Quality and safety of cocoa beans

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6

QUALITY AND SAFETY OF COCOA BEANS

LÍDIA J. R. LIMA AND M. J. ROB NOUT

Contents

6.1 Introduction

Cocoa epitomizes one of the commodities with a most complex supply chain. This is due to the need for postharvest processing in the country of origin prior to industrial transformation into a variety of commercial products. The postharvest processing, consisting of cocoa bean fermentation and drying (as addressed in previous chapters), has a pivotal role in the value chain as it determines the range of subsequent cocoa bean applications. Cocoa bean batches that have not undergone fermentation or that have been poorly fermented are unsuitable for the manufacture of cocoa powder and chocolate, and can only be used for fat extraction. Thus, the progression of "commercial cocoa beans" (i.e., beans that have undergone some kind of postharvest processing prior to trading) in the chain depends on their score on selected quality traits, ultimately determining farmers' remuneration. In addition to quality parameters, the industrial requirement of assuring consumer health adds a dimension of safety to the global evaluation of commercial cocoa beans.

To understand the factors affecting the quality and safety of commercial cocoa beans, it is important to critically analyze the chain of cocoa bean production. Six main features may be identified:

1. There are more than 40 producing countries in the world (ADM Cocoa 2009; ICCO 2011c) and within each country, and sometimes even regions within the same country, the planting material, the cultivation conditions, and the exact postharvest processing method vary, which results in commercial cocoa beans of distinct characteristics (yield of edible material, degree of bean fermentation, potential to produce chocolate of strong flavor, etc.) (Aculey et al. 2010; Baker et al. 1994; Clapperton et al. 1994a; Davies et al. 1991; Motamayor et al. 2008; Nielsen et al. 2007). The fact that about 90–95% of all cocoa in the world is produced by small-holder farmers contributes to the high variability of cocoa characteristics in the market (ICCO 2008).
2. It is estimated that between 20% and 40% of the global primary production of cocoa is lost annually, due to fungal diseases and insect attacks. Black pod disease (caused by fungi-like *Phytophthora* spp.), witches' broom (caused by the

fungus *Moniliophtora perniciosa*), mirids (insects from the family Miridae), and the cocoa pod borer moth (insect belonging to the species *Conopomorpha cramerella*) constitute the most widespread and devastating pests (pests are here defined as any organism that harms crops) (Bateman 2009; Fowler 2009). Control of these pests requires strategies employing various types of pesticides in combination with adequate phytosanitary practices.

3. The fermentation and postfermentation handling of cocoa beans is still nowadays performed under very rudimentary conditions, relying on environmental contamination and conducted in open-air systems, where microbiological control is limited or nonexistent. This inevitably results in batches containing not only high microbial levels but also considerable proportions of adulterants and foreign material (Burndred 2009). Moreover, the absence of rigorously implemented processing protocols and use of defined microbial starter cultures undermine the attainment of batches with homogeneous quality.
4. Cocoa bean plays a major role in the economy of many countries, notably in West African countries (Akinnifesi et al. 2006; Folayan 2010; Ntiamoah and Afrane 2008), and for many farmers it is their only source of revenue. This means that, in order to increase throughput, some agronomic and processing practices may be neglected, impairing the quality of the final commercial product.
5. For some applications of cocoa beans, namely, for cocoa butter extraction, bean fermentation is not always a requirement. Consequently, unless preagreements on separate circuits have been made, unfermented beans will contribute to increase the fraction of beans with flavor defects in the market.
6. Although dried cocoa beans constitute a reasonably stable product, precautions are needed to avoid infestation by insect pests and molds during storage and transportation (Bateman 2009; Dand 1993). Although residue-free methods based on temperature and atmosphere control have proven to be technologically effective (Fowler 2009), they are not cost-effective and chemical strategies are still the basis of control.

All these factors determine the characteristics of commercial batches of cocoa beans and have led to the establishment of a framework to evaluate their quality and safety, providing guidelines along which cocoa beans are traded.

In this chapter, the quality and safety requirements of commercial cocoa beans are addressed followed by a discussion of methods that are presently used to determine bean quality and safety. Attention is given to regulatory bodies and legislative aspects. Finally, we critically discuss and analyze future prospects in this field.

6.2 Quality and Safety Requirements for Commercial Cocoa Beans

6.2.1 Standards for Commercial Cocoa Beans

"Quality" is frequently defined as "the total of features and characteristics of a product or service that bears on its ability to satisfy given needs" (ASQC 2010) or simply "fitness for use" (Luning et al. 2006). "Safety" refers to the "need of absence of hazards with an acceptable risk" (Luning et al. 2006), with hazards encompassing biological, chemical, and physical agents or conditions, which can affect consumer health (ISO 2005). Safety can be understood as an intrinsic attribute of quality. However, for clarity of explanation, we will keep these two concepts separate in this chapter.

Generally speaking, good-quality commercial cocoa beans should be a synonym of excellent flavor potential (i.e., adequate proportion of precursor compounds of the cocoa flavor and balanced composition of metabolites of the "fermentation flavor" (Lima et al. 2011a)), excellent color (fully brown), high yield of usable material, and absence of contaminations. However, the exact criteria on which the quality of cocoa beans is assessed depend on the stage in the chain. Cocoa trade associations, namely, the Cocoa Merchants' Association of America (CMAA) and the Federation of Cocoa Commerce in Europe (FCC), have developed "standard trade contracts," which are used to trade cocoa beans in the countries of origin, and in the so-called actual markets (Fowler 2009; ICCO 2011a). These standards are based on easily measurable and observable characteristics that require only simple equipment. In the United States, the Food and Drugs Administration (FDA) and the Intercontinental Exchange (ICE) also set standards.

Producing countries frequently use FDA/ICE standards as guide for the dissemination of quality parameters among farmers and cooperatives (Fowler 2009). Later in the chain, cocoa bean processors and chocolate manufacturers, who seek to provide the market with products of consistent quality and characteristics (e.g., strong cocoa flavor), define more elaborate benchmarks (Dand 1993; Fowler 2009).

While some cocoa bean characteristics can be objectively detected or quantified, others, such as chocolate flavor, are highly subjective. Consequently, the quality definition of cocoa beans is strongly dependent on the identification of negative aspects. Different types of defects can be found in cocoa bean batches (ADM Cocoa 2009; BCCCA 1996; Dand 1993; Fowler 2009). These are

- "Smoky"—beans contaminated by smoke flavor during artificial drying. This is considered the worst off-flavor, since the incorporation of minute quantities of cocoa beans contaminated with smoke is sufficient to result in chocolate with flavor defects.
- "Moldy"—beans infected by molds. This only refers to the contamination of the inside of the beans and not on the outside. The access to the inside of the bean can take place as a result of shell fracture, due to germination-damage or insect attack. The use of as little as 3% of moldy beans for chocolate making has been found to cause an unpleasant taste in chocolate. In addition to taste, mycotoxins could be formed, if molds grow inside the beans.
- "Underfermented"—beans with a gray or violet coloration, indicating, respectively, beans that have not been fermented or beans of which the fermentation has been halted prematurely. They are commonly designated as "slaty" beans. Underfermentation results in cocoa beans that are excessively bitter, astringent, and lack cocoa/chocolate flavor.
- "Overfermented"—beans with a "putrid" or "dull" smell, resulting in chocolate with an unpleasant taste.
- "Insect-damaged"—insect-penetrated and attacked beans, rendering cocoa beans unsuitable for manufacturing.
- "Acidic"—beans with an excessively high content of organic acids, which might have resulted from fast, artificial drying

or from other not well-known causes linked to the fermentation (discussed by Lima et al. (2011a)). It is an undesirable characteristic, since even with neutralization of the acids, the chocolate flavor is negatively affected (Dand 1993).
- "Germinated"—beans of which the shell has been pierced by the growth of the first root, leaving an opening favorable to attack by insects and molds.
- "Flat"—beans that contain no cotyledons or are incompletely developed.

