ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.117

Factors Affecting Quality & Value of Coffee. A review

Ostilio R. Portillo
Universidad Nacional Autónoma de Honduras (UNAH), Departamento de Ingeniería Química.
Honduras, Centro América, email: *oportillo@unah.edu.hn*

Abstract– *The price of coffee in the international market is controlled by the interaction of supply and demand. However, purchasing companies impose a series of conditions on producing countries related to the coffee beans´ quality, which in turn affect the quality of the cup of coffee. Certain parameters are evaluated at the receiving ports through random samples taken from containers to assess the quality. However, the beans quality is not only determined by the defects´ elimination prior to shipment, but also through a series of cultural practices, many of which are applied on coffee plantations. Finally, although there are market niches where the beans price is quoted at much higher prices (gourmet coffees), most of the world's production is controlled by the average consumer, who is unwilling to pay the prices of specialty coffees. This essay presents a detailed discussion of the parameters that affect the price of the beans, and which must be considered by both producers and exporters to achieve the best prices and generate the most foreign currency for their countries of origin.*

Keywords *- specialty coffees, cultural practice, organoleptic property.*

INTRODUCTION

Until 1989, coffee prices were regulated through the International Coffee Agreement (ICA), which was established in September of 1962 with 23 member countries and supervised by the International Coffee Organization [1, 2] It consisted of a system of quotas production assigned to producing countries (Table 1) [2-6].

The ICA was an agreement signed between most producing and consuming countries, and during its validity, coffee prices were set by the ICA and tended to be relatively stable. However, when coffee prices rose on the international market, the fixed price was abandoned until it, on its own, returned to the price established by the ICA [4].

Unfortunately, this agreement came to an end due to unresolved disputes over the allocated quotas to the point that in July of 1989 the United States of America withdrew from the agreement and then it collapsed [2]; Among the disputes we can mention Indonesia's dissatisfaction with the prices and allocated quotas, which is why it requested a review of prices and quota sizes by country [1].

In contrast, countries responsible for establishing the ICA (mainly Brazil and Colombia) advocated for the agreement renewal under the originally established quota & price system.

There was discomfort among ICA member consumer countries, who protested the low prices paid by other consumer countries that were not part of the agreement. The evidence indicates that the low prices paid by non-ICA member countries corresponded to low-quality coffees such as robusta & dry-processed coffees, while the highest prices paid by member countries corresponded to high-quality coffees such as arabica and wet-processed coffees [1].

After July 4, 1989, when the ICA ceased operations, coffee prices were liberalized, resulting in a price war and intense speculation in the international market. Virtually all coffee-producing countries flooded the international market, causing a dramatic drop in prices in what became known as "The Coffee Crisis" which bankrupted thousands of coffee growers [2, 6-8].

While the price of a pound of raw coffee beans was US$ 1.2 and US$ 1.38 in 1980 and July 1989 respectively [1, 9], it dropped to US$ 0.69 & US$ 0.50 per pound between November 1991 and the 2003-2004 season respectively [1, 9].

All of this contrasts with the prices in certain market niches in which the product price is determined through a scale of values that goes beyond the conventional parameters used by the industry, as in the case of gourmet coffees or specialty coffees; a designation first introduced by Erna Knutsen in 1978 [10].

For example, in the spring of 2016, a pound of raw beans of the Mountain Blue variety from Jamaica was quoted at US$ 58 [2]; However, there are other varieties that have also been classified as specialty coffees, such as: Tres Ríos from Costa Rica, Antigua from Guatemala, Yrgacheffe from Ethiopia & Kalossi from Indonesia [11] among others.

The price of coffee is also affected by the ups and downs of the international market, where prices fluctuate based on the free interaction between supply and demand or by the occasional intervention of nature. For example, the frosts that affected Brazil starting on July 17, 1975, causing the damage or death of 1.5 billion coffee bushes [5, 7] which in turn caused a sudden increase in its price from US$ 0.55 per pound to US$ 3.4 in April 1977 [5, 12]; During the period between 1994-1997, coffee prices remained relatively high as a result of the frosts that affected the Brazilian harvest, which in turn caused a drop in global supply [3, 7, 12, 13].

Starting in 1998, coffee prices fell because of an increase in supply due to the return of Brazil to the world stage, in addition to the introduction of Vietnam as a new coffee-producing country [4, 7, 14]. It is worth noting that although coffee was first cultivated in Vietnam in 1857, it was not until 1990 that its production managed to affect the prices [15].

Today coffee prices are set at coffee exchange centers located in London for Robusta coffees [13, 16] most of which come from Africa [17] and in New York City for Arabica coffees processed through wet milling [13, 16] from Mexico, El Salvador, Guatemala, Costa Rica, Nicaragua, Honduras, Colombia, Kenya, Tanzania, Uganda, New Guinea, Peru, Venezuela, Dominican Republic, Burundi, Ecuador, India, and Rwanda [17].

According to Reference [17], there are marked differences in the way coffee exchange centers carry out buying and selling transactions of the grain. For example:

Table 1. Quotas based on coffee type and country of origin, 1988-1989.

Type of coffee and country of origin	Millions of bags*	Type of coffee and country of origin	Millions of bags*
Moderate Colombians:	1694	**Brazilians and other Arabicas:**	2518
Colombia.	1336	Brazil.	2403
Kenya.	264	Ethiopia.	114
Tanzania.	94	**Robustas:**	4151
Other moderates:	4380	Angola.	0
Costa Rica.	663	Indonesia.	2789
Dominican Republic.	12	OAMCAF	352
Ecuador.	398	Philippines.	43
El Salvador.	83	Uganda.	532
Guatemala.	581	Vietnam.	369
Honduras.	474	Zaire.	67
India.	1231	-	-
Mexico.	104	-	-
Nicaragua.	9	-	-
Papua New Guinea.	671	-	-
Peru.	155	-	-

*60 kg bags. Adapted from Reference [1].

a) In London, coffee is purchased in lots of 5 tons; however, other authors indicate that transactions are currently made in lots of 10 tons [18]; In contrast, in New York, purchases are made in individual lots of 37 500 lb of raw coffee; that is, 284 bags of 60 kg each [18, 19].
b) In London, coffee prices are quoted at sterling pounds per metric ton, while in New York, the price is quoted at US$ cents per pound.
c) In London, coffee delivery points are warehouses located in London, Avonmouth, or Amsterdam/Rotterdam; Antwerp, Barcelona, Bremen, Felixstowe, Genoa-Savona, Hamburg, Humberside, Le Havre, Liverpool, Teesside, Trieste, and Marseille [18]; Meanwhile, in New York, coffee delivery points are warehouses located in New York and New Orleans.
d) London receives coffee shipments in January, March, May, July, September, and November; meanwhile, New York receives coffee shipments in March, May, July, September, and December.

Three multinational companies [Neumann Gruppe (Germany), Volcafé & ECOM (Switzerland)] are responsible for marketing half of the world's coffee production [20] while the rest is in the hands of other multinationals such as: Cargill, Decotrade (commercial branch of Sara Lee/Douwe Egberts), [4, 21] Taloca (owned by Philip Morris/Kraft),[21] Esteve, Aron, Man, Dreyfus, & Mitsubishi [4].

However, approximately half of the world's production is purchased by five multinational companies: Nestle & Philip Morris/Mondeles (formerly Kraft) each responsible for processing 13% of production, Sara Lee/DE responsible for 10% and whose products are sold in Europe and Brazil, Tschibo (Germany) responsible for 4% y Proctor & Gamble/Smuckers responsible for processing 4% and whose products are sold in the North American market [13, 20-22].

Nestle is a Swiss company that dominates the instant coffee market with a market share of over 50%. Meanwhile, P&G/Smuckers is the smallest of the major coffee roasting companies, having acquired P&G in 2008.

Although the quality of any product is determined by the consumer, the International Organization for Standardization (ISO) established that the quality of a product should be understood as: the extent to which a group of intrinsic characteristics (physical, sensory, behavioral, temporal, ergonomic, functional, etc.) satisfy the requirements, where requirement means need or expectation, which can be explicit, generally implicit or binding [23].

