Formation and development of flavour of cocoa (Theobroma cacao L.) cultivar Criollo and Forastero: a review

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Abstract. Cocoa (Theobroma cacao L.) tree grown in tropical places, particularly in Africa, Asia, and South America. Cocoa beans is a fundamental ingredient in chocolate manufacturing. There are four cultivars namely Criollo, Forastero, Trinitario, and Nacional, which are commercially grown worldwide. Criollo and Forastero are the most intense cultivar used for making cocoa-based products. The Criollo is known as “fine” flavour cocoa yet has the lowest production, while Forastero as “bulk” cocoa has the highest contribution to the cocoa market in the world. Criollo has the complexity of aromatic components that may enhance fruity, flowery, herbal, woody, nutty and caramel aroma, and thus creating unique pleasant flavours. Compared to Criollo, Forastero offers a basic or ordinary flavour despite its highest productivity. Flavour as a sensory attribute of chocolate had a great contribution to consumer acceptance and market demand. The distinctive flavour of the final cocoa/chocolate products are influenced by several factors from farm to bar such as the cocoa cultivars, post-harvest treatment and processing techniques. Those factors changes the internal quality of cocoa beans, most importantly the flavour precursors or chemical compounds important to cocoa flavour. The aim of this review is to provide information on the formation and development of cocoa flavour during processing.

1. Introduction

Cocoa beans are derived from mature fruits of the cocoa tree (Theobroma cacao L.). The cocoa fruits visually is a squash-like pod that grow proximal to the trunk and thicker branches of the cocoa tree [1,2]. A cocoa tree grown in tropical places particularly in West Africa, Southeast Asia, and South America. Therefore, cocoa play an essential role as an agricultural product in those areas as part of an export commodity [3]. Cocoa bean is a fundamental ingredient in chocolate manufacturing. The sensory quality of chocolate is influenced by many factors, such as cocoa cultivation, post-harvest treatment, and processing of chocolate [4]. In addition, understanding the characteristics of cocoa origin and improving processing technology leads to the desire for flavour development of cocoa products.

Based on genetic references of the cocoa tree (Theobroma cacao L.) more than 14000 varieties or cultivars were found [1]. However, there are four cultivars namely Criollo, Forastero, Trinitario, and
Nacional are commercially growing worldwide [5]. Furthermore, Criollo and Forastero are the most intense cultivar used for making cocoa-based products, due to the morphological of fruit, quality of the bean, distinctive flavour characteristics as well.

The Criollo is known as “fine” flavour cocoa has contributed around 5% of the cocoa market due to the lowest production, whereas the Forastero as “bulk” cocoa has the highest contribution reaching 90% of cocoa market in the world [6]. Initially, Criollo (Theobroma cacao L. ssp. cacao Cuat) has been planted in Central America and by the time grown around Venezuela, Madagascar, Sri Lanka, and Samoa. Criollo’s fruit has a morphological yellow or red color, large and rounded beans [2,7]. Criollo has the complexity of aromatic components that enhances fruity, flowery, herbal, woody, nutty and caramel flavours [8]. Compared to Criollo, Forastero (Theobroma cacao L. ssp. shaerocarpicum Cuat) has the highest productivity, yet it has a basic or ordinary flavour and suitable for cocoa mass, cocoa powder, cocoa butter, and milk/dark chocolate production [9,2]. Therefore, understanding the characteristics of cocoa cultivar may conduct desirable flavour and quality of cocoa products.

Flavour as sensory attributes of chocolate contributes to consumer acceptance and market demands. The distinctive flavour of cocoa beans followed by post-harvest treatment and processing techniques are crucial factors affecting the final flavour of cocoa products. Currently, around 54% of consumer preferences of chocolate flavours tend to choose nutty than fruity flavour [10]. Those chocolate flavour not just influenced by the cultivars but also the post-harvest treatments and manufacturing stages. The fermentation of cocoa beans is the initial step of post-harvest treatment being a crucial process for the formation of flavour precursors. Then, the chocolate flavour compounds developed during roasting and conching processes as part of the manufacturing stages [6,11].