Table 6.1 presents an overview of the contract standards that are used for grading the quality of commercial cocoa beans in the countries of origin. Table 6.2 presents the quality and safety requirements for cocoa beans used by processors and chocolate manufacturers. In Table 6.1, the criteria basically deal with economic aspects, such as aspects related to the yield of usable material, while in Table 6.2, factors pertaining to physical properties, flavor, and safety of cocoa beans are included. In Table 6.2, economic and qualitative aspects are considered together as part of the quality components of commercial cocoa beans.

The quality and safety parameters in Tables 6.1 and 6.2 vary within regions and country of origin. This variability and diversity determines the demand for certain types of cocoa in detriment of others, as well as the definition of their price in "future markets" (exchanging platforms where agreements are made with respect to price and delivery) (ICCO 2011a).

In the following sections, after dissecting the type of categories of commercial cocoa beans, we will present quality characteristics of cocoa butter (Table 6.2—B) and discuss aspects dealing with safety of cocoa bean, specifically contamination by mycotoxins, pesticides, heavy metals, and hydrocarbon compounds (Table 6.2—C), as well as occurrence of bacterial pathogens.

6.2.2 Categories of Commercial Cocoa Beans

Commercial cocoa beans are generally classified into "bulk" cocoa and "specialty" cocoa (ADM Cocoa 2009; Dand 1993; Fowler 2009). Bulk cocoa beans consist of beans that generally derive from the

Table 6.1 Comparison of Cocoa Beans Contract Standards

			FAULTS				
	DESCRIPTION (EXAMPLE OF GROWTH/GRADE)	BEAN COUNT	MOLDY (%)	SLATY (%)	INFESTED (%)	MOISTURE (%)	FOREIGN MATERIAL
FAO model of ordinance[a]	Grade 1	NS[b](uniform in size)	3	3	3[c]	7.5	"Virtually free"
FCC[d]	Good fermented main crop	100/100 g	5[e]	5	–[e]	NS	<1.5%[f]
ICE/CMAA[g]	Ghana (main crop)	1000/kg	4[h]	10	4[h]	NS	NS

Source: Adapted from Fowler, M. S. 2009. *Industrial Chocolate Manufacture and Use*. 4th edn., Oxford: Wiley-Blackwell, pp. 10–47.

[a] FAO specifies that cocoa must be fermented, free of foreign odors, and must not be adulterated.

[b] NS—not specified.

[c] Includes germinated and flat beans as well as insect damaged.

[d] FCC specifies that the beans should be uniform in size, homogeneous, and fit for the production of foodstuff. The beans must be virtually free from contamination, which includes smoky, hammy, or other off-flavor, taste, or smell.

[e] Maximum 5% defectives (infested are included under moldy).

[f] <1.5% waste passing through a 5 mm sieve. Additionally flat beans, bean clusters, broken beans, and foreign material must not be excessive.

[g] ICE/CMAA specify that hammy or smoky cocoa are not deliverable.

[h] Maximum amount of moldy and infested beans is 6% (FAO Administration Defect Action Levels).

Table 6.2 Commercial Cocoa Beans Quality and Safety Requirements from the Point of View of Cocoa Beans Processors and Chocolate Manufacturers, and Corresponding Monitoring Methods

	SPECIFICATIONS OR LIMITS	COMMENTS	MONITORING METHOD	REFERENCES
A: ECONOMIC ASPECTS				
Moisture	<7% or 8%	Mold growth prevention and prevention edible material yield reduction	ICA analytical method 43/1993 and ICA 1/1952	ICA1 (1952); ICA43 (1993)
Bean size and size distribution	Typically 100 beans/100 g or 110 beans/110 g. Fraction of beans retained on certain sized sieves	Influence on the yield of useful material and the unit operations in the factory, such as bean breaking and uniformity of whole bean roasting	ICA analytical method 47/2001	ICA47 (2001)
Shell	Typically 12–16% (w/w)	Influence on the yield	AOAC 968.10 and 970.23	AOAC (1974a); AOAC (1974c)
Fat	Typically 50–57% in dry nib	Influence on the cocoa butter yield	ICA analytical method 14/1972 and 37/1990	(CA14 (1972); ICA37 (1990)
Foreign materials	Absent or <1–5% (FCC)	Influence on the purity and yield of edible material	Cut-test	ISO (1977)
Flat, germinated, and infested beans	<3% (FAO standard) and see Table 6.1	Influence on the yield of edible material, purity, and wholesomeness	Cut-test	ISO (1977)
B: QUALITATIVE ASPECTS				
Unfermented (slaty) beans	See Table 6.1	Excessive slaty beans give an astringent taste and grayish color to the chocolate	Cut-test	ISO (1977)
Flavor and desirable ancillary flavors	Various; often not specified	Influence on the specific flavor characteristics of the final chocolate	Sensorial analysis of chocolate	ICA 12 (1971)

Off-flavors (e.g., smoky, hammy)	Absent	Influence on the specific flavor characteristics of the final chocolate	ICA analytical method 44/1996	ICA 44 (1996)
Cocoa butter hardness	Various	Influence on the eating quality of chocolate (snap and melting properties)	ICA analytical method 4/1962 and ICA analytical method 31/1988	ICA 4 (1962); ICA 31 (1988)
Free fatty acids in cocoa butter	Max. 1.75% (EU and Codex Standards)	Increased levels contribute to a decrease in hardness of cocoa butter (Pontillon1998)	ICA analytical method 42/1993	ICA 42 (1993)
Unsaponifiable matter in cocoa butter	Max. 0.35% (w/w) for pressed butter and max. 0.5% (w/w) for butter obtained by other methods (Codex Standard 86 1981; European Council 2000)	Allows assessing the purity of cocoa butter	ICA analytical method 23/1988	ICA23 (1988)
C: SAFETY ASPECTS				
Moldy beans	3–5% (see Table 6.1)	Influence on the specific flavor characteristics of the final chocolate Potential for mycotoxins and high level of free fatty acids	Cut-test	ISO (1977)
Mycotoxins	There are no specifications for cocoa beans (Commission Regulation 2006a; Commission Regulation 2010a)	Mycotoxins should be monitored due to the occurrence of different mycotoxin-producing fungi in the cocoa chain	AOAC Official Method 2005.08	AOAC (2005); Commission Regulation (2006b); Commission Regulation (2010a)
Infested or insect damaged beans	3–5% (see Table 6.1)	Influence on the wholesomeness	Cut-test	ISO (1977)

continued

Table 6.2 (continued) Commercial Cocoa Beans Quality and Safety Requirements from the Point of View of Cocoa Beans Processors and Chocolate Manufacturers, and Corresponding Monitoring Methods

	SPECIFICATIONS OR LIMITS	COMMENTS	MONITORING METHOD	REFERENCES
Pesticides	Absent or below maximum residue limits (MRLs) defined by Commission regulations (Commission Regulation 2005; Commission Regulation 2008)	Influence on consumer safety	Residues analytical methods No. SANCO/10784/2009 from the European Commission (EC)	European Commission (2009)
Heavy metals	There are no specifications for cocoa beans (Commission Regulation 2006b)	May require regular monitoring due to existence of maximum levels for commercial cocoa butter and chocolate	We provide the examples of lead: AOAC 934.07 and 972.25; and cadmium: AOAC 945.58 and 973.34	AOAC (1974b); AOAC (1976); AOAC (1993a); AOAC (1993b)
Hydrocarbons	There are no specifications for cocoa butter (Commission Regulation 2006b)	Can result from cocoa coming into contact with smoke during artificial drying or mineral oils in jute sacs used for their transport	ISO 15302:1998, ISO/AWI 22959 and ISO/AWI 24054	ISO (1998); ISO (2004a); ISO (2004b)

