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IMPACT OF FIELD PESTS AND DISEASES ON COFFEE QUALITY

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More than 900 species of insects (Bardner, 1985), various other pests (including nematodes, molluscs, birds and mammals) and a large number of diseases attack coffee crops. These pests and diseases may not only reduce yield but they may also affect the quality of the coffee. Most pest species are spatially distributed, with many of them being restricted to only one continent. Only a small number of pests are widespread throughout the tropics: the majority of these pantropical pests infest stored coffee beans and have been accidently disseminated in coffee shipments (Bardner, 1985).

Coffee originated in Africa and, as a consequence, most of the coffee field pests and pathogens also come from this continent. However, coffee is also attacked by pests and diseases encountered in other continents where it has been introduced. Most coffee diseases are caused by pathogenic fungi and less frequently by bacteria and viruses (Waller, 1985). Root rot disease, rusts and Coffee Berry Disease can attack healthy trees without any particular physiological weakness, whereas most of the other diseases of economic importance only occur in trees which are physiologically weakened. Pests and diseases of coffee reduce yields -sometimes killing trees- and adversely affect the quality of the coffee. The impact on quality can be sanitary, physical and organoleptic. ISO 10470: 2004 defines 3 classes of increasing sensorial impacts on roasted coffee for each defect (0 no effect; 0.5 medium effect; 1 extensive effect). The grade of coffee is calculated on physical attributes, including the number of defects of the coffee beans and the bean size. This classification is used for commercial purposes. Stakeholders have several approaches to quality. Even if quality criteria vary along the coffee supply chains, physical and organoleptic qualities are elements taken into account when establishing coffee bean prices (Perriot et al., 2006).

The effect of pests and diseases on productivity and quality depends on the organism involved, the plant organ it affects and on the severity of the attack. To obtain high quality coffees, plantations need to be considered as a whole system in which pest and disease populations and management methods play a major role. The effects of diseases and pests on quality are discussed in terms of (i) pests and diseases that directly attack coffee fruits, (ii) pests and diseases affecting other plant organs, and (iii) the impacts of pest and disease control methods. Biological information on pests and diseases is given when useful for understanding how management methods influence coffee quality.

PESTS AND DISEASES THAT ATTACK COFFEE FRUITS

Pests and diseases that attack berries have a direct impact on the quantity and quality of the harvest. They impair the physical and sanitary quality, and alter the organoleptic characteristics of beans. They induce changes in the chemical composition and physical appearance of beans and hence cup quality (Table 1).

The most important pests and diseases that attack coffee fruits directly are Coffee Berry Borer (CBB), and Coffee Berry Disease (CBD). Antestia bug and the Mediterranean fruitfly *Ceratitis capitata* are also described as pests that attack coffee berries.

Coffee Berry Borer

The Coffee Berry Borer (*Hypothenemus hampei* Ferrari), is found in all the main coffee growing areas of the world and is the most important pest that adversely affects coffee bean quality. Even at low levels of infestation CBB may reduce the quality of coffee beans. The CBB is a Scolytinae indigenous to Africa. Robusta is probably its original host but CBB attacks both Arabica and Robusta (Damon, 2000). CBB spread to many parts of the world during the 16th and 17th centuries. It is now present in all major coffee producing countries except Papua New Guinea and Nepal (Vega et al., 2009). In spite of strict importation rules including quarantine fumigation, CBB was detected in Hawaii in 2010.

The damage caused by CBB is quantitative and qualitative. Yields are reduced as young bored berries may fall prematurely, and all harvested bored berries have at least one bean affected with a consequent loss of weight. The presence of damaged berries affects the sensory quality of coffee samples (ISO, 2004) and reduces the commercial value. While there are few reliable assessments of the economic losses due to CBB, ICO (2009) estimates losses due to CBB at around US$ 0.5 billion per year. Very high fruit infestation levels have been reported in several countries: 60% in Mexico and Colombia, 80% to 90% in Uganda and Tanzania (Vega, 2004). In some regions, lower infestation levels are reported but they still have an economic impact. In Togo, Wegbe et al., (2003) reported mean fruit infestations between 5.6 and 6.4% with yield losses between 2.6 and 3.2%.

Table 1 : Direct impact on bean appearance and cup quality of pests and diseases

Identification	Area of presence	Kind of attack	Impact on bean appearance	Impact on cup quality	Other impacts on quality	Correcting method
Coffee Berry Borer *Hypothenemus hampei* Ferr.	Almost worldwide	Feeds and breeds in the bean. Produces insect-damage or insect-infested bean	Holes and galleries in the bean. Clean cut and circular holes with a diameter of 0.3 to 1.5 mm. When progenies are abundant, beans have a ragged appearance due to tissue eaten by the CBB	Medium impact: slow and irregular roasting, reduction in aroma, flavor and acidity depending on the severity of the damage. If damages are heavy, the cup is bitter and can present off-flavors (chemical, tarry, fermented, mouldy)	Facilitates attacks by mould (risk of off-flavors and contamination by ochratoxin)	Difficult (manual)
					Heavy damages result in broken beans or bean fragments; induces uneven roasting and risk of fire. Cup can lose acidity and have a burnt or unclean flavor	Mechanical sorting techniques (densimetric)
Various fungi that attack berries including *Colletotrichum kahawae* (Coffee Berry Disease) and other *Colletotrichum* (brown blight) that attack berries	*Colletotrichum kahawae*: limited to Africa but major threat to Arabica plantations in high altitude	Pathogen of pulp. Can cause undesirable fermentations. Sometimes necrosis of the bean	Brown spot, greenish yellow to brown bean	Heavy impact (brown bean): loss of aroma and acidity, common flavor. Can cause astringency, sourness and off-flavors (fermented, onion, winey, acetic and stinky)	High risk of contamination by ochratoxin	Special techniques (color)
	Other *Colletotrichum*: worldwide	Produces brownish spot, brown bean, black or partially black bean	Interior black or partially black	Heavy impact (black bean): diminution of aroma, flavor and acidity. Can cause bitterness, astringency and off-flavors (chemical). Slow to roast	Some fungi contribute to die-back (see part 2)	

