

## **GROWTH AND PRODUCTION OF COFFEE**

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**Keywords:** Agro-ecological systems, best agricultural practices, coffee, crop husbandry, cup quality, diversification, environment, post harvest processing sequestration of carbon.

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### **Summary**

Coffee (*Coffea spp.*) is widespread throughout the tropics with more than 70 species, all of them originating from Africa. Economically important today are the Arabica (*Coffea*

*arabica*, 64% of world production) and Robusta (*Coffea canephora*, var. *Robusta*, 35%) types, cultivated worldwide on an estimated area of 10.3 million hectares. Brazil, Vietnam, Colombia, Indonesia and Ethiopia are the most important producers. The crop is produced and exported by more than 60 countries and ranks as one of the top cash crops in the developing world.

Coffee is a plantation crop adapted to tropical highlands for *C. Arabica*, and to lowlands for *C. canephora*. They require a well distributed annual rainfall, a dry season not exceeding five months, and an annual temperature between 15 - 30° C. They tolerate shade and share quite similar growth requirements with forest trees, thus predisposing them to agroforestry ecosystems. Soils should be permeable, have a good effective depth, and be well-drained and well-aerated.

The different types of coffee cultivation are discussed, with a focus on practices that promote Best Agricultural Practices (BAP). These deal with the conservation of natural resources, protection of the environment, promotion of global carbon sequestration, avoidance of health problems and enhancing quality of life for farmers and society as a whole. The four different periods in the life cycle of coffee plantations are described in the light of these BAP principles adopted for sustainable coffee growth. These include: traceability and product identification from site identification, variety selection, nursery practices to planting, and plantation management.

Traditional and modern methods of coffee harvest and post harvest treatments, roasting and brewing are analyzed. Finally the high diversity in techniques for preparing hot and cool coffee drinks, the relationship between coffee consumption, and certain medical conditions and their health and pharmacology uses are presented.

## 1. Introduction

Coffee (genus *Coffea*) is widespread throughout the tropics with more than 70 species. All cultivated species originate from Africa. Economically important today are *Coffea arabica* (Arabica, 64 % of world production) and *Coffea canephora*, (var. Robusta, 35 %). Coffee is among the most important agricultural commodities on the world market: it is cultivated worldwide on approximately 10.3 million hectares and represents the sole economic income for more than 25 million families. The crop is produced and exported by more than 60 nations and ranks as one of the top cash crops in developing countries.

The coffee plant is a fast-growing tropical bush tree, with two types of shoots: upright-growing orthotropic main shoots (stem), and horizontally growing plagiotropic shoots (branches). Traditionally, coffee trees are cultivated only for the berries, which are processed using dry or wet techniques directly in the growing areas to the final raw product, green coffee; this serves as the basis for various coffee products.

Coffee is a plantation crop well adapted to different eco-physiological conditions of the tropics. *C. arabica* is adapted to cooler temperatures of the tropical highlands above 1000 m altitude along the equator; somewhat lower at greater latitude. It needs more than seven months of rainy weather but a relatively high temperature for an abundant

differentiation of flower buds. The deep root system permits reasonably good drought tolerance. Hence, the crop grows best in tropical highlands. *C. canephora* prefers a hotter climate and is more adapted to the lowlands (below 900 m altitude), though quality improves with altitude. It requires a prolonged rainy season because of its shallower root system, tolerates high soil moisture, but needs a short dry season for extensive flowering.

Both coffee species tolerate shade and share quite similar growth requirements with various forest crops and trees, thus predisposing them to be grown in agroforestry ecosystems. Growing coffee under full sun with little or no forest canopy causes the berries to ripen more rapidly and the bushes to produce higher yields; this requires shade clearing and increased fertilizer and pesticide uses. In traditional coffee production, however, with different levels of shade, berries ripen more slowly and yields are lower, but green coffee and cup quality are superior.

There still exists public controversy on the different types of coffee cultivation and their impact on the environment. Hence, the current focus is to ensure that all practices conserve natural resources, protect the environment, promote global carbon sequestration, cause no health problems and enhance the quality of life for farmers and society as a whole.

