Modeling drying of seed maize using super absorbent hydrogel under hermetic conditions

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Abstract: The objective of this study was to establish the feasibility of applying the Page, Two term exponential, Newton, Logarithmic and Henderson and Pabis mathematical drying models for predicting the drying kinetics of seed maize using super absorbent hydrogel under hermetic conditions. To achieve this, the study was conducted using hydrogel to seed maize ratios by weight of 0:1, 1:5, 1:10 and 1:15 at four different drying temperature levels of 25oC, 30oC, 35oC and 40oC at different initial seed maize moisture contents of 16%, 28% and 53% (dry basis). The moisture data obtained were fitted into the five drying models using non-linear regression analysis (MS Excel 2003TM) based on the minimization of sum of squares by adjusting the model constants. The coefficient of determination (R2), root mean square error (RMSE) and chi-square (X2) were criteria for selecting the best model. High values of coefficient of determination (R2 > 0.95) were obtained for all the five drying models while the corresponding values of X2 and RMSE were in the range of (0.0016-0.0141) and (0.0400-0.3045) respectively. As a result Logarithmic model was the best fitted model with R2 (0.9749-0.9876) and the weakest values of X2 (0.0016-0.0036) and RMSE (0.04-0.128).

Keywords: drying model, seed maize, hydrogel, Logarithmic model

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1 Introduction

Maize (Zea mays L.) is one of the most important cereal crops in the world. It is a staple food to most developing countries (Wambugu et al., 2009). Primary processing of maize involves harvesting, threshing or shelling, drying, treatment and storage. All these processes are dependent on the moisture content of maize. Maize with high moisture content is susceptible to deterioration due to microbial activities, insect damage and germination (Uluko et al., 2006; Chakraverty et al., 2003). For safe storage at temperature up to 27^{o}C, it is critical to reduce the moisture content of maize to 13.5% (db) (Hayma, 2003).

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Various drying methods are available for maize such as thin layer drying, batch drying, sun drying and in-store drying. These drying methods are energy-intensive; thus, the efficiency of a drying operation in terms of energy and time has direct economic consequences for commercial viability (Chakraverty et al., 2003). More also each drying methods has its merits and demerits. Very common is the sun drying that is freely available and can be harnessed at relatively low cost. On the other hand, sun drying is labor intensive and exposes the seeds to contamination from dust, foreign materials, insect infestation, rodents and bird droppings (Jewell et al., 1995; Golob et al., 2002).

In forced air drying, the drying rate of the maize is determined by the inlet air conditions. Thus inlet air at low relative humidity and high temperature has a higher moisture removal rate and vice versa. After bulk drying, maize is stored in structures such as metal silos. These structures are exposed to adverse weather conditions and the stored maize experiences moisture migration when hot and cold. This results into condensation of the moisture in the structure leading to formation of 'hot spots' which are the initial stages in maize deterioration. To reduce these problems moisture in the rising air should be arrested before condensing. Drying systems using dehumidifier equipped with desiccants have been studied before. More also the relationship between air humidity, temperature and air velocity in a cold store have been studied in reference to temperature and moisture content of product as a function of time (Catalano et al., 2008).

Desiccant drying is always termed as low-cost technology. Various desiccant materials have been studied in the past by various scholars as highlighted by Kiburi et al., 2014. Hdrogels or superabsorbent polymers (SAPs) are polymers that can absorb and retain extremely large amounts of a liquid relative to their own mass (Horie et al., 2004). Based on hydrogel properties, they have potentials to be incorporated as a desiccant in maize drying systems to reduce the relative humidity of the inlet air. More also they can be used in maize storage structures such as silo and export containers to keep the relative humidity low and reduce chances of deterioration. In previous works by Kiburi et al., 2014, it was found that hydrogels can be used as potential desiccants. However, use of hydrogels in grain drying has not been fully exploited and documented. The information obtained from this study is useful for further studies.

