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The Influence of Drying on the Physical Properties of Sweet Potato Slices

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Abstract

The effects of varying drying conditions on the physical properties of sweet potato slices were studied. Fresh tubers were peeled, washed and cut into two shapes (rectangular: 50 x 60 mm and cylindrical 60 mm diameter) and two thicknesses (4 and 6mm) slices. Some slices were blanched in water at 90 ºC for 5 mins and some untreated. The slices were dried in the sun or oven (50 ºC , 70 ºC , 90 ºC). The bulk density, dimensional changes and moisture loss were investigated. Moisture loss and percent shrinkage increased with higher temperature and longer drying time. 4mm thick samples lost more moisture and higher % shrinkage than 6mm thick samples, although not significantly (P>0.05). Logarithmic equations gave best fit of moisture loss with time at the different temperatures. Initial sample thickness had a greater impact on shrinkage than sample shape. Blanching minimized % shrinkage although not significantly (P>0.05). Greater shrinkage took place in the sample thickness (up to 63%) than across product diameter or length (values up to 26.3%). % shrinkage can be predicted using either the linear or logarithmic equations. The bulk densities of dried sweet potato slices were not influenced by blanching.

Keywords: moisture content, drying kinetics, blanching, dimensional changes, bulk density.

1. Introduction

The sweet potato (*Ipomoea batatas*) is an herbaceous perennial crop, having cluster of runner stems covered with tender leaves and shoots which are edible vegetables. More importantly, underneath runner stems, found buried tuberous root - long and tapered, with a smooth skin whose colour ranges between yellow, orange, red, brown, purple, and beige (Bouwkamp, 1985). It originated from Central America, but now widely cultivated throughout the world, due to its low rainfall and soil fertility cultivation requirements. It is ranked seventh among the most important crops worldwide (Zhitian, et al., 2001). Sweet potato can be consumed as a vegetable, boiled, baked or often fermented into food and beverages (Oke & Workneh, 2013). Derived nutritional needs from sweet potato are carbohydrates, fibres, carotenes, thiamine, riboflavin, niacin, potassium, zinc, calcium, iron, vitamins A and C and high quality protein. Despite the name "sweet", it may be a beneficial food for diabetics, as preliminary studies on animals have revealed that it helps to stabilize blood sugar levels lowers insulin resistance (da Silva, et al., 2005; Oke and Workneh, 2013). Fresh sweet potato roots *(Ipomeabatatas)* are highly perishable due to high water content up to 70 % reported by FAOstat, (2007 and 2008).

Drying of agricultural produce is one of the preservative methods which reduce water activity, enzymatic and non-enzymatic actions to enhance food stability and texture. It is an essential unit operation which involves heat and mass transfer phenomena, attributed to physical and structural changes (Fusco, 1991). Shrinkage is one of the major physical changes, which influenced the texture, mechanical and rheological properties of the dried food materials (Karel, 1991). Talla et al. (2004) reported that, the percentage of shrinkage depends on the initial material thickness, shape and moisture content and likewise other physical properties, such as bulk and true densities. Blanching is a pretreatment process prior to drying, frequently applied to vegetables to inhibit enzymatic actions (Vora et al., 1999) or for enhancing the firmness after rehydration of rice paddy (Sanjuán, et al., 2000; Sanjuán, et al., 2001). Its permeability and reducing resistance to mass transfer, which leads to an increase in the drying rate (Krokida, et al., 2000). Furthermore, it increases the resistance to thermal degradation of bioactive and colouring constituents in processing steps such as cooking and drying (Mayer & Sereno, 2004). Taiwo & Baik (2007) reported that shrinkage occurs during drying of food products, which affects the physical properties of materials, such as density and porosity. Wang & Brennan, (1995) also reported that porosity influences the diffusion properties of cellular foods during drying. They emphasized that drying kinetics resulting to movement of moisture from high concentration region to lower concentration region due to capillary forces dominates. At decreasing moisture content, the amount of liquid in the pores also decreases and a gas phase is built up, causing a decrease in membrane porosity (Graziella, et al., 2011). However, it has been established by Orikasa et al, 2010 that combined mechanism of capillary forces and vapor diffusion is responsible for moisture movement in the drying of potato.

Previous studies revealed that hot air drying causes much quality degradation on potato pieces of various shapes in terms of nutritional values, color, shrinkage and other organoleptic properties (Wang & Brennan, 1995; McMinn & Magee, 1996). Achanta & Okos (2006) reviewed the shrinkage of different biopolymers and concluded that shrinkage on drying was equal to the volume of moisture leaving the material. Krokida. et al., (2000) investigated the effects of drying methods on the colour of dried potato and reported that, conventional air drying caused extensive browning with a significant drop of the lightness and an increase in hardness and yellowness of dried potato. Khraisheh et al, (2004) also reported the quality and structural changes (in terms of vitamin C destruction, shrinkage and rehydration abilities of potato during microwave and convective drying. They emphasized that the study of drying kinetics is highly essential for adequate understanding of moisture reduction and drying behavior of food products. The effect of temperature and dryer air velocity on drying potato chips was investigated and reported by Dinrifo (2012). The convective air drying was carried out under five air velocities of 1.5, 2.5, 3.5, 4.5 and 5.5 m/s, five air temperatures; 50, 60, 70, 80 and 90°C, and three sweet potato cubes of 5, 8 and 12 mm thickness. The results established that increase in temperature had no significant effect on shrinkage, except air velocity. Doymaz (2012) reported the effect of pretreatments of potato slices with citric acid solution and blanching with hot water using cabinet dryer. It was reported that shortest drying time was obtained with potatoes pretreated with citric acid solution than blanched samples. Drying rate decreased continuously with decreasing moisture content or improving drying time (Yaldiz & Ertekin, 2001; Talla, *et al.,* 2004). The shrinkage phenomenon affects in particular the diffusion coefficient of the material, which is one of the main parameters governing the drying process and also influence the drying rate. Besides, various characteristics of the material depend on its density so that the knowledge of the density variation with moisture content will be useful to characterize the behavior of this material. The determination of its variation is thus essential. Considering all these previous studies, the effect of blanching on percentage shrinkage and dimensional changes of sweet potato slices has not been fully reported. Therefore, this study reported the effect of pre-treatment condition on dimensional changes, percentage of shrinkage and moisture loss of sliced sweet potatoes at varying drying conditions.