Table 1 : Direct impact on bean appearance and cup quality of pests and diseases (continued)

Identification	Area of presence	Kind of attack	Impact on bean appearance	Impact on cup quality	Other impacts on quality	Correcting method
Antestia bug *Antestiopsis* spp.	Africa and Asia	Pierces to feed and favors attacks by microorganisms. Attacks berries, flower buds and growing tips Produces rotten bean, brown bean sometimes black or partially black bean, peasy bean	When bug attacks immature berry, beans are shrivelled, crinkled, ragged. They have dark color (brown, sometimes black). Peasy beans are common	Heavy impact: Black bean causes diminution of aroma, flavor and acidity. Can cause bitter flavor, astringency and off-flavors (chemical). Brown bean causes loss of aroma and acidity. Can cause astringency, sourness and off-flavors (onion, winey, acetic, stinky). Secondary infection by bacteria can cause a raw potato flavor or peasy flavor even on normal appearance bean	Favours secondary infection by fungi and potential sanitary contamination	Special techniques (color); not possible for normal peasy beans with peasy or potato off-flavor
Fly *Ceratitis capitata*	Mostly Africa and America	Feeds on the mucilage. Favors attacks by microorganisms Produces insect-damage or insect-infested bean	Darker spot	May cause off - flavors (stinky)	Secondary infection by bacteria can cause a raw potato flavor (methoxy-2-isopropyl-3-pyrazine)	

Coffee Berry Borer life cycle

The CBB life cycle occurs mostly in the berry (Figure 1 to 4, page 293 to 295). An inseminated female enters a berry when the endosperm of the seed reaches an adequate consistency (over 20% dry matter, large green berry stage or later) (Figure 5, page 295). It bores galleries in the seed and deposits an average of 74 eggs (Benavides et al., 2006). Larvae feed and develop inside the seeds, criss-crossing them with galleries. Mating takes place inside the berry, implying a high degree of inbreeding. Most of the newly inseminated females leave their native berry to look for a new berry to colonise, probably guided by volatiles released by berries. Flying and walking are the two means of dispersal. This is the only period when the CBB is outside the berry and can be trapped or predated by birds. Dispersal by a short flight or walk may explain the aggregated spatial structure of infestations (Rémond, 1996). Due to the particular spatial distribution, special sampling methods are needed to accurately assess CBB abundance at field level. CBB completes its life cycle in well-developed berries that may still be on the tree or that have fallen to the ground.

The population dynamics are linked to the availability of coffee berries. Harvests directly remove CBB that are in infested berries and also reduce the potential sites for reproduction by removing berries. Climate factors, particularly rainfall, also affect fruit availability and hence CBB populations. In climates with a marked dry season, blooms and hence harvests occur at specific times of the year. After each harvest, the only berries remaining in the plot are those on the ground or left on the tree. CBB can survive the interseason in these berries, which constitute a source of infestation in the following crop. CBB is favoured by early flowering or delayed harvesting, both of which are often related to changes in the rainfall pattern. In some equatorial climates with no marked dry season, fruiting is continuous throughout the year, with up to 7 or 8 generations per year.

CBB can survive and reproduce over a wide temperature range (20-30°C) (Jaramillo et al., 2009). Temperature influences the survival period of adults (shorter at 30°C than 20°C). A decrease in relative humidity increases CBB mortality and decreases fecundity rate, the optimum for CBB being between 90 and 95 % (Baker et al., 1994). The behaviour of females leaving the berries to colonize new ones is a complex phenomenon. The presence of free water on berries after rain is associated with females leaving dry cherries to colonize new ones. However, this behaviour is also influenced by heat and solar radiation. Furthermore, Mathieu et al., (1993) showed that exits are more numerous in the presence of green berries. Rain does not necessarily lead to increased populations: Borbon-Martinez (1989) indicated that high humidity on the ground during the interseason can cause fallen berries to rot, thereby reducing CBB populations. Similarly, delayed flowering, by increasing the interseason period, increases the decomposition of fallen berries and reduces the number of berries that remain on the trees. Shade probably affects CBB populations by modifying temperature and humidity, however no consistent effects of shading have been demonstrated. Soto-Pinto et al., (2002) found no significant effect of shade and sunlight on CBB in Mexico. Wegbe (2004), in Togo, reported more severe attacks when shade was heavy, whilst also indicating that milder attacks occurred rather under medium shade than in unshaded plantations. Bosselman et al., (2009), in Colombia, also found that the occurrence of CBB is greater under shade. In contrast, Decazy et al., (1989), during a study on a large number of plots in Guatemala, found no consistent relation between shade and levels of infestation. Soil cover could have an impact on CBB populations by altering the environment of fallen berries. Pohlan et al., (2008) found that plots with *Carnavalia ensiformis*, cut and mulched in February, were less attacked than plots with no cover crop. Fertilizer applications have been reported to increase CBB populations, however the mechanism is not well understood (Dwomoh et al., 2008).

Numerous natural enemies of CBB have been reported, including fungi such as *Beauveria bassiana* Balsamo; parasitoids such as *Cephalonomia stephanoderis* Betrem, *Phymasticus coffea* Lasalle or *Prorops nasuta* Waterson; and predators such as ants or birds and nematodes. In 2010, the International Coffee Organization (ICO) notified its members of a report in Kenya of a species of trips (*Karnyotrips flavipes)* predating the eggs and larvae of CBB.

Impact of Coffee Berry Borer on coffee quality

CBB damages coffee beans by boring galleries and feeding. The direct damage to the beans facilitates secondary infections by bacteria and fungi. CBB has a negative impact both on the organoleptic quality of coffee as well as on sanitary quality by favouring production of fungal toxins (Taniwaki, 2007). ISO (2004) classifies beans damaged by CBB as "insect-infested beans" or "insect-damaged beans". According to this ISO standard, CBB has a medium influence (0.5) on the sensory quality of beans.

