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Review

Bases for the Establishment of Robusta Coffee (*Coffea canephora*) as a New Crop for Colombia

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Abstract: Robusta coffee (*C. canephora*) covers 36% of world coffee production and has strategic relevance as a beverage that it is produced by thousands of small-scale producers around the world. Although mainly grown in Africa and Asia as opposed to Latin America, this situation is changing. Colombia is recognized as a producer of high-quality Arabica (*C. arabica* L.) coffee, however we argue that Robusta represents a great economic opportunity for small scale producers, for the industrialization of new products and for emerging coffee chains. Therefore, the objective of this review is to outline the agronomic value of Robusta coffee as a "new crop" in Colombia. As background we compare the better-known Arabica to the Robusta coffees from a Latin American perspective. Robusta shows differences in geographical distribution, genetics, originating species, physiology and phenology. Robusta and Arabica also differ in their chemistry, sensory attributes, industrial use, segments of market and price. Despite the marked differences between the two coffees, the popularity and consumption of Robusta has been on the increase due to the expansion of markets in emerging economies and in developed markers for home espresso preparation where it is used in high quality coffee blends. Robusta is currently replacing areas of other coffees due to hotter temperatures to which it is adapted. Although Robusta is still new to Colombia, this species has potential adaptation in lowland areas considered "non-traditional" for Colombian coffee cultivation and as a valuable component of agro-ecological production systems. Robusta is a novel crop option for certain regions that is needed for the future of coffee in Latin America and for growth of coffee production and consumption in Colombia.

Keywords: agronomic adaptation; coffee blends; ecological regions; market opportunities; new crop

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1. Introduction to Difference between Robusta and Arabica Coffees

Coffea canephora (syn. *Coffea robusta*), known as Robusta coffee, is a species from the Rubiaceae Family (Order Gentianales) that has its origins in central and western sub-Saharan Africa. Native to the tropical forests around Lake Victoria in Uganda, it was introduced to Southeast Asia in 1900 after leaf rust (*Hemileia vastatrix* Berk. and Br.) destroyed all of Ceylon's arabica coffee crops in 1869 and most of the low-lying plantations of Java in 1876 [1,2]. Currently, it represents 36% of world production and is grown in tropical countries from Indonesia and Vietnam, through Sub-Saharan Africa to Brazil.

The genetic structure of cultivated Robusta coffee parallels natural populations of *C. canephora* and in ex situ germplasm collections with specific studies by geographic regions, phylogenetic groups, phenotypic, biochemical, and molecular evaluations that determine the existence of wide genetic diversity with population structure composed of two groups: the Congolese group and the Guinean group. The Congolese group is subdivided into five subgroups: SG1, SG2, B, C, and UW. In the production chain of

caffeinated coffee, those of the SG1 subgroup are known as *C. canephora* var. *kouilou* (in Brazil, known as conilon coffee), and the others are known as *C. canephora* var. *robusta* (or Robusta coffee) [3]. The Guinean group is less well studied.

Robusta differs from Arabica coffee in being two different sub-species, but also shows important differences in their origin, geographical distribution, genome conformation, ploidy level, genetic variability, morphology, physiology, and phenology (days to flowering, etc.), as well as in chemistry and organoleptic quality, industrial uses, market segments and price [4]. Table 1 shows 44 characteristics and/or attributes of Robusta and Arabica coffees, with the species *C. canephora* compared to *C. arabica*, recognizing that despite overall similarity between the two species as sources of coffee products there are many differences amongst them.

Table 1. Main differences between *Coffea arabica* and *Coffea canephora*.