However, the companies described above regulate the price of raw coffee in the international market based on supply and demand, but also on other parameters that influence the grain quality such as the species, the classification of the International Coffee Organization (ICO), the grain lots' physical inspection, and organoleptic analysis.

EVALUATION PARAMETERS

THE CULTIVATED SPECIES

Defining coffee quality should never be considered an easy task; however, the cup quality of Robusta coffee is generally considered inferior to that of Arabica coffee [2, 24-27] due to its bitter taste, greater astringency, and aroma resembling 'wood or wet cardboard' [28-30] which is why Robusta coffee beans are priced at approximately half the value of Arabica coffee beans [2, 31].

THE INTERNATIONAL COFFEE ORGANIZATION CLASSIFICATION

Arabica coffees, generally processed through wet processing, are classified based on their origin into three large groups: the 'Colombian moderates' considered to be of the highest quality and include coffees from Colombia, Kenya, and Tanzania; the 'other moderates' considered to be of intermediate quality and include coffees from Guatemala, Mexico, and India [3, 4, 12] and the 'Brazilian moderates' which are Arabica coffees considered to be of low quality [12].

Robusta coffees subjected to dry processing are called 'natural Brazilian' or unwashed, are considered of inferior quality and are of Brazilian, Ethiopia [3, 4] and Vietnam origin [6]; According to Reference [4] there is an additional category that covers robusta coffees from any other country such as Vietnam, the Ivory Coast, Indonesia, & Uganda.

INTRINSIC AND EXTRINSIC PARAMETERS

The quality of the coffee beans is also assessed through the visual inspection of 300 g samples taken from 60 kg bags [32]; To do this, the inspector assesses the quality of the batch of beans based on intrinsic and extrinsic parameters.

Defects are often classified as primary and secondary damage [33-35]. Primary defects negatively affect cup quality (e.g., black & sour beans) while secondary damage affects both the visual appearance and cup quality (e.g., broken beans, partially black, bitten, insect damaged, etc.) [34, 35].

Among the intrinsic parameters we have the color, size, grain's shape, the moisture percentage and the presence of grains with physical defects (e.g., blackened grains, grains damaged by insects, broken and immature grains, sour or fermented grains) [36]. Among the extrinsic parameters we have the percentage of foreign bodies (e.g., stones, remains of parchment or pulp, leaves, foreign seeds, etc., Fig 1) [32, 37-40], storage stability and the presence of biological and chemical contaminants.

The New York Coffee and Sugar Exchange created a classification system based on the number of defects present, by category, in a 300 g sample [39]; According to this system, the defects found are classified according to their category and a certain number of defects per category are equivalent to a black bean which in turn is equivalent to a defect (Table 2A).

One large stone found in a coffee sample is equivalent to five black beans, which in turn is equivalent to five defects. Similarly, five unripe (green) beans are equivalent to one black bean, which in turn is equivalent to one defect [33]. In other words, it is a system through which a certain number of secondary defects are equivalent to one primary defect.

The number of defects found in the sample determines the category to which it belongs (Table 2B) which in turn affects the price of the entire lot.

The Specialty Coffee Association of America developed its own equivalency scale based on the number of defects found in 350 g samples of arabica coffee (Table 3) [33, 34]; In contrast, the Coffee Quality Institute and the Uganda Coffee Development Authority established an equivalency system for defects found during inspections of 350 g samples of robusta coffee (Table 4) [33].

The ICO recommends, for export purposes, no more than 86 defects per 300 g sample for Arabica coffees & no more than 150/300 g sample for Robusta coffees [34].

Grains with physical defects are generated due to poor development or poor processing and represent 15-20% of the harvest based on weight [37, 39, 41-44] and can be identified by their fluorescence when exposed to UV light [36].

The following are considered grains with physical defects: immature grains, immature grains with black or oxidized cuticle, blackened grains extracted from over-ripe fruits & poorly fermented grains due to inadequate processing [32, 41, 45].

Since coffee flowering is not a uniform phenomenon, neither is the ripening of the fruit [36], which causes the harvest to be heterogeneous, that is, the volume harvested at a given time is a beans mixture in different stages of development and ripeness (unripe, ripe, and overripe) [41, 46] which increases the percentage of defective beans to the detriment of the quality of the lot unless they are eliminated.

Most of the defective grains are separated from the grain lots destined for export manually or through electronic classifiers [47, 48] that can identify them based on their color [48]; Unfortunately, once the defective grains are separated, instead of being discarded, they are marketed in the national markets of the producing countries [48].

The reasons why grains with physical defects reduce the quality of the batch are:

a) Unripe (green) or overripe fruits alter the pH and increase the beverage's astringency, thus altering the coffee's organoleptic properties [31, 32, 41, 46, 49]; Green or unripe fruits contain less sucrose [43, 50] and more chlorogenic acids (CAs), which, during roasting, degrade into other compounds (e.g., 4-ethylcatechol, catechol, guaiacol, 4-ethylguaiacol, phenol, pyrogallol, and hydroquinone) which impart unpleasant odors and flavors to the beverage, affecting its quality [51, 52].

   There are reports of the presence of 4-heptenal in immature coffee beans, which is a metabolite that imparts a rotten fish-like odor [53].

   Black seeds are characterized by having a black or dark green espermodermis [46] and impart bitter flavors and strong, unpleasant tobacco-like odors [41, 47] and originate from over-ripe fruits that, due to the action of the elements (e.g., wind & rain) or during the harvest, fall to the ground where microorganisms begin their fermentation [31, 37, 38, 40, 41].

   Black seeds also originate from carbohydrate deficiencies during their development or from their fermentation when they're still on the bush [31, 41, 46] for this reason they're deficient in reducing sugars (glucose & fructose) and saccharose [54]; They also have a lower lipid concentration [43].

   Certain metabolites serve as markers for the identification of black grains such as the hydrocarbon 3-ethyl-2-methyl-1,3-hexadiene derived from lipid oxidation, 2-pentylfuran which is produced by *Bacillus´* bacteria during fermentative processes & imparts a moldy or anise-like odor [31, 41, 46], ochratoxin A [42], 2-furylmethanol acetate, and 2-methylpyrazine [43].

b) Bad-smelling or sour beans usually have a normal appearance, but in some cases, they have an endosperm

Table 2. Defects of arabica coffee according to the New York Coffee and Sugar Exchange.

(A) Equivalences based on the type and number of defects.

Type of defect and quantity	Equivalence	Equivalence
1 black bean.	1 black bean.	1 defect
2 sour grains.	1 black bean.	1 defect
5 immature grains.	1 black bean.	1 defect
⅖ grains damaged by insects.	1 black bean.	1 defect
1 small stone.	1 black bean.	1 defect
1 large stone.	5 black beans.	5 defects
1 small twig.	1 black bean.	1 defect
1 large twig.	5 black beans.	5 defects

(B) Categories according to the number of defects

Type	No. of defects allowed/category
NY 2	6
NY 3	13
NY 4	30
NY 5	60
NY 6	120
NY 7	240
NY 8	450

Adapted from Reference [39] & Reference [40].

Table 3. Arabica coffee defects according to the Specialty Coffee Association of America.

Type of defect	Equivalence	Type of defect	Equivalence	Type of defect	Equivalence
Black grain.	1 defect	Parchment.	5 defects	Partially sour.	3 defects
Sour grain.	1 defect	Immature grain.	5 defects	Partially black.	3 defects
Dried cherry.	1 defect	Withered grain.	5 defects	Pulp.	5 defects
Damaged by fungi.	1 defect	Broken/fractured/bitten.	5 defects	Ears or shells.	5 defects
Severely damaged by insects.	5 defects	Slightly damaged by insects.	10 defects	Foreign matter.	1 defect

Adapted from Reference [33].

