Journal of Applied Science and Agriculture, 10(7) Special 2015, Pages: 18-23

AENSI Journals

JOURNAL OF APPLIED SCIENCE AND AGRICULTURE

ISSN 1816-9112

Journal home page: www.aensiweb.com/JASA

A Review of Quality Coffee Roasting Degree Evaluation

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ARTICLE INFO

Article history:
Received 12 February 2015
Accepted 1 March 2015
Available online 28 March 2015

Keywords:
Coffee roasting
Roasting degree evaluation
On-line assessment
Chemical composition

ABSTRACT

Background: Roasting is the most essential part in coffee processing; the desired aroma and flavors of coffee are developed in the process. During this process, the beans undergo a series of reactions leading to the changes in physical properties and chemical composition. It is important to control the roasting process, and stop the process when the aromas have fully developed and the color of the coffee is homogeneous throughout the whole bean. Therefore, a method to evaluate the coffee roasting doneness in real-time is necessary. Many studies have been done to evaluate the quality of roasted coffee experimentally using different parameters such as aroma, flavor, color, bean temperature, pH, and chemical composition. However, these techniques could not be implemented in real-time and have their own limitations. **Objective:** This paper presents a review of recently developed approaches and latest researches carried out for evaluating the quality of roasted coffee beans. The review is based on some selected refereed journal articles. **Results:** The review indicates that end product alone, i.e. beans weight loss and color are not suitable to determine the roasting degree of doneness. **Conclusion:** Future direction should investigate on the chemical compositions in high quality roasted beans, and more effort must be done in establishing a large database of v formation dynamics during roasting.

To Cite This Article: A.M. Noor Aliah, A.M. Fareez Edzuan, A.M. Noor Diana., A Review of Quality Coffee Roasting Degree Evaluation. ***J. Appl. Sci. & Agric.,*** *10(7): 18-23, 2015*

INTRODUCTION

In recent years, the quest of knowledge regarding coffee is spreading due to the growing appreciation of coffee. Consumers are no longer content with instant coffee and now crave for the experience as well as flavors of freshly roasted-high quality coffee. The quality of coffee beverage is closely related to the chemical composition of the roasted beans, which is affected by the composition of green beans and postharvest processing conditions, i.e. drying, storage, roasting and grinding (Franca, *et al*., 2005; Illy & Viani, 2005). Green coffee beans contain a wide range of different chemical compounds and complex composition (Franca, Oliveira, *et al*., 2005). However, green coffee by itself does not have an attractive taste or aroma.

The desired aroma and flavors of coffee are developed in the roasting process; thus this step is probably the most important step in coffee processing. In this process, the beans undergo a series of reactions leading to the desired changes in physical properties and chemical composition (Illy & Viani, 2005; Pittia *et al*., 2001). Nevertheless, this process is highly complex, since the quantity of heat transferred to the bean is crucial. In coffee roasting, the green beans are heated to high temperatures (in the case of an Italian-style roasting it ranges between 200°C and 240°C bean temperature) for different times depending on the desired characteristics of the final products (Pittia *et al*., 2001). During the roasting process, coffee beans are subjected to a steady weight loss (Hernández *et al*., 2007; Jokanovic *et al*., 2012) due to the water loss and loss of volatile materials. At the same time, the coffee beans undergo a significant increase in volume (Dutra *et al*., 2001). Consequently, the coffee beans density decreases and the typical porous structure of roasted coffee bean is formed (Pittia *et al*., 2001). In addition, coffee beans undergo other major changes in terms of color, form, pH, flavor and aroma. To achieve a homogeneous roasting profile, the process must be precisely controlled, aiming at small temperature gradients throughout the bean (Illy & Viani, 2005). Finally, the beans must be cooled

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Journal of Applied Science and Agriculture, 10(7) Special 2015, Pages: 18-23

rapidly to stop the reactions (using water or air as cooling agent) and prevent excessive roast which will alter product quality (Schwartzberg, 2002). This paper presents a review on the various roasting degree evaluation of quality coffee beans and proposes some further studies that could be conducted to improve the existing method on roasting degree evaluation.

2. Coffee Roasting Degree Evaluation:

Coffee roasting process is the most crucial part in coffee processing because it is important to generate and control the correct temperature at the right moment, then stop the process when the aromas has fully developed and the color is homogeneous throughout the whole beans. The extent of roasting reactions depends on both reaction rate (which is dependent on temperature and reactant concentration) and reaction duration. Therefore, in order to reproduce the supply of desired coffee flavor it requires control of bean temperature-time history during almost the entire roast, since the concentration of some reactants used in later-stage reactions depends on the early stage reactions. Most roasters in the market do not yet utilize this system to achieve such control; they rely on monitoring bean/hot gas temperature and provide a constant fuel flow/hot gas flow rate (Schwartzberg, 2002).

