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Coffee: Botany, Distribution, Diversity, Chemical Composition and Its Management

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***Abstract**: Coffee is an important commodity crop that plays vital role in socio-economy of more than 50 countries. Coffee belongs to the genus Coffea on the family Rubiaceae and it was believed to be originated from tropical Africa. Coffea species were grouped into four sections (Agrocoffea, Paracoffea, Mascarocoffea,Eucoffea). The two most important commercial species are Coffea arabica and Coffea canephora. All the species are diploid with 2n=2x=22 chromosomes except C arabica which is tatraploid with 2n=4x=44. Evaluation of the genetic diversity and available resources with the genus is an important step in coffee breeding. A variety of techniques like morphological, biochemical and genetic markers had been used to measure genetic variation of Coffea species. Coffea arabica has been found to have low polymorphic compared to other species. Coffee is prone to lot of diseases infestation. Two most prominent of them are coffee berry disease and coffee leaf rust which impaired photosynthesis, premature defoliation and reduced folia initiation. Coffee especially C arabica and C canephora are susceptible to insect pest. The most important insect pests are leaf miner and coffee stem borer. Caffeine is the most important chemical component of coffee beans and it varies in value (0.8% and 1.4% in Arabica coffee and 1.7% and 4.0% for canephora). Other components of coffee beans are cellulose, minerals, sugars, lipids, tannin and polyphenols. Coffee storage behavior is intermediate and low temperature is detrimental to the surviving of coffee seeds. Abscisic acid (ABA) induces dormancy and inhibit germination and seed priming is used to enhance uniformity of germination for better crop establishment. The effect of shade on coffee are higher in coffee bean weight, larger bean size, higher antioxidant activity with total phenolic content, and higher chlorogenic acid content.*

***Keywords**: coffee, diversity, chemical composition, shade, pest and diseases.*

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I. Introduction

Coffee is one of the most valuable commodity crops in the world trade. It contributes largely to the economy of more than 50 countries in Asia, Latin America and Africa (Dinesh *et al*., 2011). Coffee stands next to Petroleum in the international trade. In many producing countries, beside its tremendous contribution to the foreign exchange, it serves as a means of livelihood for millions of people and plays a vital role in their socio-economic values (Orozco Castillo *et al.*, 1994; Carneiro, 1999; Anthony *et al.*, 2001a; Stieger *et al.*, 2002).sIn India the area under Coffee cultivation is about 3,48,995 hectares of which arabica and robusta accounted for 48 and 52 percent respectively (Dinesh *et. al*., 2009).

The Federal Department of Agriculture (FDA), Nigeria reported the introduction of coffee into Nigeria as far back as 1920, the crop was introduced earlier, as shown by export figures of 5.5 tons in 1896, 25.5 tons in 1909 (Williams, 1989). Prior to the FDA introductions, the most widely cultivated species were *C. liberica* and *C. abeokutae*, which are indigenous to Nigeria. Following the dwindling demand for the indigenous coffee, other commercially important coffea species were introduced to farmer in the 1930s. *C. canephora* and *C. arabica* account for 96% and 4% of coffee export respectively (Williams, 1989). Except for the Mambilla Plateau of Taraba State, Jos Plateau, Plateau State and some parts of Obudu cattle ranch in Cross River State where C. arabica is cultivated, most of the coffee planted in Nigeria is *C. canephora*. Nigeria is a major producer in Robusta coffee .Coffee is cultivated in 14 states of the federation, covering over 5,000 hectares. From all the introductions, the main species now cultivated in Nigeria are Robusta (94%), Arabica (4%) and Liberica (2%), Hence Nigeria coffee is a target to instant coffee market. Java and Quillou account for 85 and 15 percent respectively of cultivated Robusta (CRIN, 1989).Coffee growing states are, Oyo, Ogun, Ondo, Ekiti, Kwara, Kogi, Edo, Delta, Abia, Cross River, Akwa Ibom, Taraba and Jos. Sustainability in production irrespective of the ever-changing demands in agro-climatic conditions and the commercial markets require continuous efforts especially in the development of better genotypes (Baruah *etal*., 2003)

BOTANY, TAXONOMY AND CYTOGENETICS OF COFFEE

Coffee belongs to the genus *Coffea* in the Rubiaceae family, and is mostly grown in the tropical and subtropical regions of the world (Berthaud and Charrier, 1988). Of the 100 known species in the genus *Coffea*, *Coffea arabica* L. (Arabica coffee) and *Coffea canephora* P. (Robusta coffee) are the two most important commercial species. By quality profile rating, *C. arabica* stands out and contributes more than 70 percent of the world coffee production (Lashermes *et al.,* 1997; Carneiro, 1999; Anthony *et al.,* 2001a; Anthony *et al.,* 2002; Stieger *et al.,* 2002).