Mathematical drying models are used to estimate drying periods in agricultural materials. They are used to generalize the drying curves (Doungporn et al., 2012). Thus modeling allows engineers to choose the most suitable and appropriate drying conditions. Experimenting with the actual system is usually costly and disruptive. Some of the frequently used mathematical models include Page, Two term exponential, Newton, Logarithmic and Henderson and Pabis drying models (Corrêa et al., 2009). These models are given by Equations (1)-(5) respectively.

$$MR = \exp(-kt^n) \tag{1}$$

$$MR = a\exp(-kt) + (1-a)\exp(-kbt) \tag{2}$$

$$MR = \exp(-kt) \tag{3}$$

$$MR = a\exp(-kt) + b \tag{4}$$

$$MR = a\exp(-kt) \tag{5}$$

Where, t is drying time (h); k is drying constant (1/h); a, b, c, g, *η are* model's parameters, dimensionless.

Moisture ratio term for the models is computed using Equation (6) (Erenturk et al., 2004).

$$MR = \frac{M_i - M_e}{M_o - M_e} \tag{6}$$

Where, M_i is the moisture content (% dry basis) at drying time *t* (hours), M_e is the equilibrium moisture content (% dry basis), and M_o (initial moisture content, % dry basis) at *t*= 0.

The objective of this study was to develop a drying equation for predicting the drying of seed maize using hydrogels under hermetic conditions. The study was conducted by varying drying temperature and percentage initial moisture content of the seed maize.

2 Materials and methods

2.1 Experimental set up

Figure 1 shows the schematic of the hermetic drying and storage system that was used in this study. The system consisted of an air tight glass container with lid, wire mesh basket and a stand. The air tight glass container cylindrical in nature fitted with a lid will form the hermetic system and was purchased from glass ware supplier. This air tight glass container had capacity of 750 ml with a height of 110 mm to the neck and a base diameter of 90 mm. The container and lid were made of glass that had uniform thickness of 3 mm. The container lid had an outside diameter of 67 mm. To ensure that the system was air tight a rubber seal was fitted between the container neck and the lid. The rubber seal had a diameter of 67 mm and height of 15 mm. In the hermetic system there was a cylindrical stainless steel wire mesh basket that was used to hold the grains. The wire basket was placed on a stainless steel stand so that the sample was not in direct contact with the hydrogel. The cylindrical wire mesh basket was fabricated from a 4 by 4 mm hole opening wire mesh and had a height of 90 mm and diameter of 65 mm. The baskets helped in containment of the seed for ease of weighing. The stands were fabricated from rods with height of 15 mm and 60 mm base ring diameter. Both the wire basket and base stand were fabricated at the Biomechanical and Environmental Engineering department workshop, Jomo Kenyatta University of Agriculture and Technology.

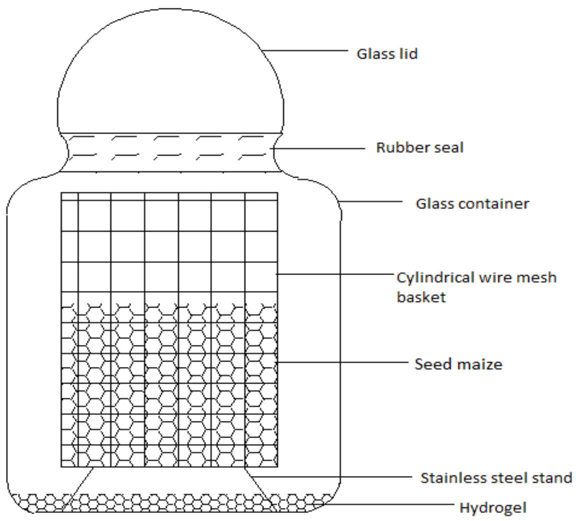

Figure 1 Schematic diagram of the hermetic drying and storage system that was used in this study

2.2 Sample preparation

The materials used for this study included unprocessed seed maize and super absorbent hydrogel. The seed maize (KH 600- 15A) was obtained from East African Seed Company limited, Nairobi while the super absorbent hydrogel, which is Poly-acrylic acid, sodium salt and lightly cross-linked, was purchased from Sigma Aldrich®. The hydrogel was dried in an oven at 40^{o} C to remove moisture before using it in drying the seed maize.

