Effect of moisture content on thermal properties of cowpea flours

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Abstract: The effects of moisture content on thermal properties of cowpea flour were investigated on a range of 3.81% to 28.31% wet basis at 5% intervals, totaling six moisture levels, using a KD2 Pro Thermal Properties Analyzer. The considered thermal properties were thermal conductivity, thermal diffusivity, and specific heat. As the moisture content increased from 3.81% to 28.31 %, the thermal conductivity, thermal diffusivity, and specific heat increased from 0.109 to 0.213 W m^{-1} K^{-1}, 0.099 to 0.136 mm^2 s^{-1}, and 1.092 to 1.573 MJ m^{-3} K^{-1}, respectively. The data are necessary for design of equipment for handling, transportation, processing, and storage of cowpea flour.

Keywords: cowpea, *Vigna unguiculata*, flour, thermal properties, KD2 Pro, moisture content

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1 Introduction

Cowpea (*Vigna unguiculata*), an annual indigenous African legume, is commonly referred to as southern, black-eyed, purpled-eyed, field, and crowder pea, and lubia, niebe, coupe or frijole (Davis et al., 1991; Nagai, 2008; Ampah et al., 2012). It is a drought-resistant crop with the nodule bacteria *Bradyrhizobium* spp. and is able to survive in hot, dry soil conditions with low fertility requirements (Yeung, 2007). Cowpea seed is composed of about 11% moisture, 23.4% protein, 56.8% carbohydrate, 3.9% fiber, 3.6% ash, 1.3% fat, and provides 343 calories per 100 g of seed (Deshpande and Damodaran, 1990; Singh 2003). Cowpea is widely grown in Africa, Latin America, and Southeast Asia and in the Southern United States (Davis et al., 1991; Appiah et al., 2011), Nigeria being the largest producer of cowpea in the world (Henshaw, 2008). In the U.S., cowpeas are mainly grown in the states of Georgia, California and Texas, accounting for 65% of the total production in the U.S. (Singh, 2003).

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Thermal processes such as pasteurization, concentration, drying, heating, cooling, sterilization, thawing, cooking, refrigeration, freezing, and evaporation are frequently used in food processing, transportation, and preservation operations. Knowledge of thermal properties of foods is thus crucial not only for equipment design but also for the prediction and control of various changes occurring in foods during heat transfer processes associated with storage and processing. Thermal properties data are required both for existing foods and for new products and processes. Besides processing and preservation, thermal properties also affect sensory quality of foods as well as energy savings from processing (Fontana et al., 1999).

Thermal conductivity is defined as the ratio of heat flux density to temperature gradient in a food material. It is a measure of the ease with which heat flows through a food material and this property can be used to predict or control heat flux in food processing operations such as cooking, freezing, sterilization, drying or pasteurization (Fontana et al., 1999). Thermal diffusivity is the ratio of thermal conductivity to specific heat and is the rate at which heat diffuses within a food material. This property helps in estimating processing time of heating, cooling, freezing and cooking (Fontana et al., 1999). It is also used in calculating temperature change in storage bins because of fluctuations in external and internal temperature (Irtwange and Igbeka, 2003). Specific heat or heat capacity is the amount of heat required to raise the temperature of a unit mass of a food material by 1℃. It is the ability of a food material to store heat relative to its ability to conduct (loose or gain) heat. Specific heat is an important thermal property used in heat transfer and energy balance calculations (Kaletunç, 2007). Because water is one of the major constituents of food materials, understanding of the effect of moisture content on thermal properties would contribute extensively to analysis of thermal processes (Wang and Brennan, 1993).

Taiwo et al. (1996) evaluated thermophysical properties (density, specific heat, and thermal conductivity) of hydrated cowpea flours as a function of temperature and moisture content. The effective thermal conductivities of defatted soy flour (Wallapapan and Sweat, 1982) and wheat flour (Muramatsu et al., 2002) were measured at various moisture contents, temperature and bulk densities. Kim et al. (2003) measured the effective thermal conductivity of wheat flour milling co-products. Božiková (2003) related thermal conductivity and thermal diffusivity of corn flour and wheat flour to moisture content and bulk density. Mahapatra et al. (2011) determined the thermal conductivity and thermal diffusivity of rice flour and rice protein at various moisture contents, temperatures, and bulk densities. Muramatsu et al. (2005) investigated the effects of moisture content, temperature, and bulk density on thermal conductivity of rice flour.

A review of literature revealed that data on effects of moisture content on thermal conductivity, thermal diffusivity and specific heat of cowpea flours is lacking. The objective of this study was to determine the effect of moisture content on thermal properties of cowpea flour. The considered parameters were thermal conductivity, thermal diffusivity, and specific heat.