Many attempts have been done to evaluate the quality of roasted coffee experimentally using different parameters such as aroma, flavor, color, bean temperature, pH, chemical composition, bean pop, weight loss, exhaust gas composition and volume (Alessandrini *et al*., 2008; Dutra *et al*., 2001; Hernández *et al*., 2007; Hernández, Heyd, & Trystram, 2008; Illy & Viani, 2005; Schwartzberg, 2002). However, in the industry it is very difficult to evaluate these parameters on-line; to identify the optimal roasting doneness in order to stop the roasting process at the right moment. The analytical methods used in the industry are often complicated, costly and time-consuming since they require sample preparation and even chemical manipulations to predict the product quality offline in a laboratory (Dutra *et al*., 2001). Furthermore, they are non-effective because the quality of raw materials varies between laboratory measurements (Santos *et al*., 2012). Consequently, in most cases the roast master plays an essential role.

3. Methods Used to Determine Roasting Degree:

Studies on coffee roasting degree evaluation have been carried out extensively in the past few decades. Various parameters have been used to determine the roasting degree, and these parameters can be categorized into two major groups, i.e. physical properties and chemical compositions. Studies on the evaluation of roasting degree by some researchers have been summarized in Table 1 below:

Table 1: Some Studies on Roasting Degree Evaluation.

Author	*Methodology*	*Results*
(Hernández *et al*., 2008)	PHYSICAL PROPERTIES Image analysis was used to determine brightness and surface area on-line during roasting. Roasting stop automatically when grey level from image acquisition system reached the target grey level of optimally roasted coffee beans.	Initially, the color of beans remained the same. Color darkened slightly when internal temperature of beans reached 100°C, then it became slightly lighter at temperature above 160°C, and darkened gradually until finish roasting. Roasting assessment was performed in real-time.
(Alessandrini *et al*., 2008)	PHYSICAL PROPERTIES Near infrared (NIR) spectroscopy was used to observe the coffee spectra. Partial Least Square (PLS) correlation between coffee spectra region to physical changes (weight loss, density and moisture) was obtained and regression models to predict roasting variables were proposed. Then, another experiment was conducted with 56 samples to validate the predicted values.	Different roasting degrees were predicted with high accuracy, leading to high correlation coefficient results between measured and predicted roasting variables.
(Romani *et al*., 2012)	PHYSICAL PROPERTIES Electronic nose and artificial neural network (ANN) model was used to determine physical properties (density, moisture weight loss, color).	Physical properties and roasting time calculated by ANN models provided good agreement with experimental results.
(Dutra *et al*., 2001)	CHEMICAL COMPOSITION Chemical composition profile was observed using gas chromatograph. pH level of the exhaust gas was also monitored.	Significant increase in peak intensities was detected for the roasting period of 6 to 8 min. At optimum roasting degree the pH of exhaust gas was found to be lowest.
(Dorfner *et al*., 2004)	CHEMICAL COMPOSITION Roasting process was analyzed by direct injection of roaster gas into laser mass spectrometer. Ionizing technique was done to monitor mixtures of volatile organic compounds (VOC). Principle component analysis (PCA) was applied on time-intensity traces of nine VOCs.	10 important VOCs were discussed in connection with their formation chemistry during roasting. The roasting degree was traced as a consistent path on the score plot of two most significant principle components.

(Franca, Mendonça, & Oliveira, 2005)	CHEMICAL COMPOSITION Arabica coffee samples previously classified by cup quality were observed for both green and roasted beans. Caffein, trigonelline and 5-caffeoyilquinic acid (5-CQA) concentrations were analyzed by high-performance liquid chromatography (HPLC). pH was measured with pH meter.	Higher protein level, may be due to high caffeine contents were found in good quality beans. No correlation between 5-CQA level and cup quality were found. Acidity levels decreased significantly after roasting and the lowest acidity level was found in good quality beans. Defective beans were detected using pH level and chemical composition in green and roasted beans.
(Farah *et al*., 2006)	CHEMICAL COMPOSITION HPLC was used to determine sucrose, caffeine, trigonelline and 5-CQA for five samples of Arabica coffee beans with different cup quality and a Robusta coffee bean.	Trigonelline levels were lower for green Robusta beans and quite similar to the levels in worst quality Arabica sample. There were no correlations between sucrose and beans quality. Higher caffeine contents were found in highest quality green beans. Lower quality green beans have higher 5-CQA level.
(Franca *et al*., 2009)	CHEMICAL COMPOSITION Volatile profiles of green and roasted coffee beans were observed using gas chromatograph. Coffee beans were roasted with two different processing temperature (i.e. high temperature-short time and low temperature-long time)	Different volatile profiles for different processing temperature were observed although weight loss and color of roasted coffee beans were similar.
(Ribeiro *et al*., 2009)	CHEMICAL COMPOSITION 58 Arabica samples from different origins were analyzed using gas chromatograph. The results were compared with those from sensory evaluation adopting five-point scale; assessing flavor, body, cleanliness and overall quality.	13 compounds found from gas chromatograph and discriminant analysis (PLS-DA) considered as possible markers for the overall differentiation of cup quality. Good agreement between regression models prediction and the sensory evaluation.