Since the seed maize samples had moisture content less than the experimental requirements of 16, 28 and 53% (dry basis), the seeds were conditioned in batches of 16, 28 and 53% moisture contents (dry basis). Seed conditioning was done by soaking them in distilled water at 4^{o}C for a range of 6 to 24 hours. Soaking ensured uniform water access to seed maize for uniform moisture distribution (Chemperek and Rydzak, 2006) while keeping the soaked sample at 4^{o} C (Doungporn et al., 2012; Tabatabee et al., 2004) in a refrigerator helped in preventing mould growth. A colander was used to drain water from seed maize. Excess water on the surface of the seed maize was further removed using paper towels (Maskan, 2002). Once the water was completely drained from seed maize surface the seeds were left at room temperature overnight. This allowed the seeds to reach room temperature resulting in reduction of thermal stress during drying.

2.3 Data collection procedure

The modeling of drying characteristics of seed maize using super absorbent hydrogel under hermetic conditions required determination of seed maize equilibrium moisture content. Three treatments consisting of 1:5, 1:10 and 1:15 hydrogel to seed maize ratio by weight under different temperatures of 25^{o}C, 30^{o}C, 35^{o}C and 40^{o}C, and moisture content of 16, 28 and 53% (dry basis) were used to evaluate the performance of the super absorbent hydrogel in drying seed maize. A control that did not utilize hydrogel was used. The highest constant temperature used in the tests was 40^{o}C as seeds should not be dried under temperature exceeding this value (Hayma, 2003). The moisture contents were selected such that they represented the minimum, intermediate and the maximum possible moisture contents during seed harvesting. For the 40^{o}C a total of thirty six samples of 120 g seed maize (12 samples for each of the three moisture contents namely 16, 28 and 53% dry basis) were weighed in wire baskets of known weight using analytical mass balance (Mettler Toledo PB8001) with measurement precision of ±0.01 g. Based on 120 g of seed maize nine samples of 24, 12 and 8 g of hydrogel were weighed to attain 1:5, 1:10 and 1:15 hydrogel to seed maize ratios by weight, respectively.

The samples were left to equilibrate in environments of different relative humidity created by the different hydrogel ratios at temperature of 25°C, 30°C, 35°C and 40°C. Moisture content of seed maize was monitored and recorded at three hour intervals for the first day from 8:00 a.m to 5:00 p.m. The three hour interval helped in monitoring the moisture removal rate as most drying of biological products occurs during the falling-rate period (Srikiatden et al., 2007). Thereafter, moisture data was recorded at 12 hour intervals until no further change in moisture content was be observed. The interval was increased to 12 hours because the drying rate in the second falling rate period is extremely slow (Srikiatden et al., 2007). At any sampling time during drying the weight of the seed maize was determined and recorded as W_2.

Control involved drying seed maize under similar hermetic conditions without using the super absorbent hydrogel which is equivalent to a ratio of 0:1 hydrogel to seed maize ratio by weight. This control ran in tandem with other treatment. The same procedure was repeated for other drying temperatures (i.e., 25°C, 30°C and 35°C).

2.4 Data process and analysis

The moisture content of the seed maize M_t at time t was calculated using initial weight of the seed maize W_1 and initial moisture content dry basis, M_o, Equation (7) (FAO, 2011).

$$M_t = 100 - W_1\left(\frac{100 - M_o}{W_2}\right) \tag{7}$$

In order to demonstrate that existing drying models described in Section 1.0 can be used to predict the drying of seed maize using hydrogel under hermetic conditions, several assumptions were made. It was assumed that during drying the heat of hydration was negligible and that drying was based on static desiccant drying system. It was further assumed that drying took place in three stages which included moisture movement from seed maize into the air and surrounding the seeds, moisture adsorption by the hydrogel from the air and a change in relative humidity of the air due to the resultant moisture content of the seed maize and hydrogel.

