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Moisture Sorption in Commercial Hybrid Maize (*Zea mays* L.) Seeds During Storage at Ambient Tropical Conditions

[1]I.O. Daniel, [1]K.O. Oyekale, [1]M.O. Ajala, [2]L.O. Sanni, [3]M.A. Okelana, [4]J.A. Adetumbi, [1]D.A.C. Akintobi and [1]M.A. Adebisi

[1]Department of Plant Breeding and Seed Technology, [2]Department of Food Science and Technology, [3]Department of Horticulture, University of Agriculture, Abeokuta, P.M.B. 2240, Abeokuta, Ogun State, Nigeria

[4]Post-Harvest Improvement Technology Programme, Institute of Agricultural, Research and Training, Obafemi Awolowo University, P.M.B 5029, Moor Plantation, Ibadan, Nigeria

Corresponding Author: I.O. Daniel, Department of Plant Breeding and Seed Technology, University of Agriculture, Abeokuta, P.M.B. 2240, Abeokuta, Ogun State, Nigeria

ABSTRACT

Seed moisture sorption isotherms were determined for 2 tropical hybrid maize varieties stored at simulated humid tropical conditions using the static method. Sealed containers with saturated salts solutions were used to generate 8 relative humidity conditions inside an incubator set at 31±4°C for 12 months. Changes in seed moisture content were evaluated at intervals. Seed moisture sorption isotherms were constructed for the 2 varieties and fitted to five different sorption models (Henderson, Henderson-Thompson, Chung-Pfost, modified Halsey and GAB). Seed moisture sorption isotherms for the 2 seed lots were the expected sigmoidal curve. The point of inflexion of the curve was at 55% relative humidity, indicating when seed drying was initiated and maximum relative humidity for drying and/or dry-storage at the ambient temperature. The sorption isotherms for the 2 seed lots however differed in magnitude, thus equilibrium seed moisture at this point was ~8% for Suwan-1-SRY and 5% for Oba-Super-1. Fits of the sorption isotherms to mathematical models differed also differed among seed genotypes. The Henderson-Thompson and Chung-Pfost models exhibited best fits (%D = 13.413 and 6.038) to the moisture sorption data of Oba Super-1 and Suwan-1-SRY seed lots, respectively. The results suggested the need to determine sorption isotherms for tropical hybrid maize genotypes in relationship with seed morphology. Meanwhile, generalized prediction of seed moisture during drying or dry-storage of these varieties in tropical seed stores can be done using the Henderson-Thompson and Chung-Pfost models.

Key words: Maize, tropical hybrids, dry seed storage, seed moisture content, moisture sorption isotherms

INTRODUCTION

Seeds absorb or release moisture to equilibrate with the relative humidity and temperature of the surrounding air in storage. This hygroscopic characteristic of seeds hampers the development of the hybrid seed industry in Nigeria with humid tropical climates where ambient RH and temperature in seed stores are high (Daniel and Ajala, 2006). Thus in storage under ambient conditions before sales, seeds tend to absorb moisture from the surrounding air, leading to increased seed Moisture Content (MC) and rapid deterioration. This is responsible for low seed physiological quality associated with commercial production and storage of hybrid seeds in Nigeria (Daniel, 2007, 2009). High seed MC also predispose seeds to microbial infections and reduction in market values of grains due to mycotoxins production by storage microbes. For example, varying amounts of aflatoxin was found in Nigerian maize stored at 26°C and seed mc of 22.3-24.9%, whereas no aflatoxin production was observed at 5.4% seed MC (Aja-Nwachukwu and Emejuaiwe, 1994). It is therefore essential to evaluate the kinetics of seed moisture sorption under tropical storage conditions.

The hygroscopic characteristics of a seed lot describe relationships between seed MC and storage Relative Humidity (RH) at a given temperature which can be displayed graphically by sorption isotherm curves. Sorption isotherms predicts moisture kinetics of seeds in confined environment (Sanni *et al.*, 1997; Kouhila *et al.*, 2001), which can help to determine optimal conditions for seed drying and store environment adjustments for longevity enhancement in storage (Walters *et al.*, 1998). Since, moisture sorption isotherms vary substantially between different products or seed types, it is essential to determine sorption isotherms for each material at different conditions (Chottanom and Phoungchandang, 2005; Vishwakarma *et al.*, 2007; Idlimam *et al.*, 2008; Alakali *et al.*, 2009; Chottanom and Srisa-Ard, 2011). The objectives of this work were to determine moisture sorption isotherms for Nigerian commercial hybrid seeds, recommend RH conditioning of seed stores and models for predicting seed MC during storage at ambient conditions.

MATERIALS AND METHODS

Two commercial hybrid maize varieties in Nigeria namely Oba super-1 (Oba) and Suwan-1SRY (Suwan) produced in the 2004 season were used for the study.