Specie	***C. arabica*, Arabica**	***C. canephora*, Robusta**
Origin	Ethiopia, Sudan, Kenya	Guinea and Congo
Altitude of origin in meters above sea level (masl)	1300–2000	0–1000
Genetic variability	Low, due to its origin from few plants and its self-pollinating condition.	High, due to outcrossing (natural interbreeding between and within populations).
Genetic structure	Segmental allotetraploid (cross *C. eugenioides* × *C. canephora*). Amphidiploid	True Diploid with polymorphic populations and highly heterozygous heterotic groups
Number of chromosomes	2n = 4x = 44	2n = 2x = 22
Fertilization and compatibility	Self-pollinated (more than 90% autogamous) and self-compatible	Self-incompatible gametophytic type of monogenic nature and synchronized flowering
Plant type	Shrub	Tree and/or shrub
Growth habit	Erect	Umbrella shape
Propagation type	Sexual (seed)	Asexual (cuttings-clonal) and sexual (seed)
Canopy structure	Pyramidal	Irregular
Root type	Deep-rooted	Shallow-rooted
Symbiotic associations	Dependent to obligate	Dependent, mycorrhizae obligate
Stem type	Uni-caulate (woody)	Multi-caulate (woody)
Grain-color (before roasting)	Greenish tone	Pale and yellowish tone
Grain-shape (dry)	Larger, oval, flat and elongated	Small, rounded, oval or elliptical; notable tips; domed or convex
Retention of grain by the plant	Lower	Higher
Inflorescences (number)	Lower (2–3 peaks/crotch)	Higher (3–5 peaks/crotch)
Flowering (regularity)	Regular (after rains)	Irregular
Flowering (months)	9	10–11
Photoperiod sensitivity (hours)	Short days (13.5)	Shorter days (11.0)
Grain earliness (months from anthesis to fully ripe)	6–8 (earlier)	9–11 (later)
Time to induce the inactive flowering-period (months)	2–4	2–4
Biannual production	Present	Absent
Latitude range (degrees)	Less than 10 N and 10 S	Between 10 N and 10 S

Table 1. *Cont.*

Specie	*C. arabica*, Arabica	*C. canephora*, Robusta
Optimal temperature (°C)	18–21	22–30
Optimum precipitation (mm)	1500–2000	2000–3000
Relative humidity required (%)	70%	85%
Altitude for cultivation in meters above sea level (masl)	1000–2000	0–700
Genetic improvement scheme	Hybridization, inbreed, backcross (*per* autogamy)	Reciprocal recurrent selection (*per* allogamy)
Yield (kg/ha) of green coffee	Usually lower performing (1500–3000)	Higher performing (2300–4000) with intensive production 6000
Cherry (fresh): green coffee	Lower (4:1 to 5:1)	Higher (5:1 or above)
Rust resistance	Susceptible	Wide resistance spectrum (source of resistance in Timor hybrid)
Nematode resistance	Susceptible	Source of genetic resistance
Planting density	High	Low
Cup quality	Subtle taste, aromatic	Stronger taste, fragrant
Caffeine content average (%)	1.7	3.4 (2× more content)
Isoflavones (micrograms)	40	285 (7× more concentrated)
Total reducing sugars (%)	0.10	0.40 (4× higher)
Saccharose (%)	8.0	4.0 (less than 50%)
Chlorogenic acid (%)	Green grain (6.4–7.1); semi-ripe grain (4.7–7.9); ripe grain (5.5–6.9)	Semi-ripe grain (7.8–8.0); ripe grain (8.2–10.6)
Trigonellin (dry matter basis)	0.79–1.06	0.66–0.68
Market segment	Premium and mainstream	Instant, blended coffees, washed
Production cost	Higher	Lower (17%) (no irrigation costs)
Price	High	Low

When we compare the two coffees for production statistics, we see that Arabica is currently the dominant type. Arabicas represented 64% of world production in 2020/2021 with 6.1 million tons (measured as 101.9 million bags) produced. By comparison, Robusta coffee has a 36% market share, with 4.4 million tons (or 73.5 million bags) [5]. In terms of quality, Arabica is known for a pronounced aroma and acidity that is favored in the gourmet and international markets. Sometimes it is considered mild coffee. Robusta is known for having greater body but lower aroma [6], and it is consumed in emerging and developed markets as a mixed product or instant coffees.

The two types of coffee are planted in different geographical areas: Robusta in lowlands with high humidity and hot conditions, compared to Arabica under moderate temperatures of highland regions. Robusta is used as a substitute for Arabica in some places in mid-elevation Africa, lowlands of Asia, island nations and territories of the Caribbean (CARICOM) and the Pacific (Hawaii and Papua New Guinea), and increasingly in Latin America (notably Brazil and Mexico) given better adaptation to warm environment and resistance to leaf rust [7]. The edaphoclimatic conditions and the flat topography that occur in lowlands together with the architecture of the Robusta coffee plant allows potential mechanization and therefore higher productivity of this type of coffee [8]. This is important in Colombia and Brazil where labor prices are significantly higher than in Asia or Africa. *C. canephora* coffees, of either Robusta or Conilón type, can produce between 2 to 4 t/ha/year with a technological management, compared to 1.5 and 3 t/ha/year for Arabica.