The first botanical description of a coffee tree under the name *Jasminum arabicanum,* was made in 1713 by A. de Jussieu, who studied a single plant originating from a botanic garden at Amsterdam. However, Linnaeus (1737) classified it as a separate genus *Coffea* with the then only one known species *C. arabica*. However, many more species of *Coffea* were discovered during exploration of the tropical forests of Africa since the second half of the nineteenth century. Efforts of several botanists to describe the species in the genus had led to confusion such that numerous epithets were later discovered to be synonyms of the same species. However, the respective work of Lebrun (1941) in Central Africa (Zaire) and Chevalier (1947) in Africa and Madagascar on coffee is remarkable.

Chevalier (1947) grouped the species within the genus *Coffea* into four sections:
Argocoffea, Paracoffea, Mascarocoffea, Eucoffea.

However, Leroy's (1967) suggested that *Argocoffea* should be excluded from the genus *Coffea* because the seed does not resemble coffee beans and that *Paracoffea* should be considered as a sub-genus of *Psilanthus*. Classifications within *Eucoffea* and *Mascarocoffea* now mostly fit correctly in the genus*Coffea.* Within the *Eucoffea*, there are five subsections (Chevalier, 1947), based on some diverse criteria: tree height *(Nanocoffea),* leaf thickness *(Pachycoffea),* fruit colour *(Erylhrocoffea,Melanocoffea)* and geographical distribution *(Mozambicoffea).* The sub-sectional grouping within *Eucoffea* according to Chevalier (1947) is shown in the Table 1.

Cytotaxonomy and Reproductive Systems (Chromosome Number)

Results of studies on chromosome numbers in coffee carried out since the1930s was reviewed by Sybenga (1960). The basic genome of the genus (x = 11 chromosomes), is typical for most of the genera in the family *Rubiaceae.* Chromosome counts were made for most species of the genus *Coffea* and for some representatives of the genus of *Psilanthus.* In the section Euc*offea,* all species are diploid with 2n = 22 chromosomes, except for the tetraploid *C. arabica* which has 2n = 4x = 44 chromosomes. The diversity at the somatic level within this section offers a possibility for enhanced genetic improvement within the section. The chromosome number of more than 20species within *Mascarocoffea* has been determined (PortBres, 1962; Leroy and Plu, 1966; Friedman,1970; Louam, 1972). Species belonging to this section are diploid (2n = 22). Interestingly, very large variability exists in this section though not attributable to ploidy variation within species.

GEOGRAPHICAL DISRTIBUTION AND WIDE ADAPTABILITY OF COFFEE

As remarked by Berthaud and Charrier (1988) most of the coffee species originated from tropical Africa. Ethiopia (tetraploid *Coffea arabica*) and Central and West Africa (other coffee species) (The Arabica coffee majorly cultivated in Latin and Central America, and Asia have a narrow genetic bases with respect to seeds/plants which are few. The specie is equally autogamous(Orozco-Castillo *et al.,* 1994; Lashermes *et al.,* 1996; Carneiro, 1999; Anthony *etal.,* 2002; Stieger *et al*., 2002; Raus *et al*.,2003).

According to Bellachew (1997), the adaptability of indigenous cultivars of Arabica coffee in Ethiopia are location specific; this implies the availability of wide genetic variability in natural Arabica coffee populations in micro agro-climatic ecologies. Denich and Gatzweiler (2006) reported site-specificity of wild-coffee for drought tolerance. These populations exist in different forms: as wild coffee that are inaccessible and non-used, forest and/or semi-forest coffee and garden (landraces) coffees. The within population genetic diversity decreases as we go from wildpopulation to landraces (Senbeta andDenich, 2006).