Seed storage: The seeds were stored for 12 months (May 2005-April 2006) in 2 L capacity, air-tight plastic containers conditioned to 8 different RH levels ranging from 10 to 80% inside an incubator set at 33°C but mean actual temperature reading on thermo-hygrometer was 31±4°C. The static method was used to equilibrate seeds of each hybrid variety over slurries of saturated salt solutions to generate different RH levels inside each container at the set temperature (Table 1). The salt slurries were prepared by dissolving 10 mL of distilled water in glass petri-plates till saturation. The plates containing the salt slurries were then placed at the bottom of each container and a mesh of half inch wire gauze were placed 7.5 cm above the salt slurries to separate the salt and seed compartments. Two replicates of ~400 g each of the seed lots packed in polythene net bags were placed with a digital thermo-hygrometer (Tfa™ Germany) in the seed compartment of each container to monitor temperature and RH during the storage.

Seed moisture content determination: The seed MC was determined before storage and at monthly intervals during storage in air-tight containers conditioned to various RH levels at a constant temperature. Seed MC of the seed lots was determined by a modification of the gravimetric (forced air) oven method (ISTA, 1985). Empty cans were weighed and heated in the oven at 130°C for 2 h or till constant can weight was derived. Two replicates of 5 g of fresh seeds were then placed in the dried cans. The fresh seeds were dried at 130°C for 3 h when constant weight was achieved and then the seed dry weight was then taken. Percentage SMC was calculated on fresh weight basis (fw. b) as follows:

$$\%\text{Seed MC (fw. b)} = (M2\text{-}M3)/(M2\text{-}M1)\times 100$$

where, M1 is weight of can, M2 is weight of can+fresh seeds and M3 is weight of can+dried seeds. RH values from hygrometer were recorded against corresponding percent seed MC.

Data analysis: Seed moisture sorption isotherms were plotted for the 2 seed lots using the RH and seed MC data. PROC NLIN statements of SAS were used to model the moisture sorption characteristics of seeds from the seed moisture content and water activity (a_w) data. Water activity was estimated according to Rizvi (1995). Five sorption models were fitted with the data including Henderson, Henderson-Thompson, Chung-Pfost, modified Halsey and GAB models. The linear forms of the fitted models are presented in Table 2. The goodness-of-fit of the sorption isotherms to the fitted models was determined by using the percentage average deviation (%D) as defined below:

$$\%D = (100/n) \times \Sigma\ [(m_{cal} - m_{act})/m_{act}]$$

where, m_{cal} and m_{act} are the calculated and experimental (actual) values of the equilibrium moisture content, respectively and n is the number of experimental values or observations.

RESULTS AND DISCUSSION

Variations in the %RH in each container with various salt slurries and the equilibrium seed MC after 12 months of storage at 31±4°C are presented in Table 1. The container conditioned with Zinc Chloride had lowest RH of 15.6% and the order of increasing RH in conditioned containers was Zinc Chloride, Calcium Chloride, Calcium Nitrate, Sodium Bromide, Ammonium Nitrate, Ammonium Chloride and Potassium Chloride (Table 1). Seeds stored under the control treatment (in closed container without salt conditioning) had 56.5%.

The moisture sorption isotherms for the 2 hybrid maize seeds at 31±4°C are shown in Fig. 1. The sorption isotherms for Suwan and Oba generally followed the sigmoidal curve model (Fig. 1) which is expected for equilibrating seeds in sealed containers (Alhamdan and Alsadon, 2004) and food materials like tapioca grits (Sanni *et al*., 1997; Adebowale *et al*., 2007). For potential seed longevity enhancement under the high storage temperatures of the tropics (Daniel, 2007; Daniel *et al*., 2009).

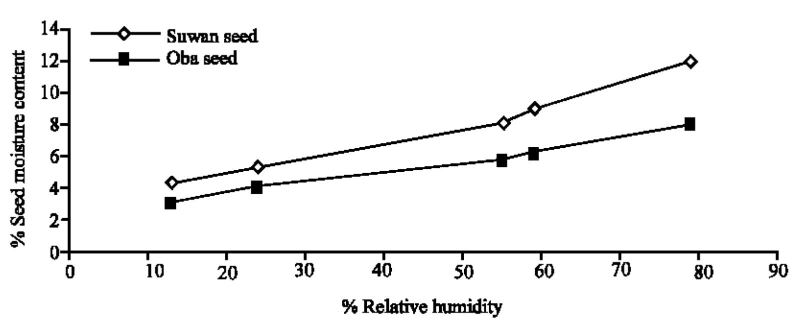

Fig. 1: Sorption isotherm curves for seeds of two commercial maize varieties during storage in closed containers conditioned to various RH values at 31±4°C

Table 1: Average relative humidity and equilibrium seed moisture content attained during storage of 2 Nigerian commercial hybrid maize varieties over different salt solutions at 31±4°C for 12 months

