from both the fresh and the treated samples. Four (4) replicates of equilibrium moisture content (e.m.c.) at the set temperatures and relative humidity (rh) were carried out and the mean values were used for each plot.

The temperatures 20 °C, 25 °C and 40 °C were obtained by submerging the experiment chamber in thermostatically controlled water in a bath, with an accuracy of ± 0.5 °C. A total of 299 samples were used for the experiment. The temperature ranges used represented the average prevailing storage temperature variation in the tropics throughout the year. For the interpretation of the local isotherm, the equilibrium relative humidity (e.r.h.) range was divided into three parts:

i. A monolayer region (Region A) or local isotherm one (L.I.1) which ranges between 0-20 % e.r.h.

ii. A multilayer region (Region B) or local isotherm two (L.I.2) which ranges from 20-70 % e.r.h.

iii. Capillary condensation region (Region C) or local isotherm three (L.I.3), which ranges between 70-98 % e.r.h. (Labuza et al., 1970).

## Results and Discussion

### Results

The results of the visual inspection and textural evaluation carried out on the fresh and treated samples are shown in **Tables 1** and **2**. Results on germination tests and shape variation are presented in **Tables 3** and **4**. The sorption data obtained was used to compute variation in moisture content at each e.r.h. level at various temperatures and presented as stability curves, **Figs. 1** to **6**.

**Table 3** Grain germination variation, %

| Fresh | L.I.1 | L.I.2 | L.I.3 | Crop |
|---|---|---|---|---|
| 90 | 45 | 88 | 0 | Maize |
| 80 | 82 | 85 | 0 | Sorghum |
| 90 | 0 | 90 | 0 | Millet |

**Table 4a** Average grain shape variation for maize

| | Major diameter | Minor diameter | Thickness | Projected area | Circular area | Sphericity |
|---|---|---|---|---|---|---|
| Fresh | 10.894 | 8.695 | 5.100 | 70.313 | 84.102 | 0.863 |
| SD | 0.77 | 1.530 | 0.917 | 11.128 | 21.532 | 0.084 |
| Region A (L.I.1) | 10.351 | 8.508 | 4.663 | 69.989 | 86.287 | 0.841 |
| SD | 1.648 | 0.871 | 0.827 | 17.668 | 25.316 | 0.151 |
| Region B (L.I.2) | 10.892 | 8.703 | 5.062 | 70.293 | 84.293 | 0.865 |
| SD | 1.77 | 1.138 | 1.407 | 12.802 | 12.802 | 0.220 |
| Region C (L.I.3) | 10.961 | 8.760 | 4.525 | 72.103 | 89.167 | 0.872 |
| SD | 0.713 | 0.778 | 0.468 | 14.811 | 17.860 | 0.044 |

**Table 4b** Average grain shape variation for sorghum

| | Major diameter | Minor diameter | Thickness | Projected area | Circular area | Sphericity |
|---|---|---|---|---|---|---|
| Fresh | 4.563 | 3.998 | 2.662 | 16.620 | 16.400 | 0.883 |
| SD | 0.462 | 0.216 | 0.187 | 1.680 | 1.510 | 0.041 |
| Region A (L.I.1) | 4.374 | 3.968 | 2.617 | 15.212 | 15.126 | 0.847 |
| SD | 0.354 | 0.346 | 0.257 | 3.108 | 2.457 | 0.091 |
| Region B (L.I.2) | 4.584 | 4.029 | 2.684 | 16.613 | 16.399 | 0.884 |
| SD | 0.234 | 0.197 | 0.260 | 1.732 | 1.519 | 0.039 |
| Region C (L.I.3) | 4.585 | 4.216 | 2.788 | 16.982 | 16.466 | 0.920 |
| SD | 0.296 | 0.273 | 0.251 | 2.098 | 2.095 | 0.040 |

