Effect of Superheated Steam and Convection Roasting on Changes in Physical Properties of Cocoa Bean (*Theobroma cacao*)

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Received November 16, 2012; Accepted December 26, 2012

Roasting is one of the important unit operation steps in cocoa base food industries. Cocoa beans (*Theobroma cacao*) were roasted using superheated steam oven (Healsio, AV-1500V, SHARP) in superheated steam mode and convection mode operated at three set of temperatures (150°C, 200°C and 250°C) for 5 to 35 min. The changes occurred in the physical properties; colors, texture (hardness and fracturability), moisture content and heat inside the beans were examined at the same temperature and time. During superheated steam roasting the color values were more affected than convection roasting. Hardness of the cocoa beans were more affected by the convection roasting mode as compared to superheated steam while fracturability values were more affected in superheated steam mode as compared to convection roasting. The moisture losses of the cocoa beans were lower at each temperature in superheated steam roasting as compared to convection roasting whereas the heating rate inside cocoa beans was higher in superheated steam.

Keywords: cocoa bean, superheated steam, convection, roasting, color, texture and moisture

Introduction

The cocoa is taxonomically classified under the family of Sterculiaceae under the order of Malvales and it belongs to the genus *Theobroma*. The cocoa bean are the seed from the fruit *Theobroma cacao* tree which is the essential ingredient of chocolate and chocolate base products obtained from cocoa butter, cocoa liquor, cocoa powder and cocoa cake (Krysiak, 2011). The cocoa beans are rich in history because of its good flavor and aroma. The Aztecs of Central America and the Mayan Indians considered the cocoa to be a valuable bean and believed the cocoa tree to be of divine origin, hence the name of 'Theobroma' meaning 'food of the gods' (Minifie, 1989). The most important technological unit operation in the processing of cocoa beans is roasting which develop characteristic favor and brown color and texture of roasted beans. In addition, excess moisture is driven off early in this stage of processing and the heat treatment also serves to loosen the shell when whole beans are roasted (Krysiak and Motyl-Patelska, 2006). The most commonly used method of thermal processing of raw cocoa beans is convection roast-

ing method (Świechowski, 1996; Nebesny and Rutkowski, 1998). Roasting intensity of cocoa beans varies from 150°C to 250°C for 30 to 120 min depending on the color, flavor, texture and application desired (Ramli *et al.*, 2006). A number of drawbacks have been reported on convection roasting because of traditional ways of heat and energy transfer. This heat treatment process takes too long and may contribute increased bitterness of bean and loss of aroma. It can bring an undesirable burned flavor and odors coming from bean (Świechowski, 1996). The temperature difference from 10 to 12°C between the kernel and the husk of cocoa beans is also disadvantages of this method. In this traditional convection roasting of cocoa bean, another major demerit is to transfer of cocoa butter from kernel to husk of the bean. It is economically important because industries only use the kernel (Nebesny and Rutkowski, 1998; Krysiak and Motyl-Patelska, 2005).

Modern superheated steam is a clear, colorless gas obtained by the application of heating ordinary steam under normal pressure at 100°C to a higher temperature. Due to possibly reuse of the latent heat of evaporation superheated steam as drying medium is an energy efficient process compared to conventional hot air (Fitzpatrick, 1998; Berghel and

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Renstrom, 2002). It has been reported that during the reheating process of food stuffs with high initial water content superheated steam has advantages than conventional (Frail and Burg, 1997). Studies have shown that superheated steam oven baths food with spray of superheated steam that is 100% dry saturated steam from the addition of sensible heat to water which raise its temperature at the given pressure above saturation temperature. Because of its high heat transfer capabilities, it can be applied to a wide range of fields including food processing such as roasting of cocoa beans. It has been also claimed that this technology heated foods while retaining vitamins and other essential nutrients known as healthy cooked (Chen *et al.*, 1992; Mujumdar, 1995; Huang *et al.*, 2004; Pronyk *et al.*, 2004; Head *et al.*, 2011).