Besides influenced by the cultivar, the origin or geographic location of cocoa also contribute to volatile compounds, thus affecting flavour profiles [12]. Furthermore, the formation of flavour precursors and flavour development of cocoa and chocolate is obtained by the initial step of post-harvest treatments, cocoa processing, and chocolate manufacturing [4]. The aim of this review is to provide information on the formation and development of cocoa flavor, mainly Criollo and Forastero cultivars, during processing steps such as fermentation, drying, roasting, and conching.

2. Methods
In this paper, a systematic review was adopted as the main methodology to analyse the newest and updated literature. A systematic review is a structured and comprehensive approach for capturing and selecting relevant theoretical perspectives and practices in principal literature [17]. A literature survey has been accomplished of quantitative and qualitative empirical studies published in several leading international journals such as Journal of Food Engineering, Food Research International, Food Science and Food Safety, Food Science and Technology, Food Composition and Analysis, and other journals. Journal publications within the scoping review have been established and extracted through the employment of an aggregator database including Scopus, and within the publisher database including Elsevier, Taylor & Francis, and Springer. The paper is discovered using keywords such as “cocoa bean”, “chocolate flavour”, “volatile compounds”, “chocolate processing”, “single-origin cocoa”, “cocoa flavour”, and “cocoa bean processing”. The publication were analysed for the period between 2008 and 2020. As a result, after screening and reading through the article contents, only 45 articles were acknowledged as final samples for further review and analysis.

3. Results and Discussion

3.1. Fermentation
The cocoa cultivar, harvesting technique and post-harvest treatment provide a significant role in flavour development [4]. Fermentation is an initial step of post-harvest treatments. It is a crucial stage of processing cocoa beans that determines the formation of flavour precursors, reducing bitterness and astringency level, and color development of cocoa beans [13]. The outcome of fermentation is influenced by pulp compositions since it is utilized by yeast and bacteria to develop flavour precursors
The Forastero bean has a longer fermentation time up to 5 to 6 days than Criollo beans which only 1 to 3 days [3].

In general, the fermentation process takes place in the first 24 to 36 h after harvesting and opening pods. The fermentation process is divided into 2 phases. The first phase is an anaerobic condition, when the yeasts, bacteria, as well as filamentous fungi, start to ferment the beans and pulp. In this phase, yeasts are dominated by the fermentation process. The number of yeast is Saccharomyces cerevisiae, Kluyveromyces marxianus, Saccharomyces exiguous, Candida castellii, Candida saitoana, Candida guilliermondii, Schizosaccharomyces ombe, Pichia farinose, and Torulopsis spp. [15]. The yeasts are able to catalyze sucrose, glucose and fructose of the acidic pulp (pH below 4) and generate the ethanol as a fermentation product [3]. The yeast helps pectin degradation that favors aeration [16].

The second phase is an aerobic condition, starts after 48 to 96 h and dominated by lactic acid bacteria since the yeast activity is inhibited by aeration, followed by alcohol concentration and increased pH causing the growth of lactic acid bacteria. Before this phase is ended, lactic acid bacteria are replaced by acetic acid bacteria. Some acetic acid bacteria found in this fermentation are Acetobacter lovaniensis, Acetobacter rancens, Acetobacter xylinum, Gluconobacter oxydans, Lb. fermentum, Lb. plantarum, Leuconostoc mesenteroides, and Lactococcus (Streptococcus) lactis [15]. The domination of acetic acid bacteria creates an acidic condition which increases cocoa mass that causing diffusion and hydrolysis of proteins in the cotyledons. Acetic acid bacteria have a significant role in the formation of flavour precursors [3,5]. In the first phase, some chemical compounds have been changed such as sucrose has partially hydrolyzed to reducing sugars, changed of protein to peptides and amino acids, and some polyphenols were hydrolyzed and oxidized. Then, the second phase is more about the sensory attribute which is the reduction of astringency level caused by the oxidation of protein-polyphenol complexes and condensation of carbonyl-amino [13].

The method and duration of cocoa bean fermentation are the main variables to determine flavour precursors. The breakdown of sugars from the pulp of cocoa beans after 72 h resulting in an increasing level of some organic acids, such as propanoic acid, 2-methylpropanoic acid, 3-methylbutanoic acid and acetic acid [18,19]. Those organic acids are responsible for odor-active compounds in cocoa [18]. In addition, some derivate of amino acids are produced during fermentation, including 3-methylbutanol, phenylacetaldehyde, 2-methyl-3-(methyldithio) furan, 2-ethyl-3,5-dimethyl- and 2,3-diethyl-5-methylpyrazine [20,21]. The appropriate method (box or heap) and duration during fermentation lead to the optimal formation of flavour precursors.