**Table 4c** Average grain shape variation for millet

| | Major diameter | Minor diameter | Thickness | Projected area | Circular area | Sphericity |
|---|---|---|---|---|---|---|
| Fresh | 3.082 | 2.502 | 1.719 | 6.820 | 8.028 | 0.826 |
| SD | 0.136 | 0.924 | 0.567 | 2.338 | 1.364 | 0.207 |
| Region A (L.I.1) | 3.006 | 2.368 | 1.751 | 6.727 | 7.128 | 0.792 |
| SD | 0.196 | 0.143 | 0.142 | 0.618 | 0.922 | 0.088 |
| Region B (L.I.2) | 3.067 | 2.492 | 1.772 | 6.809 | 7.989 | 0.824 |
| SD | 0.151 | 0.056 | 0.059 | 0.933 | 1.380 | 0.108 |
| Region C (L.I.3) | 3.271 | 2.569 | 1.852 | 7.123 | 8.477 | 0.843 |
| SD | 0.319 | 0.179 | 0.119 | 0.688 | 0.568 | 0.060 |

SD = Standard deviation

## Discussion

Observations show that the physical conditions of grains kept under ambient condition exhibits similar properties as those stored under local isotherm 2. This indicates that although variations do occur in temperature and equilibrium moisture contents of these grains stored at ambient condition, the variation oscillate around the simulated conditions under local isotherm 2. Consequently, the colour, texture, physical dimensions as well as the germination rates under these conditions are similar.

Under a very low relative humidity typified by local isotherm one, the colour takes a deeper shade. The grain texture also is more rough and brittle and there is a physical appearance of elongation although under this same condition, maize looses about 50 % of its germination capacity. The physical dimensions generally tend to shrink under this condition. There is a marked reduction in both the major and minor diameters, the thickness and the projected areas of the grains as well as the sphericity.

Plots of (m/r h) versus (m) for maize, sorghum and millet at various temperatures were used to establish the stability curve of the grains. These curves (**Figs. 1** to **6**) showed a definite pattern of moisture content for optimum storage stability of grains.

The curves showed that there exists a range of moisture contents where the stored grains are most stable. Using the sorption curves, the stability range could be obtained. This is shown in **Table 5**.

This range denotes the moisture content region where least physical property change per unit change in relative humidity occurred. This is vital information for storage purposes. It is difficult to keep moisture content of stored grain constant under natural storage condition. Therefore, the range indicates the safe moisture content within which grains could be stored and the time for drying, aeration or humidification if the natural moisture condition fluctuates beyond the safe limits.

It is also interesting to note that the range for all the grains fall within the L.I.2, which conforms to the