Attacked beans are easy to recognise (Figure 6 to 8, page 296 to 297). They display one or more clean cut, circular holes with a diameter of 0.3 to 1.5 mm. If attacks are heavy, the bean has a ragged appearance due to tissues eaten by CBB. Currently the only effective way of eliminating damaged beans is through manual selection, which is costly, tedious and difficult (Wintgens, 2004).

Secondary infestations occur in the galleries excavated by the CBB, with the beetle being a carrier of several fungal species including *Fusarium* spp. and *Aspergillus ochraceus*. *A. ochraceus* produces the mycotoxin ochratoxin A (Vega et al., 1999), which is nephrotoxic and carcinogenic. Under European Union regulations, Ochratoxin content in roasted coffee must be less than 5 μg/kg and in soluble coffee less than 10 μg/kg.

CBB-damaged beans have been reported to roast irregularly, with a darker color after roasting. When multiple attacks occur on the same bean, it may break. Broken beans are smaller, hence they roast faster and may burn.

The impact of CBB on cup quality depends on the number of holes per bean. Slight to moderate damage (one hole per bean) is frequently associated with a reduction in aroma, flavor and acidity. If damage is heavy (more than one hole per bean), the cup is bitter and can exhibit off-flavors (chemical, tarry, fermented, mouldy). Montoya-Restrepo (1999) evaluated the effect of the proportion of infested beans and of the bean damage severity on coffee quality. A sample with 10% of beans with slight damage increased bitterness, although the cup was still evaluated as acceptable. Low percentages of severely damaged beans yield a cup with off-flavors that get worse with storage. Castaño and Torres (1999) were only able to detect a decline in cup aroma and body when more than 50% of beans were severely damaged. Perceived bitterness was higher than for healthy beans. In addition, the quality of coffee extracts produced by the cryo-concentration process for soluble coffee depends on the severity of bean damage (Castaño and Quintero, 2004). Beans with one or two holes do not affect the physical, chemical and organoleptic qualities of extracts. Beans with heavier damage give an extract with a higher pH, less body and lower acidity and bitterness.

Coffee Berry Disease *(Colletotrichum kahawae)* and other *Colletotrichum* diseases that affect coffee beans

Coffee Berry Disease (CBD) is caused by the fungus *Colletotrichum kahawae* Waller and Bridge (Figure 9, page 297). This fungus was first detected in 1922 in Kenya. Although the evolution of *C. kahawae* is recent and limited for the moment to Africa, some geographical variability has been found (Bridge et al., 2008). It is specific to *Coffea arabica* berries (Bieysse et al., 2002) which are infected at early development stages, causing severe berry dropping. It is not clearly established that *C. kahawae* has an impact on mature berries. *Colletotrichum kahawae* is a specie distinct from other *Colletotrichum* spp. that are involved in die-back or brown blight such as *C. gloeosporioides*. This fungus is very similar to *C. kahawae* but is not restricted to berries. It is found worldwide.

Although CBD is still limited to Africa, it is a major threat to Arabica plantations in other continents, particularly in high altitude areas, due to lower temperatures that favour the fungus. The high altitude mountainous coffee producing areas of Latin America, where much of the best coffee quality coffee is produced, are at particular risk. The risks of introduction to currently free areas are increasing with the increase in South to South exchanges of coffee material.

Coffee Berry Disease development cycle

The fungus forms conidia on the surface of infected berries. Conidia need moisture and a temperature close to 20°C to germinate and infect berries. Infection depends on the physiological stage of the berries. The active form of the fungus, which damages the crop, develops during the rainy season on fruits ranging in age from 8 to 20 weeks after flowering, corresponding to the development phases between the rapid expansion of the pericarp stage and endosperm formation (Mouen Bedimo et al., 2007). The fungus can destroy all the berry tissues in a few days, or it can remain latent and develop later as the berries mature (Muller, 1980). The development of the disease depends on the simultaneous occurrence of a particularly susceptible berry stage and weather conditions propitious for infection. In the case of older berries, new infection produces a dry lesion or scab that is analogous to a resistance reaction (Muller et al., 2004). On mature berries, CBD is generally found with other *Colletotrichum* spp. and it is not possible to distinguish CBD lesions from those of other *Colletotrichum* spp. and other fungi. Recently, it has been reported that *C. gloeosporioides* can be associated with *C. kahawae* on green coffee berries, and that this association enhances the CBD infection process under field conditions (Chen et al., 2005). Infection of mature berries causes a premature ripening or softening.

Dispersal is favoured by free water and splashing and by physical contact with anything that can transport conidia. The presence of many fruits is conducive to infection. Similarly, when successive production cycles overlap, disease transmission is favoured and the epidemic becomes more severe (Willson, 1999). It is still not clear where the fungus survives in the period when there are no berries in the crop. It is, however, well established that mummified berries are an important source of primary inoculum. Mouen Bedimo et al., (2007) indicate that CBD can infect a plot within three weeks, starting from primary foci where inoculum may have survived in the interseason.

CBD thrives in tropical regions with cooler temperatures and high humidity, generally found at high altitudes (over 1500 meters above sea level at the equator). However, it may also be found at lower altitude, depending on the climate and latitude. Muller (1980) suggested that CBD has a lower impact at low altitude because the berry susceptibility period is shortened due to its faster development. Mouen Bedimo et al., (2010) demonstrated that rainfall is a key physical factor favouring severe epidemics.

In Arabica coffee there are varietal differences in susceptibility. Caturra is highly susceptible (Muller et al., 2004), whereas, Java variety exhibits field resistance which has been exploited in Cameroon (Bouharmont, 1992). The variety Ruiru 11 was bred and selected for resistance to CBD in Kenya (Van der Vossen and Walyaro, 2009).

