General Introduction

Coffee, a well known beverage in the world is an important agricultural export commodity and the second largest export product from developing countries next to oil. Being one of the chief plantation crops essentially grown in southern states (Karnataka, Kerala and Tamilnadu) and to a little extent in northeastern states of India, coffee is grown in many countries around the world with 70% being produced by small hold farmers. Besides being a source of income for millions of people, it represents a production of foreign currency. Coffee cultivation is limited generally to hilly tracts of Western and Eastern Ghats in India. Though coffee cultivation is a large-scale monoculture system, the coffee plant is by itself a trained perennial bush grown under the canopy of various species of wild trees and thus an environment-friendly crop, which sustains rich biodiversity. Coffee plantations present a pleasant habitat for different species of soil fauna, insects, birds and mammals (Anonymous 1997). Most of the countries grow either only arabica or robusta, but some countries, like Brazil and India, grow both the varieties. Coffee is one of the world’s most popular stimulants, consumed by about one-third of the world’s population. Its total consumption as a beverage is second only to tea. The coffee industry provides more employment, in world trade. It is one of the few crops that small farmers in third-world countries can export profitably (Jami 2003).

Origin and history of coffee

The word 'coffee' is derived from the arabic word 'quahweh' which originally some people say was a poetic term for wine. Since wine is forbidden to strict Muslims the name was transferred to coffee, and through its Turkish equivalent kahweh became cafe (French), caffe (Italian), Kaffee (German), koffie (Dutch) and coffee (English), and the Latin Coffea for the botanical genus (Anonymous 1985).

As a beverage, history of coffee is an interesting and exciting blend of political, financial, cultural and religious influences. According to legend, the effect of coffee was first noticed by a goat herder named Khaldi in southern Abyssinia around the year 850.
He observed that his goats became mostly frisky after eating the leaves and “berries” of the coffee tree. He tried some himself and was soon as active as his herd. A nearby monastery followed Khaldi’s example and found it an effective method of keeping them awake during all-night prayers (Jami 2003).

Coffee, even though taken its name from Arabia, is not a native plant of that country, but of, Abyssinia (now Ethiopia) where it is found both in the wild and cultivated state. From Abyssinia it was brought to Arabia in very recent times. It was stated that coffee was first used there about the year 1450. It was not known to the Arabs, therefore, for more than eight hundred years after the time of Mahomed, and was introduced only between forty and fifty years before the discovery of America. The Arabians called coffee kahwah, which means wine in their language. This word gave rise to a dispute about the legitimacy of its use among Mahomedan doctors, who were, mistaken the word for the thing it represented, denounced as a narcotic that which was anti-narcotic. They were packed down, and coffee has ever since become a legitimate and favorite drinkable of the Arabs (Crawford 1852). At the beginning of 18th century a visiting Arab trader also found this drink agreeable and from then on coffee was shipped to the Arabian peninsula. A demand for coffee quickly developed amongst the peoples of Arabia and coffee plantations were established in Yemen. During the 18th and 19th centuries, there was a steady expansion of drinking coffee throughout the world and Arabica coffee was exported to many countries, with the source planting material originating from either Ethiopia or Yemen (Wintgens 2004).

A Turkey merchant of London, of the name of Edwards, brought the first bag of coffee to England, and his Greek servant made the first dish of English coffee (Crawford 1852). The development of coffee begins in Ethiopia where local people have been drinking coffee for many centuries. The advantages of the spontaneous growth of coffee trees of the species *Coffea arabica* were recognized and developed at a very early stage. The raw beans were not allowed out of the country of origin without first being steeped in boiling water or heated to destroy their germinating power. Strangers were not allowed to visit the plantations. The Dutch were the first Europeans to take coffee seed from Yemen, first to the Malabar coast of southern India and to Ceylon and, from there, material was transferred to Java during the 1690s (Ukers 1935; Wrigley 1988). A plant from Java was
taken to the Amsterdam botanic gardens in 1706, where it flowered and produced berries: this was evidently the ‘typica’ variety of coffee (C. arabica L. var. arabica) which came to be planted throughout the New World.