**Fig. 1** Adsorption moisture stability curve for maize

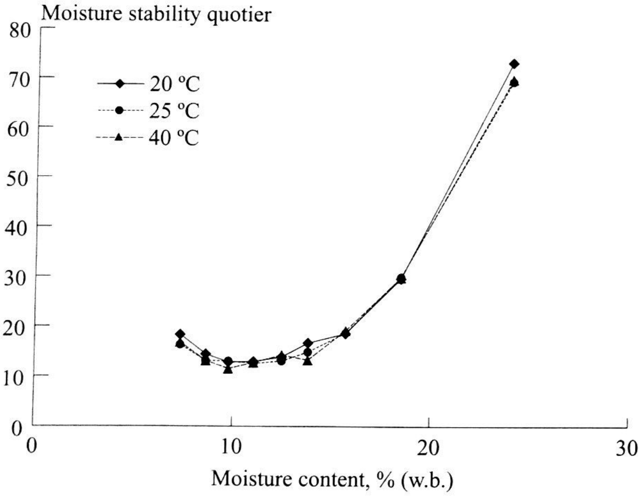



**Fig. 2** Desorption moisture stability curve for maize

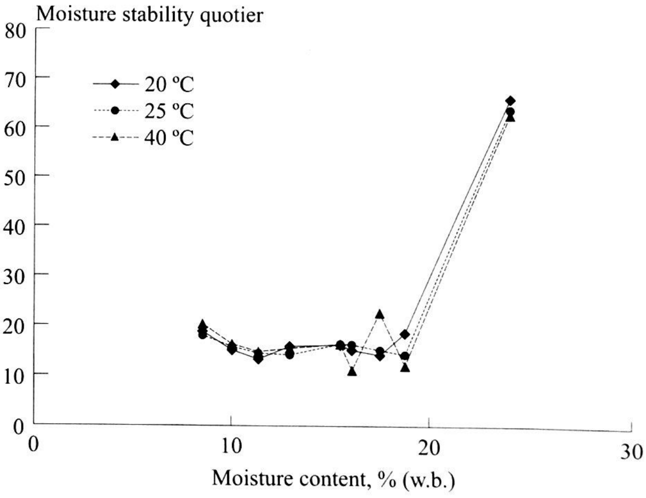



**Fig. 3** Adsorption moisture stability curve for sorghum

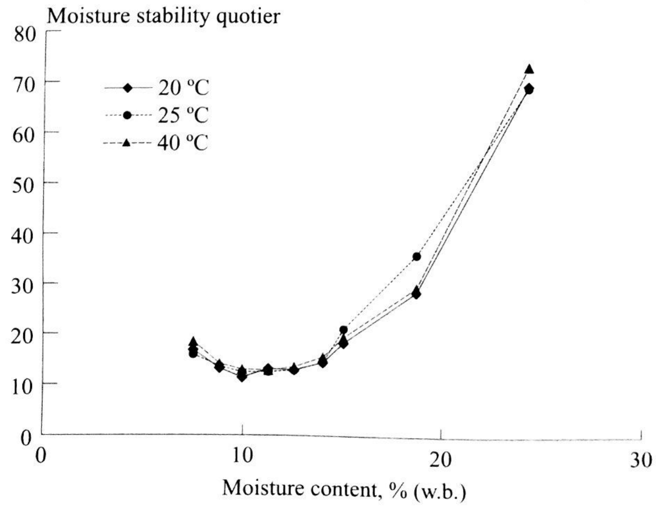
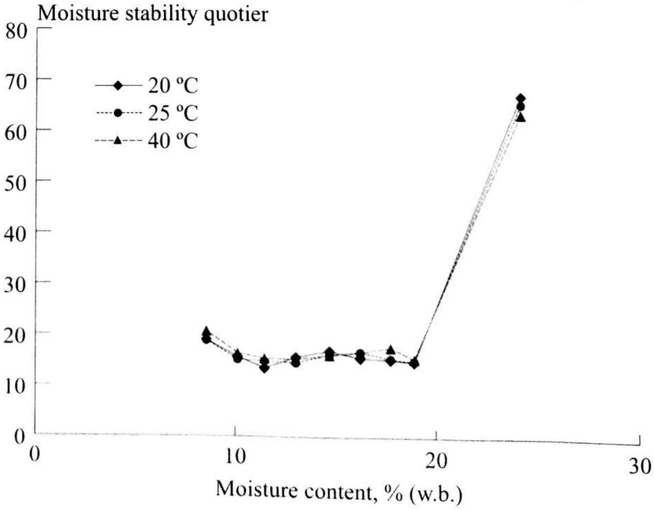



**Fig. 4** Desorption moisture stability curve for sorghum



prediction of Rockland (1969). The desorption data range does not only falls within the L.I.2 but it is wider and similar in pattern to the theoretical stability model proposed by Rockland and Nishi (1980). Stability curves from adsorption data exhibited two maximum values (6.90 and 23.93 % at 25 °C, 5.90 and 23.49 % at 40 °C for maize; 7.08 and 24.13 % at 25 °C, 6.00 and 23.69 % at 40 °C for sorghum; 9.38 and 26.43 % at 25 °C, 8.29 and 26.00 % at 40 °C for millet) and one minimum value (10.76 % at 25 °C, 8.50 % at 40 °C for maize; 9.68 % at 25 °C, 10.00 % at 40 °C for sorghum; 11.99 % at 25 °C, 12.28 % at 40 °C for millet) at 25 °C and 40 °C. At 20 °C however two minimum levels (9.77 and 13.78 % for maize; 9.95 and 12.57 % for sorghum and 12.24 and 13.35 % for millet) were also recorded. This is an indication of the effect a reduced temperature has on stored produce.

Desorption data on the other hand produced at least two minimum values in all cases and at all temperature levels. They were for maize, 11.40 and 18.81 % at 20 °C, 12.75 and 18.84 %, at 25 °C, 15.00 and 18.48 % at 40 °C; for sorghum, 11.46 and 18.92 % at 20 °C, 11.36 and 18.92 % at 25 °C, 12.29 and 18.62 % at 40 °C; and for millet 13.45 and 19.81 % at 20 °C, 14.79 and 21.20 % at 25 °C, 14.25 and 20.55 % at 40 °C. From this observation, it is possible to propose extending the range of storage temperature coverage of the experiment, Desorption curves in grains might produce a sinusoidal curve, which would probably be negatively skewed towards the capillary condensation region. The implication is that the higher minima values of the curves could be the moisture content points at which the grains are relatively stable, in other words meta-stable points, outside of which grains are expected to degenerate fast.