In addition, the methods of coffee harvest and post harvest treatments, roasting and brewing are considered important. Today, coffee is prepared and presented in a great diversity of varieties and prepared drinks. An interesting development is the relationship between coffee consumption and certain medical conditions, as well as its health and pharmacology uses.

## 2. Origin and Distribution

All commercial coffee species originate from Africa and belong to the genus *Coffea*. The high quality *Coffea arabica* species originates from the rainforests in the southwestern highlands of Ethiopia. One theory suggests that the Ethiopians took it to Yemen when they conquered the country by AD 500. Another hypothesis says that Arab merchants brought it initially to Yemen and the Arabian Peninsula, where it was cultivated and has contributed to the prosperity of the seaport of Mocca. This explains why Arabica coffee is associated with the name *Mocca*, although the prime centre of origin and diversity is on the African continent.

*C. canephora* varieties, including Robusta coffee, grow at lower altitude and fit well in the equatorial, warm and wet tropics below 1000 m; they occur naturally in the western Congo basin. Robusta coffee is resistant to coffee leaf rust (*Hemileia vastatrix*) and, therefore, with the expansion of coffee production in the world it replaced Arabica in the areas where coffee leaf rust was devastating the production. As for Arabica, some early Brazilian coffee was labeled after its major port of export, Santos.

There exist also two additional minor coffee species. *Coffea liberica* originates from West Africa around Liberia. *C. excelsa* comes from the more continental and drier parts of Central Africa, mainly the Central African Republic. Genetically, the latter two

species are now considered as a single complex. Nevertheless, practically all present cultivars are descendants of early coffee introductions from Ethiopia to Arabia (Yemen), where they were subjected to a relatively dry ecosystem without shade for a thousand years before being introduced to Asia and Latin America.

The early history of coffee growing followed the major colonial routes dominated by France, Great Britain, Spain, Portugal, The Netherlands, Germany and Belgium. The material that followed these routes is of narrow genetic basis. One such cultivar “*Bourbon*” originates from Bourbon (now Réunion) Island, the then French colony, and formed the basis of a larger part of Arabica plantations worldwide due to its excellent cup taste. Unfortunately, this cultivar is susceptible to coffee leaf rust. Many crossing programs used *Bourbon* to cross with *Hybrido de Timor*, a natural inter-specific cross between *C. arabica* and *C. canephora*, but having a lower cup quality.

The expansion of Arabica coffee far beyond its natural ecological requirements resulted not only in overproduction but also into the development of marginal coffee areas which can only make a profit when world market prices are very high. A solution to this problem is to reconvert these threatened regions into other activities. In some cases horticulture can offer a way-out, though on steep slopes this is less evident due to the difficulty to bring the produce to the markets.

### 3. Botany

#### 3.1. Cultivars and Classification

The genus *Coffea*, comprising more than 70 species, belongs to the family of *Rubiaceae*. This family forms part of the major group of dicotyledonous sympetales, wherein the petals of the flowers are fused. The flowers are fragrant, with an anise-like scent. Only three coffee species have commercial significance.

***Coffea arabica* Linné** – This species is divided in several varieties, some tall (*Bourbon*, *Typica*, ...) and some dwarf (*Caturra*, *Catuai*, ...). It is a tetraploid species ( $4n = 44$ ) that yields a clearly superior coffee taste combining low caffeine content with fine aroma. It is generally susceptible to coffee leaf rust and, unfortunately, the more spread varieties like *Bourbon* tend to be the more susceptible.

Among the more than 200 existing Arabica varieties, the most important tall varieties are:

- *Typica*: Grown mainly in Brazil; most of the existing varieties originate from it;
- *Bourbon*: Has a 25% higher production than *Typica*;
- *Mocha*: Originates from Ethiopia;
- *Mundo Novo*: This is a natural cross between *Bourbon* and a variety from Sumatra;
- *SL28* and *Ruiru 11* from Kenya;
- *Pache Comun* and *Pache Colis*: Both are mutations from *Typica*;
- *Maragotype*: A mutation from *Typica*, characterized by broad beans; it originates from Brazil;
- *Marella*;

- Kent, S288 and S795: All of these originate from India;
- Blue Mountain: The famous variety from Jamaica.