Moisture, color and texture measurement are valuable indicators of the quality of roasted cocoa bean. Changes in moisture content or seed color are currently used as quality standards to determine flavor of cocoa after roasting. The carbonyl derivative also produced from the Maillard reaction reacts with free amino acids in the food product because of the degradation of amino acids to aldehydes, ammonia, and carbon dioxide. This aldehydes and their derivatives that are produced during roasting contribute to the aroma. During roasting step, the flavors produced from a combination of 400 – 500 compounds including aldehydes which are formed during roasting, through the Maillard reaction of amino acids and sugars. The high temperatures and low moisture contents are the ideal conditions for the Maillard reaction and these conditions can be found in suitable roasting method (Heinzler and Eichner, 1992).

The aim of this present study was to investigate a comparison between roasting by superheated and convection mode with regard to changes in colors, texture, moisture and heat inside the beans of the cocoa bean (*Theobroma cacao*).

Materials and Methods

Roasting of cocoa beans Cocoa beans (*Theobroma cacao*) were collected from Cocoa research and development center, Hilir Perak, Malaysia and stored in a chiller (7°C) allowed to equilibrate at room temperature overnight before roasting. A single heat treatment was applied to 200 g portions of medium size raw beans with a diameter of 18 – 24 mm (moisture content: 6.45 ± 0.12 %/weight) distributed in a single layer on a plate regardless of the roasting method. The beans were roasted by a superheated steam oven (Healsio, AV-1500V, SHARP) in superheated steam mode and convection mode that was preheated to the appropriate roasting temperature. The roasting was carried out at 150, 200 and 250°C and the oven door was only opened once to remove the beans. All experiments were repeated two more times for

a total of three replications with every roasting time and temperatures.

Color measurement After calibration against white and black glass standards the surface color of the roasted cocoa bean samples were measured using a Minolta CM-3500D colorimeter (Light source, Pulsed xenon arc lamp; Reflectance, d/8; Measuring head hole, 8 mm; Measurement time, 2.5 sec). The measurement of colors were expressed in CIELAB color values (L^* , a^* , b^*) where the L^* value represents the lightness to darkness gradation, a^* value represents the greenness to redness spectrum and the b^* value represents the blueness to yellowness spectrum. The whiteness index (WI) value can also be obtained from the colorimeter readings of L^* , a^* , and b^* values according to equation 1.

Whiteness Index (WI) =

$$100 - ((100 - L^*)^2 + (a^*)^2 + (b^*)^2)^{0.5} \quad (\text{Eq. 1})$$

Texture profile analysis Universal Texture Analyser (CNS, Farnell, UK) equipped with the Texture ProTM texture analysis software were used to carry out texture profile of the roasted beans. For the measurement of texture, a 36 mm cylindrical probe P/36 R was used in terms of compression force (g) and the instrument was calibrated with a 30 kg load cell. The probe was allowed to compress 5 mm into the sample and the samples were placed onto the platform while the target value was set at 15 mm at 1 mm/s. The texture profile analyzer enabled to calculate the hardness, adhesiveness, cohesiveness, springiness, resilience, chewiness, gumminess and fracturability of the sample beans. The properties of texture were obtained from the force time curves. Fracturability (N) (first peak of first compression) and hardness (N) (maximum peak of first compression) were considered to evaluate the textural properties of the cocoa beans (Bourne, 1982).

Heat inside the beans and moisture measurement Temperatures inside the beans were measured by laser gun thermometer (GHC Specialty Brands, USA. Model: T7350) after roasting which measured the temperature at a spot on the surface of whole beans. The laser gun thermometer focused energy through its lens and created an electrical signal by transforming the temperature with microcomputer processor and displayed the output on the panel of the thermometer. After deshelling and grinding, approximately 5 g of raw and roasted beans were used to determine the moisture content. The moisture determinations were performed using the automatic AnD MX-50 moisture analyzer (A&D Store, Inc. Japan) at 140°C.