Materials and methods

The freshly harvested sweet potato tubers (*Ipomoea batatas*) were bought from the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife. These healthy and undamaged tubers were peeled, washed and sliced into thickness of 4 and 6 mm. slices were cut into rectangular shape of 50 × 60 (mm) using Vernier caliper and knife and cylindrical shape of radius 30 mm using a core borer (AOAC, 2007. Some of the samples were subjected to blanching (dipped in water at 90 ^{o}C for 5 min) and the unblanched used as control samples. The blanched slices were drained prior to drying.

Sun Drying

Potato slices of blanched and un-blanched samples were spread thinly on a metal tray and directly exposed to the sun. Their respective weights were taken at one hour intervals for the first 6 hrs and later every 4 hrs till they were bone dried (Olawale & Omole, 2012) at average atmospheric temperature was 50 ^{o}C + 1.4^{o}C over 3 days of drying.

Oven Drying

Using AOAC (2007) samples of sweet potato slices were weighed and loaded inside oven at the varying temperatures (50, 70 and 90 ^{0}C) with air velocity (1.5 m s^{-1}) respectively. Loaded samples were weighed at an interval of one hour until the last three consecutive weights were constant, indicating equilibrium condition.

Dimensional changes

The dimension of the sliced samples were determined using vernier calipers before and after it had been pretreated and after each drying interval. The dimensional changes were taken every hour for six hours or until there are no longer any changes in dimensions Taiwo & Baik (2007).

Bulk density

The weighed samples were placed in a cylinder containing water of known volume. The volume of water displaced was recorded to estimate the volume. The bulk density was calculated as the weight of the sample divided by the volume of water displaced (Ozguven &Vursavuş., 2005).

Moisture content-:- The moisture content was determined according to the method of AOAC (1995). The samples were weighed and placed inside Gallenkamp electric oven (model: BS OV-160 (at 70 ^{o}C) until a constant weight was observed, and then it was reweighed and recorded.

Determination of shrinkage Johnson et al 1998

Bulk shrinkage was determined by displacement method (Lozano et al., 1983).Dimensional shrinkage was determined by measuring the diameter of the cylinders using vernier caliper. Measurements were made from three intersecting lines drawn on the transverse surface before drying. All measurements were made in triplicate. The data obtained were fitted to the models given in Table 1, using non-linear regression analysis (SAS, 2005).

Results and Discussion

Fig 1a shows the effect of drying temperature on moisture loss from sweet potatoes. These curves are typical of the drying curves obtained for all the samples irrespective of sample thickness, shape or blanching condition. The range of moisture lost from the samples at the different temperatures is: sun drying – 44.53-56.60%, 50°C – 49.13-58.62%, 70°C – 50.02 – 65.36% and 90°C - 51.43 – 68.08%. The drying temperature increased with percent moisture loss and time. This is similar to the report of Sacilik & Unal (2005) on garlic slices and Karabulut, et al., (2007) on apricot that a higher air temperature produced a higher dehydration rate and consequently the drying time decreased. The authors attributed this to increase of heat transfer between the air and the garlic slices, and the acceleration of water migration inside them. At increased temperatures, molecules are in an increased state of excitation, thus increasing their distance apart and decreasing the attractive forces between them. This leads to a decrease in the degree of water sorption at a given relative humidity with increasing temperature (Kaya et al., 2007). There was no significant difference (P>0.05) in the moisture loss from sundried samples and those dried at 50°C especially after 6hrs of drying. Moisture loss from samples dried at 70-90°C were significantly (P<0.05) higher than the moisture loss from samples dried at less than 50°C. The rate of moisture loss decreased with time after about 8hrs of drying. Although moisture loss continued, the rate of loss decreased. Maskan (2000) reported that with prolonged drying time, drying rate decreased probably due to collapse (shrinkage) of the banana structure resulting in low transport of moisture.

The effects of blanching and sample thickness on moisture loss with time are shown in Fig.1b. In both blanched and unblanched samples, 4mm thick samples lost more moisture than 6mm thick samples although the difference is not significant (P>0.05). This may be as a result of the shorter distance for moisture migration and heat transfer to the surface. The observation was in agreement with the report of Onayemi (2003). Sacilik & Unal (2005) on their study on garlic slices reported that the increase in the sample thickness caused an increase in the drying time. The results of Kroikida, et al, (2003) showed that the smaller the sample size of carrot the lower the moisture content. This increase in moisture loss was due to the reduced distance the moisture travelled and increased surface area exposed for a given volume of the samples. The authors concluded that the thinner the sample, the greater the dehydration rate. Consequently, the drying time decreased with a decrease in the sample thickness. The impact of sample size on drying rate of carrot was significant only in the first two hours of drying. Tall et al. (2004) suggested that the concentration gradient in the food matrix controlled the drying rate and is temperature dependent. They reported significant differences in drying rates between 1 cm and 2 cm banana slabs at all examined temperatures and this occurred in the early stages of drying (before 3 hrs.). These differences then decreased gradually to the point when the drying rates of 1 cm, and 2 cm slabs were equal.

Moisture loss in unblanched samples was significantly (P < 0.05) higher than in blanched samples. It observed that blanching had no effect initially on the drying rate of potatoes and similar observations were reported for food materials by Almozimora and Chirife (1980); Babalis and Belessiotis, (2004).This could be due to the effect of starch gelatinization during blanching. The lack of effect of blanching is contrary to expectation as blanching has been reported to improve the drying rates of carrots, basil and green peppers and banana (Mazza, 1983; Rocha et al, 1993; Kaymak-Ertekin, 2002; Taiwo & Adeyemi, 2007). Blanching is known to increase the permeability of cell walls, thus favoring faster water migration to the surface for removal (Rocha et al, 1993). The effect of sample shape on moisture loss was not significant (P>0.005) on samples of same thickness as depicted in Fig. 1c. Kroikida et al. (2003) studied the effect of air conditions (air temperature, air humidity and air velocity) and characteristic sample size on drying kinetics of various plant materials (potato, carrot, pepper, garlic, mushroom, onion, leek, pea, corn, celery, pumpkin, tomato). The authors concluded that temperature of drying is the most important factor affecting the drying rate for all the examined materials, while the effect of air velocity and air humidity is considered lower than that of air temperature (Kroikida et al., 2001).