In the international market, the price of Robusta coffee is 25% lower than Arabica products, but this is offset by higher production, higher industrial conversion due to the high content of total soluble solids and a higher ratio of parchment "gold" beans compared to pulp or cherry. The Robusta beans are smaller, but heavier [9]. Most Robusta genotypes are resistant to rust and nematodes. Furthermore, they do not present biannual production, but rather provide either continuous monthly production or a single harvest per year in the case of synchronous varieties, which allows mechanization of all its cultural processes (depending on the topography of the region and variety) [10]. Arabica coffees sometimes produce in two seasons in regions with bimodal rainfall in Colombia and Kenya where they must be hand-picked by seasonal labor. Therefore, Robusta coffees can be more efficient to grow, allowing the problem of the low labor availability at picking times to be solved by mechanization or by employing labor that works continuously on Robusta along with harvesting other crops at other times of the year. This adapts Robusta to production on family farms.

2. Possible Agro-Ecologies for Production of Robusta Coffee in Colombia

Colombia is known for its production of high-quality "premium" 100% Arabica coffees. This has been a mainstay of a national marketing campaign to promote coffee exports to Europe and North America from the South American country. Very little Robusta coffee has been produced in Colombia despite an internal market for the lower priced beans as compared to the Arabica which are selected and sent abroad. However, the situation of Arabica coffee is changing due to a series of societal and environmental factors.

Most importantly, the production areas for Arabica coffee in Colombia have been in decline in terms of overall area and green coffee yields; due to increasing limitations placed on Arabica coffee producers by climate change, the need for forest preservation and urbanization or divisional land holdings which squeeze the zone in which the crop can be grown into a smaller and smaller altitudinal zone between 1750 masl and 2000 masl. Traditional areas of Arabica coffee production in the Andean zone down to 1500 masl and up to 2250 masl are surrounded by high biodiversity and it is neither possible nor desirable to substitute higher elevation forested regions for coffee production. Meanwhile the potential production regions for Robusta coffee are growing and widespread [9].

Studies were undertaken by the project "Macro Café Canéfora" elucidating the future of this species as a new crop in Colombia by evaluating indicators of adaptation and ecoregional productivity. The goal was to determine if Robusta coffee would do well in non-traditional areas for coffee cultivation following the certain socio-economic guidelines: (a) expansion of the coffee zones across areas with a history of civil conflict violence, (b) areas with comparative and competitive advantages for Robusta production; (c) potential to increase per capita consumption and open new market niches in lyophilized instant coffees, and (d) potential uses of bioactive products in pharmaceutical and cosmetic products.

One of the first justifications for Colombia promoting the planting and production of Robusta is import substitution. Although little publicized, Colombia imports Robusta coffee to supply the needs of the domestic market. Colombia had a production in the 2020/2021 period of 14.1 million bags with an unsatisfied internal demand of 2.2 million bags [5].

This unsatisfied domestic demand is half-way supplied by imported Robusta coffee (Table 2). These imports replaced products such as off-grade "pasilla" coffee that have been traditionally used in Colombia for domestic consumption and for the soluble and freeze-dried instant coffee industry. Robusta production locally in Colombia could substitute these imports [11] and therefore satisfy the needs of national coffee consumption. The participation of Robusta coffee to satisfy the estimated domestic demand in Colombia in 2021 would be 286,000 bags (2021), rising to 712,500 bags by 2025 [12]. The results of the study for demand of Robusta coffee in Colombia by Collazos et al. [12] are summarized in the table below.

Table 2. Projection of domestic demand for coffee in Colombia 2021–2025 (million bags of 60 kg).

Year	Imports	Domestic Consumption		Total
		Arabica Coffee	Robusta Coffee	
2021	924,000	990,000	286,000	2,200,200
2022	921,140	998,086	417,764	2,332,000
2023	903,774	1039,217	519,609	2,462,600
2024	869,550	1,106,700	658,750	2,635,000
2025	712,500	1,425,000	712,500	2,850,000

In addition, Robusta produced in Colombia could be exported, considering that at present a good part of the world's instant coffee industry uses Robusta beans have higher overall green coffee yield but higher ratio of cherry to green coffee compared to Arabica beans. Robusta has high efficiency for industrialization based on high total soluble solids contents and other quality characteristics. Another advantage for producing Robusta coffee in Colombia is that it can be produced over a large land area at a low overall cost, even when comparing other countries in which this type of coffee bean is produced. Simulated production costs for Robusta type coffee in Colombia are 27% less per ton thank in Vietnam and Brazil [11]. One of the main comparative advantages is also open farmland availability. Colombia is blessed with many areas suitable for planting Robusta coffee both in the foothills of the Andes Mountains and on the humid Pacific and Caribbean coasts. Indeed, any region with unimodal precipitation that is higher than 2500 mm/year would be adequate for Robusta coffees. The rainy season in humid areas of Colombia is sufficient for non-irrigated coffee.