The moisture ratio values obtained using Equation (6) were fitted to the five chosen models using non-linear regression analysis (MS Excel 2003^{TM}) based on the minimization of sum of squares by adjusting the model constants. The analysis were performed in order to select the best model to describe the drying curve of seed maize drying under hermetic conditions using hydrogel. The coefficient of determination (R^2), the root mean square error (RMSE) and the chi-square (X^2) were used to evaluate the goodness of fit of the established drying models to the measured data (Doungporn et al., 2012; Ronoh et al., 2009; Tabatabee et al., 2004). The best model was selected based on the highest values of the R^2, the lowest values of X^2 and RMSE (Doymaz et al., 2006; Demir et al., 2007; Doungporn et al., 2012).

3 Results and discussion

Tables 1-4 present the established drying parameters and the performance of the models at different drying temperatures. It is noticeable from the results that high values of coefficient of determination ($R^2 > 0.95$) were obtained for all the five drying models. The corresponding values of X^2 and RMSE were in the range of (0.0016-0.0141) and (0.0400-0.3045) respectively. However, the Logarithmic model had the highest values for R^2 and the weakest values of X^2 and RMSE. The high values of R^2 indicates how well the model fits the data (Doungporn et al., 2012; Ronoh et al., 2009; Saeed et al., 2008; Tabatabee et al., 2004). On the other hand, least values of RMSE signified less noise in the data whiles least values of χ^2 showed there was less deviations between the experimental and calculated moisture levels (Doungporn et al., 2012; Ronoh et al., 2009; Tabatabee et al., 2004).

The comparison of the five models shows that Logarithmic model produced the highest values for R^2 (0.975-0.988) and the lowest values of X^2 (0.0016-0.0036) and RMSE (0.04-0.128). The Page model had the lowest value of RMSE at 40°C of 0.0534 as compared to 0.128 of Logarithmic model. However, comparing the values of coefficient of determination (R^2), Chi-square (X^2) and root mean square error (RMSE), the Logarithmic model satisfactorily predicted drying of seed maize using hydrogel under hermetic conditions. The results were in agreement with previous studies conducted by Sungcome et al. (2013) that showed Logarithmic model best described drying of tomato F_1 hybrid seed by desiccant material with R^2 of (0.93-0.99).

Table 1 Established drying parameters and performance of different models at 25°C

Model	model coefficient and constants			R^2	X^2	RMSE
Page	k=0.0467	n=1.424		0.983	0.0026	0.0456
Two term exponential	k=0.0220	a=1	b=1	0.951	0.0084	0.1412
Newton	k=0.0126			0.951	0.0084	0.1412
Logarithmic	k=0.0002	a=6.8447		0.984	0.0021	0.0408
Henderson and Pabis	k=0.021	a=1.0351		0.952	0.0141	0.1117
			Maximum	0.984	0.0141	0.1412
			Minimum	0.951	0.0021	0.0408
			Average	0.964	0.0071	0.0961

Table 2 Established drying parameters and performance of different models at 30°C

Model	model co-efficient and constants			R^2	X^2	RMSE
Page	k=0.0168	n=1.0487		0.976	0.0033	0.0506
Two term exponential	k=0.0145	a=1	b=1	0.968	0.0055	0.0613
Newton	k=0.0142			0.968	0.0055	0.3046
Logarithmic	k=0.0108	a=2.2182	b=-4.2644	0.988	0.0016	0.0335
Henderson and Pabis	k=0.0135	a=1.0244		0.969	0.0045	0.1127
			Maximum	0.988	0.0055	0.3046
			Minimum	0.968	0.0016	0.0335
			Average	0.974	0.0041	0.1125