Table 4. Robusta coffee defects according to the Coffee Quality Institute and the Uganda Coffee Development Authority.

Type of defect	Equivalence	Type of defect	Equivalence	Type of defect	Equivalence
Black grain.	1 defect	Withered/shriveled grain.	5 defects	Unripe/green grain	5 defects
Sour grain.	1 defect	Fluffy grain.	5 defects	Partially sour.	3 defects
Dried cherry.	1 defect	White/discolored grain.	5 defects	Partially black.	3 defects
Damaged by fungi.	1 defect	Broken/fractured/bitten.	5 defects	Pulp.	5 defects
Foreign matter.	1 defect	Parchment.	5 defects	Ears or shells.	5 defects
Severely damaged by insects.	3 defects	Slightly damaged by insects.	10 defects		

Adapted from Reference [33].

with colors that vary from brown to red [55]; These occur when they're poorly processed due to excessive fermentation & are characterized by imparting bad odors to the beverage, producing sour and onion-like flavors [40, 46, 47, 56] and presenting a lower lipids concentration and sucrose than healthy beans [43].

There're a series of metabolites that are exclusively present in smelly beans such as 2-acetylpyrazine, β-linalool, 2-methyl-ethylbutanoate, ethyl butanoate, ethyl isobutanoate, isoamyl acetate, isobutyl acetate, *n*-hexyl acetate [41, 46], 2,3-butanediol [46], γ-butyrolactone [43], ethyl-2-methylbutyrate, and ethyl-3-methylbutyrate, the latter two caused by uncontrolled coffee bean's fermentation [53].

c) Poorly fermented beans and those with black or oxidized cuticle affect the quality because they contain up to 25% more 3-caffeoylquinic acid, 4-caffeoylquinic acid and 4-feruloylquinic acid than good quality beans [45] causing an increase in the beverage acidity [43].

COFFEE SENSORY EVALUATIONS (TASTINGS)

The fact that a coffee lot has a uniform bean size and a good presentation due to the elimination of any defects does not guarantee its good flavor.

For this reason, coffee bean quality is also evaluated through organoleptic analysis, which measures the quality of the cup of coffee based on its sensory properties [38] which are developed through a series of physical and chemical reactions that occur during the bean pyrolysis [57].

Factors such as the contact time between the ground roasted coffee and water, the extraction time, the ratio of ground roasted coffee to water, the particle diameter, the water temperature, and the selected brewing method also affect the sensory properties of the cup of coffee.

According to Reference [58], 'experiments documented by other researchers determined the temperature and time of roasting influence the quality of the product'. They determined that volatile compounds´ formation begins at 170 ºC due to the release of a roasted peanut smell, while from 180-190 ºC a slight roasted coffee aroma is perceived which is accentuated between 220-230 ºC. Beyond this point, it is considered slightly burnt & between 250-260 ºC it is considered burnt.

In short, there must be a balance between roasting time and temperature according to the desired product, since a light profile results in a product with poor sensory characteristics while a well-roasted (black) coffee is not necessarily the most aromatic [59, 60]; On the contrary, they tend to develop undesirable flavors as well as a greater degree of bitterness and astringency [61, 62].

The Specialty Coffee Association of America (SCAA), founded in 1982 [63] published the first edition of its coffee cupping manual (*Coffea arabica*) written by Ted R. Lingle in

1984 [33]; Although the original method was based on this manual, the current protocol has undergone modifications.

This protocol is known as the "Q" scoring system and consists of a quantitative evaluation of 10 organoleptic attributes of the roasted grain, normally carried out by panels of judges (Fig 2) who assign a score between 0-10 to each of the selected sensory properties, i.e.: fragrance/aroma, flavor, astringency, acidity, body or density, balance and the overall evaluation [19, 33, 41, 64].

In contrast, cup uniformity, cleanliness & sweetness are rated through five tick boxes, each of which represents a cup of coffee (Fig 2) [19]. The final evaluation is equal to the sum of the scores assigned to each evaluated parameter and this constitutes a measure of the coffee sample's quality [41].

Coffees with a score of 80 or higher on a 100-point scale are classified as *specialty coffee* [10, 19, 33] and, being considered of the highest quality, command higher prices than other coffees on the international market. For example, *specialty coffees* command a 20-50% premium over conventional coffees [35].

Sensory evaluations are the preferred mechanism used to assess the quality of the roasted bean (CAS: 68916-18-7) and the coffee beverage, even though they're considered subjective since men and women tend to describe the coffee aroma and flavor in different ways [65] and to compensate for this phenomenon the panels of evaluators are mixed.

These evaluations don't provide any information regarding the coffee bean's chemical composition at any of its processing stages (i.e., raw, light, medium & well roasted) and to ensure impartiality, the results from the cupping tests are conducted in such a way that the evaluators should not have any information regarding the sample's geographical origin, the producer name, coffee variety, among others. Each sensory attribute of the scoring system is briefly described below:

FRAGRANCE & AROMA

The fragrance emanating from coffee is evaluated during the first 15 min after grinding the roasted beans [33]. To evaluate the aroma, 3-5 min after pouring the hot water over the ground coffee, the foam that forms on the beverage surface is removed with a spoon to appreciate the gases emanating from the infusion. Of course, there is a marked difference between the perceived volatile molecules coming from roasted and ground coffee versus those displaced by hot water.

FLAVOR

Once the beverage temperature has dropped to 70 ºC, the coffee infusion's flavor is evaluated without any additives (e.g., sweeteners, creamer, etc.). This activity occurs through the perception of water-soluble molecules that stimulate the taste buds in combination with the perception of volatile molecules that come into contact with the nasal mucosa [33].

ASTRINGENCY

The astringency is defined as the rough and dry sensation perceived in the mouth caused by the lack of lubrication due to the precipitation of salivary proteins rich in proline when they interact with coffee polyphenols, thus forming insoluble complexes.

ACIDITY AND BODY

The infusion's acidity results from the synergistic action of organic acids. Acidity is one of the beverage's sensory properties that varies considerably among wet-processed Arabica coffee varieties. In contrast, Robusta coffee varieties are described as having little or no acidity [64].

Although the infusion's acidity level can be evaluated through taste tests, it can also be measured more precisely using a pH meter, with 5.51 to 5.92 being the typical acidity level of the coffee beverage [66].

Finally, the beverage's viscosity, also called "the body of the infusion", is evaluated. This is perceived in the mouth as a creamy sensation [33, 62, 67, 68] and is a product of the increase in the polysaccharides concentration in solution (e.g., arabinogalactans) [62].

UNIFORMITY

Uniformity is assessed by cupping five cups of coffee to identify off-flavors once the beverage temperature has dropped below 37 ºC [33]. This is achieved by dividing 250 roasted beans into five groups of 50 beans each and then grinding them individually. Once ground, each coffee sample is used to prepare a brew for a total of five cups.

This practice is based on the idea that defective beans (e.g., unripe, over-fermented, sour) that could impart unpleasant flavors to the beverage would be isolated to one, two, or more cups, but not all of them. In contrast, if all 250 roasted beans were ground together; the defective beans present would affect the flavor of every cup of coffee.

CLEANING

Cup cleanliness is not a parameter linked to health aspects but rather based on the search for odors and flavors foreign to coffee in the five cups described above. These unpleasant flavors and odors are acquired through: a) poor processing, b) poor storage conditions, or c) during the beans transport inside transport units, which are also used to transport a range of products with strong odors [33].

