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Impact of Different Temperature-Time Profiles during Superheated Steam Roasting on Some Physical Changes of Robusta Coffee

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ABSTRACT

Roasting is the most important step in the coffee processing. The impact of superheated steam roasting temperature (150, 200, 250°C) and time (10-50 min) on the color (L*, a*, b*, browning index), moisture and hardness attributes of *Coffea canephora* (Robusta coffee) beans were studied. Increases in roasting temperature and time caused a decrease in all the responses except for browning index, a* and b* values of roasted coffee beans. A decrease in the hardness of coffee bean during roasting has been correlated to the loss of moisture content. Coffee beans exhibit greater bean volume, pore volume and larger micropores during roasting process, which indirectly lead to the loss of moisture content. With regards to the prolonged superheated steam roasting, it significantly affects colour attributes and moisture content. As the roasting temperature increased up to 250ºC, colour attributes such as browning index, a* and b* values decreased significantly whereas moisture content increased slightly.

Keywords: Superheated steam, roasting, coffee bean, moisture, color and hardness

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INTRODUCTION

Coffee plants belong to the botanical genus *Coffea* in the family of flowering plants called *Rubiaceae*, which contains around 600 genera and 13,500 species. Although the genus *Coffea* L. have more than 100 species, only two, *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee), are commercially cultivated (Mishra

& Slater, 2012). Coffee is one of the most widely consumed beverages around the world (Ding et al*.,* 2014). Coffee gains its popularity around the world for its aroma and flavour. Besides, its popularity is also attributable to the stimulating effects of its caffeine content. Recent studies suggest that coffee consumption may have beneficial effects on human health and coffee has been identified as major contributor to the *in vitro* antioxidant capacity of the diet (Van Dam, 2008).

Coffee roasting is an important unit operation to develop the specific organoleptic properties (aroma, flavour and colour) in which the process has a great degree of influence on coffee final quality (Hernández et al*.,* 2008; Mussatto et al*.,* 2011). Roasting is a highly complex process as it involves various chemical reactions and considerable physical changes, which all depend on the temperature-time profiles used during roasting process (Wang, 2012). Heat and mass transfer occur simultaneously inside coffee beans. The roasting process consists of two stages, first the drying stage where the moisture is rapidly driven out of the bean. Moisture content significantly decreases during the first 5 to 10 minutes of roasting (Kristin, 2011). Colour development has been reported to occur rapidly after the initial drying stage.

Colour development is one of the parameters that is used to measure the degree of roast and acts as an indicator of final quality product (Manzocco et al*.,* 2000; Baggenstoss et al*.,* 2008). Clarke and Vitzthum (2008) reported that Maillard reaction and oxidative polymerisation or degradation of phenolics compounds are the major reactions responsible for colour formation during roasting process. The chemistry underlying the Maillard reaction is very complex as it involves not only one reaction pathway but a whole network of various reactions (Martins, 2003).

In addition, changes in the textural characteristics undergo during roasting plays an important control parameter for coffee bean roasting. During the roasting, beans become more crumbly and brittle as they lose their strength and toughness, which are typical characteristics of roasted products. Besides, a decrease in moisture content affects the texture properties, which causes the beans to become more fragile and brittle upon roasting (Kita & Figiel, 2007). Reaching of a certain degree of brittleness is very important for the grinding process, which is carried out before the extraction of coffee brew (Jokanovic et al*.,* 2012). Meanwhile, the fineness of grind affects the extraction of soluble solids, which relates directly to the brewing extraction (Pittia et al*.,* 2001).

Roasting is a heating process that drives off the free and bound moisture of a food sample. The coffee roasting process is carried out in many ways; these is done by conduction using hot metal surfaces (conventional drum roasters), convection using air as the heating medium (fluid bed roasters) and radiation methods (infrared roasters). A widely used method of roasting coffee beans is convection roasting which is based on subjecting the raw beans to a flow of hot air in the temperature range between 200 to 230ºC for 12 to 20 minutes (Jokanovic et al*.,* 2012). However, it has a number of drawbacks such as difficulty in handling particulate solids and lowering the product quality (Panda, 2013). The processing method used on coffee is usually limited to the traditional roasting method; thus, superheated steam roasting may offer an alternative method. Superheated steam is a type of unsaturated steam generated when additional heat is applied to raise the steam temperature above the saturated dry steam (Zzaman et al*.,* 2013). When drying with superheated steam, the water removed from the product during the drying process becomes part of the drying medium, whereas in hot-air drying method, the moist air must be replaced by fresh air (Moreira, 2001; Borquez et al*.,* 2008). Superheated steam is cleaner and it provides higher evaporation rate, yields better colour and less oxidation in food, thus reducing the loss in nutritional value during the drying process (Moreira, 2001; Wang et al*.,* 2012).