Table 3 Established drying parameters and performance of different models at 35°C

Model	model co-efficient and constants			R^2	X^2	RMSE
Page	k=0.0057	n=1.3336		0.976	0.0043	0.0591
Two term exponential	k=0.012	a=1	b=1	0.965	0.0054	0.0632
Newton	k=0.0138			0.965	0.0150	0.0641
Logarithmic	k=0.0068	a=1.8254	b=-0.8386	0.985	0.0019	0.0400
Henderson and Pabis	k=0.0142	a=1.0233		0.964	0.0051	0.0652
			Maximum	0.985	0.0150	0.0652
			Minimum	0.964	0.0019	0.0400
			Average	0.971	0.0063	0.0583

Table 4 Established drying parameters and performance of different models at 40°C

Model	model co-efficient and constants			R^2	X^2	RMSE
Page	k=0.0038	n=1.6024		0.975	0.0040	0.0534
Two term exponential	k=0.0173	a=1	b=1	0.943	0.0105	0.0783
Newton	k=0.0143			0.942	0.0101	0.0828
Logarithmic	k=0.0157	a=5.5013	b=-4.1376	0.975	0.0036	0.1280
Henderson and Pabis	k=0.0150	a=1.0516		0.946	0.0092	0.1212
			Maximum	0.975	0.0105	0.1280
			Minimum	0.942	0.0036	0.0534
			Average	0.956	0.0075	0.0927

The results comparing measured and predicted moisture ratios using the Logarithmic model are shown in Figure 1. The low values of χ^2 and RMSE exhibited by Logarithmic model together with results in Figure 1 show that there was indistinct difference between the observed and predicted moisture ratio by the model. This observation further confirms that Logarithmic model is suitable for modeling seed maize drying using superabsorbent hydrogel under hermetic conditions.

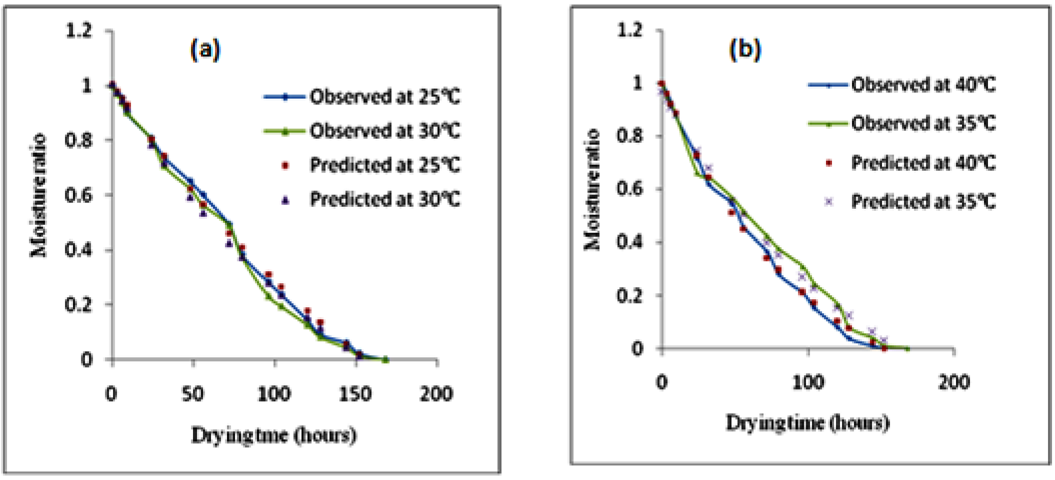

Figure 1 Relationship between the measured and predicted moisture ratios for the Logarithmic model

4 Conclusions and recommendations

All the five models considered had high values of coefficient of determination (R^2 > 0.95) with corresponding values of χ^2 and RMSE in the range of (0.0016 - 0.0141) and (0.0400 - 0.3045), respectively. Logarithmic model was found to be the best fitted model to predict seed maize drying using hydrogel under hermetic conditions with R^2 (0.9749 - 0.9876) and the weakest values of χ^2 (0.0016 - 0.0036) and RMSE (0.04 - 0.128).