Information on Coffee fromNigeria

Coffea liberica is a species indigenous to Nigeria. Following the dwindling demand for the indigenous coffee in the world market (i.e liberica coffee), other commercially important Coffea species (*C. canephora* and *C. arabica)* were introduced to farmer in the 1930s. (Williams, 1989). Except for the parts of Mambilla and Jos Plateau and some parts of Obudu in Cross River State of Nigeria where *C. arabica* is cultivated, majority of the coffee planted in Nigeria is *C. canephora.*

DIVERSITY STUDY IN COFFEE

Future crop security in agriculture and industry is dependent on plant genetic diversity (Jump *et al*., 2008). Like in many crops, evaluation of the genetic diversity and available genetic resources within the genus *Coffea* is an important step in coffee breeding (Cubry et al., 2008). New coffee varieties are continuously being developed through hybridization. Continuous evaluation of diversity within species to determine genetic potentials of available genetic resources is a need in Coffee (Gichimu and Omondi, 2010a). Genetic stability within varieties is also essential to quality assurance for any agricultural product. Narrowed genetic diversity is reported to compromise the ability of populations to evolve new variants to cope with environmental changes. This reduces the chance of long-term persistence of the species (Frankham *et al.,* 2002). Determination of genetic diversity is therefore important not only in coffee but also to other crops. Although, the overall genetic diversity of *Coffea arabica* low polymorphic compared to other relative species, however, observed diversity at a centre of origin particularly South-Western Ethiopia was remarkable for many agronomic characters. Results of different methods of diversity supported that there exits wide variability within *C. Arabica*: morphological (Ameha and Belachew, 1987; Carvalho, 1988), biochemical (Silvarolla *et al*., 2000; Silvarolla *et al.*, 2004) and DNA-based molecular markers techniques (Lashermes *et al*., 1995; Lashermes *et al*., 1996; Lashermes *et al.,* 1997; Anthony *et al.,* 2001a; Anthony *et al.,* 2001b; Moncada, 2004). A variety of techniques have been utilized to measure genetic variation of coffee species. For instance, Walyaro (1983) successfully determined the diversity of eleven coffee genotypes using morphological characteristics. Gichimu and Omondi (2010b) also determined the morphological diversity among five s newly developed and two existing commercial cultivars of coffee in Kenya. The study demonstrated low morphological variation hence, low genetic variation among the varieties tested. Morphological markers are reportedly inefficient because they are generally under the influence of dominant traits, there are often the exhibition of epistatic interactions with other genetic traits; moreover, morphological markers can be influenced by the environment (Weising et al., 2005). In Brazil, the genetic structure and diversity of wild and cultivated accessions of *Coffea arabica* were assessed with Simple Sequence Repeat (SSR) markers (Silvestrini et al., 2007). In addition, accessions of *C. eugenioides*, *C. racemosa*, and *C. canephora* were also sampled. By cluster analysis based on Jaccard's coefficient, all species were distinguished and cultivated *C. arabica* accessions were distinguished from spontaneous and sub-spontaneous ones. The Brazilian cultivars were distinguished from Yemen-cultivated accessions; however, both groups exhibited a very low genetic diversity. Their result agreed with the initial remark that *C. arabica* has narrow genetic base. The gSSR and EST-SSR markers were successfully used for genetic diversity evaluation of valuable accessions of a Brazilian coffee breeding program. The gSSR markers were more efficient in this evaluation, especially in differentiating *C. arabica* related accessions. Nevertheless, the combined use of gSSR and EST-SSR markers was recommended by Missio et al. (2011) because they may provide complementary information. Their investigation provided a selection protocol of a more informative combination of gSSR and EST-SSR markers for further studies.