Water stress is a main limitation to Robusta coffee production and a major part of the cost structure in Vietnam and Brazil is taken up by irrigation needed across most phenological stages of the crop, representing 17% of farm costs. This indicates that the model for Robusta coffee in Colombia is under rainfed conditions with no supplemental water but in wet regions. High rainfall is an important comparative advantage of Colombia over further South American or Southeast Asian producers.

3. Marketability and Further Production Advantages of Robusta Coffee from Colombia

Robusta coffee demand has been increasing worldwide due to several factors: First, a greater expansion of emerging economies with a significant trend towards the consumption of soluble coffee. Second, the growing trend in the consumption of instant coffees worldwide, which has all resulted in a doubling in consumption of Robusta beans in the last twenty years. Third, coffee roasters have begun to make blends and mixtures that supply the North American market for single serving coffees. All this favors the use of Robusta due to its price and industrial conversion efficiency which is due to a higher degree of total soluble solids compared to Arabica. Shipping of Robusta coffee is favored by a cherry/green coffee ratio 5 and above compared to Arabica which is in the range of 4:1 to 5:1. Finally, worldwide coffee is increasingly consumed outside the home and the preparation of espresso has become fashionable, which mostly uses Robusta coffee [13].

An internal advantage for production of Robusta in Colombia, according to Leibovich and Llinás [11] is based on the prevalence of small to medium sized farms and the low competitiveness of other export crops in these areas (palm oil, corn and soybeans in Orinoquia and palms of various species in the Pacific region) in contrast to the comparative opportunity of Robusta coffee. In this regard, it is important to mention the maximum average values of the Family Agricultural Unit in each of the departments where the experimental crops of Robusta coffee can be established: Meta (696.34 ha), Córdoba (33.35 ha) and Nariño (13.3 ha). Additionally, the business of producing Robusta coffee is attractive since the price of imported material is US $2600 per ton and the estimated production costs are US $1650 to as low as $1100 per ton, allowing a profit margin of at least 57%.

In Colombia, research on coffee is mandated by the central government to be in the hands of the producers of this important signature crop. In this case, the Federation of

Coffee growers, a nationally and regionally supported organization located in Manizales, Caldas set up Cenicafé (CC), as its research center in the early 20th century. As an institution CC conducts breeding on Arabica coffee and promotion of this type of bean. In their strategic framework, research on Robusta coffee is not prioritized. Therefore, germplasm of Robusta coffee has so far only been used in breeding to create interspecific hybrids between *C. arabica* X *C. canephora* for resistance to leaf rust (*Hemileia vastatrix*). However, CC introduced only 60 Robusta genotypes from Costa Rica during the 1970s, only evaluating them under field conditions such as those of Arabica coffee at the El Naranjal Experiment station [14]. That study was carried out in three trials (1971, 1975, and 1978) under the names Canephora I, II and III. In each trial, 18 genotypes were evaluated in comparison with control varieties Borbón, Mundo Novo and Caturra, all *C. arabica*. In the three experiments, even under less than ideal conditions, the Robusta genotypes significantly out-yielded the Arabica controls starting from the second-year harvest and in the accumulated five-year period (Table 3).

Table 3. Average production in bushels/ha of 18 Robusta coffees and two varieties of Arabica coffee during five years of production (by harvest and accumulated as % of Mundo Novo yields) from unpublished work [14].

Species or Variety	Year of Production					Accumulated Production	%
	1	2	3	4	5		
Robustas	130	327	344	149	261	1209.8	139
Caturra [1]	159	176	175	68.7	109	688.9	79
Mundo Novo [1]	134	246	185	169	138	871.9	100
L.S.D. [2] (0.05)	25.7	43.4	45.9	29.3	38.9	114.1	

Footnotes: [1]/: varieties of *C. arabica*. [2]/: Least Significant Difference (L.S.D.).