The results of this study can be used as basis of further studies on use of hydrogel in storage structures such as silos to reduce condensations and in export containers during shipping to keep the maize dry and reduce deteriorations. It is also important to carry out further test on use of hydrogel as a dehumidifier in a forced air drying system.

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References

Catalano, P., F. Fucci, F. Giametta, and G. La Fianza. 2008. A system for food drying using humidity control and low temperature. Agricultural Engineering International: the CIGR Ejournal. Manuscript Manuscript FP 07 012. Vol. X.

Chakraverty, A., A. S. Mujumdar, G. S. V. Raghavan, and H. S. Ramasawamy. 2003. *Handbook of Postharvest Technology*. Marcel Dekker Inc. New York, USA, ISBN: 0-8247-0514-9

Chemperek, P., and L. Rydzak. 2006. Vacuum wetting of soybean seeds and maize grains at different temperature and time conditions. Teka Kom. Energy Rollin, 6(A), 24-31.

Corrêa, P. C., F. M. Botelho, G. H. H. Oliveira, A. L. D. Goneli, O. Resende, and S. C. Campos. 2009. Mathematical modeling of the drying process of corn ears. DO1: 10.4025/actasciagron.v33i4.7079.

Demir, V., T. Gunhan, and A. K. Yagcioglu. 2007. Mathematical modelling of convection drying of green table olives. *Biosystem Engineering*, 98(1): 47–53.

Doungporn, S., N. Poomsa-ad, and L.Wiset. 2012. Drying equations of Thai Hom Mali paddy by using hot air, carbon dioxide and nitrogen gases as drying media. *Food Bioproduction Process*, 90(2): 187–198.

Doymaz, ˙I., N. Tu˘ grul, and M. Pala. 2006. Drying characteristics of dill and parsley leaves. *Journal of Food Engineering*, 77(3): 559–565.

Erenturk, S., M. S. Gulaboglu, and, S. Gultekin. 2004. The thin-layer drying characteristics of rosehip. *Biosystem Engineering*, 89(2): 159–166.

Golob, P., G. Farrel, and J. Orchard. 2002. Crop post-harvest: science and technology. Vol 1, Principles and practice. Blackwell science limited. ISBN 0-632-05723-8.

Hayma, J. 2003. The storage of tropical agricultural products. 4th edition, Agromisa Foundation, Wageningen, ISBN 90-77073-60-4.

Horie, K., M. Barón, R. B. Fox, J. He, M. Hess, J. Kahovec, T. Kitayama, P. Kubisa, E. Maréchal, W. Mormann, R. F. T. Stepto, D. Tabak, J. Vohlídal, E. S. Wilks, and W. J. Work. 2004. Definitions of terms relating to reactions of polymers and to functional polymeric materials (IUPAC Recommendations 2003). *Pure and Applied Chemistry*, 76(4): 889–906.

Jewell, D. C., S. R. Waddington, J. K. Ransom, and K.V. Pixley. (eds). 1995. Maize research for stress environments. Proceedings of the fourth Eastern and Southern Africa regional maize conference, held at Harare, Zimbambwe, 28 March- 1 April 1994. Mexico D.F. ISBN 968-6923-51-9.

Kiburi, F. G., C. L. Kanali, and D. O. Mbuge. 2014. Evaluating the performance of super absorbent hydrogel in drying of seed maize under hermetic conditions. Proceedings of 2014 International Conference on Sustainable Research and Innovation, Volume 5, 7th-9th May 2014

Maskan, M. 2002. Effect of processing on hydration kinetics of three wheat products of the same variety. *Journal of Food Engineering*, 52(4), 337–341.