The duration of fermentation has consequences on pH and temperature, then affecting some inactivation of enzymatic processes such as inactivation of aminopeptidase, invertase, and polyphenoloxidase, partially inactivate of carboxypeptidase, while endoprotease and glycosidases remain active. If the fermentation continuous too long and the pH value becomes too acidic, thus some of those enzymes will be inactivated and the flavour precursors are decreased [22]. The unfermented cocoa bean has a little development of cocoa and chocolate flavour, while over-fermented cocoa beans are related with increasing pH value, hammy and putrid flavours, and the bean is darkening or blackening [13,21,23]. Therefore, an optimal duration of fermentation is 6 days considered to the production of flavour precursors effectively [5].

3.2. Drying
Following the fermentation process is the drying process. Drying of cocoa beans is reducing the moisture content from about 60% to 7% [24] to prevent over-fermentation, bean damage [13] and mould infestation during storage [25]. This phase allows to improve flavour development since some chemical changes initiated during fermentation still continue. Those chemical changes during the drying process also responsible for sensory attributes such as reducing acidity, bitterness, astringency, as well as the characteristic of flavour and brown colour development [13,26]. When the drying process occurs slowly, it affects poorer colour cocoa beans and allows some volatile acids decreased resulting in low acidity [27,28,29]. If the beans are quickly dried it causes shell hardening and preventing loss of acetic acid, thus increasing the acidity of the beans [30].
The polyphenol oxidase actively catalysing polyphenol oxidizing reactions, enhancing new flavour components and inducing brown colour formation by losing membrane integrity. It also reduces bitterness and astringency level, as well as develops the chocolate brown colour of well-fermented beans [6]. Generally, there are four changes during the drying process. First, the formation of volatiles by the reaction of non-enzymatic browning affecting on decreasing of reducing sugars. Second, during the first of drying, the decreasing of non-reducing sugars indicate that fermentation still continue. Third, the hydrolysis process of bean proteins leads to a decreasing in protein concentration; and fourth, the existence of lipase in cocoa beans also increasing free fatty acids [21].

Drying methods give different results of chocolate flavour. Sun-drying method gives a strong chocolate flavour [13]. In contrast, artificial drying can generate off-flavours, such as smoky, hammy, rubber, or gasoline notes [31]. Good quality of cocoa beans produced from well-dried beans, visually has a brown colour, low astringency and bitterness, and also has no off-flavours. If the bean has incomplete drying, it will produce off-flavours (hammy) and a high concentration of carbonyl compounds [13].

3.3. Roasting
Roasting is an initial step of industrial chocolate processing. It is an important step for further development of chocolate flavour from flavour precursors formed during fermentation and drying [32,33]. The combination of roasting time and temperature determine the chocolate flavour [34]. The range of time and temperature starts from 5 to 120 minutes and 120-150 °C [32]. The suggestion of suitable conditions for roasting has an impact on sensory acceptance. Roasting time is 30 minutes for whole bean, 12 minutes for nibs, and 2 minutes for liquor, followed by the temperature at 120-140 °C [35].

The roasting process causing some reduction of sourness and bitterness of the cocoa beans due to the evaporation of volatile acids. Applying high temperature can reduce some volatile acids with low boiling point such as acetic acid, while the oxalic, citric, tartaric, succinic and lactic acids which are less volatile are remained unchanged [13,36]. The acetic acid as an undesired volatile is eliminated and the moisture content is reduced to 1% to 2% [5]. The reduction of astringency is affected by the interaction between polyphenols and proteins during roasting [37]. The Maillard reaction has a significant role in flavour development during roasting. Flavour precursors that are produced during fermentation and drying such as free amino acids, oligopeptides, and reducing sugars are participated in non-enzymatic Maillard reaction and Strecker degradation [1]. This reaction generates some desirable flavour compounds such as pyrazines, alcohols, esters, aldehydes, ketones, furans, thiazole, pyrones, acids, imines, amines, oxazoles, pyrroles and ethers [38]. The Criollo bean has the most abundant of pyrazines as flavour compounds [39].