The three initial trials were an important point in recognizing the yield potential of Robusta coffee in Colombia [14,15]; however, the introduced Robusta genotypes were evaluated in the regional conditions of an Arabica coffee production zone and unfortunately were not promoted in other regions. Green coffee yields of Robusta are known to reach 4000 to 6000 kg/ha in other parts of the world. Therefore, there is a need for studying Robusta coffee in the lower elevation areas known to be recommended for this species. For this reason, the national government directly entrusted its national research arm of the Ministry of Agriculture now known as AGROSAVIA (previously as Corpoica) to estimate the feasibility of production in non-traditional areas outside the Coffee Zone. This initiative is called the "Coffee Mission", and is in charge of future testing of Robusta coffee.

4. Potential Experimental Sites and Production Zones for Robusta Coffees in Colombia

The Coffee Mission, mentioned above, includes experts from AGROSAVIA and the National Coffee Research Center. So far, it has conducted two studies to determine potential areas for Robusta coffee cultivation in non-traditional Arabica regions of Colombia with the required climatic characteristics [15,16]. In both studies, two important variables required for the growth of Robusta coffee were assumed: (1) precipitation would need to be 2000 to 3000 mm and with unimodal distribution that allows for a single annual harvest and possible mechanical harvesting and (2) average temperatures would be in the optimal ranges between 24 and 30 °C. Likewise, both studies coincided in defining three ecoregions with potential for cultivation: Orinoquia to the East, Pacific coast region to the West and humid Caribbean to the North of the country. Both studies emphasized the need for a research program into production constraints and varietal adaptation.

According to Herrón [15] when it comes to planting coffee in "non-traditional areas" it is very important to ensure that the selected areas comply with the environmental conditions that the plant requires for its normal growth and production. In the case of precipitation, the proximity of Colombia to Pacific Ocean currents and the layout of its mountain ranges, means that the rainfall has an intra-annual distribution in two totally

different conditions, (1) Unimodal (with a single maximum peak in the year) or (2) Bimodal (with two maximum rainfall peaks in the year). The rainfall regimes with only one rainy period in the year occurred in the following regions: Eastern Plains and Amazon region with maximum rainfall in the months of June and July; and the Caribbean Plains, in the regions of influenced by the Northern Trade Winds such as the, Guajira and the Catatumbo River basin, where the rainfall peaks occur in the months of October and November.

Bimodal-type distributions occur in the regions where the Intertropical Confluence Zone (ITCZ) passes at two times of the year, with rain peaks in the months of April and May and in the months of October and November. This is the rain regime that occurs in traditional Arabica coffee growing areas. The areas that are selected for planting Robusta coffee must meet the characteristic of being Unimodal since it is an essential requirement to be able to concentrate a single annual harvest and thus be able to use the mechanical harvesting of the crop in the potential areas where the topography allows it [15].

In the second work carried out by Cenicafé [14], five non-traditional areas with adequate environmental offer for the potential production of Robusta coffee were identified, with a total potential area greater than 4.5 million hectares: (1) Cesar River valley (between the rancheria river and the Cesar River). Between 100 and 400 m above sea level, 4000 ha; (2) Sinú River Valley (between the Abibe and San Jeronimo mountains), between 100 and 200 masl., 10,000 ha; (3) Urabá (León River basin, municipalities of Turbo, Apartadó, Chigorodó), 100 masl., 20,000 ha; (4) Sabana de Torres (municipality of Sabana de Torres), 400 masl., 10,000 ha and (5) Orinoquía (Departments of Arauca, Casanare, Meta, Vichada), between 200 and 500 masl., 4.5 million ha.

Apart from the studies described above the national agricultural research system, AGROSAVIA (a.k.a Corpoica) conducted a preliminary review of Robusta coffee and reported the crop as: "a promising option to intensify and diversify production systems in the tropical lowlands of Colombia". The same entity carried out a third complementary study [16] that made it possible to determine, the Corporation's research centers in the country that could provide support for the first evaluations of Robusta coffee genetic based on the variables of altitude, temperature (maximum and minimum) and radiation (Table 4). A map of these centers' locations is shown in Figure 1.

Table 4. AGROSAVIA research centers suitable for the evaluation of Robusta coffee in Colombia.