Source: Adapted from Fowler, M. S. 2009. *Industrial Chocolate Manufacture and Use*. 4th Edition, Oxford: Wiley-Blackwell, pp. 10–47.

widely cultivated *Forastero* variety of bean. They represent over 95% of the total cocoa traded in the world, being used for the manufacture of milk and dark chocolate, cocoa powder, and extraction of cocoa butter (Fowler 2009; ICCO 2011f). Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil, and Ecuador are some examples of suppliers of bulk cocoa beans. In this group, commercial cocoa beans from Ghana embody the regular supply of adequately fermented and dried cocoa beans, setting a reference against which all other cocoa beans are evaluated (Fowler 2009). Commercial cocoa beans from other countries have often been criticized for inconsistent quality, underfermentation problems (specifically Ivory Coast, Nigeria, Ecuador, and Indonesia), or off-flavor defects (smoky in Cameroon and Brazil and acidic in Brazil) (ADM Cocoa 2009; Fowler 2009).

Specialty cocoa is a broad category, which comprises commercial cocoa beans with a distinguishing feature. Such features consist of "flavor" or "fine," which are specific for a certain origin and are characterized by exquisite flavor traits; "environmentally friendly," such as organic and rainforest protection-certified; cocoa produced under a system of predefined operations, as in UTZ certified; and cocoa marketed under a commitment to improve growers and farmers' livelihood, for example, "fair trade" (Fowler 2009).

Fine commercial cocoa beans have special ancillary flavor notes and/or a special color, and are especially used to manufacture dark chocolate. This category of beans, which presently represents less than 5% of the total cocoa bean supply, originates from *Criollo*, *Trinitario*, and a *Forastero* cross called *Nacional*. *Nacional* subvarieties, also known as *Arriba*, are found in Ecuador. Ecuador is the world's largest supplier of fine cocoa, followed by Papua New Guinea, Venezuela, Madagascar, Indonesia, Trinidad and Tobago, São Tomé and Principe, Grenada, and Jamaica (Fowler 2009; ICCO 2011c). In this group of countries, only Venezuela, Madagascar, Trinidad and Tobago, Grenada, and Jamaica grade the total output of cocoa beans exported as fine. For the remaining countries, this percentage varies between 1% and 75% (Fowler 2009). Fine cocoa beans are known for character descriptors, such as "fruity" (e.g., Jamaica and São Tomé and Príncipe), "floral" (e.g., Ecuador and Papua New Guinea), and "raisin" (e.g., Jamaica and Trinidad and Tobago). Besides commanding higher price in the market, fine commercial cocoa beans have their own supply circuits and a tighter quality control than bulk cocoa beans (Fowler 2009).

The specific flavor requirements for both bulk and fine cocoa beans vary according to the manufacturer's in-house recipes for cocoa liquor and chocolate (Table 6.2—B).

In some regions, due to relatively dry climatic conditions, it is possible to conduct production by organic farming. These include regions of Madagascar, Tanzania, Uganda, Belize, Bolivia, Brazil, Costa Rica, Dominican Republic, El Salvador, Mexico, Nicaragua, Panama, Peru, Venezuela, Fiji, India, Sri Lanka, and Vanuatu (ICCO 2011e). Currently, the organic cocoa market share is estimated to be less than 0.5% of the total production. Similarly to fine cocoa, organic cocoa has the advantage of attracting premium prices from consumers, rendering increased revenue to farmers (ICCO 2011e).

UTZ CERTIFIED is a "worldwide certification program officially launched in 2002 that sets standards for responsible agricultural production and sourcing" (UTZ 2011). The designation UTZ comes from the Mayan word "Utz," which means "good" (UTZ 2011). In 2007, a joint initiative of different cocoa bean processors and chocolate manufacturing companies together with the UTZ CERTIFIED organization launched a framework for cocoa. The aim of the initiative was to increase transparency in the operations dealing with the primary production and postharvest processing of cocoa beans, as well as to ensure better prices for farmers. Within this program, farmers are obliged to grow cocoa trees and process cocoa beans according to an internationally accepted "Code of Conduct" (UTZ 2009). The UTZ certification has been applied in the Ivory Coast, the Dominican Republic, Ghana, Nigeria, Peru, Tanzania, and Vietnam, and extensions within these and other cocoa-producing countries are foreseen (UTZ 2011).

Rainforest alliance certification aims to promote the access of farmers to resources, the development of their livelihood, and general regional economic growth, in equilibrium with the sustainable preservation of the ecosystems (Rainforest Alliance 2011). In this certification, farmers should follow social and environmental practices, defined in the standards established by the Sustainable Agriculture Network (SAN 2011).

Fair trade is a social movement that seeks to promote and improve trading conditions for farmers, by creating credit and market access to farmers and shortening the path from primary production to consumer. Ultimately, the aim of this movement is to increase farmers' income and livelihood (Fair Trade 2011).

6.2.3 Cocoa Butter Characteristics

Cocoa butter, a yellow fat extracted from cocoa bean, is a high-priced component of cocoa bean and one of the most expensive commodity-based vegetable fats (ADM Cocoa 2009). Cocoa butter is the ingredient in chocolate that determines its physical characteristics, such as the hardness, peculiar melting behavior at human body temperature, plasticity, viscosity, soft texture, and gloss (Hanneman 2000; Liendo et al. 1997).

Cocoa butter is defined in the European directive 2000/36/EC (European Council 2000) as the "fat obtained from cocoa beans or cocoa beans parts, with a free fatty acid (FFA) content (expressed as oleic acid) not higher than 1.75% (w/w), and an unsaponifiable matter not higher than 0.5% (w/w), in the case of expelled and refined butter, and 0.35% (w/w) in the case of pressed butter." The definition on the Codex Standards (Codex Standard 86 1981) is essentially the same as the European Directive.

Cocoa butter characteristics are largely determined by its triacylglycerols (TAGs), which represent about 97% of the total composition. The remaining fraction includes FFAs, mono- and diacylglycerols, phospholipids, glycolipids, and unsaponifiable matter (Pontillon 1998). With respect to the content of fatty acids, three fatty acids generally account for over 95% of the total composition in cocoa butter: these are palmitic (C16:0), stearic (C18:0), and oleic (C18:1 cis-9) acids. Of the remaining acids, linoleic acid (C18:2(n-6)) makes up the highest fraction (Talbot 2009a). However, the exact composition of cocoa butter is a function of the type of cocoa tree, age of the plant, country of origin, and season of pod harvesting (Clapperton et al. 1994b; Lehrian et al. 1980; Talbot 2009a). Furthermore, factors such as type and duration of the fermentation could also play a role on its composition and physical characteristics (Lima et al. 2011a).

In contrast with other fats, cocoa butter is predominantly composed (up to higher than 80%) of symmetrical monounsaturated TAG molecules, that is, molecules which bear oleic acid in the 2-position of glycerol, while the saturated fatty acid palmitic and/or stearic occupy 1- or 3-positions. These TAGs are often referred to as SOS, where "S" means saturated fatty acid and "O" oleic acid (Talbot 2009b). The remaining TAGs are of the following types: trisaturated (SSS), monounsaturated (SSU and SUS), diunsaturated (SUU and USU), and triunsaturated (UUU) (ADM Cocoa 2009).