SWEETNESS

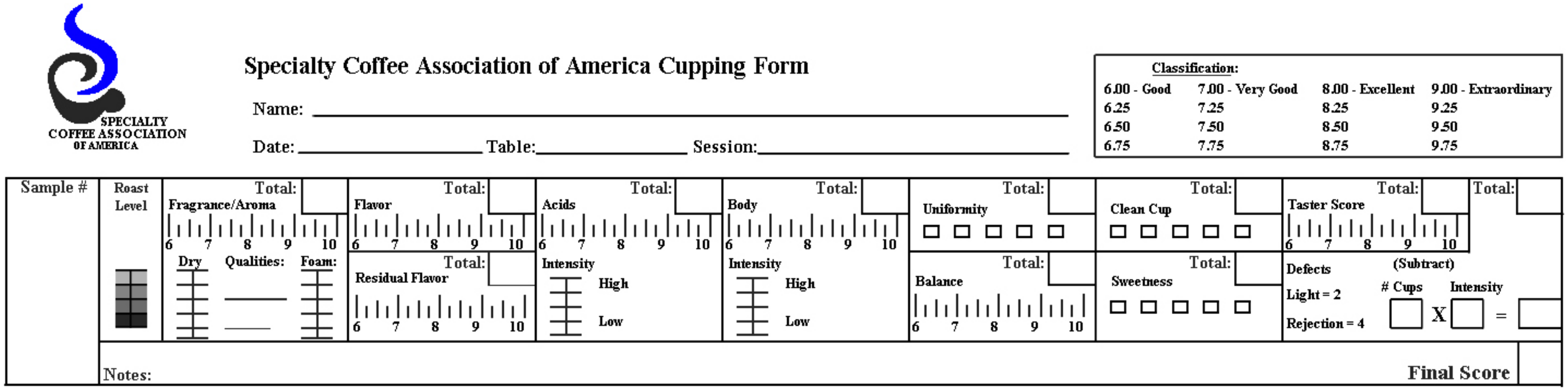
Sweetness is linked to the monosaccharides and disaccharides content dissolved in the infusion; but it can also be attributed to a low organic acids content or salts in solution [33].

After finishing evaluating each sample, tasters usually rinse their mouths with purified water or eat saltine crackers to eliminate residual flavors and aromas before beginning to taste new samples.

CHEMICAL EVALUATIONS

Evaluations carried out by large companies are mostly based on the visual inspection of grain batches, these evaluations are gradually shifting to more objective determinations based on the raw grain's chemical composition, which in turn determines the quality of the cup of coffee [40] This, in turn, is affected by the species (*C. arabica vs C. canephora*) or

Fig 1. Defects that affect the visual quality of coffee bean batches. Reproduced with permission of the Honduran Quality Organization (OHC).



SPECIALTY COFFEE ASSOCIATION OF AMERICA

Specialty Coffee Association of America Cupping Form

Name: ______

Date: ______ Table: ______ Session: ______

Classification:

6.00 - Good	7.00 - Very Good	8.00 - Excellent	9.00 - Extraordinary
6.25	7.25	8.25	9.25
6.50	7.50	8.50	9.50
6.75	7.75	8.75	9.75

Sample # | Roast Level | Fragrance/Aroma Total: 6 7 8 9 10 Dry Qualities: Foam: | Flavor Total: 6 7 8 9 10 | Residual Flavor Total: 6 7 8 9 10 | Acids Total: 6 7 8 9 10 Intensity High Low | Body Total: 6 7 8 9 10 Intensity High Low | Uniformity Total: | Balance Total: 6 7 8 9 10 | Clean Cup Total: | Sweetness Total: | Taster Score Total: 6 7 8 9 10 | Total: | Defects (Subtract) Light = 2 Rejection = 4 # Cups X Intensity =

Notes: Final Score

Fig 2. Specialty Coffee Association of America (SCAA) evaluation form for arabica coffees. To download the form: https://bit.ly/CVAformsenglish_2025 cultivated variety (Fig 3), environmental conditions (e.g., climate, soil, altitude, rainfall, and temperature) or agronomic management (e.g., pruning, fertilization, and degree of solar radiation exposure) [60, 69]; fruit ripeness at the time of harvest, and post-harvest treatment (processing & storage methods) [40, 41, 60, 70-72], the blends of grains before or after roasting; the grain roasting & grinding, and the beverage preparation method [40, 41, 71].

Coffees grown under shade in soils of volcanic origin, at considerable altitude above sea level and at low temperatures are usually associated with the development of good sensory characteristics [73].

There are several parameters used to measure the quality of roasted coffee during storage, such as 2-furfurylthiol, which is related to the freshness degree of roasted coffee. Due to degradation processes (autoxidation), the concentration of 2-furfurylthiol tends to decrease during storage [57, 63]; In other words, the longer the storage time, the lower the concentration of 2-furfurylthiol, which translates into a loss of quality.

Other researchers suggest the use of several parameters at once such as 2-/3-methylbutanal, 2,3-butanedione, 2,5-dimethylfuran [57, 74], 2-methylfuran, 2-methylpropanal, and methanethiol whose concentrations also tend to decrease during storage due to degradative processes [57, 63, 75].

Other authors suggest the use of aroma indices as indicators of the freshness degree of roasted coffee. Aroma indices are obtained by calculating the ratio between some analytes identified in roasted coffee such as: 2-methylfuran/2-butanone [41, 57, 74], dimethyl disulfide/methanethiol [63], methanol/2-methylfuran, 2-methylfuran/2,3-butanedione, 2-methylfuran/propanal, methanethiol/2,3-butanedione, methanethiol/hexanal, methanethiol/2-butanone, and 2-furfurylthiol/hexanal [41, 57, 75].

The effect of cultural practices

The effect of altitude on coffee quality is a well-studied phenomenon. Coffee grown at higher altitudes above sea level ripens more slowly, and its beans are denser and larger [69] and are therefore considered to be of better quality (e.g., larger beans) than those grown at lower altitudes [26, 64, 69, 72].

In the case of robusta coffees, when these are planted above 1000 m.a.s.l. they produce harder beans [33] In addition, at higher altitudes there is a greater lipids synthesis in the coffee bean [64].

The effect of shade on coffee plantations is a well-known phenomenon [64, 72]; *C. canephora* grows best under conditions of full sun exposure; in contrast, *C. arabica* grows best under partial shade conditions [41] since when exposed directly to the sun its photosynthetic apparatus becomes saturated, leading to free radicals production (e.g., H_2O_2) which in turn creates favorable conditions for intracellular oxidative stress [76].

Experiences reported by Reference [77], suggest that both grain yield and average grain size increase under low light conditions until reaching a maximum and then decline under excessive shade conditions. Based on this, it can be inferred that 60% shade is the maximum permissible under which the highest grain yield, highest plant height, highest average grain weight (average weight of 1000 grains) and highest number of branches are recorded (Fig 4).

Coffee plantations grown under severe shade experience a significant reduction in bean production [64, 69, 77] due to the development of more widely spaced internodes, a lower number of active floral nodes, lower floral induction and larger coffee beans [77].

The effect of shade on grain size varies depending on the genotype. When *C. arabica* var. Catimor y *C. arabica* var. Caturra were grown under the same shade conditions, the grain size of var. Catimor was larger than that of var. Caturra, revealing a clear interaction effect between genotype and environment [64].

Another disadvantage of excessive shade is the significant reduction in the coffee bean's saccharose concentration due to a decrease in the saccharose synthase & saccharose phosphate synthase's metabolic activity which are enzymes involved in the disaccharides synthesis [64]. According to Reference [77] the optimal light intensity for carbohydrate biosynthesis ranges between 9800-12 500 lux which corresponds to 50-60% shade (9500-12 500 lux) in the coffee plantation.

The shade cast by trees not only protects the plants from excess light and excessive weed growth, reduces ambient temperature protecting from heat stress thus reducing transpiration, but slows down fruit development [69, 77].

As ambient temperature increases, there is rapid fruit development along with an increase in the malformed fruits proportion, thus affecting cup quality [76]; In contrast, according to Reference [41], Arabica coffee quality improves under cool conditions with average temperatures of 18-22 °C; In contrast, Robusta varieties (e.g., Indian series BP, SA, S274 & BR; IF series from the Ivory Coast & the Brazilian cultivar Apoata) develop best under warm (22-26 °C) and humid conditions typical of tropical climates.

Furthermore, the size of the fruit load in combination with shade exerts an effect on fruit size. Reference [78] reported that in studies carried out in Costa Rica in 1999, a significant increase in fruit size was detected when the size of the fruit load was reduced.