DISEASES AND PESTS OF COFFEE IN NIGERIA

Diseases of coffee

It has been commonly said that coffee (*Coffea arabica*) is a tree practically free from disease. Actually, the coffee plant is subject to more than 40 diseases ailments due to lack of minor elements, virus troubles, mild bacterial infections of roots and fruits, and attacks by fungi and parasitic flowering plants. A century of effort has been expended on agronomic and horticultural problems in coffee, but only in the past 50 years has intensive work been done on its diseases. Although coffee is not a food crop, it represents for most coffee-growing countries the major source of revenue for foreign exchange. Limiting factors of coffee production include major diseases, such as the coffee leaf rust (or orange rust) and the coffee berry disease (CBD) caused by the fungi *Hemileia vastatrix* Berkeley and Broome and *Colletotrichum coffeanum* Bridge and Waller, respectively. Other coffee rust diseases (powdery, yellow rust or grey rust), caused by the fungus *Hemileia coffeicola* Maubl and Rog., have not been considered so important economically as leaf rust. The symptoms of the disease are characterised by a dusty or powdery coating of yellow uredosori covering the underside of the coffee leaves, in contrast to *H. vastatrix* that forms distinct blotches or pustules (Rodrigues Jr. 1990; Adejumo, 2005). Other fungal diseases like coffee wilt disease or tracheomycosis caused by *Fusarium xylarioides* Steyaert (teleomorph: *Gibberella xylarioides* Heim and Saccas) is becoming important in some regions.

Leaf rust

Coffee leaf rust, CLR or orange rust is a 'classic' among plant diseases. Also called the oriental leaf disease is by all odds the most serious disease of coffee. It does not occur in the Western Hemisphere, may be just by pure luck. There are two species of rust: The classic *Hemileia vastatrix*, which is so destructive and is found in most of the coffee regions of Africa, the Near East, India, Asia, and the Pacific Islands, and *H. coffeicola*, equally dangerous rust but still confined to the Cameroons of West Africa and the nearby island of Sao Tome. Spores of the rust are long-lived, withstand drying and other vicissitudes, and may be easily

transported on live plants or as invisible dust from one country to another. One of the most feared pathogens to coffee growers is *Hemileia vastatrix* Berk. and Br. (Uredinales), or the coffee rust fungus. Coffee rust is characterized by yellow-orange powdery lesions on the abaxial surface of leaves where it attacks through stomata; it rarely occurs on stems or fruit. All *Coffea* genotypes are susceptible to some degree, though cultivars such as Timor and Icatu exhibit a high resistance (Ferreira and Boley, 1991). The fungus is a co-evolved pathogen of *Coffea* spp. in Africa and affects both wild and cultivated *Coffea* species, but causes most damage to *C. arabica*. It now occurs in almost all coffee-producing countries (CMI, 1989). Impaired photosynthesis, premature defoliation, and reduced floral initiation constitute most of the damage (Brown *et al.* 1995). This reduced photosynthetic capacity and the heavy carbohydrate sink created by fruits limit the amount the growth of woody tissue that gives rise to the next season's crop. Therefore, the following season's crop is reduced. In fact, losses due to coffee leaf rust can reach 70%, although 15-20% is more typical (Ferreira and Boley, 1991; Brown *et al.* 1995). Controlling *H. vastatrix* is a daunting task; chemicals such as propiconazole, tridimenol, tridemfon and copper oxychloride are just partially effective. Amongst them, copper containing fungicides like copper oxychloride are the most effective and widely used. High solubility, variability in the target, the inability of pests to evolve resistance, high adhesiveness to leaves (allowing for fewer applications) and the ability to serve as a nutritional supplements among other properties account for the exceptional utility of this metal complex (Mabbett, 1998). Non-chemical control consists of pruning infected leaves and reliance on resistant cultivars (Hillocks *et al.*, 1999). Finally, a better understanding of the life cycle may lead to further advances in the control of *Hemileia vastatrix*. The economic impact of coffee rust occurs not only through reduction of both quantity and quality of yield, but also through the need to undertake expensive control measures on susceptible cultivars. Because of the difficulty of accurately partitioning and measuring losses caused by coffee rust from those caused by other pests and disease, agronomic factors and their interactions, there are relatively few records of accurately quantified yield losses caused by rust. The major effect of coffee rust is to cause premature shedding of leaves; this reduces the photosynthetic capacity of the plant and restricts the growth of new stems on which the next season's crop is borne. Disease severity in one year therefore directly affects the cropping potential in the following year, and the disease has an insidious, debilitating effect on the plant over successive seasons. The disease can render coffee cultivation uneconomic wherever it reaches epidemic proportions. Severe disease can also affect the crop of the current season, as defoliation causes carbohydrate starvation of heavily bearing trees. This leads to premature ripening of berries that produce poor-quality, 'light' coffee beans.

