1. INTRODUCTION

1.1. Background

The safety aspect of artificial food preservative had become a public concern for a long time. This concern arise as consequences from wide access of information that can inevitably leads to misleading perception. Combined with the lack of essential information, this may cause suspicion and misunderstanding toward the safety of artificial food preservative (i.e., benzoate and sulphite). Starting from this concern, a demand of replacement to natural compounds has become an urgent necessity of food industry. Therefore, the research on natural compounds with antibacterial properties had been conducted on different plants (Bearth, *et al*., 2014).

Caffeine is one of the bioactive compound that naturally available on raw coffee bean, together with phenolic acid and polysaccharides (Borrelli *et al.*, 2002). The high amount of bioactive compounds on raw coffee bean, especially phenolic acid, lead to a suggestion of raw coffee bean potential with antibacterial properties. However, Lou *et al* (2011) and Daglia *et al.* (1994) reported the absence of antibacterial activity on raw coffee bean and found a significant antibacterial properties on roasted coffee bean. This finding then leads to further analyzation of antibacterial components on roasted coffee, as well as the change in composition during the roasting process (Daglia *et al.*, 1998)

One of the change in composition is attributed to the Maillard reaction that produce various compounds, such as melanoidin. Most literature reports the significant amount of this compound on roasted coffee (25% of roasted coffee dry matter) (Borrelli *et al.*, 2002) together with the antibacterial properties. Melanoidin has been found to exert higher antibacterial activity than the rest of roasted coffee bioactive compounds. Rurian and Morales (2008) observed the antibacterial activity toward *Escherichia coli* by chelating the membrane stabilizer cation Mg^{2+}. The same authors also reported melanoidin activity toward other strains of bacteria (i.e., *Bacillus cereus, Staphylococcus aureus, Pseudomonas aeruginosa*) with both bacteriostatic and bactericidal activity (Rufián and Cueva, 2009).

In addition to melanoidin, other natural compounds of roasted coffee such as phenolic acid (i.e. chlorogenic acid, trigonelline, caffeic acid), caffeine and alfa dicarbonyl compounds are found with antibacterial properties. Several types of phenolic acid has been shown to inhibit the growth of different strains of *Enterobacteria* (Almeida *et al.*, 2006) together with the inhibition of trigonelline toward different type of oral bacteria (Silva *et al.*, 2014). Similarly, the antibacterial properties of caffeine have been demonstrated, especially toward the major oral bacteria, *Streptococcus mutans* (Antonio *et al.*, 2010) and several strain of *Enterobacteria* (Almeida *et al.*, 2006). However, Mueller *et al.* (2011) proposed the presence of hydrogen peroxide in roasted coffee as the only contributor of roasted coffee antibacterial properties. In line with this result, the author has stated the role of other bioactive compounds (i.e., chlorogenic acid, caffeine, melanoidin) as the indicator of roasting degree, despite of their antibacterial activity reported in many studies (Mueller *et al.*, 2011).

In view of existing different research and contradictive results, therefore a review is needed to present a critical overview on what has been published regarding this topic. There are reviews on coffee functional properties, either on the coffee bean or the by-products (Esquivel and Jiménez, 2012; Mussatto *et al.*, 2011). The review on specific bioactive compounds on roasted coffee has been studied as well, such as coffee phenolic compound (Farah and Donangelo, 2006) and coffee melanoidin (Moreira *et al.*, 2012). However, the review that summarize these antibacterial compounds on roasted coffee is not available yet. Therefore, the aim of this review is to compile and interpret numerous research on roasted coffee antibacterial compounds. Moreover, the overview in this paper may be able to fill the gap of information in several studies, as well as to provide a conclusion in several contradictive results.

1.2. Literature Review

Coffee is first introduced by the travellers toward Europe community at 1600 and have gained a massive popularity by its rich flavour and biological properties. The consumption of coffee started to reach the peak as the stimulatory effect of caffeine is reported and nowadays, coffee is the most consumed beverages after water. The high volume of trading is reported as well as coffee appear as the second ranking of the most traded item in the wold (after petroleum) (Farah and Santos, 2014)

Coffee as the part of *Rubiaceae* family are first grew at African forests by nature and continued into massive cultivation in tropical areas, starting from Indonesia, India, America continent and the island alongside the equator line. Between a wide range of species, *Coffea arabica* and *Coffea canephora* stand as the most cultivated variety for commercial purpose. Commercially, *C. Arabica* and *C. Canephora* are mentioned by the name Arabica and Robusta. While *C. Arabica* commercial term are mentioned similiary with the species name, the use of 'Robusta' toward *C. canephora* has been a little misleading as 'Robusta' is one of the subvariety of *C. canephora* so it mustn't use as a complete replacement for this species (Farah and Santos, 2014; Mussatto *et al*., 2011).