Methodology Comparison:

The studies in Table 1 above investigated the relationship between coffee beans physical properties and chemical composition with cup quality. All studies were done by experiment and most of the papers quantify the physical attributes of the beans after roasting, i.e. weight loss, density and moisture loss. Since the studies in Table 1 focus on the quality of roasted coffee, Arabica green beans of high quality were utilized; except for study by Farah *et al*. (2006) where Robusta coffee beans were also observed. Hernández *et al*. (2008) used a static roaster and attached a CCD (charge-coupled device) video camera to perform roasting experiments of eight Colombia Arabica coffee beans. Alessandrini *et al*. (2008) and Romani *et al*. (2012) conducted experiment of eight green coffee samples in a pilot plant roaster with a rotating drum; both authors proposed analytical models to predict roasting degree. Alessandrini *et al*. (2008) developed a correlation between NIR spectral data of 168 representative and suitable green and roasted coffee samples with each roasting variables (weight loss, density and moisture), based on PLS regression. While, Romani *et al*. (2012) utilized electronic nose and ANN models to predict the roasting variables including brightness and red index.

Different than the measurement methods used before, chromatography devices were used to measure the chemical composition of the volatiles in studies by Dutra *et al*. (2001), Franca, Mendonça, & Oliveira, *et al*. (2005), Franca *et al*. (2009) and (Farah *et al*., 2006). In the experiment by Dutra *et al*. (2001) single origin Arabica beans were roasted in a lab-scale stovetop popcorn popper. The gases evolved were condensed and analyzed with a gas chromatograph in 2 min interval. In the studies carried out by Franca, Mendonça, & Oliveira, *et al*. (2005) and Farah *et al*. (2006), HPLC was utilized to determine caffeine, trigonelline and 5-CQA levels in different quality of Arabica coffee samples (green and roasted). In addition, nitrogen and fat contents of the coffee samples were determined according to official AOAC procedures (AOAC, 1995) in the study by Franca, Mendonça, & Oliveira, *et al*. (2005). Convective oven was used (Franca, Mendonça, & Oliveira, *et al*., 2005; Franca *et al*., 2009), while electric lab scale roaster was utilized by Farah *et al*. (2006). In the later study by Franca *et al*. (2009), various roasting conditions were applied to analyze the volatiles profile using gas chromatograph.

Study Results Comparison:
Physical Properties:

The results from the compared studies above have shown that the physical properties and chemical composition of the roasted beans varied significantly in different roasting profiles. It was observed that the volume of the roasted beans increased between 15% to 70% in air temperature between 190°C and 300°C (Hernández *et al*., 2008). Dutra *et al*. (2001) determined a 120% increase in volume after roasting for 12 min at an air temperature of 275°C; and mentioned that the increase in the volume was caused by: water vaporization, the release of carbon dioxide, and the release of volatile components from beans. Coffee beans were also subjected to a gradual weight loss; 18% after roasting 19 min at 200°C in a pilot plant roaster with a rotating drum (Romani *et al*., 2012) and an average of 19% weight loss were found after roasting 120 min at 200°C in an oven (Franca *et al*., 2009). While Dutra *et al*. (2001) found a significant decrease of 45% in weight loss (roasting time and temperature: 12 min 275°C) and the weight loss curve presents a behavior similar to Franca *et al*. (2009) for oven temperature of 300°C.

The average moisture content of green beans was 12.5% (measured in 100 beans samples) and decreases with roasting time, reaching to a minimum of 0.72% in 12 min of roasting at 275°C (Dutra *et al*., 2001). Meanwhile, Franca, Mendonça, & Oliveira, *et al*. (2005) found the average of 9g/100g moisture content in green coffee samples (which was within the range reported in the literature by Clarke (1985); 8.5-13g/100g). The moisture content then decreased to an average of 1.5g/100g after roasting. In the study by Farah *et al*. (2006), the degree of luminosity of green Arabica samples increased significantly as their quality decreased. These results were also found in literature by Franca, Mendonça, & Oliveira, *et al*. (2005), which determined that both black and sour defective beans presented lower luminosity and color saturation values in comparison to non-defective ones.