Insect pest of coffee

Both *C. canephora* and *C. arabica* are susceptible to insect pest. More than 850 insects have been reported to attack coffee (Le Pelley, 1968 & 1973). Of these, the most significant includes leaf miner (*Lecoptera coffeella*), Coffee berry borer (*Hypothenemus hampei*), and Coffee stem borer (*Plagiohammus* spp).

In Nigeria, studies carried out on Arabica coffee on the Mambilla plateau showed that four species of scale insect *Coffea arabica* on the plateau, they include:*Stictococcus viridis* (green); *Pseudococcus njalensis* (Laing); *Ceroplastes brevicauda* (Hall); *Saisetia coffea* (Walk). Location survey where the insects were found to occur included Kusuku, Mayo-Kusuku, Ardo-gori, Lekitaba, Gembu, Maisamari, Kakara, Mayo-Ndaga, Tamnya, Antere, Yelwa and Mbamnga. The scale insects were commonly found on the non-lignified part of coffee tree, attacking the growing shoot, the fruit and the fruit-bearingstem of the plant. Tree attacked by the scale-insect had poor growth of new leaf flushes and poor development of coffee berries Major foliar pest that infest *Coffea canephora* are *Epicampoptera spp,Cephonodes hyla* and *Leucoplema dohertyi;* all belong to the family Lepidoptera.

COFFEE SEED

Biology of Coffee Seed

Coffee seed is elliptical having a plane convex and possesses a longitudinal furrow on the plane surface (Dedecca, 1957). The endocarp which is brown encloses the seed. The endosperm is a living tissue, contain a hard external region and soft internal region, which surround the embryo (Krug and Carvalho, 1939; Mendes, 1941; Dedecca, 1957; De Castro and Marraccini, 2005). The tissue of the endosperm has a high content of polysaccharides (Wolfrom *et.al.,* 1961). The cell walls are composed of cellulose and hemicelluloses while the cell walls of the coffee seed endosperm are mainly composed of mannans (Hulexy, 1964; Wolfrom et al, 1961). Caffeine is the most known component of coffee beans. In raw Arabica coffee, caffeine can be found in values varying between 0.8% and 1.4% (w/w), while for the Robusta variety these values vary between 1.7% and 4.0% (w/w) (Belitz et al. 2009). However, coffee bean is constituted by several other components, including cellulose, minerals, sugars, lipids, tannin, and poly phenols. Minerals include potassium, magnesium, calcium, sodium, iron, manganese, rubidium, zinc, copper, strontium, chromium, vanadium, barium, nickel, cobalt, lead, molybdenum, titanium, and cadmium. Among the sugars, sucrose, glucose, fructose, arabinose, galactose, and

mannose are present. Several amino acids such as alanine, arginine, asparagine, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tyrosine, and valine can also be found in these beans (Belitz et al. 2009; Grembecka et al. 2007; Santos and Oliveira 2001). Additionally, coffee beans contain vitamin of complex B, the niacin (vitamin B3 and PP), and chlorogenic acid in proportions that may vary from 7% to 12%, three to five times more than the caffeine (Belitz et al. 2009; Lima 2003; Trugo 2003; Trugo and Macrae 1984).

Coffee seed storage

The storage behaviour of Coffee seeds was defined as intermediate (Ellis *et.al.*,1990, 1991; Hong and Ellis 1995). The major impediment to storing intermediate seeds lies in the understanding of the physiology of the limit to which Coffee seeds can be dried and the interaction of temperature and water content on the seed survival (Miran *et.al.,* 2006). Low temperature is detrimental to the survival of coffee seeds. Chilled coffee seeds according to Man and Toole (1960) do have poor germination. Critical water content increases with decreasing temperature thereby making it to have interdependent effect on seed (Dussert *et. al.,* 1997).