The content of SOS molecules in cocoa butter is responsible for its hardness, high stability, and narrow melting range (ADM Cocoa 2009; Talbot 2009b). The presence of the natural antioxidant tocopherol also confers high stability to cocoa butter (Talbot 2009b). The ratio between the SOS and SOO types within the TAGs has shown to vary across cocoa butter samples from different origins, resulting in cocoa butters with different hardness. For instance, Brazilian cocoa butters have a higher level of SOO than the Ghanaian, Malaysian, and Indonesian butters and, therefore, are less solid at room temperature. On the other hand, Malaysian and Indonesian cocoa butters are harder than the Ghanaian butters. In addition to the origin, it was demonstrated experimentally for pods from Brazilian plantations that a lower average daily temperature during the lasts months of pod development contribute to softer cocoa butters (Lehrian et al. 1980).

The aforementioned factors are taken into account for the purpose of chocolate making, where an ideal melting point and solidification (crystallization) behavior of chocolate is sought (Talbot 2009a).

In Table 6.2, the criteria for cocoa butter quality are summarized. These contemplate aspects related to the amount of fat (Table 6.2—A), hardness, content of FFAs, and unsaponifiable matter (Table 6.2—B). Cocoa industrials seek beans with a high fraction of fat and a low level of acidity and unsaponifiable matter (fraction of material in the fat which is not saponified by an alkali or that is not volatile (Dand 1993)). The fraction of fat varies according to the type of cocoa population and genotype (Khan et al. 2008; Pires et al. 1998). With respect to FFAs, when present at low concentrations, these are regarded as contributing to the normal flavor of cocoa. However, at higher concentrations, FFAs contribute to softening of cocoa butter and to flavor deterioration, and, for this reason, a benchmark of maximum 1.75% FFAs was set to control the quality of cocoa butter (Table 6.2—B).

There are no criteria defined with respect to safety (Table 6.2—C), although the Codex standard for cocoa butter to be used in the manufacture of chocolate defines maximum levels for heavy metals, specifically arsenic (0.5 mg/kg), copper (0.4 mg/kg), lead (0.5 mg/kg), and iron (2 mg/kg) (Codex Standard 87 1981).

6.2.4 Safety of Commercial Cocoa Beans

6.2.4.1 Mycotoxins Mycotoxins are secondary metabolites of fungi that can cause acute or chronic disease in vertebrate animals upon ingestion of contaminated food or feed (Frisvad et al. 2007; Magan and Aldred 2007). This definition does not include fungal toxins active against other living forms, such as bacteria and nonvertebrate animals, and toxins produced by members of *Basidiomycota phylum* (i.e., mushrooms and related fungi) (Frisvad et al. 2007).

Several mycotoxins were described to date, but two of them are of special concern, due to their broad span of occurrence and high toxicity. These are Aflatoxins (AFs) and Ochratoxin A (OTA). AFs are notable as being potently carcinogenic, while OTA is notable as a nephrotoxic agent (Frisvad et al. 2007; Pfohl-Leszkowicz and Manderville 2007). AFs are produced by certain species of the genus *Aspergillus* (e.g., *A. flavus* and *A. parasiticus*) and *Emericella* (e.g., *E. olivicola*). OTA is also produced by species within the *Aspergillus* genus (e.g., *A. carbonarius*), in addition to species of the genus *Penicillium* (e.g., *P. verrucosum*) and *Petromyces* (*P. alliaceus*) (Frisvad et al. 2007).

Not all strains within a fungal species appear to have the ability to produce mycotoxins. Furthermore, production of mycotoxins depends on environmental factors, such as temperature, water activity, pH, and type of growth medium (Amézqueta et al. 2008; Esteban et al. 2006; Frisvad et al. 2007; Mounjouenpou et al. 2008). For instance, higher production of OTA was observed for a strain of *A. carbonarius* when grown at 20°C than at 30°C (Esteban et al. 2004) and for growth at a water activity of 0.90 than at 0.99 (Esteban et al. 2006). However, for another strain of *A. carbonarius*, no toxin production was detected at water activities of 0.90 or below (Esteban et al. 2006). As a consequence, there may be little correlation between the presence of molds in cocoa beans and the occurrence of mycotoxins (Fowler 2009).

The Commission Regulation (EC) 1881/2006 (Commission Regulation 2006a) sets maximum levels for different mycotoxins in foodstuff, including AFs and OTA. In this regulation, cocoa and cocoa-derived products are not considered to be an important source of AFs or OTA and, therefore, no maximum limits have been established (Commission Regulation 2010b) (Table 6.2). This regulation superseded an initial proposal to establish a maximum level of 2 µg/kg for OTA for commercial cocoa beans and cocoa-derived products (European Commission 2003). Nevertheless, different research groups have investigated the incidence of mycotoxins, especially OTA, in commercial cocoa bean and final commercial cocoa products, as well as the ability of the production of mycotoxins among fungal species isolated from these products.

Strains of *A. flavus* and *A. parasiticus* isolated from cocoa beans have been shown to be active producers of AFs, while strains from *A. carbonarius*, *A. niger* aggregate, *A. ochraceus*, *A. melteus*, and *A. westerdijkiae* were implicated in the production of OTA (Amézqueta et al. 2008; Mounjouenpou et al. 2008; Sánchez-Hervás et al. 2008; Scott 1969).

In a study by Bonvehí (2004), 76% of the analyzed commercial cocoa beans originating in West Africa and Cameroon were positive for the presence of OTA, with levels varying from 0.1 to 3.5 µg/kg. Copetti et al. (2010) found 51% of sun-dried Brazilian cocoa beans to be positive for OTA, but only 1.2% had levels higher than 2 µg/kg (maximum level was 5.54 µg/kg). Similarly, Magalhães et al. (2011) reported an incidence of 55% of OTA contamination in dried (bulk) Brazilian cocoa beans, but no samples had levels higher than 2 µg/kg. Curiously, in the latter study, OTA contamination of specialty cocoa (fine and organic) was much higher, reaching 100% incidence for fine cocoa from the early crop season. However, also in this case, the fraction of samples with levels higher than 2 µg/kg was low (11.1%, with an average level of 5.43 µg/kg).

In vitro studies on AF production have shown a high susceptibility of *A. parasiticus* to increasing levels of caffeine in cocoa beans (Lenovich and Hurst 1979). This could be partially responsible for the low incidence of mycotoxins in cocoa.

Despite the fact that shelling of cocoa beans may give a reduction of OTA by levels between 50% and 95% (Amézqueta et al. 2005; Manda et al. 2009), OTA has been detected in a number of samples of cocoa mass (50%), cocoa cake (92.5%), and cocoa powder (93%), at levels ranging from 0.1 to 9 µg/kg (Bonvehí 2004). Such findings emphasize the need for more stringent control of conditions for storing cocoa-derived products. Copetti et al. (2012) observed that growth and OTA formation by *A. carbonarius* and *A. niger* was lowered in bean fermentations in which higher levels of acetic, lactic, and citric acid accumulated.

6.2.4.2 Bacterial Pathogens *Salmonella* is the most important bacterial pathogen of concern to cocoa processors and chocolate manufacturers, due to the implication of low levels of *Salmonella* in outbreaks of salmonellosis linked to consumption of chocolate (Hockin et al. 1989; Werber et al. 2005). The source of contamination of chocolate in the outbreaks reported by Hockin et al. (1989) and Werber et al. (2005) was unknown. In fact, difficulties in identifying the source of contamination by *Salmonella* has been a major hindrance in the development of measures aimed at controlling *Salmonella* in commercial cocoa products (Burndred 2009).

The concern about the occurrence of *Salmonella* in commercial cocoa products is reflected in the microbiological quality guidelines defined by industrial processors for cocoa liquor and cocoa powder. These guidelines specify the absence of *Salmonella* in 30 samples of 25 g, that is, in 750 g (Kamphuis 2009).