Impact of Coffee Berry Disease on coffee quality

CBD is known to causes heavy losses in yield, however its impact on sensory quality is poorly documented. It can be mistaken for other diseases, such as "brown blight", and damage may be enhanced by secondary infections from other diseases. Yield losses are mainly due to CBD development on young berries which causes berries to rot and fall off (Muller, 1980). However, both infections on young and ripe berries can affect quality.

Infection of the pulp alters the physiology of the fruit and the pulp may rot. Rotting pulp tends to stick to the beans making wet processing more difficult and reducing coffee quality (Waller, 1985). There is not much information about chemical changes that occur in the bean. Generally CBD infects only the pulp, but sometimes the bean itself may be stained and carved (Muller, 1980).

CBD attacks facilitate secondary infections by toxin-producing fungi such as *Penicillium* spp. or *Aspergillus* spp.. In Kenya, brownish spots on coffee beans, supposedly from CBD-damaged berries, were shown to be a cause of high ochratoxin A content in coffee, a toxin normally produced by *Aspergillus* spp. (Duris et al., 2010).

The interior of beans attacked by CBD may become black or partially black (ISO, 2004; Teixeira and Teixeira, 2005). The bean may be shrunken and the surface may be granular. Black beans have a marked impact on cup quality. Black beans are slow to roast, giving a yellowish color after roasting. The cup is harsh, bitter, with low acidity and poor aroma (old flavor). Ashy or chemical off-flavors may occur.

Black beans are not specific to *C. kahawae*. Other *Colletotrichum* and fungi can have similar impacts on coffee quality. Irrespective of the causal agent, black beans can be eliminated by hand or by color sorting techniques (Figures 10 and 11, page 298).

Other pests and diseases that affect coffee bean quality

Insect attacks generally weaken the bean and decrease its density (Barel and Jacquet, 1994). For example, antestia bugs (*Antestiopsis spp*.), which attack berries, flower buds and growing tips of coffee, feed by piercing. The act of piercing provides access for attacks by other micro-organisms. In the case of fungi, spores may be injected directly into the tissue. Secondary infection by fungi can lead to rotten beans, causing floaters, brown beans (ISO, 2004) and black or partially black beans (Wintgens, 2004). When bugs affect immature berries, the beans are shrivelled, crinkled, or ragged. They have a dark color (brown, sometimes black). The impact on sensory quality is considerable. Black beans cause a reduction in aroma, flavor and acidity, and even an increase in bitterness, astringency and off-flavors (chemical). Brown beans (Figure 12, page 299) cause a loss of aroma and acidity, and sometimes higher astringency, sourness and off-flavors (onion, winey, acetic and stinky). Defects can be eliminated by hand or by using color sorting techniques. Secondary infections by the yeast *Nematospora* often results in "zebra beans" (Bardner, 1985), with a striped appearance in wet parchment, resulting in off-flavors due to continuing microbiological decay inside the beans (Waller, 1985). These zebra beans are difficult to recognize when the parchment is dry (Mitchel, 1985) and therefore difficult to eliminate by sorting. In addition, a bacterium probably transmitted by antestia bugs has been reported to cause a green pea or a raw potato flavor (Teixeira and Teixeira, 2005).

Larvae of the Mediterranean fruit fly, *Ceratitis capitata,* feed on berry mucilage. Attacks on immature berries may cause premature berry fall (Bardner, 1985). Attacked beans are classified as insect-damaged or insect-infested beans. This pest favours secondary infections by microorganisms with negative effects on cup quality. It can induce off-flavors, especially during the wet process, due to microbiological decay inside the bean (Waller, 1985). Teixeira and Teixeira (2005) suggest that this is one of the possible causes of stinker beans which seriously affect cup quality. Secondary infection by bacteria can cause a raw potato flavor (Crowe, 2004).

PESTS AND DISEASES THAT HAVE AN INDIRECT IMPACT ON CUP QUALITY

Many pests and diseases affect flower buds, leaves, stems, branches and roots of coffee trees. They can weaken coffee trees. They may reduce the capacity for photosynthesis and for water and nutrient uptake. Defoliation affects the leaf to fruit ratio the maturation of fruits and may even lead to bean death or abortion. A reduction in raw sap (e.g. by nematodes) or elaborated sap (e.g. by mealybugs) circulation may also reduce coffee sensory quality. Depending on the intensity of the attack, all these pests and diseases (even though they do not directly attack the coffee berries) have the potential to adversely affect cup quality (Table 2).

In addition, when a tree is stressed, the berries themselves may be more susceptible to direct attacks by diseases and pests. For example, a nutritional imbalance, frequently associated with high potential yields, can favour *Cercospora coffeicola* attacks on berries and branch die-back (Waller, 1985). Die-back diseases can be caused by several pathogens including fungi and bacteria that affect immature coffee branches but also leaves and fruits.

Impact of pests and diseases that reduce leaf to fruit ratio

Leaf diseases reduce the photosynthetic capacity of a coffee tree (Figure 13, page 299). American leaf spot (*Mycena citricolor*) and Coffee Leaf Rust (*Hemileia vastatrix*) can cause major defoliation in coffee plantations. Other pests, such as the coffee leaf miner (*Leucoptera coffeella*), have the same effect. Photosynthesis provides carbohydrates for fruits and vegetative growth. When photosynthetic capacity is reduced, vegetative growth is affected and, as a consequence, moderate defoliation may reduce the following season's crop with relatively little effect on the current crop (Waller, 1985). However, when photosynthetic capacity is severely reduced, the growth and ripening of the current crop will be affected. All diseases and pests that affect the leaf-to-fruit ratio logically induce changes in fruit nutrition. Berries may even fall, inducing quantitative losses. However, if this occurs at early stages of development, losses can be compensated through new flower production. Furthermore, Bardner (1985) suggested that some loss of

Table 2: Indirect impact on bean appearance and cup quality of pests and diseases