Numerous studies have been conducted on *Coffea arabica* (Arabica coffee) varieties using the conventional roasting method but no studies have been done on superheated steam roasting of *Coffea canephora* (Robusta coffee). Therefore, the purpose of this work is to study the changes in moisture, colour and hardness of *Coffea canephora* using superheated steam roasting in order to predict their effect with different time-temperature profiles.

MATERIALS AND METHODS

Sampling

Green coffee (*Coffea canephora*) was obtained from the local Hang Tuah Coffee factory located in Tasek Gelugor Seberang Prai, Malaysia. The beans were stored in a dry place, which is also known as "out-gassing". The purpose is to excrete and separate moisture from the beans. The beans were then subjected to sorting and selection processes manually at the laboratory of Food Technology Department. The defective beans (black, partly black, broken, infested) were discarded and the non-defective beans were packed in hermetically sealed containers. The moisture content of green coffee was 10.06 %.

Superheated Steam Roasting

The roasting process was carried out by placing the Robusta coffee beans in the superheated steam drying oven and exposed them to the roasting temperatures of 150, 200, 250ºC at different time intervals (10-50 min). Sharp AX-1500 K superheated steam oven with a pressure of approximately 1 bar, steam generation capacity of 16 cm^3/min, and steam engine heater of 900 W was used during the roasting process. Roasted beans were stored in an air tight container for further analysis.

Moisture Content Determination

Moisture content was determined using a halogen moisture analyser (HB43-S model, Mettler Toledo, UK). The results were the mean of three measurements.

Colour Measurement

Colour measurement was done using CIE Lab scale (CM-3500D Minolta spectrophotometer, Minolta, Japan). Three measurements were done for each sample. The reflectance used was d/8 (diffuse illumination/ 8 ° viewing angle) geometry, pulsed xenon arc lamp as the light source and 2.5 s for the measurement time. The instrument was calibrated with zero calibration (CM-A100) and followed by white calibration plate (CM-A120) before measuring the sample. The colour values are expressed as L* (whiteness or darkness), a* (redness/ greenness), and b* (blueness/ yellowness). The L*, a*, and b* values are the three dimensions of the measured colour, which gives specific colour value of the material. The browning index (BI) (Eq. (1)) was also used to estimate total colour changes during roasting (Maskan, 2001).

$$\text{BI} = \frac{[100\ (x - 0.31)]}{0.17} \qquad [1]$$

where

$$\text{x} = \frac{(a + 1.75\ L)}{(5.645\ L + a - 3.012\ b)} \qquad [2]$$

Texture Measurements

The texture analysis of the Robusta coffee beans were performed using a Universal Texture Analyser (CNS, Farnell, UK) equipped with the Texture Pro™ texture analysis software. A bean was placed horizontally on the platform and double compression was applied using a 36 mm cylindrical probe P/36 R at a test speed of 5.0 mm/s. The instrument was calibrated with a 30 kg load cell, 15 mm of return distance, 10 mm/s of return speed and 5 g of the contact force. The maximum peak of the first compression (N) in the force-time curves indicates the hardness value (Kahyaoghu & Kaya, 2006; Shakerardekani et al., 2011).

Statistical Analysis

The moisture contents, colour values, and textural parameters of roasted coffee beans were analysed using the two-way analysis of variance method (ANOVA) to determine the effects of temperature and time on these responses. The ANOVA tests were performed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Moisture Content

Moisture content of green and roasted coffee beans typically varied within the ranges of 9.06 – 9.24 and 1.11-3.12 wt. (%), respectively (Bicho et al., 2012). The moisture content of coffee bean has a strong influence on the degree of brittleness and it is important during the grinding process as it influences the coffee extraction (Jokanovic et al., 2012). As shown in Figure 3, increasing the roasting temperature from 150 to 250°C causes the moisture content to decrease significantly ($P < 0.05$).

During the early phase of roasting, progressive decrease in moisture content was observed in Robusta coffee bean due to water evaporation as the bean core temperature is increased above the boiling point of water (Wang, 2012). According to Correa et al. (2010), increased roasting temperature activated the water molecules to higher energy levels, allowing them to break away from their sorption sites, and thus reducing the moisture content of roasted beans.

From Figure 3, moisture content increased slightly from 30 to 50 min for 250°C. This might be attributed to the hygroscopic nature of coffee beans (Ismail et al., 2013; Coradi et al., 2014). Superheated steam is sprayed onto the beans during roasting process and since coffee beans are hygroscopic in nature, the water molecules which condense on to the bean surface will rapidly be absorbed (Clarke & Macrae, 1988).

Colour Changes

Colour is an important quality indicator in the roasting process which is typically used as an indicator of the degree of roast (Chu, 2012). The changes in the CIE L*, a*, b* and BI values of roasted Robusta coffee at different temperatures are shown in Figure 1. The two-way ANOVA indicated that temperature and time significantly ($P<0.05$) affected the colour values of ground Robusta coffee during roasting.