High temperature and low moisture content are the optimal conditions for the Maillard reaction during roasting. The carbonyl groups of glucose and fructose from Maillard reaction react with free amino acids [40]. This reaction explained some routes. First, obtaining Schiff bases such as glucosyl amines and fructosyl amines then undergo further tautomerization to 1,2 enamiols and the arrangement to Amadori compounds (1-amino-1-deoxy-2-ketoses). Then, these amino acids these amino compounds are broken down to 3-deoxyhexuloses that subsequently lose water allowing hydroxymethylfurfural and other furfural products. Those processes are conducted under acidic conditions. Besides, Strecker degradation leads to the formation of some volatile compounds such as aldehydes, pyrazines, and other compounds which contribute to the aroma [41].

3.4. Conching
Conching is a process to develop the final flavour and improve the texture of chocolate [42,1]. The process reduces the concentration of free acids and other volatile by-products of cocoa beans [36,5]. Conching is the last manufacturer process related to flavour development. Hence, become the last opportunity to obtain the desired flavour of cocoa products [35]. According to the process, it cannot rework the previous errors during bean to chocolate processing or post-harvesting. The step starts with
processing the chocolate flake and crumb into fluid phase. The applied temperature is depend on the chocolate formulation and desired flavour [4]. The combination between time and temperature determines chocolate flavour. Each chocolate product has different recommendation for conching temperatures. For instance, milk chocolate suggested below 50 °C to avoid Maillard reaction [4], while dark chocolate suggested 70 °C or up to 82 °C [13]. Therefore, conching is an important role in flavour development by eliminating undesirable volatile compounds in chocolate manufacturing process.

4. Flavour Compounds Based on Cocoa Genotype
Two cocoa cultivars are intensely used for chocolate production. They are categorized as fine cocoa for Criollo cultivar, while Forastero cultivar as bulk cocoa. Differences in flavour between Criollo and Forastero are determined by the type and amount of proteins, carbohydrates, polyphenols, and the activity of the enzymes within the seeds. Besides, the chemical composition and the production of flavour precursors are initiated during the fermentation process [43]. The precursors are transformed during roasting the beans into flavour compounds that establish the sensory profiles such as flowery, green, chocolate, caramel, nutty, and fruity notes [44].

According to the cultivars mentioned above, Forastero is generally used for the production of cocoa paste, powder, cocoa butter, also dark and white chocolate [45]. This cultivar has lower aromatic potential, thus, has a lower quality compared to Criollo cultivar. Forastero also needs a longer fermentation time in order to generate the flavour precursors [33]. The difference from Forastero, Criollo becomes fine products since it has excellent flavours quality achieved by shorter fermentation time. The Criollo has soft and highly aromatic flavours with floral, fruity, nutty, tea, caramel, and molasses notes.

The aromatic richness in Criollo may be due to the high concentration of flavour precursors (non-volatile compounds) such as amino acids, peptides, and reducing sugars before roasting. Besides, Criollo has lower concentrations of polyphenols (procyanidins) causing astringency and bitterness in chocolate [45]. The Criollo cultivar has higher pyrazines than others [13,5]. Estimated 80 pyrazines contributed to the overall cocoa flavour [13]. Therefore, pyrazines become the most abundant volatile compound which is contributed to desirable cocoa and chocolate flavour.

5. Conclusions
Flavour formation and development in chocolate is unique and complex. Chocolate flavours can be influenced by multiple factors including cocoa cultivars, post-harvest treatments, cocoa bean processing, and chocolate manufacturing. Fermentation is an initial key process where the important flavour precursors formed, and thus producing a distinct and pleasant aroma and flavour of cocoa products. The Criollo cultivar has an excellent flavours as compared to Forastero potentially due to higher concentration of important precursors such as amino acids and reducing sugars. The composition of non-volatile and volatile compounds produced by cocoa and chocolate processing contribute significantly to the aroma. Since aroma and flavours cannot be corrected in the final process of chocolate manufacturing, thus, monitoring and process control are required from the early stage (from bean to bar). Besides, the improvement of chocolate flavours is required to fulfil consumer demands related to sensory quality, health benefits, and sustainability.

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