Statistical analysis Every sample with each time and temperature parameter was measured in triplicate and the obtained data was expressed as the means of measurements $\pm$ S.D. The software package MINITAB 11.12 was used to

analyze the experimental data and all the tests of statistical significance were based on the total error criteria with a confidence level of 95%.

Results and Discussion

Analysis of color formation The most important appearance attributes of food material is color that influences consumer preference to purchase a product, regardless of its texture quality (Maskan, 2001). Color is also used for controlling of a process parameter. On the basis of color formation roasting operations are controlled because the brown pigment develops as browning and caramelization reaction progress during roasting periods (Saklar *et al.*, 2003).

The relationship between the color values with the duration of roasting at different temperature of conventional and superheated steam roasting of cocoa beans expressed as L^* , a^* , b^* and WI of the samples were shown in Table 1.

The sample cocoa beans were heated in conventional and superheated steam mode under three set of temperature and time to complete roasting. Using the regression fitted line plot test, the p-value and correlation coefficient (r) of each temperature were analyzed at each temperature with the duration of time. The r -value represents the strength of association between color analyses with the time of heating in this study. The value vary between +1 and -1, where +1 (positive correlation) indicating a strong correlation with both variables increasing together while one variable decreasing as the other increase indicating -1 (negative correlation) and 0 means (zero correlation) no correlation with each other's. A correlation coefficient between -0.20 and 0.20 is not strong enough to be considered significant with each other's (Epstein *et al.*, 2002)

The lightness value decreased over time although the r -value was not statistically significant in both methods. At

Table 1. The relationship between the color values with the duration of roasting at different temperature of convectional and superheated steam roasting of cocoa beans.

Analysis	Roasting method	Temperature (°C)	Time (min)	Mean $\pm$ SD (N)	p-value	r-value
L^*	Raw	—	—	41.36 $\pm$ 0.18		
	Conventional	250	5 – 15	20.7 – 15.88	0.181	-0.960
		200	15 – 25	28.51 – 25.01	0.335	-0.865
		150	25 – 35	28.22 – 22.43	0.116	-0.983
	Superheated steam	250	5 – 15	33.8 – 19.89	0.180	-0.960
		200	15 – 25	37.45 – 20.27	0.186	-0.958
		150	25 – 35	25.27 – 18.87	0.196	-0.953
WI*	Raw	—	—	41.19 $\pm$ 0.43		
	Conventional	250	5 – 15	20.44 – 15.16	0.185	-0.958
		200	15 – 25	27.34 – 23.30	0.288	-0.899
		150	25 – 35	27.77 – 19.87	0.100	-0.988
	Superheated steam	250	5 – 15	32.44 – 16.77	0.189	-0.956
		200	15 – 25	36.71 – 18.74	0.177	-0.962
		150	25 – 35	23.57 – 15.06	0.098	-0.988
a^*	Raw	—	—	2.83 $\pm$ 0.08		
	Conventional	250	5 – 15	3.92 – 8.28	0.280	0.905
		200	15 – 25	10.29 – 12.32	0.214	0.944
		150	25 – 35	5.96 – 12.47	0.047	0.997
	Superheated steam	250	5 – 15	8.15 – 17.47	0.187	0.957
		200	15 – 25	5.02 – 9.87	0.101	0.987
		150	25 – 35	12.05 – 16.79	0.142	0.975
b^*	Raw	—	—	3.41 $\pm$ 0.11		
	Conventional	250	5 – 15	5.07 – 7.21	0.132	0.979
		200	15 – 25	7.84 – 10.31	0.159	0.969
		150	25 – 35	5.32 – 15.73	0.013	1.000
	Superheated steam	250	5 – 15	10.73 – 14.29	0.321	0.876
		200	15 – 25	8.24 – 12.16	0.028	0.999
		150	25 – 35	10.57 – 18.72	0.164	0.967

200°C in superheated steam roasting showed a better relationship of lightness (L^*) value with time ($r = -0.958$, $p > 0.05$) as compared with the convection roasting where r-value was -0.865 (Table 1).