The L-value indicates the whiteness of a sample. Results showed that the L-value was significantly ($P < 0.05$) influenced by the roasting temperature and time. In general, the L-value of coffee beans tends to decrease during the roasting process which may be due to the brown pigment produced by non-enzymatic browning (Sacchetti et al., 2009; Wang, 2012). As an exception, the L- value of the coffee beans increased slightly up to 10 min of roasting time and decreased thereafter for the entire roasting temperature from 150 to 250ºC. The initial increase in the L-value during the early periods of roasting was similar to the observation for hazelnut (Özdemir & Devres, 2000), corn kernels (Chung et al., 2014) and sesame seeds (Kahyaoglu & Kaya, 2006). Özdemir and Devres (2000) reported that the reason of the initial lightening in roasted hazelnuts may be due to the denaturation of soluble protein. Meanwhile, according to Kahyaoglu and Kaya (2006), denaturation of proteins, concentrated amount of oil particles embedded in the protein matrix and low moisture content were the factors contributing to the initial lightening in sesame seeds.

The a-value shows redness for roasted products. The a-value of Robusta coffee roasted at temperature below 250ºC tended to increase over the entire roasting period; however, the beans roasted at 250ºC increased up to 20 min of roasting and then decreased over the remaining period. Gökmen and Şenyuva (2006) reported that changes in CIE a* colour value are correlated with the acrylamide content in coffee. The amount of acrylamide increased rapidly at the onset of roasting then decreased exponentially as the rate of degradation exceeds the rate of formation. The CIE a* profile followed a similar trend. It is also reported by other researchers (Taeymans et al., 2004) that darker coloured coffee contains lower acrylamide content than the light coloured coffee. Hence, an initial increase in a-value to an apparent maximum as there is an increased rate of brown pigments formation through the Maillard reaction. However, a-value decreased at 250 ºC after 20 min was possibility due to the acrylamide degradation.

The b-value shows the degree of yellowness (Figure 1). The b-value of roasted coffee increased at the lower roasting intensity but decreased significantly with a higher roasting intensity. The b-value of the coffee beans roasted at 150, 200 and 250ºC decreased gradually after 40, 30 and 20 min of roasting, respectively. According to Afoakwa et al. (2014), an increase in the b-value with the increasing roasting time is due to thermal oxidation of polyphenols and Maillard products formation.

Browning index (BI) represents the purity of brown color develops during the roasting processes, where enzymatic and non-enzymatic browning takes place (Maskan, 2001). Generally, it is an indirect way to measure the contents of pigment compounds produced from browning reactions (Chung et al*.,* 2013). Changes in the browning index of coffee beans during roasting are shown in Figure 1. Browning index change was significantly affected ($p < 0.05$) by roasting temperature and time. The browning index of the beans roasted at 150ºC increased throughout the roasting process, especially the beans roasted at 200ºC, which sharply increased after 10 min of roasting. The increase in the browning index was probably due to the brown pigment formation from Maillard reactions, thermal oxidation, Strecker degradation

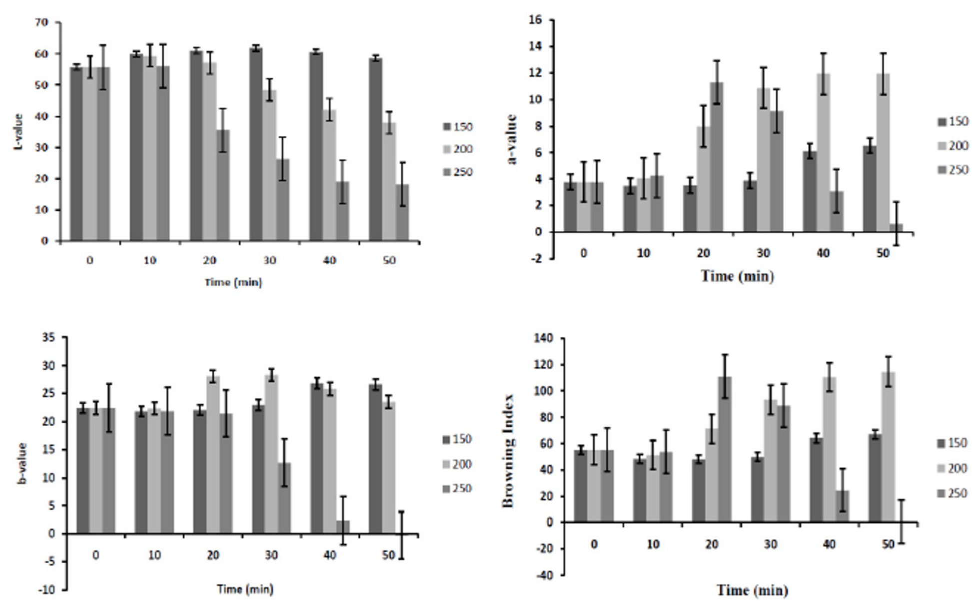

Figure 1. Changes in the colour attributes (L*, a*, b* and Browning index) of Robusta coffee bean during superheated steam roasting at different temperatures and time