Damage	Consequence	Defect	Impact on cup quality	Name	Affected organs	Area of presence
Defoliation. Impact on leaf/fruit ratio. Reduces photosynthesis	Prevents good fruit ripening	Immature bean	Loss of acidity, increased bitterness, green and common flavor	Brown eye spot due to *Cercospora coffeicola*	Leaves and berries	Worldwide
		Flaky bean	Woody flavor	American leaf spot *Mycena citricolor*	All aerial organs, including berries	America
		Light bean	Astringency and sometimes metallic taste. Risk of fermented, rotten fish flavor	Coffee leaf rust *Hemilia vastatrix*	Leaves	Worldwide
	Bean death	Brown bean	Sour flavor, sometimes off-flavors. Can evolve into black bean that has a severe impact on cup quality: reduction in aroma, flavor and acidity, eventually increase in bitterness, astringency and cause off-flavors (chemical). Slow to roast	Leaf miner *Leucoptera coffeella*	Leaves	Worldwide
				Die-back *Colletotrichum spp.* and other fungi	Branches, leaves, berries	Worldwide

Table 2: Indirect impact on bean appearance and cup quality of pests and diseases (continued)

Damage	Consequence	Defect	Impact on cup quality	Name	Affected organs	Area of presence
Reduces sap circulation in plant by feeding off sugar from plant elaborated sap, by reducing uptake of water and nutrients or interrupting water and sap circulation	Lower carbohydrate accumulation in berry	Can favour appearance of black bean or partially black bean	Severe impact: reduction in aroma, flavor and acidity, eventually increase in bitterness, astringency and causes off-flavors (chemical). Slow to roast	Mealybugs (several *Pseudoccocidae*) and scale insects, particularly the star scale (*Asterolecanium coffeae*)	Leaves, stems and fruiting branches	Worldwide
	Premature ripening	Immature bean	Loss of acidity, increased bitterness, green and common flavor	Coffee Wilt Disease *Fusarium xylarioïdes*	Trunk	Africa
	Stress, impair filling of beans	Light bean	Astringency and sometimes metallic taste. Risk of fermented, rotten fish flavor	Root nematodes *Pratylenchus coffeae* and *Meloidogyne spp.*	Roots	Worldwide
				Root rot disease Several polyphagous fungi, like *Rosellinia spp.*	Roots	Worldwide
				Mealybug root disease (*Phtiriosis*), caused by different species of mealybugs and by *Bornetina coryum*	Roots	Worldwide

berries may prevent overbearing, which has a negative impact on coffee quality (Bardner, 1985).

The impact of pests and diseases that attack branches is similar to the impact of those that attack leaves: They reduce photosynthesis, cause defoliation, and severe attacks have an impact on berry nutrition. Consequently, cup quality can be affected. Stem borers weaken the tree mechanically, resulting in breakage. If the damage is not too severe, no losses will occur in the current year's crop (Waller, 1985). However, as branch growth is affected, potential yield of the following year may be reduced.

Coffee Leaf Rust

The fungus *Hemileia vastatrix* is the causal agent of Coffee Leaf Rust (CLR) (Figure 14, page 300). Lesions produce orange propagules (uredospores) on the underside of the leaves (Figure 15, page 300). It is a severe foliar-specific coffee disease that causes significant economic losses (Muller et al., 2004). The mycelium colonizes leaf tissues, disturbs leaf metabolism to favour its own development, and causes defoliation (Figure 16, page 301). The optimum conditions for spore germination are temperatures of 22°C (20-25°C) with the presence of free water and low light intensity. As a consequence, the disease is more severe at low altitude (below 1300 meters above sea level at the equator). The disease is more likely to cause severe defoliation when the fruit load is high (Avelino et al., 1993). The same genotype can be effectively very susceptible to rust when it has a high fruit load and, conversely, can show field resistance when it has no fruit. Muller et al., (2004) indicates that the change in susceptibility is related to the status of mineral nutrition. Spores can be spread passively by the wind, rain splash or by vectors. The main source of inoculum, especially at the beginning of an epidemic, seems to be the inoculum carried by the diseased leaves of the preceding campaign that remain on the coffee trees. The spatial distribution of the disease is clumped, with foci apparently associated with high yielding spots in the field (Alves et al., 2009).

Brown Eye Spot

Cercospora coffeicola is the fungus that causes brown eye spot or *Cercospora* blotch. *Cercospora* affects both leaves and berries, both of which may fall. It is more serious on young plants which may die when defoliation is severe. Susceptibility to this disease is linked with plant nutrition deficiency, particularly nitrogen and maybe potassium, and over-exposure to sunlight (Muller et al., 2004). Infected leaves exhibit grey-brown spots with a yellow halo and berries exhibit brown lesions. The tissue surrounding the lesions on berries tends to ripen prematurely, however the beans can remain immature although the pulp seems ripe. Furthermore, the pulp is difficult to remove during the wet process and carries the risk of fermentation. Infested trees may be susceptible to die-back (Figure 17, page 301).

American Leaf Spot Disease

Mycena citricolor is the fungus that causes the American leaf spot disease. American leaf spot disease is a new-encounter disease of coffee: the causal agent existed in America before the introduction of coffee. It is not specific to coffee and is found on other plants including weeds. This disease has only been reported in the Americas and the Caribbean. It affects all the aerial organs of coffee trees. Symptoms include brown circular spots on leaves that eventually fall, leaving holes in the lamina. Leaves and affected berries may fall. Avelino et al., (2007) found that the disease is serious at high altitude (over 1200m in Costa Rica).