2 Materials and methods

2.1 Sample preparation

Ten bags of cowpeas (Blackeye peas, Food Lion, LLC, Salisbury, NC) were purchased from the local store (Harvey's, Fort Valley, GA), and were used in this study. The cowpeas were milled into flour using a Thomas-Wiley Laboratory Mill (Model 4, Arthur Thomas Co., Philadelphia, PA) and stored in Ziploc® bags (S. C. Johnson Co., Racine, WI). The initial moisture content of cowpea flour was measured.

2.2 Moisture content determination and adjustment

The evaluation of the effect of moisture content on the thermal properties of cowpea flours was carried out at six moisture levels (3.81%, 8.9%, 11.26%, 14.97%, 19.29%, 24.67%, and 28.31%). All the moisture contents were measured on a wet basis (w.b.). The cowpea flour had an initial moisture content of 8.9%. For the lower moisture content (3.81%), the cowpea flours were dried at 70℃ in an incubator (VWR, Model 1575, Sheldon Manufacturing, Inc., Cornel, OR) for about 45 min to 1 1/2 h. For the higher moisture contents (14.97%, 19.29%, 24.67%, and 28.31%) the cowpea flours were conditioned by adding predetermined amounts of pure analytical-grade water (Elix 35, Elix Water Purification System, EMD Millipore, Billerica, MA) onto the sample (White and Jays, 2001; Mahapatra et al., 2011). Pure analytical-grade water was added to the sample thinly spread in the pan while mixing the sample. The amount of pure analytical-grade water to be added was calculated using the following Equation (1) (Coşkun et al., 2005; Wang et al., 2007):

$$Q = W_i(M_f - M_i) / (100 - M_f) \qquad (1)$$

where, Q is the mass of pure analytical-grade water added, kg; W_i is the initial mass of the cowpea flour, kg; M_i is the initial moisture content of the cowpea flour in % (d.b.); M_f is the desired moisture content of the cowpea flour in % (d.b.).

The ground and conditioned cowpea flour samples were kept in separate Ziploc bags (S. C. Johnson Co., Racine, WI) and stored in a refrigerator (VWR, Model GDM-47, True Manufacturing, Inc., O'fallon, OR) at 4℃ for 24 h to enable the moisture to be distributed uniformly throughout the cowpea flours (Mahapatra et al., 2010; Mahapatra et al., 2011; Taiwo et al., 1996). Before starting a test, the samples were taken out of the refrigerator and allowed to equilibrate to the room temperature for about 30 min. Moisture content of the samples was determined in triplicates by oven drying at 103℃ for 24 h. Samples were removed from the drying oven (Lindberg/Blue, Model G01350SC, Blue M, Asheville, NC) and immediately placed in a desiccator for 30 min before weighing.

2.3 Thermal properties measurement

The thermal properties were measured using a KD2 Pro Thermal Properties Analyzer (Decagon Devices Inc., Pullman, WA), a portable field and laboratory equipment that use the transient line heat source method. The 30 mm long, 1.28 mm diameter, and 6 mm spacing dual needle SH-1 sensor measured the thermal conductivity, thermal diffusivity and specific heat (heat capacity) concurrently. Five min gap was provided between each reading. All the thermal properties were determined at the moisture contents of 3.81%, 8.9%, 14.97%, 19.29%, 24.67%, and 28.31% (w.b.) at room temperature 23.7 (±0.9) ℃.

2.4 Data analysis

All the thermal properties were measured at six levels of moisture content and the mean values calculated for nine replications at each moisture content level. Data were analyzed using the general linear models (GLM) procedures of the Statistical Analysis System version 9.1 (SAS, 2003). Least Significant Difference (LSD) among means was calculated at 5% significant level ($p < 0.05$).

3 Results and discussion

Particle aggregation was observed with increasing moisture content because of the soluble proteins going into solution with hydrating water (Taiwo et al., 1996).

3.1 Thermal conductivity

As the moisture content increased from 3.81% to 28.31% (w. b.) the thermal conductivity of cowpea flour increased from 0.109 to 0.213 W m^{-1} K^{-1} (Figure 1). The mean thermal conductivity values measured at six moisture content levels were significantly different ($p<0.05$) except between 8.9% and 14.97% (w.b.). Added water resulted in a higher thermal conductivity of moisture rich cowpea flour. Thermal conductivity of rice flour (Mahapatra et al., 2011) and corn and wheat flour Božiková (2003) increased with the increase in moisture content.