There were also a better relationship found for whiteness value (WI) with time obtained from L^* , a^* and b^* ($r = -0.962$, $p > 0.05$) as compared with the convection method where r-value was -0.899 at 200°C in superheated steam roasting. The r-value was not statistically significant in both cases although the whiteness value decreased over time.

Redness values (a^*) showed an increasing trend over time in both roasting method. Convection roasting at 150°C showed a strong positive relationship between redness values with time ($r = 0.997$) as compared with superheated steam roasting method and there was a significant relationship between those variables ($p < 0.05$).

Convection roasting method at 150°C showed a very strong relationship of yellowness (b^*) values with time ($r = 1.0$) as compared with superheated steam roasting and there was a significant relationship found between those variables ($p < 0.05$). There were a strong relationship found for yellowness value with time ($r = 0.999$) at 200°C in superheated steam roasting as compared with the convection method. There was also a significant relationship found between those variables ($p < 0.05$). Yellowness and redness values were increased as the cocoa beans darkened over time. The color values (L^* , a^* , b^* and WI) during superheated steam roasting method were more affected than the convection roasting method at the same temperature and time. It were observed less brown cocoa by superheated steam roasting compared to conventional roasting at the same temperature and time, and concluded that the superheated steam was better in term of color values.

It was found that the superheated steam affected more the color values (L^* , a^* , b^* and WI) than convectional roasting at the same temperature and time. Similar results were observed for peanuts roasting using superheated steam and convectional roasting (Idrus and Yang, 2012).

Texture analysis Another important quality control parameter for roasting of cocoa beans is texture. The cooking temperature and moisture content were significant factors that affect the texture of foods (Lin *et al.*, 2000). During roasting method the texture became more fracture (crispy) and crumbly because of the loss of moisture content (Vincent, 2004; Emily *et al.*, 2009). The relationship between the textures values with the duration of roasting at different method were shown in Table 2. The hardness values deceased throughout the roasting time in both methods at three different temperatures. There were negative relationships between the hardness values with roasting time although the r-value for both methods was not statistically significant. The results in Table 2 showed that softening behavior of cocoa beans in thermal processing is rather complicated, and the superheated steam mode softened beans faster than the convection mode at the same temperature and time. As for example during superheated roasting at 250°C the hardness value declined from 7.083 N to 5.243 N while the hardness decreased from 9.961 N to 7.328 N during convection roasting at the same temperature and time. Therefore, the convection roasting affected more on the hardness of the cocoa beans. The textural characteristic of extruded and crunchy products is known as fracturability and deformation properties and texture of food can be affected due to changes in the distribution of fracture intensities even at low level of moisture (Barrett and Kal-etunc, 1998). There were also negative relationships found between the fracturability values with roasting time and there

Table 2. The relationship between the texture values with the duration of roasting at different temperature of superheated steam and convectional roasting of cocoa beans.

Analysis	Roasting method	Temperature (°C)	Time (min)	Mean $\pm$ SD (N)	p-value	r-value
Hardness	Raw	—	—	12.74 $\pm$ 0.048		
	Superheated steam	250	5 – 15	7.083 – 5.243	0.206	-0.948
		200	15 – 25	7.345 – 5.459	0.056	-0.996
		150	25 – 35	5.610 – 4.023	0.286	-0.901
	Conventional	250	5 – 15	9.961 – 7.328	0.063	-0.995
		200	15 – 25	9.046 – 6.786	0.186	-0.958
		150	25 – 35	7.293 – 5.784	0.093	-0.989
Fracturability	Raw	—	—	14.62 $\pm$ 0.038		
	Superheated steam	250	5 – 15	9.433 – 8.315	0.023	-0.999
		200	15 – 25	9.538 – 8.591	0.172	-0.964
		150	25 – 35	8.942 – 7.503	0.223	-0.939
	Conventional	250	5 – 15	9.187 – 8.608	0.131	-0.979
		200	15 – 25	9.958 – 9.257	0.359	-0.845
		150	25 – 35	6.697 – 6.187	0.314	-0.881

Table 3. Moisture and temperature inside the beans with duration of roasting at different temperature of convectional and superheated steam roasting of cocoa beans.

