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 process. During 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 beans 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
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 (Alessandri 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>
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<th>Author</th>
<th>Methodology</th>
<th>Results</th>
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<td>Hernández et al., 2008</td>
<td>PHYSICAL PROPERTIES</td>
<td>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.</td>
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<td>Alessandri et al., 2008</td>
<td>PHYSICAL PROPERTIES</td>
<td>Different roasting degrees were predicted with high accuracy, leading to high correlation coefficient results between measured and predicted roasting variables.</td>
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<tr>
<td>Romani et al., 2012</td>
<td>PHYSICAL PROPERTIES</td>
<td>Physical properties and roasting time calculated by ANN models provided good agreement with experimental results.</td>
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<tr>
<td>Dutra et al., 2001</td>
<td>CHEMICAL COMPOSITION</td>
<td>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.</td>
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<td>Dorfner et al., 2004</td>
<td>CHEMICAL COMPOSITION</td>
<td>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.</td>
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<td>Methodology Comparison:</td>
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<td>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 quantified 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, &amp; 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, &amp; 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, &amp; Oliveira, et al. (2005). Convective oven was used (Franca, Mendonça, &amp; 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</td>
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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 Furfurylalcohol.

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:
Alessandri 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 (Alessandri 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.

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REFERENCES