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Review

Influence of genotype and environment on coffee quality

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ABSTRACT

Background: Coffee is one of the most valuable commodities exported worldwide. Greater understanding of the molecular basis of coffee quality is required to meet the increasing demands of consumers. Genotype and environment (G and E) have been shown to influence coffee quality. Analysis of coffee metabolism, the genes governing the accumulation of key components and the influence of environment on their expression during seed development supports the identification of the molecular determinants of coffee quality.
Scope and approach: The metabolism of important biochemical components of the coffee bean: caffeine, trigonelline, chlorogenic acids sucrose and lipids in coffee was reviewed. Analysis focused on how coffee metabolism was regulated by G and E throughout seed development and evaluation of transcriptome studies as an effective tool for use in understanding this system.
Key findings and conclusions: An overview of metabolism of the key components of coffee identified critical metabolic steps regulating the final concentration of metabolites that determine coffee quality. Coffee metabolism is influenced by both G and E and explains the higher quality of Arabica when compared to Robusta as well as the improvement of coffee quality by shade. Interaction of G and E (G × E) also contributes to quality. However, coffee metabolism is still not fully understood and there is scope for further studies to explain the contributions of G, E and G X E.

1. Introduction

Coffee is one of the most valuable commodities traded (Fridell, 2014; Osorio, 2002). Increasing awareness of quality, taste and health among consumers is increasing demand for high quality and speciality coffees (Ashihara & Crozier, 2001; Upadhyay & Mohan Rao, 2013). Assessment of coffee quality is usually focused on factors that influence utilization of the final product with consumer preferences being assessed in three primary ways: physical (e.g. bean size), sensorial (cup quality) and chemical analysis (key compounds attributed to quality) (Fridell, 2014) (see Table 1). However, coffee quality results from interaction among many different factors including genotype (G) and environment (E) (Muschler, 2001; Sunarharum, Williams, & Smyth, 2014). Consumers of high quality coffee may exercise preference for genotype with labelling of species (e.g. arabica) or environment of production (usually country).

Coffee quality varies in different genotypes. Arabica coffee, which contributes around 70% of the world coffee production (ICO 2013), is higher quality with lower caffeine and produces a more aromatic brew when compared to Robusta coffee (C. L Ky et al., 2001; Silvarolla, Mazzafera, & Fazuoli, 2004). Environment factors, such as shade and high altitude have been observed to improve coffee quality (Joët, Salmona, Laffargue, Descroix, & Dussert, 2010). Diversity of coffee quality due to G and E, result from influences on the biochemical components of the coffee bean accumulated during seed development (Joët et al., 2010).

To improve coffee quality, it is essential to understand coffee metabolism and the genes governing the accumulation of the molecular determinants of coffee flavor during bean development. Numerous studies have been conducted in this field, especially in relation to biochemical constituents such as caffeine, trigonelline, chlorogenic acids (CGAs), sucrose and lipids, considered to influence commercially important sensory traits. The metabolism of these compounds has been studied for decades. However, significant knowledge gaps still exist and more studies are required to more fully define G and E influences on coffee quality.

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Table 1
Key components in coffee and changes after roasting.

Component	Flavour attribute	Influence of roasting
Caffeine	Perceived strength, body and bitterness	stable (Oestreich-Janzen, 2010)
Trigonelline	Overall aromatic perception, bitterness	60–90% degraded (Clarke & Macrae, 1985)
Chlorogenic acids	Acidity, astringency and bitterness	59.7–98% degraded (Trugo & Macrae, 1984)
Sucrose	Flavour precursor	disappear (Grosch, 2001, pp. 68–89)
Lipids	Flavour carriers, texture and mouthfeel	stable (Oestreich-Janzen, 2010)

2. Overview of coffee quality traits influenced by genotype and environment

2.1. Physical attributes

2.1.1. Bean size

Price is related to bean size and small beans of the same variety bring lower prices; However, larger beans do not necessarily taste better; Ideally, roasting should be processed with uniform beans (Wintgens, 2012). When roasting with uneven beans, the smallest tend to burn or over roasted while the largest tend to be under-roasted, which affects both the visual appearance of coffee beans and cup quality (Barel & Jacquet, 1994; Muschler, 2001). Arabica coffee beans are larger than Robusta coffee beans, ranging between 18-22 g and 12–15 g per 100 beans respectively (Wintgens, 2012). Bean size also changes with different environments (Dessalegn, Labuschagne, Osthoff, & Herselman, 2008; Muschler, 2001). As a positive factor, shade increases and unifies bean size by reducing the solar radiance in the coffee canopy and results in a lower air temperature and slowing down of coffee maturation. In addition, as floral initiation is light dependent, fewer flowers developed under lower solar radiance resulting in lower fruit productivity. Both these factors enable more bean filling due to longer assimilation into fewer beans (Michael N Clifford, 2012; Muschler, 2001; Vaast, Bertrand, Perriot, Guyot, & Genard, 2006). Interestingly, even when grown in the same shade environment provided by shade trees, the adaption to shade varies in different genotypes, for example, a relatively greater increase in bean size was found in *C.arabica var. Catimor* than in *C. arabica var. Caturra* (29% and 20% increase in large bean size, respectively). This suggests that Catimor may prefer or be more adapted to shade than Caturra (Muschler, 2001). This interaction is a genotype by environment interaction (G × E) which is common in many plants (Des Marais, Hernandez, & Juenger, 2013).