Impact on coffee quality

Total defoliation results in overbearing stress and die-back of young shoots and branches (Waller, 1985). A large proportion of berries do not mature and may be harvested unripe (Figures 18 and 19, page 302). The berries themselves become more susceptible to diseases. The net result is a large amount of empty or light berries and a general loss of quality (Waller, 1985). Flaky beans may give a woody flavor. Immature beans cause loss of acidity, increased bitterness, distinctive aromas and green flavor (reminiscent of fresh green grass, green foliage, unripe fruit) (Wintgens, 2004). Light immature beans cause astringency and sometimes metallic taste. They may ferment and have a rotten fish flavor (Teixeira and Teixeira, 2005). Severe attacks of Coffee Leaf Rust may result in dead beans that transform into brown beans after the wet process (ISO 2004). These brown beans have a sour flavor and sometimes other off-flavors. The continuous degradation of the bean may lead to black bean defect, which has a severe adverse impact on cup quality that includes a reduction in aroma, flavor and acidity, and increased bitterness, astringency and off-flavors (chemical).

Impact of pests and diseases that reduce sap circulation

Pests and diseases that reduce sap circulation

Diseases that attack the trunk or roots reduce their capacity to take up water and nutrients (Waller 1985). The symptoms are leaf wilting, shedding and chlorosis. The crop may fail to mature, resulting in light or empty beans. In the case of Coffee Wilt Disease (CWD), a vascular disease of the coffee tree trunk caused by Fusarium xylarioïdes that blocks water and sap circulation, the leaves fall, branches die, berries turn red and seem to ripen prematurely (Rutherford, 2006).

Similarly, root nematodes such as *Pratylenchus* spp. and *Meloidogyne* spp. feed on the sap and weaken the tree, which then becomes more susceptible to secondary infection by fungi or bacteria (Villain et al., 2002). When the coffee tree starts producing berries, the plant becomes stressed and looses leaves (Castillo and Wintgens, 2004). Other noxious organisms such as *Rosellinia* spp. and *Bornetina coryum* -which develops on the sugary excretions of mealybugs (Phtiriosis- affect coffee stems or roots with similar impacts.

Scale insects and mealybugs attack various parts of coffee trees including the leaves, stems and fruiting branches. Mealybugs include several *Pseudoccocidae*. They have a soft body. Scale insects such as the star scale (*Asterolecanium coffeae*) are almost immobile after they have found a feeding place. They feed off the sugars in plant sap, and many of them excrete honeydew which is conducive to the formation of sooty mould (Crowe, 2004) that blocks the light from reaching the chloroplasts and hence reduces photosynthesis. Consequently, both mealybugs and scales cause poor growth and reduce yields while increasing the risk of secondary infection (Lan and Wintgens, 2004).

Impact on coffee quality

Reduced raw sap uptake and circulation stresses coffee trees. Stressed trees produce light or immature beans that have a moderate impact on coffee quality. Light beans may increase astringency and sometimes induce a metallic taste, and cupping may reveal fermented or rotten fish off flavors. Immature beans reduce acidity and increase bitterness, green and common flavor.

A lack of carbohydrates has been identified as a cause of black beans (Wintgens, 2004). Scale insects and mealybugs, which feed on sap and hence reduce carbohydrate levels in the plant, favour the appearance of black beans (Figure 20, page 303) or partially black beans, withered beans, and immature or quaker beans, which have a serious impact on cup quality. Black beans reduce aroma, flavor and acidity, and may increase bitterness, astringency and cause off-flavors (chemical).

MANAGEMENT OF PESTS AND DISEASES IN RELATION TO THEIR IMPACT ON CUP QUALITY

Managing pests and diseases may help to reduce quality losses. We use the pest management strategy for Coffee Berry Borer as an example of a success story with lessons that can be applied to better manage other pests and diseases. Disease and pest management measures may have favourable or adverse side effects on quality through mechanisms not directly related to the pest or disease they control. Four important management practices which directly affect diseases and pests and also productivity and quality are discussed within the framework of integrated pest management. They include variety selection, shade management, pesticide use, and plant nutrition (Figure 21, page 303).

Integrated pest and disease management

Coffee species, varieties, genetic characteristics of the noxious organisms, environment (including the biological environment with its beneficial organisms) and management practices all interact and affect pest or disease incidence. Pest and disease incidence varies depending on the combinations of these multiple factors and can be considered as site-specific. Effective disease and pest management is normally based on overall crop management practices that *per se* maintain disease and pest pressure at a low level. Integrated pest management (IPM) is defined by Kogan (1998) as "a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment". The objective is less to eradicate pests or diseases than to maintain populations at acceptable levels at strike a balance between pests and the enemies of pests. IPM includes cultural, biological (trap, parasites or predators) and chemical control of pests and diseases in combination with early warning systems (Söndahl et al., 2005). Thresholds can be founded on a calculated relation between populations and losses, or on experience.

IPM is not limited to the integrated application of chemical, manual or biological control methods, but includes a system approach at the plot and landscape scales in order to enhance ecological mechanisms of control. Diversity and structural complexity are particularly important to maintain a healthy system (Soto-Pinto et al., 2002). Pest and disease incidences are site-specific, as demonstrated by Avelino et al., (2006) for rust, by Avelino et al., (2007) for mycena and by Avelino et al., (2009) for nematodes. Each producer should determine which pests and diseases lead to quantitative and qualitative losses in his plantation. From this information, he can determine which control methods might be useful, taking into account that their impact on pests and diseases may also be site-specific (Muschler, 2001; Beer et al., 1998) (Figures 22 and 23, page 304). Continuous cycles of implementation, observation, interpretation and evaluation should help each grower to improve management and coffee quality (Läderach et al., 2011). The pruning of shade trees can be adapted to seasonal pest and disease risks. In Central America, in low elevation dry zones where *Cercospora* disease and Coffee Leaf Rust are economically important, Staver et al., (2001) recommended that early in the dry season, shade should be at a maximum to reduce *Cercospora* attacks due to high sun exposure and at a minimum in the middle of the rainy season to reduce CLR infection by faster leaf drying.