Using linear equation (y = ax) to relate moisture loss with time at the different temperatures gave a good correlation for most of the sample points. For rectangular shaped samples, the correlation coefficient (r^2) for blanched samples ranged between 0.6947 and 0.9743 while for unblanched samples, the correlation was between 0.707-0.9557. For cylindrically shaped samples the correlation coefficient relating moisture loss with time ranched between 0.8266 and 0.9690 for blanched samples and 0.4345 to 0.9831 for unblanched samples. This result suggests a better fit for blanched samples.

Using logarithmic equation to describe the relationship between moisture loss and drying time, the correlation coefficient ranged between 0.924 and 0.9971 (for all samples) which suggests a better fit. Using a polynomial equation of the second order ($y = ax^2 + bx + c$) did not improve the correlation coefficient (0.827 and 0.979 in Table 1). This agrees with the results of Sobukola, et al. (2008) on the convective hot air drying of blanched yam slices who reported that the highest R^2 values were obtained using logarithmic equations to relate moisture ratio and time at different temperatures (70, 80 and 90°C). The authors explained that moisture removal inside yam slices at 90°C was higher and faster than the other investigated temperatures during the time of investigation as the migration to the surface of the moisture and evaporation rate from the surface to air decreased with decrease of the moisture in the product and thus the drying rate clearly decreased. They also reported shorter time of drying at a higher temperature thus having increased drying rate. This increase was attributed to increased heat transfer potential between the air and the yam slices which favoured the evaporation of water from the yam slices.

Effects of varying conditions on percent shrinkage in product thickness are seen in Figs 2a-c. Percent shrinkage increased with drying time and temperature. As drying time increased, % shrinkage in thickness also increased. The effect of time became significant between 6 and 8th hour of drying. This result suggests a relationship between moisture lost and % shrinkage and drying time. It was observed from about the 8th hour of drying as moisture loss decreased, % shrinkage increased. It was also observed that drying temperature increased with % shrinkage in thickness. Percent shrinkage in sundried samples was significantly ($P<0.05$) lower than those in oven dried samples. The difference in shrinkage of samples dried at 50° and 70°C was not significant but that of 90°C was significant ($P< 0.05$). Shrinkage data at the end of drying (i.e. 13th hour) showed that sundried samples had shrinkage values in the range (rectangular shaped -11.12-27.30% and cylindrical shaped – 12.40-30.14%), samples dried at 50°C (rectangular shaped -25.85 – 46.44% and cylindrical shaped – 29.79 – 50.56%), 70°C (rectangular shaped -26.44 – 57.53% and cylindrical shaped – 30.94 – 61.96%) and those dried at 90°C (rectangular shaped 27.12 – 58.30% and cylindrical shaped – 32.12 – 63.90%). Lima et al. (2002) in their study on the simultaneous mass transfer and shrinkage during drying of solids with prolate spheroidal shape reported that the dimensionless shrinkage parameters changed due to the dependence on temperature and on initial and equilibrium moisture content.

The initial sample thickness had a greater impact on shrinkage than sample shape or pretreatment. Figs. 2 b and c showed that 4mm thick samples had higher % shrinkage than 6mm thick samples irrespective of shape or pretreatment (i.e. blanched or unblanched). Blanching of the samples prior to drying minimized % shrinkage although not significantly ($P>0.05$) with unblanched samples having higher % shrinkage values (1.4-63.90%) in thickness than blanched samples (1.3 – 59.78%). By the 13th hour of drying, blanched 6mm thick samples had the least % shrinkage for all conditions studied (rectangular shaped -11.12-27.12% and cylindrical shaped – 12.40-32.12%) while unblanched 4mm thick samples exhibited the highest shrinkage (rectangular shaped - 27.30 – 58.30% and cylindrical shaped – 30.14-63.90%). Talla et al. (2004) reported that the shrinkage phenomenon affects in particular the diffusion coefficient of the material, which is one of the main parameters governing the drying process and also influences the drying rate. Besides, various characteristics of the material depend on its density so that the knowledge of the density variation with moisture content will be useful to characterize the behavior of the material.

Effects of drying conditions on shrinkage of product dimensions (length in rectangular shaped samples) are shown in Figs. 3 a-c. Percent shrinkage in product length increased with drying time and this became significant ($P<0.05$) between the 6th and 8th hour of drying. The higher the temperature of drying the higher the shrinkage experienced. The shrinkage observed in samples dried at 50°C or sun dried were close in values (11.67 – 12.80%) and were significantly lower than shrinkage observed in samples dried at 70-90°C (14.38 – 23.32%) - shrinkage vales at 13th hour of drying. The effects of pretreatment and initial sample thickness on shrinkage of product length were influenced by the drying temperature. Fig. 3b is a representative graph of data for sundried samples and samples dried at 50°C. There was no significant ($P>0.05$) difference in the shrinkage values of blanched and unblanched samples as well as 4mm or 6mm samples. However, a contrary observation was made in rectangular samples dried at 70 and 90°C. From about the 6th hour of drying, effect of blanching became significant as these samples exhibited lower shrinkage values compared to the unblanched samples. Initial product thickness did not have a significant effect on shrinkage of product length but the 4mm thick samples had slightly higher values than those of 6mm thick samples. These results suggest that initial product thickness did not influence the shrinkage of product length but the effect of blanching is temperature influenced. Koc et al. (2008) in their study on the drying of quince reported that in spite of differences in shrinkage observed with the drying methods, the same model as a function of moisture content could be used for all drying methods but with different coefficients. Shrinkage values for blanched samples (at the 13th hour of drying) ranged from 11.77 – 15.60% while those of unblanched samples ranged from 11.67 – 23.32%.

Figures 4a-c shows the effects of processing parameters on shrinkage of sample diameter. As with other dimensions, shrinkage in diameter increased with drying time and drying temperature. Shrinkage in sample diameter of samples dried at 90°C (17.43-26.32%) was significantly higher ($P<0.05$) than the shrinkage values at other conditions (11.02-19.47%). The effects of blanching and initial product thickness on shrinkage of sample diameter were similar to those of rectangular samples where influence of drying temperature was evident. Fig.4b showed that there was no significant ($P>0.05$) difference in the shrinkage values of product diameter when dried at 50°C or sun dried. Also, initial product thickness (4mm or 6mm) did not influence diameter shrinkage. Data on diameter shrinkage of cylindrical samples dried at 70 or 90°C showed that unblanched samples had higher percent shrinkage (13.52-26.32%) than the blanched samples (12.04-19.96%). Initial sample thickness also influenced diameter shrinkage with 4mm thick samples exhibiting higher shrinkage values than 6mm thick samples.