The most important dwarf varieties are:

- Caturra: A mutation from Bourbon, known for its productivity and good taste; originates from Brazil;
- Catuai: A cross between Caturra and Mundo Novo;
- Catimor: A cross between Caturra and Hybrido de Timor.

***Coffea canephora* Pierre** – This is divided in many varieties, but two are mainly grown for commercial purposes: Robusta and Conilon (mainly grown in Brazil). As a whole, it is a diploid species ( $2n = 22$ ) with an inferior taste but a higher yield. It is more as resistant against coffee leaf rust (*Hemileia vastatrix*), root-knot nematodes (*Meloidogyne exigua*, *M. incognita*, *M. paranaensis*, *Pratylenchus brachyurus*, and *P. coffeae*) and the coffee berry disease (*Colletotrichum kahawae*). Important varieties are:

- Robusta: The most common variety;
- Conilon: Grown mainly in Brazil;
- Kouilou or Kwilu: With smaller grains and fruits than Robusta.

There exist also hybrids between *C. arabica* and *C. canephora*. Some are natural, as for example the Hybrido de Timor, and some are artificial, e.g. Arabusta created in Ivory Coast.

***Coffea liberica* Hiern** – This is a diploid species ( $2n = 22$ ) which includes several varieties like var. *liberica*, var. *deweyrei* and var. *excelsa*. It is known for its pungent and earthy tasting coffee. Though it combines good rust resistance, the species is declining and has become less significant as an international commodity.

Table 1 displays some specific characteristics and quality parameters of the important commercially grown coffee species discussed above.

Coffee species	Berry to dried beans weight rate	Number of green coffee beans per kg	Caffeine content (%)
<i>C. liberica</i>	10:1	365	1.4-1.6
<i>C. arabica</i>	5-6:1	456	1.0-1.5
<i>C. canephora</i>	4.5:1	685	2.0-2.5

Table 1. Quality parameters of commercially grown coffee species.

The proper choice of appropriate coffee varieties, well adapted to the growing region, is very important for the final taste and quality of the coffee in the cup. There is a general tendency to overvalue high yield performances and not enough cup quality as such. Best Agricultural Practices (BAP) combines the principles of sustainable agriculture with coffee quality. Major Arabica coffee varieties in some important producing countries are listed in Table 2.

Origin	Major varieties grown
Colombia	Bourbon, Typica, Caturra and Maragogype.
India	Kent and one of its offspring S795; these combine exceptional cup quality with good rust tolerance. S26 and S288 have some Liberica characters in their ancestry. Catimor (Cauvery) and Sin 9 present rust tolerance intro-gressed from Robusta material.
China	Catimor 7963.
Indonesia	Robusta coffee is widely grown because of the warm and wet climate. In East Java the cv. Kawisari, a cross between Arabica and Liberica, is cultivated. Cv. Sumatra is thought to be an interspecific cross between Robusta and Arabica.
Brazil	Among the better tasting Arabica varieties in Brazil one should cite Bourbon, Typica, Maragogype and the shorter Caturra. The late maturing Mundo Novo and one of its siblings cv. Catuai are widely grown.
Ethiopia	There exists a very high genetic diversity of Arabica species in the country. Wild coffee is still found in forests. Famous landraces are Harare, Sidamo, Djimmah. Some 20 varieties are now selected for productivity/resistance to the coffee berry disease, and these are currently distributed to farmers.
Kenya	Variety SL28 is highly appreciated. Ruiru 11 is high yielding, but with some Robusta characteristics.
Tanzania	N197, Typica or French mission varieties are planted.
Jamaica	Besides good tasting Bourbon and Bourbon amarello (Yellow Bourbon) are mostly planted. Jamaica coffee farmers produce the famous Blue mountain variety.
Guatemala	Pache comun, Pache colis.
Panama	Geisha and Geisha grown in Bouquet offer premium quality.
Former colonies of Portugal	Catimor (a cross between Timor and Caturra) is rust tolerant

Table 2. Major varieties in Arabica coffee growing countries.

Within the *Coffea canephora* varieties, taste quality differences are not as clear as in *C. arabica*, though this begins to change with the development of washed Robusta cvs. Some varieties originating from Angola or Congo-Kinshasa like “*Kouilou* or *Conilon*” (Kwilu) are already known for their better cup quality. Vietnam, Indonesia and Uganda have now become leading producers. For simplicity the terms Arabica (for *C. arabica*) and Robusta (for *C. canephora*) from here onwards are used.