Within the IPM framework the incidence of the diseases and pests is monitored so that growers can implement specific control measures when a certain level of disease or pest damage has been reached. This level is an intervention threshold. Simple guidelines for monitoring have been published at national or regional level. For instance, simple sampling methods to assess CBB damage have been proposed in the Dominican Republic (Morel et al., 2000) and the recommended control measures vary according to the status of CBB at a particular site. Similarly, in El Salvador, a method to assess CLR incidence has been proposed (Procafé, 2001) and recommended control measures depend on the observed incidence and the period of the year.

There has been an increasing public awareness of the risks to both health and to the environment of chemical treatments and their residues. Several products have been banned to protect human health and the environment. In addition, the accessibility and cost of chemical treatments in the context of fluctuating coffee prices makes growers wary of routine, programmed use of costly pesticides or fungicides. Furthermore, in several cases, use of pesticides has reduced the populations of natural enemies leading to an increase in pest populations a few months after treatment.

Monitoring pest and disease incidences at field level helps growers minimize chemical control. Chemical treatments can be delayed if pest and disease levels remain low: the number of spraying rounds is reduced compared with fixed treatment calendars. Furthermore, chemical control is no longer seen as the only solution to manage pests and diseases.

Consequently various means of controlling CBB populations have been proposed. CBB find an interseason safe haven in the fruits that remain on the coffee trees or fall to the ground. Sanitation harvesting, which consists of collecting all the fruits after harvest, has been recommended since the 1940s. However, this practice is extremely difficult and time-consuming. Traps with an attractant are also used to capture CBB during flight periods (Dufour and Frérot, 2008). Biological control with natural enemies of CBB, like the entomopathogen fungus *Beauveria bassiana* and the parasitoids *Prorops nasuta*, *Cephalonomia stephanoderis*, and *Phymastichus coffea* has been extensively promoted. However, in spite of the progress, biological control alone is not normally sufficient to control CBB populations. Sometimes unexpected effects have been observed. For instance, *Prorops nasuta* carries the *Aspergillus* fungus that can produce ochratoxin A (Vega et al., 2006). Another approach to control is the use of eco-friendly pesticides. Botanical pesticides based on neem oil do not drastically reduce CBB populations, but they may help to control them as part of an Integrated Pest Management programme (Irulandi et al., 2008). However, little is known at the moment about their effects on natural enemies or cup quality. Host plant resistance to CBB attacks is a potential control option, but to our knowledge, no commercially viable varietal solutions are available at present.

Practices described above for pest and disease control may have favourable or, to the contrary, adverse side effects on quality. As examples of how control methods fit into an overall integrated pest management programme, we describe in more detail four practices: variety selection, shade management, pesticide and fertilizer applications. At the same time we recognise that many other practices like pruning, which may prevent overbearing, have beneficial effects on quality (Vaast et al., 2006).

Varietal selection

The coffee variety (Figure 24, page 305) is a crucial determinant of quality (see Chapter 2.3). The coffee varieties grown in Latin America before the arrival of Coffee Leaf Rust on that continent in 1970 came from an extremely narrow genetic base. All varieties were derived from only two introductions: Typica and Bourbon.

CLR is now increasingly being controlled by using resistant varieties, generally derived from the Timor hybrid. This natural hybrid between *Coffea canephora* and *C. arabica,* discovered on the island of Timor, has the distinctive characteristic of possessing all the known genes of complete resistance to CLR meaning that it genes do not permit at all the development of the fungus (Silva et al., 2006).

Breeders have developed a family of varieties known as Catimors derived from the Timor hybrid. This level of introgression of genes from *C. canephora* into *C. arabica* was estimated at between 8 and 27%. The introgression has, in some cases, had a deleterious effect on the chemical and organoleptic characteristics of beans. However, in general, the quality of introgressed varieties is very similar to that of traditional varieties (Bertrand et al., 2006; Leroy et al., 2006; Van der Vossen, 2009). In some Catimor lines, acidity and overall standards were found to be 30% below those of traditional varieties (Bertrand et al., 2003). However, the differences are not stable over the years and only two cases of a constant drop in quality have been clearly established (CR95 and Veranero). It has been suggested that this loss of quality could have been avoided if quality, as well as resistance and yield, had been stressed in the selection process (Leroy et al., 2006; Van der Vossen, 2009). The expression of quality depends on the environmental conditions and crop management. Thus, for example, the quality of Catimor 5175 is equal to that of Caturra when cultivated under shaded conditions, but when grown without shade it was of poorer quality (Muschler, 2001).

The Catimor family is much more susceptible to American leaf spot disease (caused by *Mycena citricolor*) than traditional Arabica varieties. This disease can cause very severe defoliation in high altitude zones shortly before or during the harvest period (Wang and Avelino, 1999; Avelino et al., 2007). This prevents fruits from maturing and results in poor quality coffee.

Shade

Many diseases that directly or indirectly affect the quality of coffee can be controlled by providing moderate shade. At lower altitudes, shade itself is generally beneficial for the production of good quality coffee (physical and organoleptic) as shade extends the fruit ripening period, reduces overbearing by limiting fruit load, and eliminates many physical defects (Muschler, 2001; Vaast et al., 2006).) In the Central Valley of Costa Rica, coffee grown with 45% shade cover was 10 to 26% more acid than full sun coffee (Vaast et al., 2006). In addition, shade coffee had slightly less bitterness and body and the preference score was 8-11% higher. However, there may be tradeoffs: shade may have adverse or favourable consequences for other diseases and pests that reduce coffee quality.

Shade modifies the microclimate of the understory vegetation which, in turn, affects the development of pests and pathogens (Figures 25 and 26, page 305 and 306). For instance, shade trees may intercept rainfall and hence limit the splash dispersal of conidia of Coffee Berry Disease (*Colletotrichum kahawae*) (Mouen Bedimo et al., 2008). Similarly, shade may lower temperature and maintain higher soil moisture content and hence lower the incidence of coffee brown eye spot disease (*Cercospora coffeicola*) (Echandi, 1959; Staver et al., 2001).