Research Center	Altitude (m)	Minimum Average Temperature (° C)	Maximum Mean Temperature (°C)	Radiation (μmol photon m^{-2} s^{-1})	Potential Production
Carimagua	149	22.5	30.9	862.5–958.3	high
El Mira	21	22.6	29.3	670.8–766.6	high
La Libertad	340	21.5	29.6	862.5–958.3	high
Motilonia	111	23.3	33.5	958.3–1054.1	high
Nataima	377	22.1	32.8	862.5–958.3	high
Taluma	168	22.3	31.0	862.5–958.3	high
Turipaná	11	23.5	32.4	766.6–862.5	high
Caribia	11	22.8	32.8	958.3–1054.1	medium
El Nus	828	19.4	28.9	862.5–958.3	medium
Palmira	996	18.3	28.7	862.5–958.3	medium
Cimpa	1572	15.1	25.6	n/a	unsuitable
La Selva	2120	12.3	22.0	n/a	unsuitable
La Suiza	1628	15.6	23.3	n/a	unsuitable

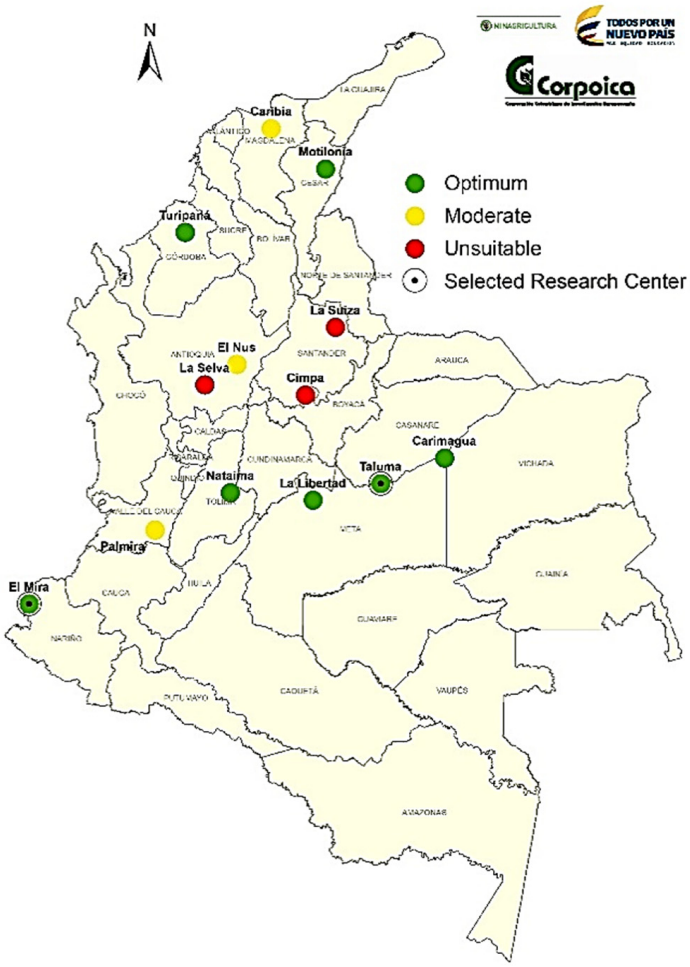

Figure 1. Optimal, moderate suitable and unsuitable National Agricultural Research System (AGROSAVIA, a.k.a Corpoica) experimental stations for the evaluation of Robusta coffees in the 32 political divisions (departments) of Colombia. Best selected research centers highlighted by bullseye.

Among the best centers to test Robusta coffee, the Taluma Experimental Station and the Carimagua Research Center are two representative sites for the soil conditions of the Colombian "altillanura". This is a region of flat terrain of moderate elevation (around 150 and 500 masl) adjacent to the Andes mountains that covers more than 4 million hectares and with a productive potential of 1.5 million in Robusta coffee, subtracting the foothill or high slope areas as unproductive. The soils are very acidic (pH between 4.5 and 5.5), and have low base saturation, high aluminum saturation and high phosphorus binding capacity. However, the development of technologies for soil improvement has made it possible to overcome the physical and chemical limitations of the soil and its low fertility. As one advantage the soils are level, allowing for easy mechanization.

Research carried out by various partners for more than 30 years has allowed the generation of management technologies that have led to a notable increase in meat and grain production (soybean and corn) in the region [17]. The two stations of Carimagua and Taluma have similar average annual temperature of 26 °C (average annual rainfall of 2400 mm) and 26.8 °C (average annual rainfall of 2135 mm) respectively with relative humidity between 65 and 90% [18]. Therefore, the Colombian "altillanura" presents good environmental conditions for the establishment of commercial Robusta coffee plantations. The region has experience in mechanization and improved soil management technologies. However, it is necessary to evaluate the accessions of the Robusta type under field condi-

tions and evaluate the economic viability and sustainability of the system in the medium term (5 to 6 years).