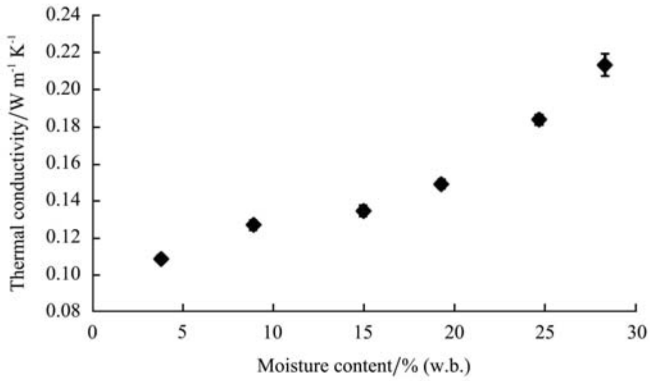

Figure 1 Thermal conductivity of cowpea flour as a function of moisture content

3.2 Thermal diffusivity

The thermal diffusivity of cowpea flour increased from 0.099 to 0.136 mm^2 s^{-1} as the moisture content increased from 3.81% to 28.31% (w.b.) (Figure 2). Increasing moisture content had a significant effect on thermal diffusivity values ($p<0.05$) except between moisture contents of 14.97% and 19.29% (w.b.). As moisture content increased, the pores and capillaries of the cowpea flour which was initially filled with air was gradually displaced by absorbed water. Heat was released by water adsorption in the cowpea flour and as a result the thermal diffusivity increased (Kostaropoulos and Saravacos, 1997). Similar pattern was observed for corn and wheat flour (Božiková, 2003). In contrast, Mahapatra et al. (2011) reported that thermal diffusivity of rice flour decreased with the increase in moisture content.

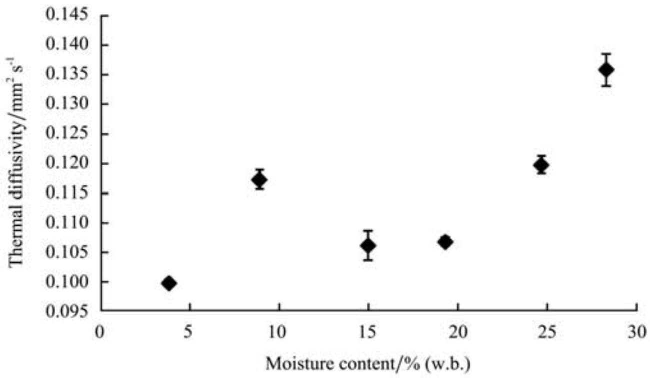

Figure 2 Thermal diffusivity of cowpea flour as a function of moisture content

3.3 Specific heat

For specific heat, increase in the moisture content led to an increase in the specific heat (Figure 3). As the moisture content increased from 3.81% to 28.31% (w. b.) the specific heat increased from 1.09 to 1.57 MJ m^{-3} K^{-1}. Increasing moisture content had a significant effect on specific heat values (p<0.05) except between moisture contents of 3.81% and 8.9% and between 24.67 and 28.31% (w.b.).

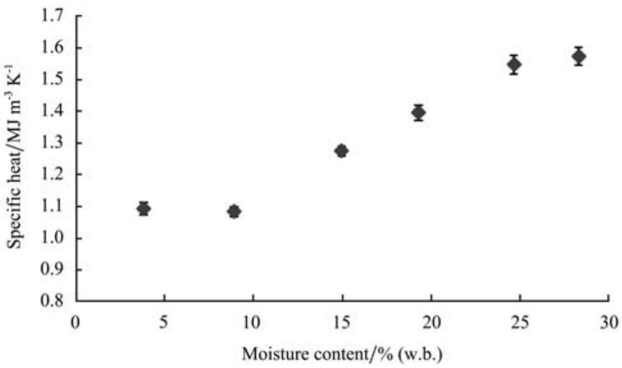

Figure 3 Specific heat of cowpea flour as a function of moisture content

4 Conclusion

The effect of moisture content on thermal conductivity, thermal diffusivity, and specific heat of cowpea flour was investigated. Thermal conductivity, thermal diffusivity and specific heat increased with an increase in moisture content. It can be concluded from this study that moisture content has a significant effect on the thermal properties of cowpea flours measured in this study.

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References

Ampah, J., A. Bart-Plange, and K. A. Dzisi. 2012. Effect of rewetting on selected physical properties of "Asontem" cowpea variety. *ARPN Journal of Engineering and Applied Sciences,* 7 (4): 389-395.

Appiah, F., J. Y. Asibuo, and P. Kumah. 2011. Physicochemical and functional properties of bean flours of three cowpea (V*igna unguiculata L. Walp*) varieties in Ghana. *African Journal of Food Science,* 5 (2): 100-104.

Božiková, M. 2003. Thermophysical parameters of corn and wheat flour. *Research in Agricultural Engineering,* 49 (4): 157-160.