Maize genotype	Salt solution	RH (%) (S.E.)	Eqnilibrium SMC (%) (S.E.)
Oba	Zinc chloride ($ZnCl_2$)	15.6 (0.95)	4.05 (0.33)
Suwan			4.53 (0.23)
Oba	Calcium chloride ($CaCl_2$)	28.7 (1.51)	4.62 (0.30)
Suwan			4.63 (0.31)
Oba	Calcium nitrate [$Ca(NO_3)_2$]	52.5 (0.78)	6.64 (0.37)
Suwan			5.95 (0.31)
Oba	Sodium bromide (NaBr)	56.0 (0.43)	7.38 (0.38)
Suwan			7.23 (0.43)
Oba	Ammonium nitrate (NH_4NO_3)	60.0 (0.72)	7.50 (0.24)
Suwan			8.46 (0.43)
Oba	Ammonium chloride (NH_4Cl)	75.4 (0.62)	7.50 (0.22)
Suwan			8.84 (0.69)
Oba	Potassium chloride (KCl)	80.5 (1.19)	8.16 (0.37)
Suwan			9.58 (0.69)
Oba	Closed container without salt	56.5 (1.48)	6.16 (0.15)
Suwan			7.49 (1.43)

S.E: Standard error of means of 12 data entries, RH: Relative humidity, MC: Seed moisture content

Table 2: Linear forms of the five sorption models used

Models	Linear Forms
Henderson	$(1\text{-}a_w) = \exp[-c_1 T (100m)^{c_2}]$
Henderson-Thompson	$(1\text{-}a_w) = \exp[-c_1 (T+a) (100m)^{c_2}]$
Chung-Pfost	$\text{In} a_w = [(-c_1/RT) \exp(-c_2 m)]$
Halsey modified	$m = (-c_1/T \, \text{In} a_w)^{1/c_2}$
GAB	$m/m_o = c_1 c_2 a_w / (1\text{-}c_2 a_w)(1\text{-}c_2 a_w + c_1 c_2 a_w^2)$

c_1, c_2: Model constants, R: Universal gas constant (J/mole K), a_w: Water activity, T: Temperature (C), m and m_o: Moisture content (%)

Sorption model estimates of seed lots: The sorption isotherm data were subjected to five established moisture sorption models whose linear forms are given in Table 2. The two estimated models parameters were c_1 and c_2, excluding the temperature term since only a single constant temperature treatment was imposed. The values of these parameters differed between the 2 hybrid seeds, generally higher in Oba than Suwan for all the models (Table 3). Generally, all models had lower %D for Suwan hybrid seeds than Oba indicating differences in fits of the sorption isotherms among maize seed genotypes. This also suggest differential responses of seed types to varying RH conditioning which can be extrapolated to seed handling activities like drying and dry storage. The differences in seed moisture isotherms of the tested seed lots can be explained by physical differences in seed morphological features like seed size and seed coat texture which had been reported to affect seed moisture sorption (Greenspan, 1977; Sopade and Ajisegiri, 1994). The hybrid seed lots tested exhibit such differences in seed coat texture, colour and seed size; while Oba is white and round, Suwan is yellow and flat. The implication of this result on drying or dry storage of seeds is that sorption isotherms of every variety or even seed lot of the same variety should be determined before imposing drying treatments. Consequently, sorption isotherms of other existing maize hybrids in the Nigerian seed industry should be further investigated with respect to seed

Table 3: Parameters of sorption models fitted with moisture sorption data of the 2 tropical hybrid maize seed lots

Model (s)	Oba	Suwan
Henderson		
c_1	24.516	6.028
c_2	2.544	2.160
D	13.550	6.088
Henderson-Thompson		
c_1	22.450	5.529
c_2	2.544	2.160
D	13.413	6.088
Chnng-Pfost		
c_1	285.900	224.800
c_2	39.767	30.542
D	14.038	6.038
Halsey modified		
c_1	-0.325	-0.288
c_2	2.574	2.261
D	16.250	6.163
GAB		
c_1	0.036	0.070
c_2	3.396	2.336
D	18.613	11.913

c_1, c_2: Model constants, D: Percentage average deviation (used to determine the extent of deviation and the best model fit)

morphological features to determine isotherms that could be used for handling specific types of seeds during drying and dry storage at ambient conditions.

Generally, fits of sorption data of the Oba seed lots, % D values for the Henderson-Thompson model was apparently the least (13.14) and while for the Suwan seed lot, the least %D estimate was 6.038 for Chung-Pfost model. This suggests that the Henderson-Thompson and the Chung-Pfost models are potential models for generalized estimation of MC of hybrid maize seed lots. It is safe at least for now, to recommend these models for generalized prediction of seed MC for handling hybrid maize seeds in Nigeria because the same models were reported to fit best to moisture sorption isotherms of mustard seeds by Barrozzo *et al.* (2008).

CONCLUSION

In conclusion, moisture sorption of commercial hybrid maize seeds in simulated ambient tropical humid environment of Nigeria was evaluated in this study. The sorption isotherms for seeds of 2 Nigerian commercial hybrid maize varieties were sigmoidal with inflexion point at 55% RH for both seed lots, an important finding for conditioning seed stores for dry storage at ambient tropical temperature. Moreover, differences observed in the fits of the sorption data of the two varieties to existing models suggested the need to evaluate moisture sorption isotherm for each hybrids based on morphological variations. However, for the 2 commercial hybrid seeds investigated in this study, the Henderson-Thompson and the Chung-Pfost models had least %D and can be recommended for use to predict their seed moisture during drying or dry storage.

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