Chemical Composition:

Dutra *et al*. (2001) observed that the average pH level of the condensed gas varied with roasting time, where it increased up to 3 min before slowly decreased to minimum pH at 9 min and then increased again. This corroborates the fact that close to optimum roast the pH of the condensed gas would reach a minimum. It was also reported that the significant increase of the peak numbers detected for the roasting period of 6 to 8 min. Intensive research works by Dorfner *et al*. (2004) concluded that 10 important coffee volatile compounds were produced during roasting process which includes 4-Vinylguaiacol, Indol, Guaiacol, Furfural, Phenol, Phenylacetaldehyde, Methanethiol, Pyridine, 2-Methylfuran and Furfuryalcohol.

Franca, Mendonça, & Oliveira, *et al*. (2005) and Farah *et al*. (2006) detected that in higher quality green Arabica coffee beans, the levels of caffeine, trigonelline, protein and pH were higher while the levels of 5-CQA and acidity were lower. This can be good precursor's selection criteria for quality green coffee beans. It was also noted that the roasted coffee beans chromatograph profiles showed no distinct variation between any sample qualities. Other work by Franca *et al*. (2009) presented different behavior of volatile profiles of coffee under two different processing temperatures which concluded that: the color and weight loss measurement alone were not reliable as roasting degree assessment criteria, and the roasting temperature must also be taken into account.

Ribeiro *et al*. (2009) reported that when compounds 3-methypropanal, 2-methylfuran, furfural, furfuryl formate, 5-methyl-2-furancarboxaldehyde and 4-ethylguaiacol appear in higher amounts, the overall quality of the roasted Arabica coffee increased. On the other hand, when compounds such as 3-methylthiophen, 2-furanmethanolacetate, 2-ethyl-3, 6-dimethylpyrazine and 1-(2-furanyl)-2-butanone were more abundant, the overall quality of the product drops. This indicated that certain precursors such as protein and trigonelline might be important to the high level production of high quality coffee compounds.

Regression Model Prediction:

Alessandrini *et al*. (2008) built various PLS regression models correlating NIR spectral data. Different roasting degrees such as weight loss, density and moisture were predicted with high accuracy, resulting in high correlation. Romani *et al*. (2012) used EN sensor response values for the prediction studies by means of ANN methods with MLP and GRNN neural network types. Prediction of density, weight loss, moisture and color can be fairly predicted. High correlation between predicted PLS regression models using chromatograph profiles with the cuppers' sensory attributes were developed by Ribeiro *et al*. (2009).

4. Future Research on Coffee Roasting:

Based on this review, there are many studies done to investigate the chemical composition that contributes to the desired taste and aroma of quality roasted beans. The studies on determination of physical changes to evaluate roasting degree are seen in some of the literatures (Alessandrini *et al*., 2008; Hernández *et al*., 2008; Romani *et al*., 2012). These studies explains the changes that takes place when green beans undergoes roasting process and proposed analytical models to predict the roasting degrees, which provides good agreement with the experimental results. However, results based on the chemical composition of the roasted beans by Franca *et al*. (2009) indicate that color and weight loss measurements alone are not reliable for roasting degree assessment criteria. This is because, beans roast at different roasting condition, thus resulting in different volatile profile and quality may have similar physical appearances.

In order to control the product quality and optimize on-line processes, practical, faster and simpler method of assessing coffee roasting degree is important. This method must be capable of being easily implemented in coffee roasting analysis to supply real-time measurements. Hernandez *et al*. (2008), proposes a method to determine brightness using image analysis in real-time during coffee roasting to measure product quality. However, as mentioned earlier the use of physical properties alone is not suitable for evaluation of coffee roasting degree. Therefore, future research must focus on determining the chemical composition that comprises a good quality roasted beans. In a recent study by Gloess *et al*. (2014), it was found that coffee samples from five different origin have different formation dynamic of VOCs. In addition, the time of VOC formation started during roasting differed for each of the coffee when roasting along the same time-temperature roasting profile. Therefore, in order to apply the on-line process control by laser mass spectrometry and PCA on the time-intensity traces of selected profile volatile compound as suggested by (Dorfner *et al*., 2004), a large database of VOCs formation dynamics must be established.

5. Conclusion:

This review has covered some of the recent researches on coffee roasting evaluation methods. In order to evaluate the roasting process, study on changes in physical and chemical composition during roasting must be widely addressed. Future studies should aim on building a database of VOCs formation dynamics and determining the compounds that are crucial in quality coffee roasting.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Universiti Malaysia Sarawak for providing the opportunity and support to conduct this research. This study is funded under Dana Pembudayaan Penyelidikan (RAGS), Ministry of Education Malaysia.

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