Because of the nature of postharvest processing and conditions in the supply chain, *Salmonella* can be expected in commercial cocoa beans, although a recent study in Brazil revealed a very low incidence of *Salmonella* at different stages of postharvest (only one sample was positive in a total of 119) (Nascimento et al. 2010). The presence of *Salmonella* in commercial cocoa beans is, nevertheless, not a reason for rejection of a commercial batch (Fowler 2009).

Salmonella is unlikely to survive cocoa bean roasting; yet, it has been detected in a microbiological survey of commercial cocoa powder samples (Lima et al. 2011b). Such findings suggest contamination by the organism after roasting and, therefore, the need for stringent control of the production environment.

6.2.4.3 Pesticides Cultivation methods, which are based on good agricultural practices (GAP), are considered to be the essential first step in the control of pests. These include adequate canopy management, weeding, regular and complete harvesting, and sanitary pruning and disposal (ICCO 2011b). However, these are not enough. The use of pesticides during cultivation of cocoa is necessary to allay or block the access of pests, which destroy or lead to loss of quality of the pod and render commercial cocoa beans unsuitable for manufacturing. Such pests comprise both fungi and insects.

Fungicides are the most common type of pesticides used in the primary production of cocoa and, within the fungicide group, copper- and phenylamide-based compounds (e.g., metalaxyl) are the most widely used (Bateman 2009). Copper-based fungicides and metalaxyl are applied, for instance, in the control of black pod disease. Copper-based fungicides are especially popular, but, as contact fungicides, they have shorter protective life duration than systemic fungicides (such as phenylamide compounds). However, the high costs of systemic fungicides make their use economically unsustainable for farmers (ICCO 2011b).

Copper-based fungicides are permitted in both conventional and organic farming systems (ICCO 2011b). However, in organic farming, their use has been restricted to a maximum application of 6 kg Cu/ha per year, as proposed in the standards by the International Federation of Organic Agriculture Movement (IFOAM) (IFOAM 2010).

Insects are also recognized as a serious threat to cocoa cultivation worldwide. Their control requires the use of different types of insecticides, which are characterized by different modes of action and spectra (Bateman 2009; ICCO 2011b). For control of mirids and the cocoa pod borer moth, the most widespread insect pests, broad-spectrum organochlorine insecticides (e.g., lindane and endosulfan) were popular. Currently, these were substituted by less toxic and more environmentally friendly insecticides, such as organophosphorus compounds and neonicotinoids (mirids), and chlorpyrifos (cocoa pod borer moth). Chemicals from the pyrethroids class are used against both pests (Bateman 2009).

Cocoa farmers must follow pesticide residue management strategies, consisting of observation of a certain number and the correct method of spray application, and the minimum number of days separating the last application of pesticides and the harvest (preharvest interval (PHI)) (Bateman 2009). Because of the importance of the fermentation for cocoa bean quality, investigations on the impact of pesticides residues on the microbial ecology of cocoa bean fermentation would seem pertinent.

During storage, cocoa beans are again susceptible to the attack by molds and insects. The control of molds during this stage, and the subsequent stage of transport, is achieved by ensuring a low moisture level (this should be between 7% and 8%). No specific chemical agents are used to prevent their growth (Fowler 2009). With respect to insects, the most effective method of control is the use of phosphine (or phosphane), which is a toxic gas generated from sachets containing metal phosphides (Bateman 2009). When correctly used, phosphides are considered to be safe and less likely to result in residue problems than, for instance, methyl bromide, which has been banned in the European Union (EU) and restricted in the United States (Bateman 2009). However, reports of increased insect resistance to phosphine over continued years of use have resulted in the need to use increased concentrations to achieve the same levels of protection (Reddy et al. 2007). This underlines the need of fostering the development of chemical-free strategies, which can offer long-term solutions.

Pesticide residues are highly regulated in Europe and in the United States, where specific information on maximum residue levels (MRLs) is provided according to the type of residue and product or group products (Table 6.2—C) In the EU, the pesticides database presents MRLs for cocoa, under the category of "tea, coffee, herbal infusions, and cocoa" (European Union 2010). For example, the MRL for fungicides metalaxyl and metalaxyl-M is 0.1 mg/kg, while for copper compounds this limit is 50 mg/kg. Regarding insecticides, MRLs for malathion (organophosphorus compound) and deltamethrin (pyrethroid compound) are, respectively, 0.02 and 0.05 mg/kg. A similar database hosted by the Codex Alimentarius can be found at http://www.codexalimentarius.net/mrls/pestdes/jsp/pest_q-e.jsp.

At the moment, the status of phosphine under the directive 91/414/EEC for placing plant protection products on the market (European Council 1991) awaits conclusion (European Commission 2008).

6.2.4.4 Heavy Metals and Hydrocarbon Compounds In addition to mycotoxins and pesticide residues, heavy metals and hydrocarbons are a matter of concern in the cocoa chain (Table 6.2—C). Heavy metals are considered rare but may occur as a result of environmental contamination from pesticides (copper), gasoline (e.g., arsenic, lead), or cocoa trees grown in volcanic soil (cadmium) (Fowler, 2009).

Hydrocarbons may contaminate cocoa beans due to the diffusion of mineral oils from jute bags, or direct contact with smoke during artificial drying with driers poorly maintained (namely, contamination by polycyclic aromatic hydrocarbons (PAH)) (Bateman 2009; Fowler 2009; Misnawi 2012). Both in Europe and in the United States, no specifications for maximum limits for these contaminants have been set (Table 6.2—C) (Commission Regulation 2006a; Fowler 2009). However, in the United States, maximum levels of heavy metals are defined for cocoa butter (arsenic, copper, lead, and iron) and chocolate (arsenic, copper, and lead), which implies the need of regular monitoring of these elements in cocoa beans (Codex Standard 86 1981; Codex Standard 87 1981).

Transport of commercial cocoa beans in jute bags is becoming less frequent, but in many parts of the world, cocoa is still dried by the use of artificial sources of heat. This may indicate the need for assessing hydrocarbon levels in cocoa beans of certain origins.

6.3 Methods for Quality and Safety Monitoring of Commercial Cocoa Beans

6.3.1 Introduction

The examination and quality control of commercial cocoa beans is based on official analytical long-standing methods. They are methods, which were developed by the International Office of Cocoa, Chocolate and Confectionary (IOCCC), now known as the International Confectionary Association (ICA). In addition, the methodology by the International Organization for Standardization (ISO), The International Union of Pure and Applied Chemistry (IUPAC), and the Association of Official Analytical Chemists (AOAC) serve as references (ADM Cocoa 2009) (see Table 6.2). In practice, many laboratories have adjusted the published methods or developed their own methods, in view of the need for simplification or taking advantage of scientific advances (ADM Cocoa 2009; Cargill Cocoa 2011a).

The quality control of commercial cocoa beans takes place at several points along the chain: at the buying stations, where commercial cocoa beans from small farmers are acquired; at the export terminals, which are the gathering points for commercial cocoa beans from different buying stations, cooperatives and intermediate traders; and at the quality control laboratories in the importing countries (ADM Cocoa 2009).

In the countries of origin, cocoa beans are essentially examined by means of visual inspection, making use of the so-called “cut-test,” although the determination of moisture, pH, fat content, and FFAs may also be performed prior to exportation, depending on the existence of company quality control laboratories (Cargill Cocoa 2011b).

Different publications emphasize the need for implementing effective sampling methods prior to undertaking analyses. These will not be dealt here, but we direct the reader to publications by the International Confectionary Association (ICA45 1996), Dand (1993), Cargill Cocoa (2011a), ICMSF (ICMSF 2002), and ADM Cocoa (2009) for more information.