Physiology of Coffee seed germination

Mature (dried) coffee seeds show slow and asynchronous germination, which makes it difficult to obtain uniform seedlings for establishment of coffee plantation (Miran *et.al.,* 2006). Valio (1980) remarked that the presence of the endocarp drastically inhibits coffee seed germination; hence, the endocarp is generally removed before any germination test is carried out. Seed priming is being used to enhance seed performance, especially in terms of the rate and uniformity of germination for better crop establishment (Taylor *et.al.,* 1998; Job *et.al.,* 2000). Information on the seed physiology of coffee is scanty. Bewley and Black (1994) observed that Abscisic acid (ABA) induces dormancy and inhibit germination in many coffee species. With respect to *Coffea arabica* seed as noted by Valio (1976), it does so by preventing embryo growth.. Da Silva*et.al.* (2004) reported that ABA inhibited extensibility of the cell wall, thus preventing the increase of the cell's turgor. Research has shown that different isoforms of endo.B-mannanase have different functions during coffee seed germination and subsequently seedling growth (Da Silva *et.al.,* 2004; Marraccini *et.al.,* 2001). According to Da Silva et.al. (2004), the inhibition of radical protrusion by exogenous Gibberrelin Acid (GA) was only observed in coffee seeds. The inhibition of germination by exogenous GA is caused by factors that are released from the endosperm during or after its weakening by endogenous GA, causing cell death in the embryo and leading to inhibition of radical protrusion (Da Silva *et.al.*,).

SHADING AND AGROECOSYSTEM IN COFFEE PRODUTION

The beneficiary role of shade management has been a controversial issue in coffee production (Mayne, 1966; Fournier, 1988; DaMatta and Rena, 2002; DaMatta *et.al*., 2007).While Chanyarin *et al*. (2011) remarked that coffee yield was higher in plants grown under shade, DaMatta, (2004) and Torre *et.al*. (2005) in the contrary reported that Coffee trees grown under shade generally have lower yield Chanyin *et.al*. (2011) concluded that the main benefits from shading in coffee were: high coffee bean weights, larger bean size, higher antioxidant activity with total phenolic content; and higher chlorogenic acid content. According to the team supporting shading in coffee plots; the advanced positivity from adequate shading includes: decreased wind speeds and temperature fluctuations within the plot, increased air relative humidity and changes in aerodynamic roughness of the cropped area (DaMatta *et.al.,* 2007). There is also decline in water loss due to excessive crop evapo transpiration, an effect enhanced by increased ground cover and a decrease in abundance of weeds (Maestri *et.al*., 2001). Coffee and shade interaction over wider ecologies at varied shading intensities is a necessary research investigation; as such information is critical for coffee establishment and productivity. Time to bean filling was remarked to be longer by Muschler (2001) when coffee grows under shade. Within the plantation, reduction in light intensity resulted in reduce fruit load arising from lower flower induction and fewer fruit nodes on branches/stem with longer internodes (Avelino et.al., 2005). Genotypes or tree whose berry bearing stem has shorter internodes length is could highly prolific. Overall, shading (agro forestry systems) has been recommended for marginal areas where adverse climatic condition may limit the successful production of coffee. (DaMatta *et.al*., 2007). According to Van Kanten and Vaast (2006), the level of shading in marginal environment should neither be excessive nor too low for effective protection of the coffee against adverse environmental conditions. There is a lack of agreement among farmers and scientists as to the importance of shade for pest and diseases management in coffee, especially, leaf rust (*H. Vastatrix*) and the coffee berry borer (*Hypothenemus hampei*). Further research is need to understand how shade tree modify the microclimate to the detriment or benefit of these diseases and pests, and hence epidemiology (Beer et.al., 1998).

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Table 1: Species of Coffee within Eucoffea

Sub-section	Species
Erythrocoffea	*C canephora* *C arabica* *C congensis*
Pachycoffea	*C abeokutae* *C liberica* *C klainii* *C oyemensis* *C dewevrei*
Melanocoffea	*C stenophlla* *C catissoi* *C mayombensis*
Nanocoffea	*C humilis* *C brevipes* *C togoensis*
Mozambicoffea	*C schmnnian* *C eugeniodes* *C kivuensis* *C racemosa* *C salvatrix* *C ligustroides* *C zanguebariae* *C mufindiensis*

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