Coffee was introduced into India and Sri Lanka (then Ceylon) in the 17th century. Mythology says that it was Baba Budan, a Muslim pilgrim to Mecca from India, smuggled out the first seeds capable of germination which were planted in Chickmagalur district in south India. The plant then spread both naturally and by cultivation across the Western Ghats which, to this day, is still an important coffee-growing area of India. In Ceylon (now Sri Lanka) its cultivation on a large scale began around 1690, after the island was taken over by the Dutch. The British introduced the coffee crop into their African territories. A single tree of var. typica, probably of West Indian origin, was taken from Edinburgh Botanic Gardens (UK) to Malawi (then Nyasaland) in 1878. Though coffee came to India when saint Baba Budan in the 1600 AD brought coffee beans from Yemen on his return from pilgrimage, it remained as a backyard plant until the British entrepreneurs converted it into commercial plantations in the 18th century (Wrigley 1988).

All Coffea species are native to the inter-tropical forest of Africa, Madagascar and islands of the Indian Ocean (Mascarene and Comoro Islands) (Maurin et al. 2007). Two species are cultivated commercially: Coffea arabica L. (Arabica type coffee) and Coffea canephora P. ex Fr. (canephora or Robusta type coffee). Arabica type coffee is typical of the highland growing regions while Robusta type coffee is grown in lowland regions. Between these two species, Arabica coffee is well known for its cup quality but is quite sensitive to different pests (fungi, nematodes and insects), where as Robusta coffee produces a lower quality coffee, but is more resistant to pests (De Castro and Marraccini 2006). Coffea canephora var. robusta was identified from more diverse origins in the forests of tropical central Africa and was later transferred to many lowland areas of Africa as well as tropical countries of Asia and America.

Ecology

In the world, cultivation of coffee is being done in the countries of the tropical belt between latitudes 21˚C N and 25˚C S of the equator, although earlier cultivation was
confined to 12˚C and 16˚C to the north and south of the equator. It grows well at a temperature range of 10˚C to 30˚C. For Arabica coffee, a cool and equable climate is preferable, while robusta thrives well in hot humid conditions. The temperature, humidity, rainfall, shade, soil condition and elevation are some of the important factors which influence growth of coffee plant. Elevation influences the species cultivated and therefore, the quality of coffee. Arabica grows well at elevations between 900 and 1200 meters, while robusta comes up well at lower elevations.

**Botanical features**

The genus *Coffea* belongs to the family Rubiaceae and comprises more than 124 species (Davis et al. 2011). All species are perennial woody bushes or trees in intertropical forests of Africa and Madagascar for the *Coffea* genus, and Africa, Southeast Asia, and Oceania for the *Psilanthus* genus (Lashermes et al. 2008). Plant contains single or multiple vertical main stems which carry primary horizontal branches at each internode to form secondary horizontal branches. Inflorescences present in both the axillary position and the terminal position. Opposite leaves with one leaf blade only, more or less leathery and thick. Stipules are often well developed. Nectar producing flowers of white or cream color with a corolla is attractive to insects. Inflorescences usually bear three to ten flowers (Anonymous 2014).

*Coffea* species are evergreen, glabrous, glossy-leaved shrubs or trees 5–10 m high and most are adapted to a forest habitat. Leaves are elliptical with pointed tips and occur in pairs. They have short petioles with small stipules, and domatia (small pits) are present on the undersides of leaves at the junction of the main veins. Flower clusters are produced in leaf axils. The fruit is a two-seeded drupe with a fleshy epicarp. The stems exhibit dimorphic branching due to the different development of two buds that occur, one above the other in each leaf axil of the main stem. The upper bud develops to produce a lateral or primary branch. The primaries develop in succession from the base upwards and grow horizontally (plagiotropic) on opposite sides of each node, and they bear the flowers and fruits. The lower bud can only develop into a vertical (orthotropic) branch, and remains dormant until the main stem has been damaged or pruned, when it grows around the primary to produce a new vertical vegetative shoot.
Figure 1.1: *Coffea arabica* plant with fruits