### 3.2. Structure

The coffee plant has the characteristic structure of the Rubiaceae where branches, twigs and leaves are formed in opposite pairs. The plant is characterized by a pronounced dimorphism between orthotropic (growing upward) and plagiotropic (side or horizontal

growing) branches/twigs. As flowering mainly occurs on one- or two-years-old plagiotropic twigs it is important to prune the coffee tree in such a way as to favor plagiotropic shoots. After some time primary twigs will divide further in other plagiotropic twigs, but a good balance must be maintained between the number of branches and fruits.

### 3.3. Pollination and Phenology

*Coffea canephora* is a typical out-crosser, meaning that it is self-incompatible. In contrast, *C. arabica* is self-compatible. Pollination occurs mainly by wind and to a lesser extent by insects. Positive effects were observed on initial fruit set in Arabica coffee in the presence of honey bee colonies, and the yield of mature berries increased significantly. These results are suggestive of a pollen grain population effect; as a large number of pollen grains germinate on the stigma and usually several pollen tubes grow within the style. When growing clonal Robusta plantations one should always use a mix of different clones to ensure proper fruit setting.

As seasons change, the coffee tree switches from vegetative (root and shoot growth) to reproductive growth and as the plant grows, it flowers, sets fruit, which in turn will mature and eventually be ready for harvest and re-growth for the next cycle. The crop cycle (see also Section 5.2) varies as a function of the physical and physiological developmental stages of the coffee plant throughout the year.

This time between flowering and fruit picking varies between 6 to 8 months for Arabica and between 8 to 11 months for Robusta according to site and variety. Hence, good plantation management encompasses appropriate timing of all cultivation steps at the different development stages, from growth, flowering, fruiting to full ripening.

## 4. Ecology and Growing Conditions

The natural habitat of all *Coffea* species is the African tropical forest. Coffee is a well adapted plantation crop to different eco-physiological conditions of tropical highlands (Arabica) and lowlands (Robusta).

Both altitude and latitude influence the optimal or near-optimal edapho-climatic conditions for cultivation and must be considered along with temperature, rainfall and water supply, soil, slope and aspect when determining where to plant coffee.

Arabica coffee requires an elevation between 1,200 and 2,200 m above sea level at the equator, but the optimal altitude can be less at higher latitudes.

Arabica coffee is cultivated between 25°N and 24°S, ranging from more inclined subtropical areas to tropical regions with greater elevations as far as the temperature requirements (15 to 30° C) are fulfilled. Robusta coffee, consequent to its central African origin, is best adapted to less elevated hot and humid forests of tropical regions. The crop is preferably grown between 15°N and 12°S in flat areas and elevations between 300 and 800 m.

#### 4.1. Climate Requirements

Arabica coffee is well adapted to cooler temperatures, needs more than seven months of rainy season and high temperatures for an abundant differentiation of flower buds; it tolerates drought when grown in deep soils.

**Temperature** - The optimum mean annual temperature ranges from 18 to 22° C. Temperatures above 23° C accelerate the development and ripening of fruits and can provoke loss of physical and beverage quality. High temperatures above 30°C during blossoming associated with a prolonged dry season may cause abortion of flowers.

The best quality Arabica coffee is grown at higher elevations with less extreme weather conditions and milder average temperatures. These include tropical mountainous regions with significant elevations, such as East Africa (Kenya, Tanzania, and Ethiopia) and the tropics within the Americas, starting in the central and southern parts of Mexico, and extending over Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama, into Brazil, Colombia, Ecuador, Peru and Bolivia. Occurrence of sporadic frosts (Brazil, Mexico) inhibits the successful cropping of Arabica coffee. Under ideal conditions Arabica prefers a low atmospheric humidity comparable to that of the Ethiopian highlands.

For *C. canephora* (Robusta and Conilon) coffees the optimum annual mean temperature ranges from 22 to 30° C. Hence, the crop is better adapted to higher temperatures than Arabica coffee. These coffee varieties grow successfully under high air humidity conditions approaching saturation. They tolerate less humid sites, provided the dry season is short.