Ronoh, E. K., C. L. Kanali, J. T. Mailutha, and D. Shitanda. 2009. Modeling thin layer drying of amaranth seeds under open sun and natural convection solar tent dryer. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1420. 11.

Srikiatden, J., and J. S. Roberts. 2007. Moisture transfer in solid food materials: a review of mechanisms, models, and measurements. *International Journal of Food Properties*, 10(4): 739–777.

Sungcome, K., S. Photchanachai, and S. Prachayawarakorn. 2013. Drying behavior and quality of tomato f_1 hybrid seed by desiccant materials. *Acta Hort. (ISHS)*, 989: 383-388.

Tabatabee, R., D. S. Jayas, and N. D. G. White. 2004. Thin-layer drying and rewetting characteristics of buckwheat. *Canadian Biosystems Engineering/Le génie des biosystèmes au Canada*, 46(3): 19-3.24.

Uluko, H., C. L. Kanali, J. T. Mailutha, and D. Shitanda. 2006. A finite element model for the analysis of temperature and moisture distribution in a solar grain dryer. The Kenya Journal of Mechanical Engineering, Fimen Publishers, Nairobi, Kenya 2(1), 47–56.

Wambugu, P. W., Mathenge P. W., E. O. Auma, and Rheenen H. A. 2009. Efficacy of traditional maize (Zea mays L.) seed storage methods in western Kenya. Aljfand online Journal. Vol 9 No. 4.

Alvarez-Martinez, L., K.P. Kondury and J.M. Harper. 1988. A general model for expansion of extruded products. *Journal of Food Science,* 53(8): 609-615.

Anderson, R.A., H.F. Conway, V.F. Pfeifer and E.L. Griffin, Jr. 1969. Gelatinization of

corn grits by roll and extrusion cooking. *Cereal Science Today,* 14(1): 4-12.

AOAC. 1995. Official Methods of Analysis. In *Association of Official Analytical Chemists, 15th Ed.* Washington, D.C.

Association of American Grain Growers (AAGG). 2010. Sorghum Handbook. In *Association of American Grain Growers Annual Report, 4th Ed.* Iowa, USA.

Chakraborty, S.K., D.S. Singh, B.K. Kumbhar and S. Chakraborty. 2011. Millet-legume blended extrudates characteristics and process optimization using RSM. *Food and Bioproducts Processing,* 89(4): 492-499.

Hseih, F., H.E. Huff and I.C. Peng. 1990. Studies of whole cottonseed processing with a twin screw extruder. *Journal of Food Engineering,* 12(4): 293-306.

Hwang, M.P and K.I. Hayakawa. 1980. Bulk density of cookies undergoing commercial baking processes. *Journal of Food Science,* 45(6): 1400-1410.

Mahasukhonthachat, K., P.A. Sopade and M.J. Gidley. 2010. Kinetics of starch digestion and functional properties of twin-screw extruded sorghum. Journal of Cereal Science, 51(3):392-401.

Matlab Computer Software (2012). 10th Version

Mkandawire, N.L., S.A. Weier, C.L. Weller, D.S. Jackson and D.J. Rose. 2015. Composition, in vitro digestibility and sensory evaluation of extruded whole grain sorghum breakfast cereals. Food Science and Technology, 62(1): 662-667.

Myat, L. and G.H. Ryu. 2014. Characteristics of destarched corn fiber extrudates for ethanol production. Journal of Cereal Science, 60(2): 289-296.

Myer, R.H. 1971. Response Surface Methodology. Allyn and Bacon, Boston, USA.

Vargas-Solorzano, J.W., C.W. Piler-Carvaiho, C.Y. Takeiti, J.L. Ramirez-Ascheri and

V.A. Vieira-Queiroz. 2014. Physicochemical properties of expanded extrudates from colored sorghum genotypes. Food Research International, 55(1):37-44.