Coşkun, M. B., I. Yalçin, and C. Özarslan. 2005. Physical properties of sweet corn seed (*Zea mays saccharata Sturt*). *Journal of Food Engineering,* 74 (4): 523-528.

Davis, D. W., E. A. Oelke, E. S. Oplinger, J. D. Doll, C. V. Hanson, and D. H. Putnam. 1991. Alternative Field Crops Manual: Cowpea. Available at http://www.hort.purdue.edu/newcrop/afcm/cowpea.html. Accessed 7 July 2012.

Deshpande, S. S. and S. Damodaran. 1990. Food legumes: chemistry and technology. In Y. Pomeranz (Ed.), *Advances in Cereal Science and Technology* (Vol. X, pp. 147-241). St. Paul, MN: American Association of Cereal Chemists, Inc.

Fontana, A. J., J. Varith, J. Ikediala, J. Reyes, and B. Wacker. 1999. Thermal properties of selected foods using a dual needle heat-pulse sensor, ASAE Paper No. 996063, St. Joseph, MI: ASAE.

Henshaw, F. O. 2008. Varietal Differences in physical and proximate composition of cowpea (*Vigna unguiculata*). *World Journal of Agricultural Sciences,* 4 (3): 302-306.

Irtwange, S. V., and J. C. Igbeka. 2003. Influence of moisture content on thermal diffusivity and specific heat of African yam beans (*Sphenostylis stenocarpa*). *Transactions of the ASAE,* 46 (6): 1633-1636.

Kaletunç, G. 2007. Prediction of specific heat of cereal flours: A quantitative empirical correlation. *Journal of Food Engineering,* 82 (4): 589-594.

Kim, Y. S., R. A. Flores, O. K. Chung, and D. B. Bechtel. 2003. Physical, chemical and thermal characteristics of wheat flour milling coproducts. *Journal of Food Process Engineering,* 26 (5): 469-488.

Kostaropoulos, A. E., and G. D. Saravacos. 1997. Thermal diffusivity of granular and porous foods at low moisture content. *Journal of Food Engineering,* 33 (1): 101-109.

Mahapatra, A. K., D. L. Harris, D. L. Durham, S. Lucas, T. H. Terrill, B. Kouakou, and G. Kannan. 2010. Effects of moisture change on the physical and thermal properties of

Sericea Lespedeza pellets. *International Agricultural Engineering Journal,* 19 (3): 23-29.

Mahapatra, A. K., Y. Lan, and D. L. Harris. 2011. Influence of moisture content and temperature on thermal conductivity and thermal diffusivity of rice flours. *International Journal of Food Properties,* 14 (3): 675-683.

Muramatsu, Y., A. Tagawa, and T. Kasai. 2005. Effective thermal conductivity of rice flour and whole and skim milk powder. *Journal of Food Science,* 70 (4): 279-287.

Muramatsu, Y., A. Tagawa, T. Kasai, K. Takeya, and M. Fukushima. 2002. Effective thermal conductivity of wheat flour. *Journal of the Japan Society of Agricultural Machinery,* 64 (1): 70-76.

Nagai, T. 2008. Competitiveness of cowpea-based processed products: A case study in Ghana. M.S diss. Lansing, MI: Department of Food and Resource Economics, Michigan State Univ.

Singh, A. 2003. Enhancing the physical and functional properties of cowpea paste used in *Akara* production through modification of milling and paste preparation methods. M.S diss. Athens, GA: Department of Food Science, Univ. of Georgia.

Taiwo, K. A., C. T. Akanbi, and O. O. Ajibola. 1996. Thermal properties of ground and hydrated cowpea. *Journal of Food Engineering,* 29 (3-4): 249-256.

Wallapapan, K., and V. E. Sweat. 1982. Thermal conductivity of defatted soy flour. *Transactions of the ASABE,* 25 (5): 1440-1444.

Wang, B., D. Li, L. Wang, Z. Huang, L. Zhang, X. Chen, and Z. Mao. 2007. Effect of moisture content on the physical properties of fibered flaxseed. *International Journal of Food Engineering* 3 (5): 1-11.

Wang, N., and J. G. Brennan. 1993. The influence of moisture content and temperature on the specific heat of potato measured by differential scanning calorimetry. *Journal of Food Engineering* 19 (3): 303-310.

White, N. D. G., and D. S. Jayas. 2001. Physical properties of canola and sunflower meal pellets. *Canadian Biosystems Engineering* 43: 3.49-3.52.

Yeung, H. 2007. Evaluation of legume cooking characteristics using a rapid screening method. M.S diss. College Station, Texas: Department of Food Science and Technology, Texas A&M University.