Comparing the shrinkage in dimensions, the above results suggest that greater shrinkage takes place in the sample thickness (having values up to 63%) than across product width or length with maximum values of 26.3%. Data also shows that effect of drying time on sample shrinkage becomes significant from about the 6th hour and up to the 10th hour after which minimal shrinkage takes place.

Tables 2 - 4 show the regression relationships between % shrinkage and sample thickness, length or diameter with time at different drying temperatures. Linear and logarithmic equations were used to relate the parameters and the correlation coefficient R^2 ranged between 0.8426 and 0.9839 and 0.8158 and 0.9918 for linear and logarithmic equations respectively for shrinkage in sample thickness and drying time at different temperatures (Table 2). The effects of different processing parameters on the regression coefficient were neither consistent nor significant. In rectangular samples regression coefficient R^2 ranged between 0.8503 and 0.9834, 0.854 and 0.9805 for linear and logarithmic equations respectively for shrinkage in sample length and drying time at different temperatures (Table 3). R^2 values relating shrinkage in sample diameter and drying time at different temperatures ranged from 0.8252 to 0.9882 and 0.8387 and 0.9789 respectively for linear and logarithmic equations (Table 4). These results suggest that % shrinkage in sample dimensions (of sweet potato) can be predicted using either the linear or logarithmic equations. Table 5 shows the regression relationship between changes in sample volume and drying time using a second order polynomial equation ($y = ax^2 + bx + c$). The coefficient of correlation ranged between 0.823 and 0.975. The influence of drying temperature, sample thickness and blanching were not significant ($P>0.05$). This agrees with the report of Tall *et al*. (2004) that the influence of temperature on the shrinkage phenomenon can be neglected in the simulation models of the drying kinetics of banana. The authors suggested that variation in volume of the product corresponded to the volume of evaporated water.

The bulk densities of sweet potato slices after drying are presented in Table 6. The values ranged from 0.14 to 0.165g/cm^3. Samples dried at 90^{o}C had the lowest bulk density values (0.140-0.144g/cm^3) while samples dried at 70^{o}C had the highest values (0.159-0.165g/cm^3). The results showed that blanching did not influence the bulk density values significantly ($P>0.05$) although the bulk density values for blanched samples were slightly higher than those of unblanched samples. Although this study did not monitor density change with time, reports of other studies suggest that shrinkage and changes in density (variation of volume) of agricultural materials during drying corresponds to the volume of evaporated water (Nguyen and Price, 2007; Koc *et al.*, 2008 and Johnson *et al.*, 1998). Johnson *et al* (1998) described change in volume of plantain pieces (shrinkage) during drying by a core drying model, while the change in dimensions was related linearly to moisture content.

Conclusion

The higher the temperature, the higher moisture loss but drying time became insignificant after 8hrs. 4mm thick samples lost more moisture than 6mm thick samples although the difference was not significant ($P>0.05$). The effects of sample shape and blanching on moisture loss were not significant ($P>0.005$). Logarithmic equations relating moisture loss with time at the different temperatures gave better correlation coefficient than linear or polynomial equations of the second order. Percent shrinkage increased with longer drying time and higher temperature. The effect of time became significant between 6 and 8th hour of drying. The initial sample thickness had a greater impact on shrinkage than sample shape or pretreatment. 4mm thick samples had higher % shrinkage than 6mm thick sample irrespective of shape or pretreatment (i.e. blanched or unblanched). Blanching of the samples prior to drying minimized % shrinkage although not significantly ($P>0.05$).Greater shrinkage took place in the sample thickness (having values up to 63%) than across product width or length with maximum values of 26.3%. % shrinkage in sample dimensions (of sweet potato) can be predicted using either the linear or logarithmic equations. The bulk densities of dried sweet potato slices were not influenced by blanching.

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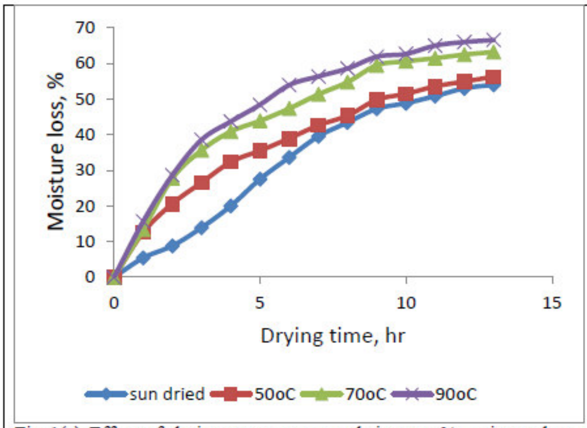

Fig 1(a) Effect of drying temperature and time on % moisture loss of un-blanched rectangular shaped 4mm thick sweet potato samples

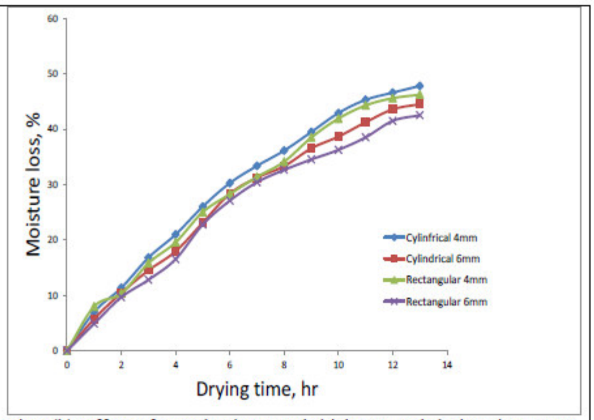

Fig 1(b) Effect of sample shape and thickness and drying time on % moisture loss of blanched sundried sweet potato slices