The tendency towards a fruit size reduction during cycles of heavy production can be attributed to severe competition between developing fruits for available carbohydrates.

Bitterness and astringency were higher in infusions made from grains harvested from sun-grown plants than in those prepared from grains harvested from shade-grown plants during two consecutive production seasons [64, 69, 78]; This was probably a consequence of a higher ACs and trigonelline concentration in grains from sun-grown plants [64, 78].

However, the evidence suggests that this occurs due to an increase in ambient temperature and not due to an increased solar radiation exposure.

Documented experiences suggest the existence of a positive correlation between ambient temperature and chlorogenic acids biosynthesis (e.g., 4-feruloylquinic acid,

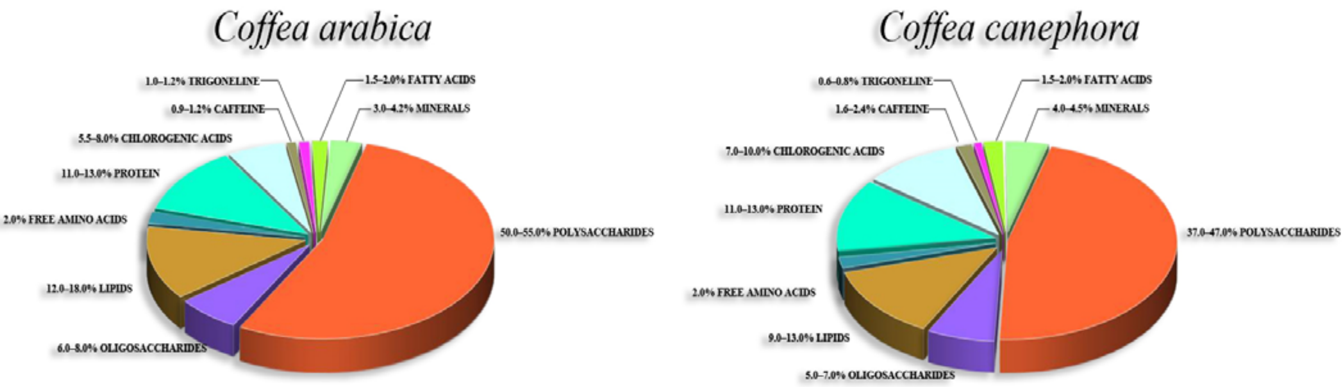


Fig 3. Chemical composition of raw coffee beans. Adapted from Reference [68].

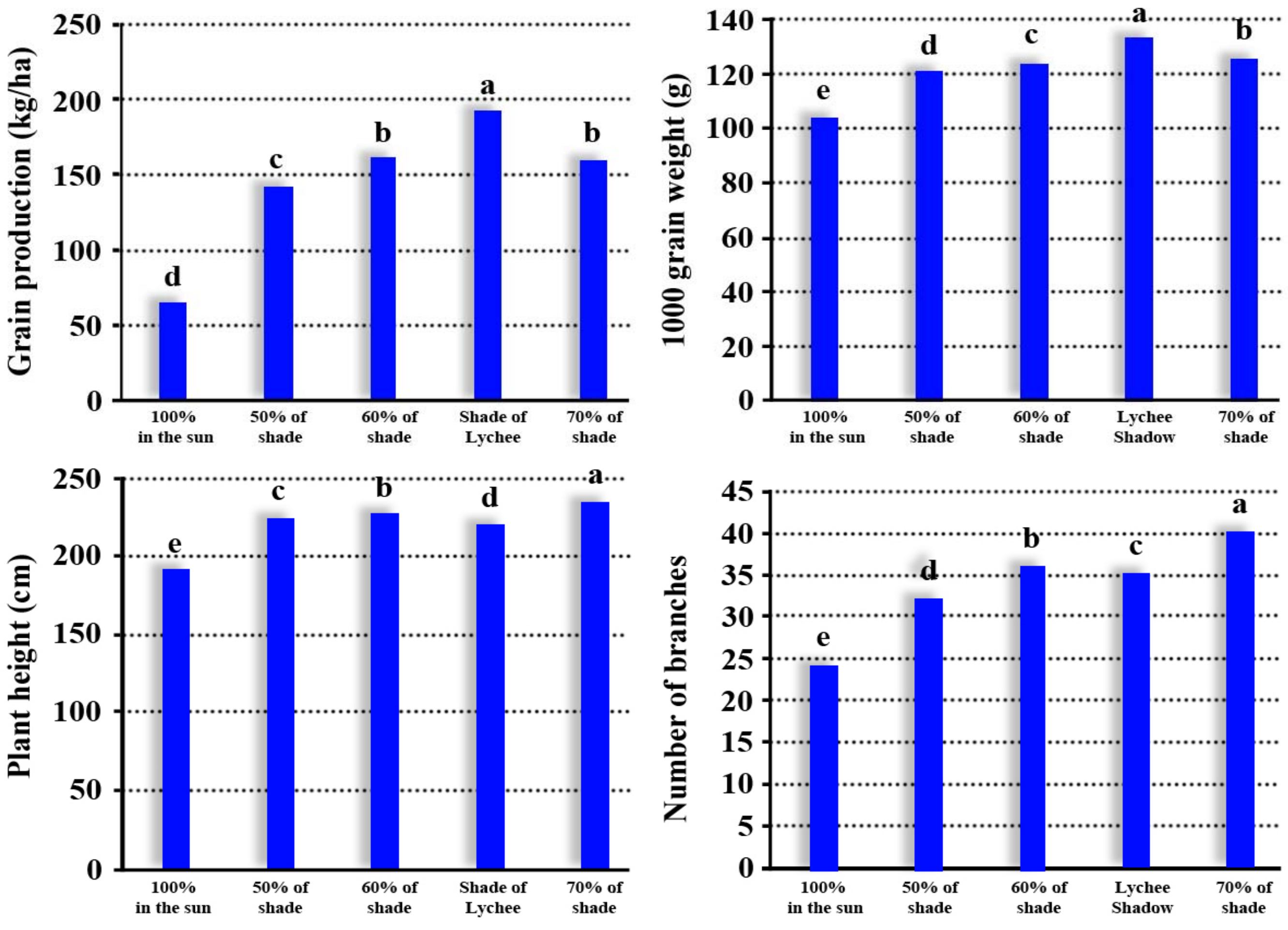


Fig 4. Shade effect on coffee trees measured through agronomic parameters.
Bars with the same letter are not significantly different. Adapted from Reference [77].

5-feruloylquinic acid, 3-caffeoylquinic acid, 4-caffeoylquinic acid, 3,4-dicaffeoylquinic acid & 4,5-dicaffeoylquinic acid) [64, 79]; That is, as ambient temperature increases, so does the accumulation of these acids; as a result of an increase in the expression (transcription) of genes linked to CAs biosynthetic pathway [64].

In contrast, the levels of 5-caffeoylquinic acid and 3,5-dicaffeoylquinic acid increased as ambient temperature decreased, indicating a negative correlation between ambient temperature and their biosynthesis [79].

Finally, the high lipids levels present in coffee have been associated with an improvement in its organoleptic properties [80] and tend to be preferred by the consumer [72]. The cultural practice of growing coffee under the shade increases the endosperm's lipids levels [64, 78] thus improving the quality of the infusion.

THE EFFECT OF GRAIN PROCESSING

The beans processing after harvest has a significant impact on the quality of the resulting cup of coffee after roasting [81]. The roasted coffee's volatile composition varies depending on the chosen processing process (dry vs. wet) and the selected degree of roasting [82].

Coffee produced from beans processed using wet processing has a better cup quality [42, 83] characterized by having less density, more acidity ($pH_{arabica}$: 4.85-5.15 *vs* $pH_{robusta}$: 5.25-5.40) and a more intense aroma compared to those processed through dry processing [83, 84]; Coffees processed through the semi-dry method also known as *honeyed coffees* have an intermediate density compared to the previous ones [83].