**Rainfall** - It is generally considered that the best amount of annual rainfall for Arabica coffee is between 1,400 and 2,400 mm, though a range between 800 and 4,200 mm remains acceptable. It is important that the rains are well distributed over the season or are continuous for about 7-8 months. The nature of the rainy season in terms of length and intensity of the rains is a key ecological factor determining the interval between flowering and seed maturation. Likewise, when the annual rainfall exceeds 3,000 mm leaf diseases from fungal infections develop more easily.

Arabica coffee is more vulnerable to leaf diseases and pests than Robusta, especially when rainfall exceeds 3,000 mm per year. Because of its shallow root system *Coffea canephora* can tolerate rainfall over long periods and high soil moisture, but requires a short dry season for massive flowering.

**Other Climatic Hazards** - Both coffee species tolerate shade and they have quite similar growth requirements with many other crops and forest trees, making them suitable for incorporation into agroforestry ecosystems. Strong winds can reduce the leaf area and the inter-nodal length of the orthotropic and plagiotropic branches and hamper the development of flowers and fruits. Hot winds increase crop evapotranspiration, thus increasing the moisture requirements of the trees. Where strong winds are frequent, windbreaks or shelter trees are recommended to improve crop performance.

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## Biographical Sketches

**Hermann Alfred Jürgen Pohlan** is an International Consultant, practicing for more than 15 years, former Professor in Tropical Agriculture, University of Bonn, Germany, and teacher and visiting Professor in German and foreign universities. He holds a Diplomagraringenieur (1972), a PhD. in citrus growing (1976) and a Post-Doctoral Degree in sustainable tropical cropping systems (1983). He is Professor emeritus of the UNA Managua, Nicaragua (2009). He has developed his career in four continents as a researcher in sustainable development of agroecosystems with coffee, cocoa and other annual and perennial tropical crops.

He has been active for more than thirty-five years both in the academic world, as a professor/researcher for agricultural and environmental development in tropical developing countries in Africa, Asia, Latin America and the Caribbean. He was a technical and scientific advisor in more than 40 development projects for international and national agencies, as well as for companies and NGOs active in inter-tropical regions. He organized several training courses in the fields of coffee and cocoa, horticulture, sugar cane, aromatic and medicinal plants, energy plants and biological water purification in Cuba, Nicaragua, Mexico, Colombia, Peru, Ethiopia, Guatemala, Panama, Vietnam, Laos, Uganda, Brazil and Sierra Leone. His special interests include the conversion of traditional coffee and cocoa growing areas with high value crops, the development of agroecosystems with energy crops, intensification of organic farming systems and applications of environmental techniques.

J. Pohlan is the author or co-author of more than 60 peer-reviewed and 130 congress papers published in national and international journals, and author or editor of 15 books or proceedings and 37 chapters in books.

**Marc J.J. Janssens** is a retired Professor for Tropical Crops at the University of Bonn, Germany. He specialized in breeding and quantitative genetics of tropical crops like sweet potato, cocoa, mate, etc. as well as in farming systems where he developed a new approach based on spatial arrangement of intercropping, crop rotations, biomass management, and energy efficiency. He was active in Congo (Kinshasa), Rwanda, Burundi, Argentina and Australia in the field of plant breeding, intercropping, plantation crops, and horticulture. He was involved in numerous agricultural development and farming systems projects in Morocco, Vietnam, Egypt, Niger, Senegal, Ivory Coast, Benin, Brazil, Cameroon, etc. As a free-lance consultant he was involved in the evaluation and organization of several national systems of agricultural research (Benin, Central African Republic, Congo-Kinshasa, Uganda, Ivory Coast, etc.).

Dr. Janssens organized several training sessions in the field of horticulture, breeding and biometrics in Guinea, Laos, Congo-Kinshasa, Burundi, Rwanda and Gambia. His special interests include the development and/or domestication of tropical fruit species, the breeding of tropical crops, and the spatial and energetic aspects of inter-tropical farming systems. He is keen at reconciling intensive agricultural development with environmental management particularly in suburban agriculture. He has published more than 100 scientific papers and book chapters.