Figure 1.2: *Coffea canephora* plant with fruits
Arabica

The most important economic species of Coffea is C. arabica L. (Figure 1.1) which is indigenous to the highland forests of Ethiopia at altitudes of 1370-1830 m above sea level and adjacent areas of the Boma plateau in south-eastern Sudan, and to Marsabit in northern Kenya. The total extent of the area in which wild C. arabica exists continuing the habitat degradation; Davis et al. (2007) consider that it is vulnerable to extinction. The origin of the cultivated species C. arabica was elucidated using complementary molecular approaches (Raina et al. 1998; Lashermes et al. 1999). C. arabica is an amphidiploid (i.e., CaEa genomes) resulting from hybridization between C. eugenioides (E genome) and C. canephora (C genome) or ecotypes related to these diploid species. Low divergence between the two constitutive genomes of C. arabica and those of its progenitor species suggests that speciation occurred very recently (Lashermes et al. 1999). Since cpDNA has a strict maternal inheritance in coffee (Lashermes et al. 1996), a phylogeny based on plastid variations clearly indicated that C. eugenioides or a related species was the maternal progenitor species of C. arabica (Cros et al. 1998).

Arabica is a species that originates from the Ethiopian highlands, and is part of the genus Coffea which contains 80 species (Cros et al. 1998). All the species of this genus are diploids 2n = 2x = 22 chromosomes, apart from the notable C. arabica 2n = 4x = 44 allotetraploid. Self-fertilization of the species is not absolute, with self pollination being estimated at 90% under plantation conditions (Carvalho 1988). Domestication of the species has been characterized by successive reductions in genetic diversity. It is presumed that C. arabica arose sometime in the late Quaternary period, when much of the area bordering Kenya, Ethiopia, Uganda and southern Sudan was forested. The coffee grown in Yemen, from which the early cultivated crop was derived, represents only a small proportion of the variability found in Ethiopia, and probably underwent some selection to produce types adapted to cultivation under the dry Yemeni conditions. The wider variability of the crop in its natural habitat has been exploited, firstly through collections made by individuals and secondly by organized botanical surveys. This has led to the selection and subsequent use of valuable genotypes, providing sources of resistance or tolerance to a number of diseases and some pests. These types were often
named after the locations from which they were collected (Rume Sudan, Geisha, Kaffa, Tefarikela, Dilla), and many have useful resistance to disease.

*Coffea arabica* is autogamous and mostly inbreeding. A degree of out-crossing (10–12%) occurs, and *C. arabica* can be crossed with most diploid species but, if this is prevented, it will breed true from seed. The flowers are heavily scented and visited by many insects that effect pollination. This is presumably largely self-pollination, but it has been shown to boost yields. A small amount of natural variability occurs within the species due to natural hybridization and mutation.

Two botanical ‘varieties’ (Haarar 1962) were earlier recognized that gave rise to the traditional cultivars grown in the 19th and 20th centuries:

- *Coffea arabica* L. var. *arabica* (syn. var. *typica* Cramer and var. *abyssinica* Chev.) was the original type first cultivated in Yemen, from where most of the ‘typica’ stocks were derived. The primary fruiting branches are slender and grow horizontally; leaves are narrow, sometimes pendulous and bronze-tipped when young. Historically, the bulk of the world’s commercial coffee production has been derived from ‘typica’.

- *Coffea arabica* L. var. *bourbon* (B. Rodr.) Choussy arose as a spontaneous double-recessive mutant, and was first taken by the French to Bourbon. The tree is more slender than ‘typica’, with primary fruiting branches borne stiffly at an acute angle and bent down only at the tips during fruiting; the leaves are green-tipped when young.

However, this species appeared to be very sensitive to parasitic threats. That is why, in Africa, during the 19th century, the spontaneous forms of other species of coffee, especially *C. canephora*, were cultivated locally.