In Table 6.2, reference to methods used to evaluate the quality and safety of cocoa beans is made. In the sections below, we will give particular attention to methods used to assess the yield of useful materials, degree of fermentation, markers to differentiate between bulk and fine cocoa, cocoa butter quality, and safety.

6.3.2 Cut-Test

The cut-test is one of the most common methods used to evaluate the sanitary and fermentation quality of commercial cocoa beans. It involves cutting lengthwise 300 beans taken randomly from a sample, followed by inspection and recording of defects (moldy, insect and germination-damaged, and flat) and the cotyledon color (gray, violet, and brown) (Dand 1993). The cut-test has the advantage of not requiring specialized equipment (simply needing a knife or a Magra cutter) or advanced training. In addition to its usefulness in quality monitoring of commercial beans, the cut-test also allows an expeditious monitoring of the status of the fermentation, as in the course of the process, the color of the cocoa bean changes from gray to violet and finally to brown. However, while the identification of visual defects can be unequivocally made, this is not always the case with respect to assessing the degree of fermentation. A brown color may be subjective, caused by putrefaction reactions and difficult to score when analyzing samples from different origins (Almeida and Leitão 1995;

Wood 1975). In this context, the cut-test needs to be combined with other analytical methods (Emmanuel et al. 2012), which facilitate an objective characterization of the degree of fermentation of commercial cocoa bean batches.

6.3.3 Advanced Methods for Monitoring Fermentation Quality

The subjectivity and difficulty of standardization of the cut-test to assess the degree of fermentation has been broadly acknowledged (Dand 1993; Fowler 2009). While the cut-test is important for its great convenience in cocoa-producing countries, in the importing countries, there is need for a more objective and reliable method, with well-established databases, to correlate specific color and flavor traits with other relevant quality parameters.

Alternative methods to the cut-test to assess the degree of fermentation of dried cocoa beans have been used in many laboratories. These are the determination of the colorimetric fraction $OD_{460\ nm}/OD_{525\ nm}$ (Gourieva and Tserevitinov 1979) and color measurement by means of a color analyzer (Aculey et al. 2010). Near infrared spectroscopy (NIRS), fluorescence spectroscopy, and nuclear magnetic resonance (NMR) are highly sensitive, specific, and relatively fast techniques that allow the simultaneous detection of certain compounds in food systems (Caligiani et al. 2010; Christensen et al. 2006; Kaffka et al. 1982). NIRS and ^{1}H NMR have been used to quantify fat, proteins, carbohydrates, polyphenols, and moisture in cocoa beans, cocoa liquor, and powder (Caligiani et al. 2010; Kaffka et al. 1982; Permanyer and Perez 1989; Ramirez-Sanchez et al. 2010; Whitacre et al. 2003). In particular, NIRS is routinely used for the quantification of moisture and fat in cocoa liquor and cocoa powder (Cargill Cocoa 2011a). These methods are of considerable interest for cocoa industrials, since traditional analytical methods for the quantification of quality parameters, such as moisture and fat (Table 6.2—A) are slow, require special chemicals, and do not produce immediately available results (Kaffka et al. 1982; Rolland 2012).

NIR, fluorescence spectroscopy, and ^{1}H NMR were successfully applied to group cocoa bean samples with distinct degrees of fermentation, providing at the same time a satisfactory segregation of samples according to the origin and population type (Aculey et al. 2010;

Caligiani et al. 2010). Davies et al. (1991) described the possibility of using NIRS to predict the potential quality of chocolate from the assessment of quality traits in the corresponding commercial cocoa bean batches.

As a result of the fermentation, a striking array of physicochemical modifications occurs in cocoa beans (addressed in Chapter 5). These include hydrolysis of proteins, sugars, and anthocyanidins, and oxidation and condensation reactions of polyphenols. In addition, different organic acids and other microbial metabolites, many of volatile nature, accumulate in the beans. Hence, the quantification of these compounds by using chromatographic techniques, such as high-performance liquid chromatography (HPLC), (high-resolution) gas chromatography coupled to mass spectrometry (GC-MS), or olfactometry, can provide an objective means to ascertain the extent to which the fermentation process has been properly conducted (Aculey et al. 2010; Almeida 1999; Frauendorfer and Schieberle 2008; Gill et al. 1984).

The potential of cocoa beans to deliver the desirable chocolate flavor is one of the most important quality parameters that chocolate manufacturers seek in commercial cocoa beans. Sensory analysis based on cocoa liquor or production on a pilot scale is a frequently used method to classify cocoa beans and predict the flavor attributes of the final chocolate. This is done by a trained panel, using standardized methods and reference samples. During flavor evaluation of cocoa liquor, these may be mixed with equal amount of granulated of powdered sugar and some water, after which the suspension, kept in a liquid form, is tasted and scored (ADM Cocoa, 2009). Nonetheless, quantification of the following compounds in commercial cocoa beans could also offer useful information with respect to flavor potential:

1. Volatiles produced during fermentation: specifically trimethyl- and tetramethylpyrazines. Moreover, certain compounds present in the raw seeds increase as a result of the fermentation and these could also be used for this purpose. These include phenyacetaldehyde, benzaldehyde, and the 2-phenylethyl acetate (Almeida 1999; Gill et al. 1984; Hashim et al. 1997; Reineccius et al. 1972).

2. The ratio epicatechins/catechins (Payne et al. 2010) and the content of anthocyanins (Pettipher 1986).
3. The ratio of reducing/total sugars (Rohan and Stewart 1967b).
4. The ratio of soluble nitrogen/total nitrogen (Rohan and Stewart 1967a).
5. The ratio of hydrophobic/total free amino acids (Kirchhoff et al. 1989).

The aforementioned compounds are suitable "markers" of the degree of fermentation and, when sufficient information is collected with respect to natural variability and country of origin, databases can be constructed to help make cost-effective predictions on the flavor potential, without the need of quantifying all the different classes of compounds. Owusu et al. (2013) used multivariate data analysis of key odorants and flavor components to model the relationship of fermentation, roasting, and conching conditions on the aroma quality of dark chocolate.

The increase in acidity of cocoa beans, as a result of the microbial action on the pulp during the fermentation, is a key determinant of the quality of commercial cocoa beans (Biehl et al. 1985). As addressed in Chapter 5, the extent of acidification of cocoa bean cotyledons determines a fine equilibrium for the optimal activity of invertase, aspartic endoprotease, and carboxypeptidase enzymes and, consequently, the formation of the precursor compounds of the cocoa flavor (Hansen et al. 1998; Voigt et al. 1994).

Commercial cocoa beans from some countries tend to have more acidic characteristics than others. This is the case of cocoa beans from Malaysia, Brazil, São Tomé and Principe and batches from some seasons in Indonesia. Conversely, cocoa bean batches from West Africa and the Dominican Republic, for instance, are considered to have a balanced level of acidity (Fowler 2009; Jinap and Dimick 1990). A high acidity content in cocoa beans has been negatively criticized for resulting in chocolate of weaker flavor than cocoa beans of intermediate or low acidity (Duncan et al. 1989).

The acidity in cocoa beans is determined by the titratable acidity (expressed in meq NaOH/g of sample) and the pH of cocoa beans filtrate. The titratable acidity of cocoa beans was shown to be highly correlated ($r = 0.91$) with the total volatile acid—predominated by acetic acid—content of cocoa beans, as well as with the pH ($r = 0.91$) (Jinap and Dimick 1990). This correlation was slightly lower with respect to content of lactic ($r = 0.85$) and citric acids ($r = 0.61$) (both the nonvolatile acids). However, studies on acidity characteristics of fermented and roasted cocoa beans by Holm and Aston (1993) revealed that while acetic acid contributes to the pH and titratable acidity, the correlation was weaker regarding the perceived acid flavor. Instead, the levels of lactic acid were found to be the determinant factor for acidic cocoa and chocolate flavor.