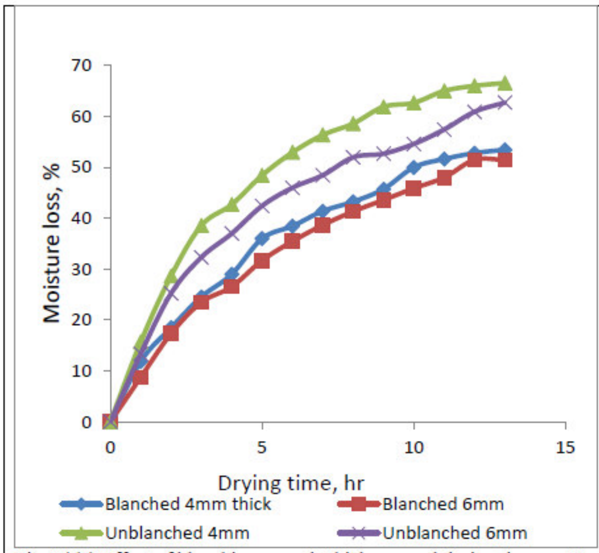

Fig. 1(c)) Effect of blanching, sample thickness and drying time on % moisture loss of rectangular shaped sweet potato slices dried at 90 °C

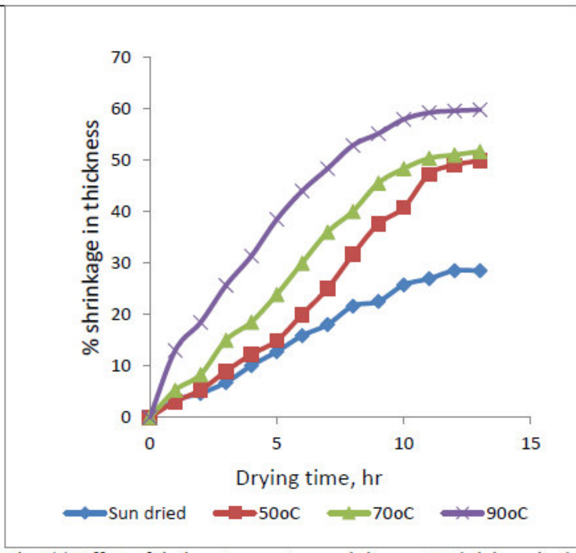

Fig 2(a) Effect of drying temperature and time on % shrinkage in the of blanched cylindrical thickness shaped 4mm thick sweet potato samples

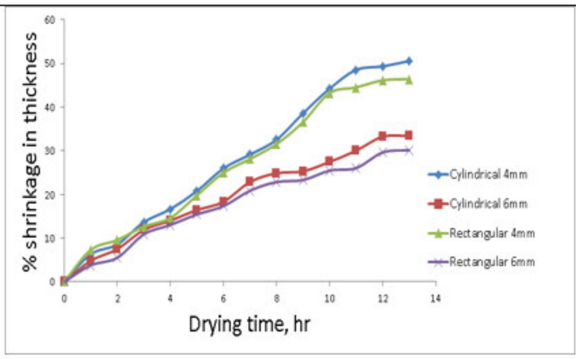

Fig 2(b) Effect of sample shape and thickness and drying time on %shrinkage in thickness of un-blanched sweet potato samples dried at 50°C

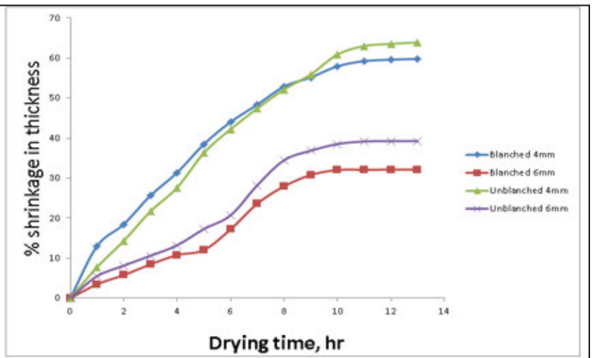

Fig. 2(c)) Effect of blanching, sample thickness and drying time on %shrinkage in thickness of cylindrical shaped sweet potato slices dried at 90 °C

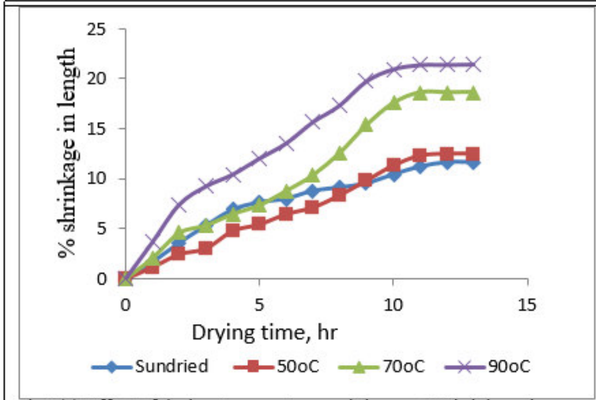

Fig 3(a) Effect of drying temperature and time on % shrinkage in sample length of unblanched rectangular shaped 6mm thick sweet potato samples

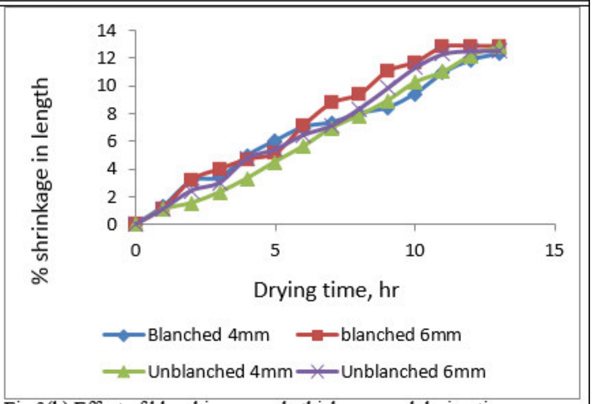

Fig 3(b) Effect of blanching, sample thickness and drying time on %shrinkage in length of rectangular shaped sweet potato samples dried at 50°C

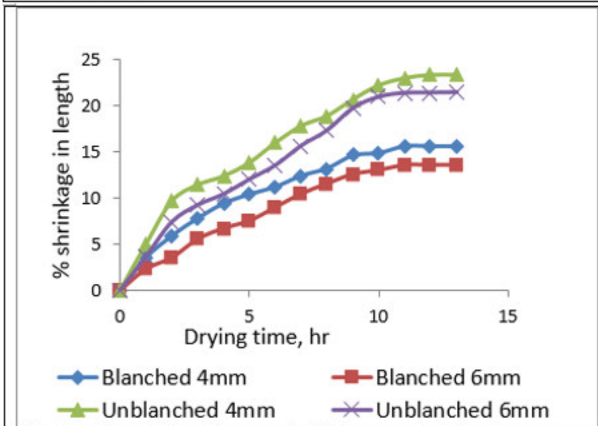

Fig 3(c) Effect of blanching, sample thickness and drying time on %shrinkage in length of rectangular shaped sweet potato samples dried at 90°C