Experiences documented by Reference [85] provide evidence that the mucilage removal via fermentation gives the raw grain a volatile composition rich in esters and alcohols which in turn contribute to the formation, during roasting, of other compounds of thermal origin that improve the grain's aromatic profile.

This improvement is manifested through the increase in the proportion of caffeoylquinic acids with respect to dicaffeoylquinic acids [86]; Furthermore, according to Reference [70], 'the coffee bean processing increases the degree of extraction of high molecular weight polysaccharides, with galactomannans and arabinogalactans being the majority fraction present in solution'.

In experiences documented by Reference [70], beverages prepared from roasted and ground grains previously processed through wet processing present the highest polysaccharides concentration in solution, which improves viscosity; mannans are directly responsible for the increase in viscosity due to their higher concentration in solution [70] in addition to having a more intense aroma and being more acidic than those processed dry [29].

The higher polysaccharides concentration in solution in beverages prepared from coffee processed through wet milling can be attributed to the metabolic activity of enzymes linked to bean germination (i.e., endo-β-mannanases, β-mannosidases and galactosidases) since these catabolize the reserve polysaccharides into their constituent monomers for use by the developing seedling.

A similar process occurs in relation to reserve proteins which are also degraded during germination, but their hydrolysis is interrupted during grain drying, resulting in a seed with a higher free amino acids concentration and short-chain carbohydrates (mono, di & trisaccharides) which act as precursors to the flavoring and aromatic compounds that develop during roasting through the Maillard reaction, the Strecker degradation of amino acids, among others.

In contrast, beverages prepared from dry-processed grains have a higher saccharose concentration than wet-processed grains [37] are less acidic and their aroma is less intense [29]. The higher saccharose concentration in dry-processed grains compared to wet-processed grains can be attributed to the fact that they are not fermented during processing.

Wet processing causes a decrease in glucose and fructose levels in the beans, regardless of the species involved [81]. This phenomenon can be attributed to the fermentation processes and the leaching of metabolites during bean washing, since this decrease is not observed in coffee beans processed through dry processing.

The evidence suggests that during coffee drying there is an increase in the γ-aminobutyric acid (GABA) concentration which is a non-protein amino acid and is therefore considered a marker of water stress [81]. GABA is produced through the enzymatic decarboxylation reaction of glutamic acid, which is catalyzed by glutamate decarboxylase.

However, at the end of drying, GABA levels are higher in beans processed through dry processing than those found in those processed through wet processing [81]; For this reason, the GABA concentration in the coffee beverage could be used as a discriminating parameter of the type of processing (wet vs. dry) used during coffee processing.

CONCLUSION

Coffee is the 2nd most consumed drink in the world after tea [2,17,98] since the latter is consumed in more countries. According to Reference [24], "for every three cups of tea drunk in the world, one cup of coffee is consumed"; However, a cup of tea is cheaper than a cup of coffee because 1 kg of tea produces 4 to 5 times more cups than 1 kg of coffee [24].

There are two economically important species used in coffee production: *Coffea arabica* L. (Arabica coffee) & *Coffea canephora* Pierre ex A. Forehner var. Robusta, with 65 and 35% of world production attributed to *C. arabica* L. & *C. canephora* P. respectively [35,39,49-51].

Coffee is grown in nearly 80 countries located in Central & South America, the Caribbean, Africa & Asia [66-68]; Regions all between the Tropic of Cancer and the Tropic of Capricorn [22,23,30,69]. That is, in the area between latitude 23.5º N and 23.5º S, also known as the "Coffee Belt" [50,67].

Additionally, while most coffee production occurs in underdeveloped countries, 71% of its consumption occurs in developed countries [24,66,70,71]. While 20-30% of global production occurs on large-scale plantations, the remaining 70-80% is in the hands of small farmers [31,72,82-85].

Considering all these facts, it is understandable why coffee is one of the most widely consumed beverages in the world and its popularity and demand, in national and international markets, is not based on its nutritional value or potential health benefits, but on its pleasant taste and caffeine´s stimulating properties.

REFERENCES

[1] D. S. Tilley, and G. K. Indahsari, “Impact of international coffee agreement abandonment on Indonesian coffee prices,” *Agribusiness,* vol. 12, no. 2, pp. 157–166, March/April 1996.

[2] J. Perez, B. Kilian, L. Pratt, J. C. Ardila, H. Lamb *et al.*, “Economic sustainability—Price, cost, and value,” in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 133–160.

[3] A. Ghoshray, “The extent of the world coffee market,” *Bull. Econ. Res.,* vol. 62, no. 1, pp. 97–107, January 2010.

[4] S. Ponte, “The `Latte Revolution'? regulation, markets and consumption in the global coffee chain,” *World Dev,* vol. 30, no. 7, pp. 1099–1122, July 2002.

[5] W. D. Greenstone, “The coffee cartel: manipulation in the public interest,” *J. Fut. Mark.,* vol. 1, no. 1, pp. 3–16, 1981.

[6] C. Bacon, “Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua?,” *World Development,* vol. 33, no. 3, pp. 497–511, March 2005.

[7] B. Kilian, C. Jones, L. Pratt, and A. Villalobos, “Is sustainable agriculture a viable strategy to improve farm income in Central America? a case study on coffee,” *J Bus Res,* vol. 59, no. 3, pp. 322–330, March 2006.

[8] P. Barone, M. Deugd, and C. Wille, “Experience and experimentation,” in *The Craft and Science of Coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 161–179.

[9] K. Watson, and M. L. Achinelli, “Context and contingency: the coffee crisis for conventional small-scale coffee farmers in Brazil,” *Geogr. J.,* vol. 174, no. 3, pp. 223–234, September 2008.

[10] F. M. Carvalho, and C. Spence, “The shape of the cup influences aroma, taste, and hedonic judgements of specialty coffee,” *Food Qual Prefer,* vol. 68, pp. 315–321, 2018/09/01/ 2018.

[11] S. Piccino, R. Boulanger, F. Descroix, and A. Shum Cheong Sing, “Aromatic composition and potent odorants of the “specialty coffee” brew “Bourbon Pointu” correlated to its three trade classifications,” *Food Res. Int.,* vol. 61, pp. 264–271, 2014/07/01/ 2014.

[12] R. Fitter, and R. Kaplinksy, “Who gains from product rents as the coffee market becomes more differentiated? a value-chain analysis,” *IDS Bulletin,* vol. 32, no. 3, pp. 69–82, July 2001.

[13] R. Gielissen, and J. Graafland, “Concepts of price fairness: empirical research into the Dutch coffee market,” *Bus. Ethics,* vol. 18, no. 2, pp. 165–178, April 2009.

[14] C. Arnot, P. C. Boxall, and S. B. Cash, “Do ethical consumers care about price? a revealed preference analysis of fair trade coffee purchases,” *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* vol. 54, no. 4, pp. 555–565, December 2006.

[15] M. R. A. Noponen, C. Góngora, P. Benavides, A. Gaitán, J. Hayward *et al.*, “Environmental sustainability—Farming in the anthropocene,” in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 81–107.

[16] S. I. Mussatto, E. M. S. Machado, S. Martins, and J. A. Teixeira, “Production, composition, and application of coffee and its industrial residues,” *Food Bioproc Tech,* vol. 4, no. 5, pp. 661–672, July 2011.

[17] S. Thompson, “Returns to storage in coffee and cocoa futures markets,” *J Fut Mark,* vol. 6, no. 4, pp. 541–564, Winter 1986.

[18] E. Nadelberg, J. R. Polit, J. P. Orjuela, and K. Ranitzsch, “Trading and transaction—Market and finance dynamics,” in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 205–223.

[19] E. Thomas, S. Puget, D. Valentin, and P. Songer, “Sensory evaluation—Profiling and preferences,” in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 419–456.