Progress has been made with respect to the development of methods for control of acidity during cocoa bean fermentation. In Malaysia, approaches consisting of pod storage for 9–12 days or sun-drying of fresh beans prior to fermentation led to a reduction in acidity and to an increase in cocoa flavor (Biehl et al. 1990; Duncan et al. 1989). Similarly, in Brazil, mechanical removal of about 20% of cocoa bean pulp yielded cocoa beans of higher pH value (Schwan and Lopez 1987). Another factor that was identified as contributing to cocoa beans' high acidity is fast artificial drying. The reason is the formation of a hard crust in the bean, which hampers the volatilization of acetic acid (Ziegleder 2009). Altogether, these data underline the difficulty in establishing an uncontroversial root of the problem of high acidity in cocoa bean, especially since detailed comparative data on the evolution of microbial species in trials where pulp reduction methods have been employed were not generated. Linking of specific microbial fermentation profiles with the characteristics of final roasted cocoa beans would shed more light on the best procedure to fully control and standardize this parameter in final commercial products.

6.3.4 Biomarkers of "Fine" Cocoa

In addition to the degree of fermentation and indices of flavor potential, a much sought index of quality is the one providing an objective differentiation between fine and bulk commercial cocoa beans. Fine cocoas are known for exquisite character descriptors, such as "fruity," "floral," and "raisin" (Fowler 2009). These characteristics are of considerable relevance for chocolate manufacturers. Different works have attempted to find biomarkers of fine cocoa, both focused on the planting material (genetic level) and on the characteristics of commercial cocoa beans (phenotypical level). For example, Lerceteau et al. (1997) used random amplified polymorphic DNA (RAPD) and restriction fragment length polymorphism (RFLP) of DNA extracts from leaves to investigate the genetic relationship among representatives of *Forastero*, *Trinitario*, and *Criollo* populations. They concluded that, although a "continuous genetic background" was found, some specific genetic traits were also present which, for example, clearly differentiated *Nacional* subvarieties from other *Forastero* populations. Motamayor et al. (2008) proposed a new classification for cocoa populations based on the analysis of microsatellite markers. This new classification encompasses 10 genetic groups, as opposed to the traditional genetic group formed by populations of *Forastero–Criollo–Trinitario*. In this investigation, representatives of *Criollo, Nacional*, and *Amelonado* hybrids were clearly segregated based on their distinct genetic profile, suggesting that microsatellites could be useful biomarkers relating the planting material and potential flavor characteristics of commercial cocoa beans.

Caligiani et al. (2010) used ^{1}H NMR to compare the composition of commercial cocoa beans originating from *Nacional (Arriba), Criollo, Trinitario*, and *Forastero* populations. *Arriba* beans were characterized by a higher level of epicatechins, caffeic acid, sucrose, and oligosaccharides, and a lower level of amino acids than other *Forastero* beans. On the other hand, *Criollo* beans had a low content of carbohydrates and high content of amino acids. Both the *Arriba* and *Criollo* beans had approximately the same total content of glucose plus fructose, as well as caffeine, this last compound being much higher than in the *Forastero* beans. The authors stressed the need of extending this type of analysis to a larger number of samples, in order to confirm the observed pattern for differentiation of fine and bulk commercial cocoa beans.

Compared to bulk commercial cocoa beans, fine cocoas were found to have higher levels of linalool, a monoterpene contributing to a flowery and tea-like flavor in cocoa (Pino and Roncal 1992; Ziegleder 1990). Thus, the quantification of this volatile in samples of commercial cocoa beans could also provide an objective categorization of samples.

Nevertheless, it can be concluded that there is a need for more studies establishing objective criteria for fine cocoa bean designation classification.

6.3.5 Cocoa Butter Quality

Different parameters are defined to assess the quality of cocoa butter. These include the determination of the solid fat content (SFC) (cocoa butter hardness index), melting point (MP), iodine value (IV) (degree of unsaturation of a fat), FFAs content, and peroxide value (PV) (degree of oxidative stability), among others (ADM Cocoa 2009). However, only standards pertaining to cocoa butter hardness and content on FFAs are crucial during cocoa beans commercialization, influencing the demand of cocoa beans of certain countries of origin (Table 6.2—B). The unsaponifiable matter or nonsaponifiable fraction, being an index of nonvolatile organic matter not natural to cocoa butter (e.g., contamination by mineral oil or shell fat), is more relevant at the stages of cocoa butter commercialization for the purpose of chocolate manufacture.

The SFC of cocoa butter is presently obtained by pulsed NMR, which gives the level of solid fat at a particular temperature. Differential scanning calorimetry is an alternative method of SFC quantification, which has the advantage of determining the crystalline state of fat (Löser 2009).

The official determination of FFAs is based on an acid–base titration method (Table 6.2—B), but other methods have been reported for FFAs analysis in fat, namely, chromatographic methods (GC, HPLC), Fourier transform infrared spectroscopy (FTIR), NIR, and ^{1}H NMR (Procida and Ceccon 2006; Satyarthi et al. 2009; Sherazi et al. 2007).

As discussed in Section 6.2.3, the origin of cocoa beans has not only an influence on the flavor of chocolate, but it also determines the characteristics of cocoa butter. Pyrolysis-mass spectrometry was successfully applied to classify cocoa butters of African, Asian, and South American origins and provided additional segregation of samples based on the type of technological treatments cocoa butters had undergone, for instance, whether deodorization had been applied (Radovic et al. 1998). Such analytical techniques for cocoa butter discrimination according to the country of origin are of great interest for cocoa manufacturers, due to the combination of speed and reliability.

6.3.6 Considerations on Safety Monitoring

In Table 6.2—C, references to methods for cocoa beans safety monitoring are summarized. The cut-test provides an expeditious way to assess the presence of molds, infestation, and damage by insects. With respect to the assessment of mycotoxins, pesticides, hydrocarbons, and heavy metals, more elaborate analytical methods are required.

Liquid chromatography (LC or HPLC) coupled to tandem MS (or alternatively to fluorescent detection) is the most widely used method for mycotoxin analysis in food (Commission Regulation 2006b) (AOAC 2005). Recently, ultra-high performance liquid chromatography has been developed to improve the sensitivity, resolution, and speed of AFs and OTA quantification (Ibáñez-Vea et al. 2011). The other methodologies are based on NIRs, electrochemical immunosensor (ECIS), and enzyme-linked immunosorbent assay (Aydin et al. 2007; Fernández-Ibañez et al. 2009).

The quantification of pesticides and hydrocarbons, such as PAH, is based on chromatographic techniques, namely, GC-MS/LC-MS and GS-MS, respectively (European Commission 2009; ISO 2004a).

Regarding the determination of heavy metals, a simple method based on the colorimetric determination of metal complexes with dithizone (dithizone method) (Hibbard 1937) or on atomic absorption spectrometry is still recommended for heavy metals quantification in cocoa butter (Table 6.2—C). However, more sophisticated and sensitive methods are available for the simultaneous detection and quantification of different heavy metals in food, such as inductively coupled plasma mass spectrometry and inductively coupled plasma atomic emission spectrometry (Baer et al. 2011).

While Food Safety Management in cocoa bean processing plants and chocolate factories is based on rigorously implemented prerequisite specifications and programs for Hazard Analysis and Critical Control Points, this is not yet the case during cocoa beans postharvest processing (Burndred 2009). UTZ certified (UTZ) is the first attempt to effectively standardize processing practices in the field and therefore control the quality and safety of commercial cocoa beans.