Differences between *C. arabica* and *C. canephora* regarding their characteristic or their optimal environment to grow are quite distinctive. Accordingly, *C. arabica* grow well at high elevation (600 – 2000 m) while *C. canephora* grow at lower elevation (below 600 m) with warmer temperatures. *C. arabica* that cover about 60% of total coffee consumption has been known as the superior one in flavour. On the other hand *C. canephora* has better resistance to diseases due to its difference in composition. *C. Canephora* have been reported to contains high amount of bioactive compound, such as phenolic acids and caffeine (Farah and Santos, 2014; Mussatto *et al*., 2011).

Normal raw (green) coffee beans contained a huge proportion of carbohydrates (59-61%), followed up by 10-16% lipids, 10% proteins, and 7-10% chlorogenic acid, 4% of minerals, 2% aliphatic acids, 1-2% caffeine, 1% trigonelline, and <1% amino acids (all on dry matter basis). The change in compostion by the process, basically causes reduction in nutrition toward carbohydrates (38-42%), proteins (8%,) and chlorogenic acids (3-4%). Other than lowering nutrition, the formation of Maillard reaction product can be found as well (Moreira et al., 2012).

Coffee bean processes consist of three major process: (1) harvesting, (2) bean separation and (3) roasting. Afterward, coffee bean mainly can be distributed, either as whole bean or grounded into powder. In harvesting, degree of maturation play as a critical point for product quality. The harvest of ripe coffee fruits known as coffee cherries must be at the exact mature phase, in which the presence of immature or overripe fruits lead to lower quality of product. There are two methods of harvesting, (1) manual; the use of hands to pick each of the fruits; (2) mechanical; the use of an apparatus to shake the tree. Considering the length of the time and high expense, manual harvesting tends to lead to better quality than mechanical harvesting. With the use of machines, the defect of coffee bean is highly inevitable, both for intrinsic and extrinsic defects that may give longer time for sorting and lowering the cup quality (Farah and Santos, 2014; Mussatto *et al.*, 2011).

The second process (separation) is mainly to separate the bean from its whole fruit and pericarp with additional sorting process to eliminate defect fruits and grading. Three methods had been available for this process, (1) dry method as the first method discovered; (2) wet method; (3) semi-dry. As the name, dry method required bean exposition toward dry air, such as sun exposure (1 to 2 weeks) or air dryers (unto 10 – 12% moisture content). The result bean are then separated from the dried pericarp, resulting in a clean dried beans commonly called as green coffee bean. This method is commonly used in country with low rainfall count and high sun exposure such as Africa and Brazil (Farah and Santos, 2014; Mussatto *et al.*, 2011).

Conversely, the wet method as the name refer, require a high use of water regarding to the soaking process. The bean will started at sorting process for ripe cherries, as this method only use ripe cherries for fermentation purpose. After sorting, ripe cherries are removed from the pulp and soaked into the water as a preparation toward fermentation process. The fermentation (natural or with the addition of microorgaisms) last for 12 – 36 hours to (1) eliminate pulp and silverskin (2) lower the pH to 4,5. This method is famous for generating a high quality product and commonly combined with manual harvesting to boost the quality even more. This method are commonly practiced in Asia and Central America (Farah and Santos, 2014; Mussatto *et al.*, 2011).

As an alternative method, semi-dry method have been developed with a combination of washing and depulping process from wet method with sortation of dry method. This three methods, as being mentioned before generate a different characteristic of product, both dry and semi-dry method will produce beans with the silver skin (mainly build of polysaccharides) attached that give more body and sweet taste (usually used for espresso). In the opposite, the wet method produces bean without the silverskin by their intense methods (Farah and Santos, 2014; Mussatto *et al*., 2011).