Furthermore, the stability curves seem to suggest that for grains intended for storage, it is better if equilibrium moisture content is attained through the desorption path. This is because of the longer range of moisture where grains are expected to be stable on this path. This also is in agreement with the recorded values of hysteretic volume, isosteric heat and entropy change in grains that showed less change in values at the desorption path than at the adsorption path (Ajisegiri, 1987).

It therefore means that the stability of grains during storage is a function of relative humidity, the path of equilibrium moisture content, temperature and the type of crop. These factors determine the respiratory rate, reaction kinetics, the enzymatic and non-enzymatic reactions, lipid and auto-oxidation as well as the microbiological activities.

## Conclusions

From this study and other supporting literature, it was concluded that there exist an optimum moisture content at which stability of grains is maximum. This optimum value is temperature dependent. For grains intended to be stored under normal air storage methods, the longest range of moisture tolerance is attained when grain is dried to the storage moisture and not through humidification.

**Table 5** Optimum storage moisture (% w.b.) for grains at 20, 25 and 40 °C

| Crop / Temp | Sorption | | | Desorption | | |
|---|---|---|---|---|---|---|
| | 20 °C | 25 °C | 40 °C | 20 °C | 25 °C | 40 °C |
| Maize | 9.77 | 10.76 | 8.50 | 11.40-18.81 | 12.72-18.38 | 15.00-17.63 |
| Sorghum | 12.57 | 9.68 | 10.00 | 11.46-18.92 | 12.81-18.90 | 12.29-18.62 |
| Millet | 12.24 | 11.99 | 12.28 | 13.45-19.81 | 14.79-21.20 | 14.25-29.85 |

**Fig. 5** Adsorption moisture stability curve for millet

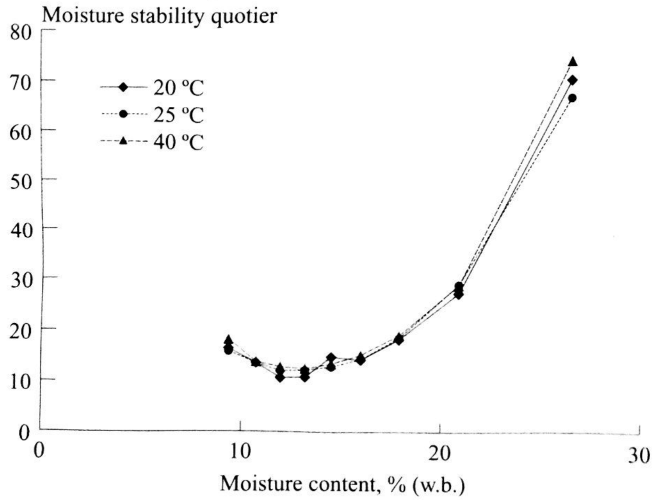
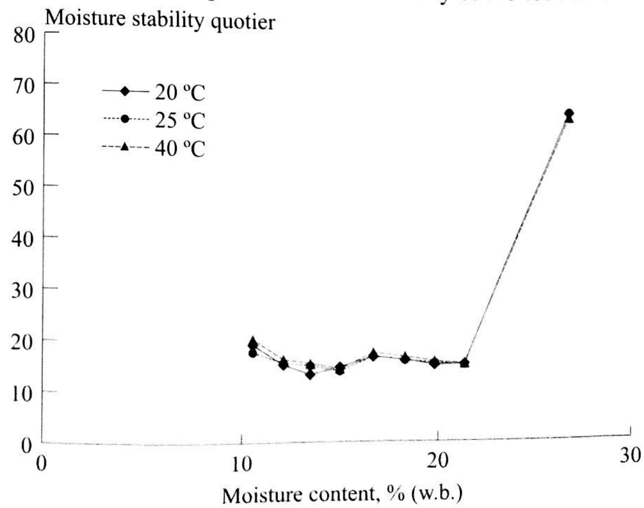



**Fig. 6** Desorption moisture stability curve for millet

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