As referred in Section 6.2.4, no maximum levels for mycotoxins, heavy metals, and hydrocarbon compounds are set for commercial cocoa beans. The definition of maximum admissible limits in food depends on the availability of information derived from toxicological studies and technological innovations in analytical methods that provide gains of sensitivity and specificity. Therefore, cocoa industrials need to be updated on the release of new data with respect to these aspects, to continuously monitor the levels of mycotoxins, pesticides, heavy metals, and hydrocarbons along the chain and be alert on the emergence of new safety risks for the consumer.

6.4 Conclusions and Future Prospects

The quality of commercial cocoa beans results from the combination of many different factors, which include the planting material and the agricultural and processing practices in the countries of origin. These are, in turn, affected by the agronomic microenvironment (e.g., climate, occurrence of pests), as well as the macroeconomic conjecture (e.g., the price of cocoa in future markets and availability of subsidies for farmers).

Table 6.3 presents our analysis of the strengths, weaknesses, opportunities, and threats (SWOT) (Kotler and Armstrong 2006) for quality and safety of commercial cocoa beans.

Although cocoa beans are spontaneously fermented, it is possible with a relatively simple technology to obtain high-quality final products, that is, chocolate and cocoa powder (Table 6.3—S). Indeed, this is probably one of the reasons why there is reluctance to elevate the technological management of cocoa bean fermentations to the level of beer or wine fermentations. At the same time, it can be expected that concerted efforts to increase the traceability and transparency of cocoa production and trading (UTZ 2011) will allow a faster and more efficient communication and cooperation among stakeholders in the chain. This, in turn, is expected to have an enduring impact on the long-term commitment of farmers in the production of good-quality cocoa beans (Table 6.3—S). This is definitely a strong point for the cocoa sector.

Table 6.3 Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis in the Field Pertaining Commercial Cocoa Beans Quality and Safety

S: STRENGTHS	W: WEAKNESSES
Compared with other crops, cocoa is considered environmentally friendly, due to the relative low level of farming inputs and for supporting high level of biodiversity (Bateman 2009; Fowler 2009) There is a great emphasis on the dissemination of knowledge on the sustainable use of pesticides in cocoa growing regions, integrated in a long-term strategy for pests and diseases management (Bateman 2009) Although cocoa beans are spontaneously fermented and characterized by a low input technology, it is possible to produce a final product which allows manufacture of high-quality chocolate An increasing number of actions are being undertaken to promote the traceability of cocoa beans in the chain and improve the livelihood of farmers and their families (Fair Trade 2011; UTZ 2011) The increasing trend toward the liberalization of cocoa trade and industry in the countries of origin contributes to the improvement of transparency in cocoa marketing and quality control over exported cocoa (ADM Cocoa 2009) Cocoa beans are a source of polyphenols with demonstrated beneficial health effects, including prebiotic action (Buijsse et al. 2006; Crozier et al. 2011; Tzounis et al. 2011)	The high susceptibility of the cocoa to different pests hampers the consistent (quantitative and qualitative) supply of cocoa There are difficulties in breeding pest-resistant varieties adapted to different regions and countries, combining both vigor and high bean quality for chocolate manufacturing (Efombagn et al. 2011; McMahon et al. 2010; Micheli et al. 2010) Although new cultivars resistant to major diseases have been identified during the last decades, studies have shown that the resistance may be overcome (Brown et al. 2005; Albuquerque et al. 2010) The cocoa sector faces many challenges derived from aging tree stocks, poor soil fertility management, and widespread difficulty of farmers access to pest control strategies; but also improper use of chemicals and uncontrolled forest conversion (ADM Cocoa 2009; Ayenor et al. 2004; McMahon et al. 2010) In many countries, a successful farm management system for the control of pests and implementation of good postharvest processing practices for cocoa is absent The supply of cocoa beans fluctuates from year to year, which has an influence on the price for farmers (ADM Cocoa 2009) Cocoa bean fermentation relies on the uncontrolled colonization of microorganisms from the environment, which creates difficulty in standardization of quality There is a great dependence of cocoa production from a small number of countries (mainly Ivory Coast followed by Ghana) (ICCO 2011c)
O: OPPORTUNITIES	T: THREATS
The chocolate taste is appreciated worldwide and there is opportunity to expand the consumption of chocolate to Asian and Arabic countries There is an increased consumer awareness about the relationship between diet and disease and aging	In some producing countries, cocoa is threatened by other crops that hold higher market prices or for which better subsidies are available (Fowler 2009) Political conflicts in the producing countries may jeopardize the supply of cocoa (Byrne 2011)

Table 6.3 (continued) Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis in the Field Pertaining Commercial Cocoa Beans Quality and Safety

O: OPPORTUNITIES	T: THREATS
There is an increasing demand for chocolate which fulfils social, ethical, and environmental standards of sustainability (ICCO 2010) There is an increasing market for exquisite and differentiated products New genomic tools, such as high-throughput sequencing and molecular biology approaches, like metagenomics, open avenues to improve the quality of the planting material (e.g., resistance to pests and flavor), and the quality of commercial cocoa beans (Argout et al. 2011; Lerceteau et al. 1997)	In some areas, cocoa production or effort to improve its quality control is highly dependent on the existence of external initiatives and subsidies (ICCO 2011d) Global economic turnover may preclude the existence of platforms for farmers' access to effective control strategies for pests, hindering their long-term commitment for the production of (high quality) cocoa

On the other hand, control of the fermentation and subsequent processing, beyond spontaneous and artisanal practices, offers opportunities for the development of new products. Defined fermentations are based on a sound knowledge of the microbiota dynamics (Lima et al. 2012; Lima 2012), and application of documented starter microorganisms (Bourdichon et al. 2012) including probiotic strains (Foong et al. 2013) in cocoa-based products such as chocolate.

The fact that the chocolate taste is broadly appreciated (Table 6.3—O) constitutes a confidence for farmers who wish to invest in the long-term activity of cocoa cultivation and commercialization. Furthermore, the elevation of cocoa to the status of a nutraceutical food and the increased consumer interest for premium, high-cocoa solid content chocolate, manufactured with beans from "exotic" origins, creates an excellent opportunity for farmers to invest in agricultural and processing practices aimed at the upgrade of quality. Capitalization on quality might be of special importance for small countries that cannot compete in quantity with the main producing countries.

Many weaknesses can be identified with respect to the quality and safety of commercial cocoa beans (Table 6.3—W). The primary weakness is the high susceptibility of cocoa to pests, which challenges the annual output of commercial cocoa beans. In addition, the fact that cocoa is mainly produced by small-holder farmers, often in remote regions, precludes the effective implementation of a widespread farm management system for the control of pests and protocols to guide the postharvest processing of “wet cocoa beans.”

In some regions, cocoa production is highly dependent on the existence of external investments (ICCO 2011d) and this may be a fragile basis for the long-term (high-quality) production in these regions (Table 6.3—T).

Although more weaknesses than strengths were identified in this SWOT analysis, opportunities stemming from the increased affordability of high-throughput sequencing techniques and other molecular approaches (Table 6.3—O) pave the way to augment knowledge aimed at devising strategies to combat cocoa pests and promote specific quality traits (Argout et al. 2008, 2011).

With respect to the characteristics of commercial cocoa beans, the postharvest processing plays an essential central role in the quality of final beans. Therefore, it can be anticipated that the ongoing research to study the influence of fermentation and drying on the quality traits of cocoa beans (e.g., Camu et al. 2008; Garcia-Armisen et al. 2010) will gradually transform the field of cocoa fermentation science.

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