and polymerisation of polyphenols to form tannins during the roasting process. However, the browning index of the beans roasted at 250ºC decreased after 20 min of roasting. These results showed that Robusta coffee roasted at the temperature below 200ºC has higher content of Maillard reaction products compared with the coffee beans that roasted at 250ºC.

Changes in Hardness

Heat treatment determines the textural characteristics of the roasted coffee. Green coffee beans have thick cell walls and lack intracellular spaces and exhibit exceptional hardness. In the coffee industry, grinding is a process which is carried out on roasted coffee beans before coffee brew extraction. Therefore, the degree of brittleness is very important in the grinding process and it influences the coffee brew extraction efficiency (Pittia et al., 2001; Nedomová et al*.,* 2013).

The hardness of roasted Robusta coffee beans showed significant decrease ($p < 0.05$) as roasting temperature and time increased, indicating a progressive increase in the brittleness of the bean. As shown in Figure 2, the hardness significantly decreased ($p < 0.05$) from 150°C to 250°C for all roasting time (10-50 min). However, there was a slight increase in the hardness at the roasting temperature of 150°C for 30 min. Based on Wilson et al. (1997), polysaccharide cytoplasmic matrix of coffee bean starts to denature during the early stages of roasting, and this is followed by moisture loss, increase in bean volume and larger cell wall micropores as the roasting process continue. Loss of moisture and disruption of parenchyma is the principal cause for the increase of brittleness, crispness and crunchiness in the roasted beans. Hence, reduction of the hardness indicates a progressive decrease in moisture content in the bean and increase in the brittleness of the coffee beans as a more porous structure formed during the roasting process (Li et al*.,* 2005).

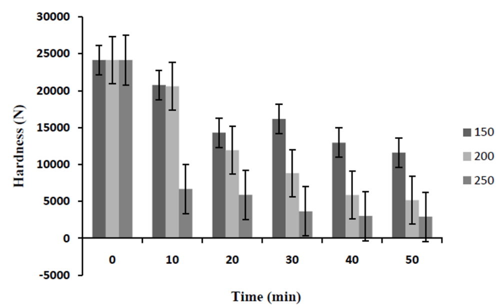

Figure 2. The effects of different roasting temperatures (150 to 250°C) and time (0 to 50 min) on hardness of coffee beans

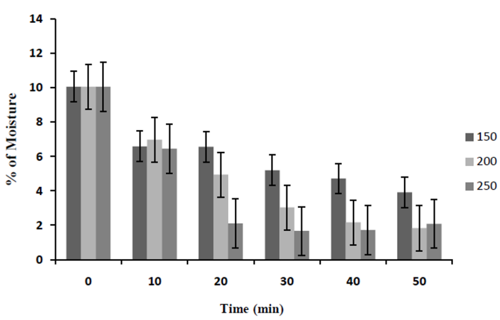

Figure 3. The effects of different time-temperature profiles during superheated steam roasting on moisture content of Robusta coffee beans

CONCLUSION

Roasting process is an important step in coffee industry, where the desired aroma, flavour and colour of coffee are developed (Noor Aliah et al., 2015). Thus, roasting process has a crucial impact on the final quality of coffee.

Colour of the roasted beans used to define the end of the roasting operation and is often correlated to the degree of roasting (light, medium, or dark roast); the higher the roasting temperature, the darker the colour of the bean (Buffo & Cardelli-Freire, 2004). Moisture content and toughness of the coffee beans have been used to study mechanical properties such as brittleness of coffee beans. Meanwhile, degree of brittleness is very important for the grinding process and it affects the extraction of soluble solids to obtain the good quality coffee brew (Nedomova et al*.,* 2013).

In this study, Robusta coffee was subjected to superheated steam roasting within an appropriate temperature range (150 – 250°C) and time (10 – 50 min) exhibited desired colour, hardness, as well as moisture content. As the roasting temperature and time increased, the colour of bean became darker, more brittle texture and thus reduced the moisture content. The results of this study showed that the effects of both superheated steam roasting temperature and time have significant influence ($p < 0.05$) on moisture content, hardness, and colour changes of Robusta coffee beans. Therefore, the new method of superheated steam can be employed to produce desired coffee and coffee products because it takes shorter time to achieve satisfactory results although slightly high temperature is required. Further studies on chemical properties will be conducted to evaluate the final coffee quality after roasting using superheated steam.

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