**Robusta**

The first European explorers found indigenous coffee (*C. canephora*) (Figure 1.2) being semi-cultivated in central Africa. Burton reported its cultivation on the islands of Lake Victoria and to the north of the Kagera river in what is now Tanzania, and noted that the boiled berry was used for chewing. The expeditions of Emin Pasha also describe trade in coffee berries in the region south of Lake Albert, and that relatively large quantities were exported northwards from what is now Uganda (Wrigley 1988).
Coffee first described as *C. canephora* by the French botanist Pierre in 1879 was collected in Gabon. However, the name *C. robusta* was also used for similar specimens and it is for this reason that the term is still used to distinguish it from ‘arabica’. Robusta coffee occurs in the wild in equatorial forest from West Africa to Lake Victoria, largely between 10° north and south of the equator, at altitudes between sea level and 1500 m. There are two main centres of diversity (Charrier and Eskes 2004): in forests of the Guinean countries and in the broader Congo basin area. It was introduced to the Dutch East Indies (now Indonesia) from Africa in the late 1800s, where there was some interest in its cultivation because it was resistant to coffee rust, which had arrived there in 1876. By the 1920s, Indonesia was producing 36,000 t of robusta coffee, becoming the world’s largest producer by the 1980s, with some 3,50,000 t.

*Coffea canephora* (*2n = 22*) is self-sterile and cross-pollination has resulted in much more variability in the species than occurs in arabica. Growing wild in African equatorial forests, it has been widely distributed around the world and is more adaptable than *C. arabica*, and able to thrive in warmer, more lowland conditions than those required for arabica. Its resistance to rust made it more popular in the Old World Tropics than in the Americas. Less demanding than *C. arabica*, *C. canephora* is cheaper to grow and is popular in blends and for the production of instant coffee. It is generally larger than arabica and produces more yield. It can be grown successfully from sea level to 1400 m with an optimum at between 300 and 800 m, but grows well around Lake Victoria in Uganda and near Bukoba in Tanzania, at 1150 m.

The robusta type was first taken to Indonesia, where it became widely grown. Robusta and Uganda were originally described as separate varieties of *C. canephora*, but although some traditional populations can be placed in these groups, there is much more variation within the species. Recent studies have shown that there are two main genetic groups of *C. canephora*, one in West Africa (Guinea area) and the other in Central Africa (Congo area) (Charrier and Eskes 2004).

**International Coffee Organization (ICO)**

This London-based intergovernmental organization for coffee was founded in 1963 in an effort to promote cooperation among coffee-exporting and coffee-importing countries and to assure a fair price for both producers and consumers. The organization
enables international exchange through high-level meetings; it launches programs and activities that improve the quality of coffee and promote consumption; it also publishes market statistics and produces in-depth economic reports and country coffee profiles (http://www.ico.org/).

**Economic and societal importance of coffee**

In particular, coffee represents one of the key export and cash crops in tropical and subtropical countries with generally a favorable impact on the social and physical environment. World coffee exports amounted to 9.94 million bags in November 2016, compared with 8.74 million in November 2015. Exports in the first 2 months of coffee year 2016/17 (Oct/16 and Nov/16) have increased by 8.5% to 19.52 million bags compared to 18 million bags in the same period in the last coffee year. In the twelve months ending November 2016, exports of Arabica totaled 72.53 million bags compared to 69.89 million bags last year; whereas Robusta exports amounted to 45.06 million bags compared to 43.72 million bags (International coffee organization, http://www.ico.org/).

**World coffee production**

The world coffee production has reached 145 million bags in 2013-14 from the level of 106 million bags in 2003-04. The remarkable feature is that the CAGR has increased to 1.7%. prior to the ten year period of 2003-04 to 2013-14, the growth of world coffee production used to be around 1.25%, however the last ten years witnessed higher growth and interestingly during the same period consumption progressed at a faster phase. The entire progress of coffee production could be attributed to four countries, particularly Brazil which has shown enormous increase in production during the last 4-5 years (Anonymous 2014). Brazil stands first in coffee export followed by Vietnam, Columbia, Indonesia, Ethiopia and India (International coffee organization, http://www.ico.org/).

**World coffee consumption**

The coffee consumption in the world is roughly growing at 2.1%. In the traditional markets like USA, Europe, Japan even though there was economic decline
during the period 2007 to 2010, the consumption did not suffer but the pace of growth was rather slow. Brazil stands first in consumption of coffee followed by Phillipines, Ethiopia, Indonesia, Mexico, Vietnam, Thailand and India (International coffee organization, http://www.ico.org/).

