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Review

Factors influencing quality variation in cocoa (*Theobroma cacao*) bean flavour profile — A review

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ABSTRACT

This review examined the factors that influence flavour volatiles of cocoa beans and the volume of work that needs to be done on these factors and their impact on the flavour volatiles of commercial cocoa beans. Cocoa bean flavour is one of the most important quality attributes as flavour is central to acceptability of cocoa beans and cocoa products such as chocolate. The complex composition of cocoa bean flavour depends on bean genotype, postharvest treatments such as pulp pre-conditioning, fermentation and drying, industrial processes such as roasting as well as the type of soil and age of cocoa tree. The bean genotype determines the chemical composition of the bean, specifically the contents of bean storage proteins, polysaccharides, and polyphenols. This determines the quantities and type of precursors formed during fermentation and drying processes leading to flavour formation, hence, influencing both flavour type and intensity. Cocoa bean fermentation and drying result in the breakdown of the storage proteins by endogenous proteases into amino acids and short chain oligopeptides while the polysaccharides are also degraded by invertase to glucose and fructose. The amino acids, oligopeptides, glucose and fructose react with each other during the roasting process to produce the typical cocoa flavour volatiles. Polyphenols are also oxidized by polyphenol oxidase during fermentation and drying which reduce the astringency and bitterness of the beans, thus, enhancing the flavour of cocoa beans. However, the extent to which other factors such as age of the cocoa tree and soil chemical compositions influence the formation of flavour precursors and their relationships with final flavour quality remains unclear. With increasing demand for sustainable production of high quality cocoa beans, greater understanding of factors contributing to the variations in flavour character would have significant commercial implications.

Contents

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1. Introduction

Cocoa (*Theobroma cacao* L.) is a cash crop of huge economic significance in the world and the key raw material for chocolate manufacturing (Krähmer et al., 2015; Ho, Zhao, & Fleet, 2015). It forms the major agricultural export commodity for several producing countries in West and Central Africa, such as Cote d'Ivoire, Ghana, Nigeria and Cameroon (Afoakwa, Quao, Takrama, Budu, & Saalia, 2011a). Cocoa belongs to the family of Sterculiaceae and the genus *Theobroma* (Prabhakaran Nair, 2010). The genus has twenty-two species of which *T. cacao* L. is commercially the most important due to the value of its seeds (Bartley, 2005; CacaoNet, 2012). The seeds, commonly known as cocoa beans, are obtained from the pods. These pods are oval in shape, measure between 12 and 30 cm long, and contain 30 to 40 beans embedded in a mucilaginous pulp, which comprises approximately 40% of the bean fresh weight (Schwan & Wheals, 2004; Lima, Almeida, Rob Nout, & Zwietering, 2011). The pulp is reported to be rich in fermentable sugars of about 9 to 13% w/w (Lima et al., 2011) such as glucose, fructose and sucrose (Lefeber, Janssens, Camu, & De Vuyst, 2010), high acidity (pH 3.0–3.5) conferred by the presence of diverse organic acids, but mainly citric acid (Guehi, Zahouli, Ban-Koffi, Fae, & Nemlin, 2010), and a protein content in the range of 0.4 to 0.6% w/w (Lima et al., 2011).

Cocoa is cultivated on lands covering over 70,000 km^2 worldwide (Kim, Lee, & Lee, 2011) between 20° north and south of the equator, in areas with suitable environment for cocoa (Fowler, 1999). About 70% of the world's cocoa production takes place in the equatorial region of West Africa, and the rest in the equatorial regions of Central and South America, the West Indies, and tropical areas of Asia (Dillinger et al., 2000). The cocoa tree is a perennial tree, 8 to 15 m in height (Fowler, 1999) and requires hot, moist conditions to grow and will not withstand prolonged drought conditions without seriously depressing the tree's vegetative and reproductive functions (CacaoNet, 2012). The fruit varies among varieties in size, shape, external colour, and appearance. These characters have often been used in classifying cocoa.

According to the World Cocoa Foundation (WCF), there are 5–6 million farmers in developing countries across tropical Africa, Asia and Latin America who produce around 90% of cocoa worldwide, and the number of people who depend upon cocoa for their livelihoods worldwide is 40–50 million (World Cocoa Foundation, 2010). In West and Central Africa, cocoa continues to be an important source of export earnings contributing significantly to the Gross Domestic Product (GDP) of these producing countries. Cocoa exports generate over $8 billion for the region's national economies (IFDC, 2014) and support about two million smallholder farm households in West and Central Africa. In Ghana, the industry employs about 70% of the national agricultural labour force in the country (COCOBOD, 2013). For these farmers, cocoa contributes about 70–100% of their annual household incomes (Anang, Mensah, & Asamoah, 2013; Nunoo, Frimpong, & Frimpong, 2014). Apart from the economic importance of cocoa, consumption of chocolate and other cocoa products is reported to contribute positively to health (Wollgast & Anklam, 2000; Afoakwa, 2010; Andújar, Recio, Giner, & Ríos, 2012). Polyphenols in cocoa beans have been reported to exhibit anti-carcinogenic (Rodríguez-Ramiro, Ramos, López-Oliva, et al., 2011; Oleaga et al., 2012), anti-atherogenic (Wollgast & Anklam, 2000) and vasodilatory (Gómez-Juaristi et al., 2011; Khawaja, Gaziano, & Djoussé, 2011) effects and they exert them mainly as antioxidants (Schinella, Mosca, Cienfuegos-Jovellanos, et al., 2010; Martorell, Forment, de Llanos, et al., 2011).