2.1.2. Bean colour

The colour of green beans is a sign of freshness, moisture content, the level of defective beans and homogeneity (Mendonça, Franca, & Oliveira, 2009). The green-bluish colour of washed Arabica beans is preferred relative to the browner beans of Robusta (Wintgens, 2012). Bean colour changes with different environments, for example, coffee grown at high altitude is often greenly-blue and if grown in soil lacking zinc, coffee beans may become light-grey in colour (Wintgens, 2012).

2.1.3. Sensory evaluation

Flavour, namely cup quality, is the primary standard in worldwide coffee trade (A Farah, Monteiro, Calado, Franca, & Trugo, 2006). Having an even bean size and good appearance without defective beans does not always result in good coffee flavour (Wintgens, 2012). For this reason, it is important to judge the flavour quality in relation to the final utilization, such as roasted, liquid canned coffee, etc. Cup quality analysis aims to evaluate coffee flavour with a group of trained people in an objective and reproducible way to create a profile using established terminology, such as aroma, flavour, body and acidity, which has been established by the International Coffee Organization (ICO).

Coffee flavour is very sensitive to G and E changes. Acidity, for example, ranges dramatically in different washed Arabica, while Robusta has been described as low or no acidity at all with coarse liquor, harsh and cereal notes and thick body (Van der Vossen & Walyaro, 1981). Ultimately, Arabica coffee is sold as blends with varying proportions of Robusta coffee, but Robusta coffees are seldom used alone (Wintgens, 2012). The same genotype planted in different environment may vary greatly in quality. For example, increasing positive attributes (appearance and preference) together with decreasing negative attributes (bitterness and astringency) was found in shade grown coffee (see Table 2) (Geromel et al., 2008; Muschler, 2001; Vaast et al., 2006). This improvement may come from a balance of filled and uniform ripening coffee berries from the shade. A positive interaction of genotype and a particular environment results in premium coffee. Similarly to bean size, Catimor flavour was found to be improved more by shade than Caturra flavour, which further suggests that Catimor is more adapted to shade (Ashihara & Crozier, 2001). Another factor positively influencing quality is high altitude, which was shown to increase beverage quality of coffee (Avelino et al., 2005). Genotypes, such as Blue Mountain, SL-28, Pluma Hidalgo are famous worldwide due to their premium flavour, however, if grown in places other than their preferred environments do not always have a good flavour (Jean, Jacques, Alejandra, & Christophe, 2006). Nevertheless, little is known about how G and E combinations generate high quality coffee.

2.1.4. Chemical attributes

The chemistry of coffee quality is highly complex with a wide range of compounds that change during fruit development. A few key components, such as caffeine, trigonelline, lipids, sucrose and chlorogenic acids (CGAs), are regarded as significant in influencing coffee quality. These components either stay stable and act as flavour attributes reaching the coffee brew or are degraded during roasting accounting for flavour precursors (see Table 1) (Wintgens, 2012).

2.1.5. Caffeine

Caffeine is one of the most important bitterness attributes contributing to coffee quality. When caffeine is consumed moderately by humans, increased energy availability, alertness and concentration, decreased fatigue and boosted physical performance have been reported, however, too much caffeine may result in undesired effects such as cardiovascular disease, depression, and even addiction (Jiang, Ding, Jiang, Li, & Mo, 2014). Nowadays, caffeine is the world's most famous behaviourally active drug and is consumed primarily from coffee (Davis, Govaerts, Bridson, & Stoffelen, 2006; Oestreich-Janzen, 2010). The recent sequencing of *C. canephora* genome revealed that caffeine evolved separately in coffee and in other plants such as tea suggesting a biologically important role for caffeine (Denoeud et al., 2014).

Arabica coffee is popular for its lower caffeine content compared to Robusta, with 0.6–1.8% and 1.2–4.0% respectively (Bicho, Leitão, Ramalho, de Alvarenga, & Lidon, 2013b; Hečimović, Belščak-