Roasting method	Temperature (°C)	Time (min)	Moisture %	Temperature (°C) inside beans
Raw	—	—	6.45	26
Conventional	250	5 – 15	4.19 – 2.62	121 – 149
	200	15 – 25	2.96 – 2.11	124 – 143
	150	25 – 35	3.04 – 2.74	103 – 129
Superheated steam	250	5 – 15	4.47 – 2.91	132 – 169
	200	15 – 25	3.05 – 2.11	147 – 161
	150	25 – 35	3.28 – 2.83	120 – 145

was a significant relationship in superheated steam roasting at 250°C in this study. The result showed that the fracturability decreased with increased of roasting time as reflected in the *r*-value in both convection and superheated steam roasting methods (Table 2).

However, during superheated roasting method the fracturability values were more affected as compared to convection roasting method. For instance, fracturability decreased from 9.433 N to 8.31 N during superheated steam roasting at 250°C while the value dropped from 9.187 N to 8.608 N during convection roasting method at the same temperature and time. The fracturability and hardness values were positively correlated with each other. Similar decreasing trends were observed in the hardness and fracturability values with roasting time using superheated steam and convectional roasting of peanuts (Idrus and Yang, 2012). The decreasing trends in the first fracture point during roasting of hazelnuts were also observed using convectional roasting method (Saklar *et al.*, 2003).

Heat and moisture measurement The moisture loss and heat inside the cocoa beans throughout roasting time were presented in Table 3.

The study observed that there were a higher moisture loss observed in convection roasting method with the same temperature and time as compared to superheated steam roasting method although it was not statistically significant ($p > 0.05$). The heating rates inside the beans were higher in superheated steam roasting method as compared to convection method at the same temperature and time. It was measured based on cocoa bean temperature throughout the roasting time in both methods and this trend were statistically significant ($p < 0.05$)

Conclusion

The physical properties of cocoa beans were affected both by superheated and convection roasting methods. The color quality, Lightness (L^*) and whiteness (WI) value decreased with roasting time. At 200°C in superheated steam roasting showed a better relationship of lightness (L^*) and whiteness

(WI) value with time as compared with the convection roasting. Redness and yellowness value showed increased trend with time in both methods and showed a strong positive relationship between redness values with time as compared to superheated steam roasting method. There was a significant relationship ($p < 0.05$) found for both cases of redness and yellowness value in convection roasting method at 150°C. During superheated steam roasting method the color values (L^* , a^* , b^* and WI) were more affected than the convection roasting method at the same temperature and time.

Textural quality (hardness and fracturability) were generally affected by both methods and the values decreased with increasing roasting time. The convection roasting affected more on the hardness of the cocoa beans as compared to superheated steam method although these values were not statistically significant while the fracturability values were more affected in superheated steam method as compared to convection roasting method and there was a significant relationship ($p < 0.05$) in superheated steam roasting at 250°C. The fracturability and hardness values were positively correlated with each other.

The moisture losses of the cocoa beans at each temperature were lower after superheated steam roasting than in convection roasting method. The heating rate inside cocoa beans was higher in superheated steam roasting as compared to convection roasting at the same temperature and time and this trend were statistically significant ($p < 0.05$).

Convection roasting used presently in food industries takes longer time that may adversely affect not only the physicochemical and nutritional quality but also costly. Therefore, superheated steam roasting can be a new unit operation tool in food processing industries because the desirable better characteristics of food can be preserving at the same temperature and time than convection roasting.

Acknowledgement We would like to acknowledge to the Fellowship Scheme of the Institute of Postgraduate Studies, Universiti Sains Malaysia for funding of this research.

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