Annual global cocoa production is reported to be more than 4 million tons per season (4.4 million tons in 2013/2014 crop season) (ICCO, 2015a). However, while global demand for sustainable cocoa is growing annually by 2 to 3%, and West Africa still contributes about 70% of the global supply, this region is confronted with a 2% annual decline in production (IDH Sustainable Trade Initiative, 2015). There is low cocoa productivity in West Africa due to poor farm management practices, planting low-yield varieties, pests and diseases, ageing cocoa trees and loss of soil fertility due to inadequate or no use of fertilizers (Abekoe, Obeng-Ofori, & Egyir, 2002; Baah & Anchirinah, 2011; Akrofi, Amoako-Atta, Assuah, & Asare, 2015). The economic and health benefits of cocoa depend on the sustainable production and intensification of high quality cocoa beans. Also, sustaining the production of high quality cocoa beans in West Africa is crucial for the millions of smallholder family farmers that depend on cocoa for their livelihoods and the millions of people who enjoy chocolate and other cocoa products around the world. In promoting sustainability, the cocoa industry wants to see growth and improvement in the quantity and quality of the cocoa beans produced as well as the standard of living enjoyed by growers.

Sustainable cocoa production also involves the production of high quality cocoa beans. Cocoa bean quality is made up of several components such as flavour volatiles, nutritional composition, polyphenolic content and fermentative quality. The most important components are the flavour volatiles of the beans as these affect cocoa bean acceptability (Owusu, 2010; Magi, Bono, & Di Carro, 2012; Krähmer et al., 2015). These compounds which constitute the flavour quality of the beans are, however, influenced by several factors. This review discussed the factors that influence cocoa bean flavour quality. The current state of knowledge in terms of research findings of these factors on the flavour volatiles of cocoa beans is presented. Research gaps in terms of the volume of work that needs to be done on these factors and their impact on the flavour volatiles of commercial cocoa beans are also exposed.

2. Factors affecting flavour quality of cocoa beans

Several indicators are used to measure the quality of cocoa beans. These include the bean size and count, bean colour and acidity of the beans. However, the most important quality indicator of cocoa beans is the amount and type of volatile flavour compounds (Magi et al., 2012; Krähmer et al., 2015). Flavour is central to acceptability of cocoa beans and cocoa products such as chocolate (Afoakwa, Paterson, Fowler, & Ryan, 2008) and, consequently, contributes to determining the quality (Owusu, 2010). The characteristic flavours of cocoa beans are due to a very rich volatile fraction composed of a mixture of hundreds of compounds (Magi et al., 2012). Currently, more than 600 flavour compounds have been identified from cocoa beans and cocoa products (Crafack et al., 2014). These compounds comprise of nitrogen and oxygen heterocyclic compounds, aldehydes and ketones, esters, alcohols, hydrocarbons, nitriles and sulphides, pyrazines, ethers, furans, thiazoles, pyrones, acids, phenols, imines, amines, oxazoles, and pyrroles (Hoskin & Dimick, 1984; Schnermann & Schieberle, 1997; Jinap, Wan Rosli, Russly, & Nurdin, 1998; Counet, Callemien, Ouwerx, & Collin, 2002; Taylor, 2002; Granvogl, Bugan, & Schieberle, 2006; Reineccius, 2006; Frauendorfer & Schieberle, 2008; Afoakwa et al., 2008; Ziegleder, 2009).

Most of these compounds possess particular flavour characteristics. Thus, while most esters confer a fruity/flowery attribute to flavour, pyrazines usually give earthy/roasted flavour (Owusu, 2010). Flavour compounds in cocoa beans are formed during roasting from flavour precursors generated during the fermentation and drying process. Flavour compounds in cocoa beans are thus influenced by factors such as type of cocoa (genotype), bean composition, soil type, age of cocoa tree, postharvest treatments such as pulp pre-conditioning, fermentation and drying, industrial processes such as roasting as well as storage and transportation (Afoakwa et al., 2008; Afoakwa, 2010; Owusu, Petersen, & Heimdal, 2011; Crafack et al., 2014).

2.1. Effect of genotype and origin of cocoa tree on cocoa bean flavour quality

Flavour quality of cocoa beans depends on the genotype and origin of the cocoa tree that has produced the beans. Cocoa beans from different genotypes and origin of cocoa tree have distinct flavour characteristics (Table 1). Currently, three broad cultivars of cocoa are commonly