**Coffee in India**

Major coffee producing states are Karnataka, Kerala, Tamilnadu and few places Andhra Pradesh and Odisha. In India for the 2016-17 the total production was 5,333 thousand 60 Kg bag of which 2,250 thousand 60 Kg bag was consumed in India (Figure 1.3).

![Coffee in India](image)

Figure 1.3: Statistics showing coffee production and consumption in India (source International Coffee Organisation)

The post monsoon crop forecast for the year 2016-17 is placed at 316,700 MT. Of the total estimate, the Arabica and Robusta break up are 96,200 MT and 220,500 MT respectively (Coffee Board, www.indiacoffee.org/coffee-statistics.).
Figure 1.4: Coffee White Stem Borer (*Xylotrechus quadripes*)
Factors affecting coffee production

For improving coffee production, the major problem to be tackled is Susceptibility to certain biotic and abiotic stresses. Arabica production is constrained by numerous diseases and pests like leaf rust (*Hemileia vastatrix* Berk & Br.), coffee berry disease (*Colletotrichum kahawae*), coffee berry borer (*Hypothenemus hampei*), Coffee white stem borer (*Xylotrechus quadripes* Chevr.) and nematodes (*Meloidogyne spp.* and *Pratylenchus spp*). In contrast, Robusta is tolerant to these diseases and pests.

Coffee white stem borer

Although several insect species have been recorded as pests of coffee in Asian countries, only some are of economic importance (Le Pelley 1968). *Xylotrechus quadripes* (Chevrolat) (Coleoptera: Cerambycidae), the coffee white stem borer (CWSB) (Figure 1.4), is the most serious pest of arabica coffee in some Asian countries (Kunhi Kannan 1925; Le Pelley 1968; Visitpanich 1994; Rhainds et al. 2002). Le Pelley (1968) briefly reviewed the status and bioecology of various pests of coffee including the CWSB. It has consistently been a major threat to arabica coffee cultivation in Asia and information on CWSB available in different sources was limited (Venkatesha and Dinesh 2012). The CWSB was first reported in India in 1838 (Le Pelley 1968). The borer is distributed in some Asian countries. *Coffea arabica* is the most preferred and principal host plant of the CWSB. Rarely, the CWSB attacks weak robusta coffee plants (Santosh et al. 2011).

*Xylotrechus quadripes* Chevrolat (Coleoptera: Cerambycidae), commonly known as coffee white stem borer (CWSB) is the most destructive insect pest of arabica coffee plants in India (Sreenath and Prakash 2006; Anonymous 2014; Venkatesha and Dinesh 2012). It is also distributed in other Asian countries like Bangladesh, Myanmar, Nepal, China, Thailand, Vietnam, Indonesia, and Sri Lanka (Rhainds et al. 2002; Lan and Wintgens 2004). The pest has been studied intensively ever since the first published account of its incidence on arabica coffee in India in 1838 (Venkatesha and Dinesh 2012). The main host of *X. quadripes* is *Coffea arabica*, but the pest is also found rarely in *C. canephora*, *C. liberica* and also other hosts like *Tectona grandis* (Venkatesha and Seetharama 1999), *Psilanthus bengalensis* (Santosh and Sreenath 2011).
Life cycle

The adult beetle emerges and starts egg laying during in October-November and during the April- May flight period (Figure 1.5). The eggs will hatch in about 14 days and the first instar larvae tunnel just under the bark for a period of 2 months. Later instars tunnel for up to a further 9 months and then bore a chamber close to the exterior of the stem before pupating. Visitpanich (1994) found that there were six larval instars in northern Thailand with a mean development time of 172 days. The larval stages are completed in 6 months, when the last instar reaches the pupal chamber. Pupation lasts for 30-40 days. The adult beetle remains in the pupal chamber for 3-7 days before making an exit hole, immediately after coming out of the stem the emerging adult searches for a mate. The adults live for 2-3 weeks but fly little, and this tends to restrict the infestations. They are, however, more active at night and can be attracted longer distances by light (Veeresh 1993). The adult female survives for 9-30 days, during which each female lays up to 100 eggs in cracks and crevices of the bark on the main stem and thick primary branches (Le Pelley 1968). The life cycle is completed in about 12 months.
Figure 1.5: Life cycle of CWSB (*Xylotrechus quadripes*)