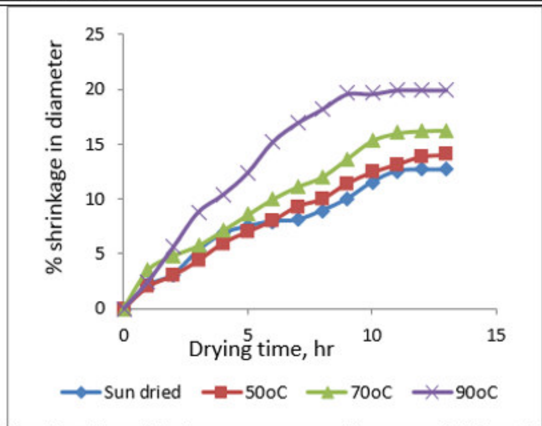

Fig 4(a): Effect of drying temperature and time on % shrinkage in sample diameter of blanched cylindrical shaped 4mm thick sweet potato samples

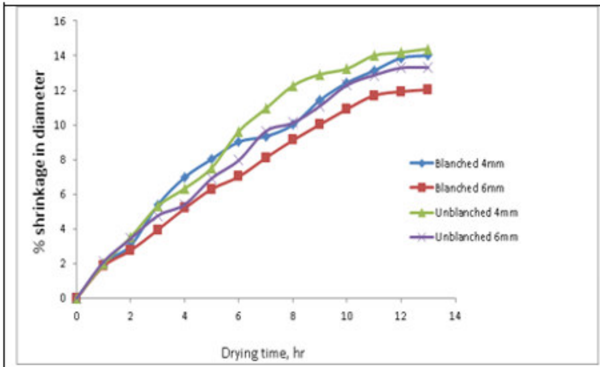

Fig 4(b): Effect of blanching, sample thickness and drying time on %shrinkage in diameter of cylindrical shaped sweet potato samples dried at 50ºC

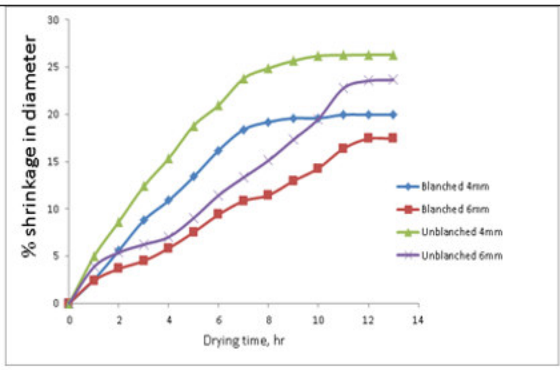

Fig 4(c) Effect of blanching, sample thickness and drying time on %shrinkage in diameter of cylindrical shaped sweet potato samples dried at 90ºC

Table 1 - Regression relationships between % moisture loss and drying time of samples at different temperatures

Shape	Pre-treatment	Thickness, mm	Drying temp, ºC	Linear equation	R^2	Logarithmic equation	R^2	$y = ax^2$	R^2
Cylindrical	Blanched	4	Sun-dried	$y = 3.8094x$	0.9690	$y = 19.743ln(x) – 6.6622$	0.9597	0.815, 3.507	0.979
			50 ºC	$y = 3.7889x$	0.9320	$y =17.844ln(x) – 2.6717$	0.9478	-0.130, 5.942	0.964
			70 ºC	$y = 4.553x$	0.8266	$y =20.839ln(x) – 1.4428$	0.9838	-1.293, 13.78	0.944
			90 ºC	$y = 4.7856x$	0.8908	$y =22.701ln(x) – 3.409$	0.9870	-2.785, 12.95	0.900
		6	Sun-dried	$y = 3.5157x$	0.9681	$y = 18.327ln(x) – 6.3871$	0.9568	0.207	0.962
			50 ºC	$y = 4.1954x$	0.8468	$y = 18.836ln(x) – 0.6113$	0.9924	-0.794	0.964
			70 ºC	$y = 4.4106x$	0.8624	$y = 20.284ln(x) – 1.6931$	0.9921	-1.308	0.944
			90 ºC	$y = 4.5697x$	0.8594	$y = 21.262ln(x) – 2.2633$	0.9901	-1.802, 15.36	0.928
	Unblanched	4	Sun-dried	$y = 4.5227x$	0.9598	$y = 24.739ln(x) – 10.801$	0.9439	0.659, 1.886	0.956
			50 ºC	$y = 5.0123x$	0.7291	$y = 22.02ln(x) + 0.6639$	0.9915	0.414, 8.93	0.867
			70 ºC	$y = 5.7995x$	0.6882	$y = 24.747ln(x) – 2.3566$	0.9762	1.942, 13.60	0.882
			90 ºC	$y = 6.5225x$	0.4345	$y = 26.928ln(x) – 5.3483$	0.9239	2.625, 222	0.888
		6	Sun-dried	$y = 4.437x$	0.9472	$y = 23.79ln(x) – 9.461$	0.9458	0.136, 4.637	0.966
			50 ºC	$y = 4.3621x$	0.9831	$y = 23.978ln(x) – 10.862$	0.9323	-0.389, 7.652	0.977
			70 ºC	$y = 5.4733x$	0.6429	$y = 23.506ln(x) + 2.0516$	0.9634	-1.211, 11.23	0.946
			90 ºC	$y = 5.7893x$	0.5636	$y = 23.972ln(x) + 4.1955$	0.9494	-2.540, 19.21	0.906
Rectangular	Blanched	4	Sun-dried	$y = 3.7255x$	0.9685	$y = 19.377ln(x) – 6.7175$	0.9462	0.234, 5.05	0.974
			50 ºC	$y = 3.6986x$	0.9743	$y = 18.786ln(x) – 5.921$	0.8926	-1.029, 12.08	0.951
			70 ºC	$y = 4.426x$	0.6947	$y =18.944ln(x) – 1.7139$	0.9868	-1.355, 15.52	0.909
			90 ºC	$y = 4.517x$	0.8786	$y = 21.299ln(x) – 2.8899$	0.9914	-2.829, 24.49	0.833
		6	Sun-dried	$y = 3.3633x$	0.964	$y = 17.85ln(x) – 6.8197$	0.949	-1.111, 13.11	0.952
			50 ºC	$y = 4.0546x$	0.9134	$y = 19.975ln(x) – 4.554$	0.9813	-0.638, 8.276	0.960
			70 ºC	$y = 4.0873x$	0.8974	$y = 19.27ln(x) – 2.6882$	0.9859	-1.419, 13.16	0.949
			90 ºC	$y = 4.255x$	0.91	$y = 20.598ln(x) – 3.9682$	0.9884	-2.333, 19.09	0.901
	Unblanched	4	Sun-dried	$y = 4.415x$	0.9524	$y = 24.129ln(x) – 10.5$	0.9362	-0.994, 12.50	0.929
			50 ºC	$y = 4.7413x$	0.8469	$y = 21.666ln(x) – 1.4695$	0.9948	-1.712, 16.62	0.916
			70 ºC	$y = 5.5572x$	0.7701	$y = 24.965ln(x) – 0.5531$	0.9875	-2.692, 20.24	0.887
			90 ºC	$y = 5.9136x$	0.7407	$y = 26.318ln(x) + 0.048$	0.9904	-2.396, 20.60	0.915
		6	Sun-dried	$y = 4.2196x$	0.9557	$y = 23.061ln(x) – 10.017$	0.943	-0.651, 9.422	0.970
			50 ºC	$y = 4.3529$	0.978	$y = 23.764ln(x) – 10.495$	0.924	-1.382, 13.39	0.916
			70 ºC	$y = 5.2147x$	0.707	$y = 22.385ln(x) + 1.8308$	0.9944	-2.432, 21.16	0.865
			90 ºC	$y = 5.2517x$	0.8087	$y = 23.814ln(x) – 1.093$	0.9971	-2.744, 24.31	0.827