The third process (roasting) hold a crucial part towards the organoleptic properties and chemical composition. Within a certain amount of time, roasting of coffee bean will be conducted on high temperature. As it reaches the required degree, the bean must be cooled quickly to prevent further roasting that will lower bean quality. Afterward, the end products will be categorized in three categories based on their roasting degree; (1) light roasted; (2) medium roasted; (3) dark roasted. The process of categorizing is mainly based on the coffee bean colours. Aside from those three processes, the additional process such as decaffeination, may be conducted depending on the requirement of the end product (Farah and Santos, 2014; Mussatto *et al*., 2011).

For instant coffee, the processing steps are a bit different. Coffee bean must be grounded and thus goes into the extraction process by water under pressurized conditions to maintain the liquid phase of water. The water at 175ºC are then used to extract both solids and volatile compounds responsible for the coffee flavour. Removal of the water to gain concentrated content are then conducted, either by evaporation or freeze concentration and followed up by conversion into dried forms (spray or freeze drying method) (Farah and Santos, 2014; Mussatto *et al*., 2011).

In regard to the processing methods, the composition of roasted coffee bean is different for each industry and each roasting degree. The antibacterial activity of roasted coffee is therefore proposed to change according to the chemical composition of roasted coffee. Specific difference is observed in the antibacterial activity of dark roasted coffee bean and light/medium roasted coffee bean. According to Daglia *et al.* (1994), the antibacterial properties of dark roasted coffee bean is much stronger than the light/medium roasted coffee. Additionally, Antonio *et al.* (2010) reported the superiority of high molecular weight antibacterial compounds of roasted coffee toward the low and intermediate weight antibacterial compounds. Those compounds later are observed to generate by Maillard reaction during the roasting process (Borrelli *et al*., 2002).

The high molecular weight antibacterial compounds of roasted coffee is identified as melanoidin. This compounds had been reported in different studies related to the functional properties and its contribution to the antibacterial activity of roasted coffee (Moreira *et al*., 2012). On the other hand, several low molecular weight antibacterial compounds is observed to generate during Maillard reaction, such as alfa dicarbonyl compounds and 5-hydroxymethylfurfural (5-HMF) (Daglia et al., 2007; Daglia *et al.*, 1994). Furthermore, the remaining bioactive compounds after the roasting process is found, such as chlorogenic acid, trigonelline, caffeic acid and caffeine (Almeida *et al*., 2012; Moreira *et al.*, 2005).

Related on the availability of different bioactive compounds on roasted coffee, it is understandable that roasted coffee possess several functional properties. Various reviews have comprehensively summarize the functional properties, such as the psychoactive, neurological and psychology effect of drinking coffee (Dorea and Costa, 2005). Other author (Mussatto *et al.*, 2011) address several variation in production, composition and the application of coffee with its by-products. Additionally, review on the functional properties of coffee by-products has been published as well (Esquivel and Jiménez, 2012). Moreover, the review on specific bioactive compounds (i.e. melanoidin) has been done by Moreira *et al.* (2012). This review cover for its structure, formation mechanisms and the potential health impacts that include the review regarding its antibacterial properties (Moreira *et al*., 2012).

The antibacterial properties of roasted coffee antibacterial properties are only briefly discussed on those reviews. Dorea and Costa (2005) mentioned that the antibacterial activity of roasted coffee is exhibited by several type of phenolic acid. The antibacterial activity is specifically described as anti-adhesive properties that act against oral bacteria (anticariogenic). Furthermore, extensive review on coffee anticariogenic effects on coffee has been done by Antonio *et al.* (2011). Esquivel and Jimenez (2012) then added the potential activity of roasted coffee toward *Stapylococcus aureus* and several strain of *Enterobacteria*. At the last, the antimicrobial properties of coffee melanoidin is discussed in the review of Moreira *et al.* (2012) with the observed minimum inhibition concentration (MIC) ranged between 2 and 10 mg/mL for most strains (Moreira *et al.*, 2012).

1.3. Objectives

The objective of this study is to provide a critical overview on roasted coffee antibacterial compounds from a large number of research that has been done. This review will summarize the activity of roasted coffee antibacterial compounds on both gram positive and negative bacteria, together with the antibacterial mechanisms and their possible synergistic interaction toward each compounds.