[20] D. Levy, J. Reinecke, and S. Manning, “The political dynamics of sustainable coffee: contested value regimes and the transformation of sustainability,” *J Manage Stud,* vol. 53, no. 3, pp. 364–401, May 2016.

[21] V. S. Ribeiro, A. E. Leitão, J. C. Ramalho, and F. C. Lidon, “Chemical characterization and antioxidant properties of a new coffee blend with cocoa, coffee silverskin and green coffee minimally processed,” *Food Res. Int.,* vol. 61, pp. 39–47, 2014.

[22] A. Kolk, “Mainstreaming sustainable coffee,” *Sustain Dev,* vol. 21, no. 5, pp. 324–337, September/October 2013.

[23] P. R. A. B. de Toledo, M. M. R. de Melo, H. R. Pezza, A. T. Toci, L. Pezza *et al.*, “Discriminant analysis for unveiling the origin of roasted coffee samples: a tool for quality control of coffee related products,” *Food Control,* vol. 73, pp. 164–174, 2017/03/01/ 2017.

[24] I. Flament, and Y. Bessière-Thomas, *Coffee flavor chemistry*, 1 ed. West Sussex, PO19 1UD, England: John Wiley & Sons (in eng), 2001.

[25] G. Downey, and J. Boussion, “Authentication of coffee bean variety by near-infrared reflectance spectroscopy of dried extract,” *J. Sci. Food Agric.,* vol. 71, no. 1, pp. 41–49, May 1996.

[26] P. J. S. Cramer, F. L. Wellman, Ed. *A review of literature of coffee research in Indonesia* (Miscellaneous publications series). Turrialba, Costa Rica: Inter-American Institute of Agricultural Sciences (in eng), 1957, p. 262.

[27] L. Servillo, A. Giovane, R. Casale, D. Cautela, N. D’Onofrio *et al.*, “Glucosylated forms of serotonin and tryptophan in green coffee beans,” *Lwt,* vol. 73, pp. 117–122, November 2016.

[28] H. Čížková, V. Soukupová, M. Voldřich, and R. Ševčík, “Differentiation of coffee varieties according to their sterolic profile,” *J Food Nutr Res,* vol. 46, no. 1, pp. 28–34, 2007.

[29] S. Rocha, L. Maeztu, A. Barros, C. Cid, and M. A. Coimbra, “Screening and distinction of coffee brews based on headspace solid phase microextraction/gas chromatography/principal component analysis,” *J. Sci. Food Agric.,* vol. 84, no. 1, pp. 43–51, January 2004.

[30] M. T. Kreuml, D. Majchrzak, B. Ploederl, and J. Koenig, “Changes in sensory quality characteristics of coffee during storage,” *Food Sci Nutr,* vol. 1, no. 4, pp. 267–272, July 2013.

[31] A. Farah, “Coffee constituents,” in *Coffee*, Y.-F. Chu Ed., editors., 1 ed. Oxford, UK: Wiley-Blackwell, 2012, pp. 21–58.

[32] A. P. Craig, A. S. Franca, and L. S. Oliveira, “Discrimination between immature and mature green coffees by attenuated total reflectance and diffuse reflectance Fourier transform infrared spectroscopy,” *J. Food Sci.,* vol. 76, no. 8, pp. C1162–C1168, October 2011.

[33] T. R. Lingle, and S. N. Menon, “Cupping and grading - Discovering character and quality,” in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 181–203.

[34] J. R. Santos, M. C. Sarraguca, A. O. Rangel, and J. A. Lopes, “Evaluation of green coffee beans quality using near infrared spectroscopy: a quantitative approach,” *Food Chem.,* vol. 135, no. 3, pp. 1828–1835, Dec 1 2012.

[35] K. Tolessa, M. Rademaker, B. De Baets, and P. Boeckx, “Prediction of specialty coffee cup quality based on near infrared spectra of green coffee beans,” *Talanta,* vol. 150, pp. 367–374, Apr 1 2016.

[36] A. Farah, and T. Ferreira dos Santos, “The coffee plant and beans,” in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 5–10.

[37] K. Ramalakshmi, I. R. Kubra, and L. J. Rao, “Physicochemical characteristics of green coffee: comparison of graded and defective beans,” *J. Food Sci.,* vol. 72, no. 5, pp. S333–S337, June 2007.

[38] A. Belay, Y. Bekele, A. Abraha, D. Comen, H. K. Kim *et al.*, “Discrimination of defective (full black, full sour and immature) and nondefective coffee beans by their physical properties,” *J. Food Process Eng.,* vol. 37, no. 5, pp. 524–532, October 2014.

[39] A. S. Franca, J. C. F. Mendonça, and S. D. Oliveira, “Composition of green and roasted coffees of different cup qualities,” *LWT - Food Science and Technology,* vol. 38, no. 7, pp. 709–715, November 2005.

[40] A. S. Franca, L. S. Oliveira, J. C. F. Mendonça, and X. A. Silva, “Physical and chemical attributes of defective crude and roasted coffee beans,” *Food Chem.,* vol. 90, no. 1–2, pp. 89–94, March/April 2005.

[41] P. R. A. B. Toledo, L. Pezza, H. R. Pezza, and A. T. Toci, “Relationship between the different aspects related to coffee quality and their volatile compounds,” *Compr Rev Food Sci Food Saf,* vol. 15, no. 4, pp. 705–719, July 2016.

[42] P. Esquivel, and V. M. Jiménez, “Functional properties of coffee and coffee by-products,” *Food Res. Int.,* vol. 46, no. 2, pp. 488–495, May 2012.

[43] F. Wei, and M. Tanokura, “Organic compounds in green coffee beans,” in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 149–162.

[44] L. S. Oliveira, A. S. Franca, J. C. F. Mendonça, and M. C. Barros-Júnior, “Proximate composition and fatty acids profile of green and roasted