Table 2 - Regression relationships between % shrinkage in sample thickness and drying time at different temperatures

Shape	Pretreatment	Thickness, mm	Drying temp, ºC	Linear equation	R^2	Logarithmic equation	R^2
Cylindrical	Blanched	4	Sun-dried	$y = 2.2223x$	0.9754	$y = 12.206\ln(x) – 5.5124$	0.9251
			50 ºC	$y = 3.4838x$	0.9357	$y = 21.121\ln(x) – 13.609$	0.8158
			70 ºC	$y = 4.0842x$	0.9683	$y = 22.746\ln(x) – 10.872$	0.9112
			90 ºC	$y = 5.1754x$	0.8924	$y = 25.123\ln(x) – 4.9348$	0.979
		6	Sun-dried	$y = 0.9355x$	0.9882	$y = 5.051\ln(x) – 2.1543$	0.9132
			50 ºC	$y = 2.2843x$	0.9802	$y = 11.927\ln(x) – 4.2716$	0.9364
			70 ºC	$y = 2.3812x$	0.9825	$y = 12.383\ln(x) – 4.3354$	0.9423
			90 ºC	$y = 2.6171x$	0.9375	$y = 14.754\ln(x) – 7.3845$	0.8777
	Unblanched	4	Sun-dried	$y = 2.4281x$	0.9441	$y = 13.766\ln(x) – 6.8938$	0.9233
			50 ºC	$y = 3.756x$	0.9839	$y = 20.947\ln(x) – 10.027$	0.8896
			70 ºC	$y = 4.9327x$	0.9498	$y = 27.638\ln(x) – 13.479$	0.8976
			90 ºC	$y = 5.2707x$	0.9558	$y = 27.878\ln(x) – 10.407$	0.9532
		6	Sun-dried	$y = 1.1845x$	0.9858	$y = 6.3122\ln(x) – 2.568$	0.8935
			50 ºC	$y = 2.5358x$	0.9762	$y = 13.175\ln(x) – 4.5634$	0.9452
			70 ºC	$y = 2.7979x$	0.9687	$y = 15.542\ln(x) – 7.3204$	0.9215
			90 ºC	$y = 3.2005x$	0.9475	$y = 17.619\ln(x) – 8.064$	0.8902
Rectangular	Blanched	4	Sun-dried	$y = 1.9433x$	0.9713	$y = 10.028\ln(x) – 3.3254$	0.9511
			50 ºC	$y = 3.233x$	0.9377	$y = 19.706\ln(x) – 12.77$	0.8337
			70 ºC	$y = 3.8624x$	0.9600	$y = 21.519\ln(x) – 10.216$	0.9193
			90 ºC	$y = 4.7705x$	0.8426	$y = 22.322\ln(x) – 2.5571$	0.9918
		6	Sun-dried	$y = 0.827x$	0.9662	$y = 4.7201\ln(x) – 2.5004$	0.8763
			50 ºC	$y = 1.9142x$	0.9879	$y = 10.298\ln(x) – 4.301$	0.9226
			70 ºC	$y = 2.0551x$	0.9698	$y = 10.835\ln(x) – 4.0132$	0.9531
			90 ºC	$y = 2.2536x$	0.9358	$y = 12.732\ln(x) – 6.3175$	0.9083
	Unblanched	4	Sun-dried	$y = 2.1279x$	0.9751	$y = 11.613\ln(x) – 5.0672$	0.9413
			50 ºC	$y = 3.5419x$	0.9811	$y = 19.295\ln(x) – 8.6154$	0.8909
			70 ºC	$y = 4.6565x$	0.9338	$y = 26.297\ln(x) – 13.104$	0.8953
			90 ºC	$y = 4.8959x$	0.9364	$y = 26.133\ln(x) – 10.1$	0.95
		6	Sun-dried	$y = 1.0145x$	0.9574	$y = 5.3094\ln(x) – 1.8828$	0.9516
			50 ºC	$y = 2.3165x$	0.972	$y = 12.22\ln(x) – 4.5517$	0.95
			70 ºC	$y = 2.5977x$	0.9725	$y = 14.625\ln(x) – 7.2624$	0.917
			90 ºC	$y = 2.8808x$	0.9504	$y = 15.591\ln(x) – 6.5579$	0.9206

Table 3 - Regression relationships between % shrinkage in length of rectangular shaped samples and drying time at different temperatures