Microclimate modifications also affect host physiology and hence, indirectly, pests and diseases. Coffee Leaf Rust epidemics are known to be more intense when coffee yield is high (Avelino et al., 2004; Avelino et al., 2006), a condition which is often reached with full exposure to sunlight. As a consequence, shade may reduce yield and hence reduce the severity of CLR (Avelino et al., 2004; Avelino et al., 2006). Similarly, *Colletotrichum spp.*, which is associated with overbearing and causes die-back, can be almost completely suppressed by shading, which reduces the number of flowers and hence regulates overbearing.

Several pests and pathogens thrive in the microclimatic conditions of shaded plantations. Shade favours *M. citricolor* (Avelino et al., 2007), probably due to the associated higher humidity. Similarly, Coffee Berry Borer´s life span is greater under high humidity and when temperatures are close to 23-25°C (see 1.1.1), conditions which are frequently provided under shade (Feliz Matos et al., 2004; Bosselmann et al., 2009)d.

Some plant species may constitute alternate hosts or reservoirs for pests and pathogens. Indeed, several pests and diseases of coffee are not specific to coffee. In particularly, *M. citricolor* is able to attack more than 150 plant species belonging to 45 families, including legume trees, which are commonly used as shade trees in Mesoamerica. The CBB has also been reported to find refuge and breed in other fruits (Damon, 2000; Gumier-Costa, 2009).

Pesticides

Generally, disease and pest control methods including chemical pesticides help to improve coffee quality by preventing the proliferation of pests and diseases which negatively affect quality. Pesticides used to control pests and diseases are known to affect the sanitary quality of food products and in some cases they may also affect organoleptic quality. That is the case of organochlorine pesticides. Organochlorine pesticides have been banned and are no longer used for control of CBB due to both the potential toxicity of residues in the coffee beans themselves and also adverse effects on the environment where coffee is grown. Use of a systemic fungicide and a cupric fungicide reduced the number of defects and hence improved the classification of coffee samples. Silveira et al., (1983) found no differences in beverage quality between plots where different fungicides were applied. However, repeated used of cupric fungicides can contaminate soils and plants, and reports of high Cu content in coffee beans could suggest a possible toxicity problem (Loland and Singh, 2004). Nevertheless, the overall use of pesticides tends to reduce physical defects and to improve the organoleptic quality of coffee. At the same time it should be noted that excessive or inappropriate use of pesticides could lead to potential health problems for consumers and may also have a negative impact on the environment. Judicious use of pesticides in a well-managed integrated pest management programme will improve coffee quality.

Plant nutrition

Some diseases, such as die-back due to *Colletotrichum* spp. or brown eye spot due to *Cercospora coffeicola*, are closely associated with management practices that affect the physiology of the plant. Both these diseases, which can reduce coffee quality, are less severe when plant nutrient status is optimal. In general, plants with good nutritional status can replace dead tissues more easily. This effect has been suggested for Coffee Leaf Rust and American leaf spot, where the disease intensity was negatively associated with number of fertilizer applications (Avelino et al., 2006; Avelino et al., 2007). In addition, adequate plant nutrition can increase the resistance of plants to pathogens. The disease severity of facultative parasites, which kill host plant cells in order to feed, is normally reduced by nitrogen applications (Dordas, 2008). This has been reported for brown eye spot disease and die-back associated with *Colletotrichum* spp. infections in coffee. Potassium is important for fruit development and maturation. Lack of potassium and zinc can lead to die-back, but spraying the foliage with zinc may aggravate the damage caused by *Colletotrichum* spp. depending on sanitary precautions. Organic matter is likely to favour various microorganisms which help controlling root diseases (Snoeck and Lambot, 2004). Furthermore, mulching has been reported to help withstand the effect of infections, particularly during the dry season (Adejumo, 2005). Mulching leads to increased bean size probably by favouring conservation of soil water. Mulch can cause a K/Mg soil imbalance, which may reduce bean quality and cause a loss of acidity (Lambot and Bouharmont, 2004). Excessive use of fertilizers may also negatively modify coffee sensory characteristics. Excess of potassium may lead to harder beverages, whereas more bitter coffees are obtained with abundant nitrogen applications.

CONCLUSION

The potential negative impact of pests and diseases on coffee quality is clearly established. They impair physical quality by producing defective beans. They alter sensory quality of beans which may produce a common cup or a cup with off-flavors (Figures 27 and 28, page 306 and 307). They impair health quality by increasing the risk of ochratoxin A contamination. Data are available on the visible damage caused by pests such as Coffee Berry Borer and the relationships between infestation rates and cup quality. However, effects are often underestimated because most of the deleterious effects of disease and pest attacks are the result of combinations of several factors. Black beans may be the result of diseases, insufficient water during ripening or a lack of carbohydrates induced by scale and mealybug attacks. Little is known about the threshold level of pests and diseases which cause damage to coffee quality, making it difficult to determine when control measures are justified.

Many of the techniques for managing pests and diseases –multiple varieties, shade, pesticides and fertilizers- directly influence the quality of the coffee, and although they may reduce disease and pest damage, they may sometimes actually decrease coffee quality. Nevertheless, judicious use of control measures will almost certainly improve coffee quality by reducing physical defects and improving cup quality. Pest management programmes vary in space (site specific) and in time (both during the year and between years). Monitoring of pests and diseases using simple guidelines that now exist assists growers in pest management and helps them avoid excessive use of pesticides or other control measures. In order to manage coffee quality effectively, the plantation should be considered as a whole system, with pest and disease control and management integrated with the overall production system. To our knowledge, few studies consider the whole system.

Finally, coffee growers are facing a new challenge with climate change. Modifications of temperature and rainfall patterns will affect pest and disease distribution. Moreover, coffee trees under physiological stress induced by climate change are expected to be more susceptible to pests and diseases. Establishment of risk maps under different climate change scenarios, coupled with continuous site-specific monitoring, will improve our understanding of which agronomic practices should be implemented to control pests and diseases and assist in avoiding quality changes.

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