defective coffee beans," *LWT - Food Science and Technology,* vol. 39, no. 3, pp. 235–239, July 2006.
[45] A. Farah, and C. M. Donangelo, "Phenolic compounds in coffee," *Braz. J. Plant Physiol.,* vol. 18, no. 1, pp. 23–36, January/March 2006.
[46] A. T. Toci, and A. Farah, "Volatile compounds as potential defective coffee beans' markers," *Food Chem.,* vol. 108, no. 3, pp. 1133–1141, June 1 2008.
[47] D. L. Kalschne, T. Biasuz, A. J. De Conti, M. C. Viegas, M. P. Corso *et al.*, "Sensory characterization and acceptance of coffee brews of *C. arabica* and *C. canephora* blended with steamed defective coffee," *Food Res. Int.,* vol. 124, pp. 234–238, October 2019.
[48] R. C. E. Dias, P. Valderrama, P. H. Marco, M. B. Dos Santos Scholz, M. Edelmann *et al.*, "Quantitative assessment of specific defects in roasted ground coffee via infrared-photoacoustic spectroscopy," *Food Chem.,* vol. 255, pp. 132–138, Jul 30 2018.
[49] M. K. Mishra, and A. Slater, "Recent advances in the genetic transformation of coffee," *Biotechnol Res Int,* vol. 2012, p. 580857, 2012.
[50] J. E. G. van Dam, and P. Harmsen, *Coffee residues utilization*, Wageningen UR Food & Biobased Research, Report 2010. Available: http://library.wur.nl/WebQuery/wurpubs/503808
[51] C. Marin, and G. I. Puerta Q., "Contenido de ácidos clorogénicos en granos de *Coffea arabica* L. y *C. canephora* según el desarrollo del fruto," *Cenicafé,* vol. 59, no. 1, pp. 7–28, December 1 2008.
[52] M. W. Cheong, K. H. Tong, J. J. M. Ong, S. Q. Liu, P. Curran *et al.*, "Volatile composition and antioxidant capacity of Arabica coffee," *Food Res. Int.,* vol. 51, no. 1, pp. 388–396, April 1 2013.
[53] S. Oestreich-Janzen, "Chemistry of coffee," in *Comprehensive natural products II.* Oxford: Elsevier, 2010, pp. 1085–1117.
[54] P. Mazzafera, "Chemical composition of defective coffee beans," *Food Chem.,* vol. 64, no. 4, pp. 547–554, March 1999.
[55] M. H. Taniwaki, A. A. Teixeira, A. R. R. Teixeira, M. V. Copetti, and B. T. Iamanaka, "Ochratoxigenic fungi and Ochratoxin A in defective coffee beans," *Food Res. Int.,* vol. 61, pp. 161–166, July 2014.
[56] R. R. M. Paterson, N. Lima, and M. H. Taniwaki, "Coffee, mycotoxins and climate change," *Food Res. Int.,* vol. 61, pp. 1–15, July 2014.
[57] K. Marin, T. Požrl, E. Zlatić, and A. Plestenjak, "A new aroma index to determine the aroma quality of roasted and ground coffee during storage," *Food Technol. Biotechnol.,* vol. 46, no. 4, pp. 442–447, 2008.
[58] S. Schenker, C. Heinemann, M. Huber, R. Pompizzi, R. Perren *et al.*, "Impact of roasting conditions on the formation of aroma compounds in coffee beans," *J. Food Sci.,* vol. 67, no. 1, pp. 60–66, January 2002.
[59] R. A. Buffo, and C. Cardelli-Freire, "Coffee flavour: an overview," *Flavour Fragr J,* vol. 19, no. 2, pp. 99–104, March/April 2004.
[60] D. Pacetti, P. Lucci, and N. G. Frega, "Unsaponifiable matter of coffee," in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 119–127.
[61] M. A. Rostagno, R. M. S. Celeghini, I. C. N. Debien, G. C. Nogueira, and M. A. A. Meireles, "Phenolic compounds in coffee compared to other beverages," in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 137–142.
[62] L. Poisson, I. Blank, A. Dunkel, and T. Hofmann, "The chemistry of roasting - Decoding flavor formation," in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 273–309.
[63] C. Yeretzian, I. Blank, and Y. Wyser, "Protecting the flavors - Freshness as a key to quality," in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 329–353.
[64] B. Cheng, A. Furtado, H. E. Smyth, and R. J. Henry, "Influence of genotype and environment on coffee quality," *Trends Food Sci. Technol.,* vol. 57, pp. 20–30, 2016/11/01/ 2016.
[65] E. Nebesny, and G. Budryn, "Evaluation of sensory attributes of coffee brews from robusta coffee roasted under different conditions," *Eur. Food Res. Technol.,* vol. 224, no. 2, pp. 159–165, December 2006.
[66] X. Wang, J. William, Y. Fu, and L. T. Lim, "Effects of capsule parameters on coffee extraction in single-serve brewer," *Food Res. Int.,* vol. 89, no. Pt 1, pp. 797–805, November 2016.
[67] J. Simoes, P. Madureira, F. M. Nunes, R. Domingues Mdo, M. Vilanova *et al.*, "Immunostimulatory properties of coffee mannans," *Mol. Nutr. Food Res.,* vol. 53, no. 8, pp. 1036–1043, August 2009.
[68] F. Wei, and M. Tanokura, "Chemical changes in the components of coffee beans during roasting," in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 83–91.
[69] C. Lambot, J. C. Herrera, B. Bertrand, S. Sadeghian, P. Benavides *et al.*, "Cultivating coffee quality - Terroir and agro-ecosystem," in *The craft and science of coffee*, B. Folmer Ed., editors.: Academic Press, 2017, pp. 17–49.
[70] A. Tarzia, M. B. Dos Santos Scholz, and C. L. De Oliveira Petkowicz, "Influence of the postharvest processing method on polysaccharides and coffee beverages," *Int. J. Food Sci. Technol.,* vol. 45, no. 10, pp. 2167–2175, October 2010.
[71] K. Sanchez, and E. Chambers, "How does product preparation affect sensory properties? an example with coffee," *J. Sens. Stud.,* vol. 30, no. 6, pp. 499–511, December 2015.
[72] F. Decazy, J. Avelino, B. Guyot, J. J. Perriot, C. Pineda *et al.*, "Quality of different Honduran coffees in relation to several environments," *J. Food Sci.,* vol. 68, no. 7, pp. 2356–2361, September 2003.
[73] H. T. Tran, L. S. Lee, A. Furtado, H. Smyth, and R. J. Henry, "Advances in genomics for the improvement of quality in coffee," *J. Sci. Food Agric.,* vol. 96, no. 10, pp. 3300–3312, August 15 2016.
[74] C. F. Ross, K. Pecka, and K. Weller, "Effect of storage conditions on the sensory quality of ground arabica coffee," *J. Food Qual.,* vol. 29, no. 6, pp. 596–606, December 2006.
[75] N. Dulsat-Serra, B. Quintanilla-Casas, and S. Vichi, "Volatile thiols in coffee: a review on their formation, degradation, assessment and influence on coffee sensory quality," *Food Res. Int.,* vol. 89, pp. 982–988, November 1 2016.
[76] F. M. DaMatta, E. Rahn, P. Läderach, R. Ghini, and J. C. Ramalho, "Why could the coffee crop endure climate change and global warming to a greater extent than previously estimated?," *Clim. Change,* vol. 152, no. 1, pp. 167–178, January 01 2018.
[77] C. Somporn, A. Kamtuo, P. Theerakulpisut, and S. Siriamornpun, "Effect of shading on yield, sugar content, phenolic acids and antioxidant property of coffee beans (*Coffea arabica* L. cv. Catimor) harvested from north-eastern Thailand," *J. Sci. Food Agric.,* vol. 92, no. 9, pp. 1956–1963, July 2012.
[78] P. Vaast, B. Bertrand, J.-J. Perriot, B. Guyot, and M. Génard, "Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions," *J. Sci. Food Agric.,* vol. 86, no. 2, pp. 197–204, January 30 2006.
[79] T. Joet, J. Salmona, A. Laffargue, F. Descroix, and S. Dussert, "Use of the growing environment as a source of variation to identify the quantitative trait transcripts and modules of co-expressed genes that determine chlorogenic acid accumulation," *Plant Cell Environ,* vol. 33, no. 7, pp. 1220–1233, July 2010.
[80] B. M. Gichimu, E. K. Gichuru, G. E. Mamati, and A. B. Nyende, "Biochemical composition within *Coffea arabica* cv. Ruiru 11 and its relationship with cup quality," *J Food Res,* vol. 3, no. 3, pp. 31–44, 2014.
[81] M. Kleinwächter, G. Bytof, and D. Selmar, "Coffee beans and processing," in *Coffee in health and disease prevention*. San Diego: Academic Press, 2015, pp. 73–81.
[82] O. Gonzalez-Rios, M. L. Suarez-Quiroz, R. Boulanger, M. Barel, B. Guyot *et al.*, "Impact of "ecological" post-harvest processing on coffee aroma: II. roasted coffee," *J Food Compost Anal,* vol. 20, no. 3-4, pp. 297–307, May 2007.
[83] W. B. Sunarharum, D. J. Williams, and H. E. Smyth, "Complexity of coffee flavor: a compositional and sensory perspective," *Food Res. Int.,* vol. 62, pp. 315–325, August 1 2014.
[84] L. W. Lee, M. W. Cheong, P. Curran, B. Yu, and S. Q. Liu, "Coffee fermentation and flavor - an intricate and delicate relationship," *Food Chem.,* vol. 185, pp. 182–191, Oct 15 2015.
[85] O. Gonzalez-Rios, M. L. Suarez-Quiroz, R. Boulanger, M. Barel, B. Guyot *et al.*, "Impact of "ecological" post-harvest processing on the volatile fraction of coffee beans: I. green coffee," *J Food Compost Anal,* vol. 20, no. 3-4, pp. 289–296, May 2007.
[86] A. Stalmach, "Bioavailability of coffee chlorogenic acids," in *Coffee*, Y.-F. Chu Ed., editors. Oxford, UK: Wiley-Blackwell, 2012, pp. 59–76.