Pre-treatment	Thickness, mm	Drying Temp, ºC	Linear equation	R^2	Logarithmic equation	R^2
Blanched	4	Sun-dried	$y = 0.8623x$	0.9834	$y = 4.7416\ln(x) – 2.2141$	0.8795
		50	$y = 0.8997x$	0.9834	$y = 4.7538\ln(x) – 1.8189$	0.9279
		70	$y = 1.0344x$	0.9825	$y = 5.5728\ln(x) – 2.3811$	0.8888
		90	$y = 1.3592x$	0.8503	$y = 6.3193\ln(x) – 0.6508$	0.9932
	6	Sun-dried	$y = 0.9593x$	0.9551	$y = 5.1812\ln(x) – 2.1551$	0.9303
		50	$y = 1.0104x$	0.9745	$y = 5.5251n(x) – 2.4688$	0.911
		70	$y = 0.9651x$	0.9777	$y = 5.2558\ln(x) – 2.3193$	0.9062
		90	$y = 1.1384x$	0.9426	$y = 5.7804\ln(x) – 1.6997$	0.9606
Unblanched	4	Sun-dried	$y = 1.0117x$	0.9289	$y = 5.2401\ln(x) – 1.7175$	0.9626
		50	$y = 0.8791x$	0.9685	$y = 5.1367\ln(x) – 2.9679$	0.854
		70	$y = 1.6232x$	0.9116	$y = 7.9006\ln(x) – 1.6197$	0.9789
		90	$y = 1.914x$	0.9006	$y = 8.9776\ln(x) – 1.1741$	0.9805
	6	Sun-dried	$y = 0.9694x$	0.8946	$y = 4.7252\ln(x) – 0.9624$	0.9849
		50	$y = 0.9489x$	0.9798	$y = 5.3061\ln(x) – 2.6098$	0.8949
		70	$y = 1.4243x$	0.9705	$y = 7.8493\ln(x) – 3.6825$	0.8743
		90	$y = 1.8028x$	0.936	$y = 8.9432\ln(x) – 2.2192$	0.965

Table 4 - Regression relationships between % shrinkage in diameter of cylindrical shaped samples and drying time at different temperatures

Pre-treatment	Thickness, mm	Temp, ºC	Linear equation	R^2	Logarithmic equation	R^2
Blanched	4	Sun-dried	$y = 1.0203x$	0.9452	$y = 5.1031ln(x) – 1.3617$	0.9576
		50	$y = 1.1197x$	0.9444	$y = 5.6916ln(x) – 1.6849$	0.9625
		70	$y = 1.2635x$	0.9717	$y = 6.5768ln(x) – 2.397$	0.8825
		90	$y = 1.7733x$	0.8673	$y = 8.9756ln(x) 2.4648$	0.9557
	6	Sun-dried	$y = 0.8553x$	0.9844	$y = 4.4214ln(x) – 1.5129$	0.9292
		50	$y = 0.9515x$	0.9784	$y = 4.9748ln(x) – 1.7822$	0.9465
		70	$y = 1.1407x$	0.9852	$y = 5.9206ln(x) – 2.0633$	0.9352
		90	$y = 1.3043x$	0.9882	$y = 7.0567ln(x) – 3.044$	0.9083
Unblanched	4	Sun-dried	$y = 1.0679x$	0.9582	$y = 5.3531ln(x) – 1.4565$	0.9640
		50	$y = 1.2044x$	0.9262	$y = 6.2449ln(x) – 2.0691$	0.9519
		70	$y = 1.6232x$	0.9116	$y = 7.9006ln(x) – 1.6197$	0.9789
		90	$y = 2.372x$	0.8252	$y = 11.393ln(x) – 1.8794$	0.9745
	6	Sun-dried	$y = 0.978x$	0.9698	$y = 5.2829ln(x) – 2.2131$	0.932
		50	$y = 1.0659x$	0.9736	$y = 5.5524ln(x) – 1.9536$	0.9395
		70	$y = 1.3727x$	0.9615	$y = 7.6878lln(x) – 3.8882$	0.8387
		90	$y = 1.7487x$	0.9824	$y = 9.4654ln(x) – 4.1525$	0.8773

Table 5 - Regression analysis of the relationship ($y = ax^2 + bx + c$) between changes in volume and time at different drying temperatures

Pre-treatment	Shape	Thickness, mm	Drying Temp. (ºC)	Regression Constant (a,b)	R^2
Un-blanched	Cylindrical	4	90	-I.840, 13.18	0.897
			70	-1.604, 13.39	0.901
			50	-1.479, 13.37	0.911
			SD	-1.438, 13.48	0.914
		6	90	-1.932, 13.17	0.907
			70	-2.101, 14.25	0.899
			50	-2.256, 15.46	0.888
			SD	-2.785, 19.27	0.823
	Rectangular	4	90	-1.840, 13.18	0.897
			70	-1.604, 13.39	0.901
			50	-1.429, 13.37	0.911
			SD	-1.438, 13.48	0.914
		6	90	-1.932, 13.17	0.907
			70	-2.101, 14.25	0.899
			50	-2.256, 15.46	0.888
			SD	-2.785, 19.27	0.823
Blanched	Cylindrical	4	90	-0.104, 4.874	0.975
			70	-0.786, 7.879	0.959
			50	-1.771, 13.67	0.892
			Sun drying	-2.450, 17.69	0.840
		6	90	-2.721, 18.16	0.852
			70	-2.421, 17.27	0.887
			50	-2.590, 18.80	0.865
			Sun drying	-2.291, 18.11	0.853
	Rectangular	4	90	-1.610, 5.588	0.946
			70	-1.810, 12.24	0.889
			50	-1.158, 10.65	0.897
			Sun drying	-1.470, 12.42	0.882
		6	90	-1.869, 13.91	0.893
			70	-1.889, 14.87	0.912
			50	-1.593, 13.78	0.928
			Sun drying	0.938, 12.19	0.928

Table 6 - Bulk densitiesof sweet potato samples at different drying conditions

Drying temperature, ºC	Pre-treatment	Bulk density unit (g/cm^3)
90	Blanched	0.144± 0.003
	Unblanched	0.140± 0.002
70	Blanched	0.165± 0.002
	Unblanched	0.159± 0.001
50	Blanched	0.160 ± 0.003
	Unblanched	0.157± 0.004
SD	Blanched	0.150 ± 0.002
	Unblanched	0.148± 0.003