Meanwhile representative of the Northern coastal region, the Turipaná Research Center, located at an altitude of 11 m, is defined by an average annual temperature of 28 °C, with unimodal-bi-seasonal precipitation pattern (average annual rainfall of 1218.2 mm and monthly average of 101.5 mm). The rainy season runs from May to October and represents 79% of the annual total; June has the highest recorded rain with 176.5 mm falling. The period of lower rain intensity is from November to April. January, with 12.6 mm falling, is the month with the least precipitation. Relative humidity averages 80.1% with very little variation throughout the year, with March being the month with the lowest value (76.2%) and November the highest (83%). The climate according to the Thornthwaite classification is C1d'A'a', semi-dry tropical forest with no water surplus. The potential evapotranspiration (ETP) values of the dry period are above the precipitation values and indicate a water deficiency of 544.6 mm that becomes noticeable between January and February. The month that presents the maximum ETP value is July with 162 mm and corresponds to the wet period; the minimum value of 132.8 mm is recorded in November.

Finally, among the best locations for Robusta research, the experiment station named El Mira is an AGROSAVIA research center representative of the humid tropical forest of the Pacific region of Colombia. Most soils are acidic Ultisols and Inceptisols with high clay content and variable soil fertility [19]. The station is located at an altitude of 16 m, with a rainy season in the first months of the calendar year. The least rainy months are from July to November and a dry season occurs between the months of August and November. The average annual rainfall is 2792 mm/year. Annual average temperature is 26.1 °C with a solar intensity of 1374.1 h/year. The temperature coincides with the summer of the southern hemisphere and maximum average value is 31.8 °C. Relative humidity presents an average value of 84.3%; evaporation is 600 mm/year in the shade and 1000 mm/year outdoors. The landscape is dominated by native forests located on in hilly or flat terrain. Parts of the Cauca, Nariño and Valle de Cauca departments have similar coastal rain forest environments.

During the last few years, the Pacific Coast region has experienced a rapid expansion of oil palm and cocoa plantations under agroforestry systems or clear cutting by colonists growing coca to produce cocaine fueling a need for more legal alternatives for small farms. Robusta coffee could be planted as an addition to cocoa in the hillside regions. Together coffee and cocoa could be planted on 10,000 ha and become a substitute to replace the illicit production of coca that currently dominates the region.

5. Regional Advantages and Limitations of Robusta Coffees in Colombia

Several of the regions discussed have limitations but most have advantages overall for Robusta coffee. As for limitation in the Pacific zone, some of the flatter lowlands are prone to excess moisture that could limit plant growth. Growth of Robusta with cocoa in the same plot is not recommended as they have different shading requirements and both demand fertilization, competing in the same layer of topsoil for nutrients. However, being more deep-rooted than coca, the two tree crops would improve soil quality and protect the soils from nutrient loss which is occurring in the area.

The coffee management systems developed in the Amazon region of Brazil in the state of Rondonia in particular, based mainly on Robusta-type clonal varieties [20], is a reference for the viability and profitability of production model under similar agroecological conditions to this rain-forested area of Colombia.

Economically, Robusta coffee has great potential in lower altitude regions of Colombia. With investments, Robusta coffee in regions such as the Altillanura, the Pacific coast, the humid Caribbean region and Orinoquia, another rainforested region of Eastern Colombia, could replicate the development and well-being that Arabica coffee has brought to the highland Andean region for more than a century. A holistic approach to agricultural production would use Robusta coffee as an income generator and one of the pillars of

small-scale agriculture in these areas. Robusta coffee production would not require large productive areas to be competitive and various production schemes could be proposed based on the size of the Family Agricultural Unit (FAU) in each region. For example, in the department of Meta the FAU averages 314 ha, in Casanare 140 ha and in Vichada 1237 ha.

Given the impressive tradition of coffee in Colombia, Robusta would not be starting from scratch, as there is a large body of knowledge that could be adapted to the production of this coffee in these potential regions and with new farming communities. Regarding the labor required in the production process, this may come in part from the small farm population of the region, or colonists/refugees coming in from other regions of Colombia. The possibility of involving ex-paramilitary and guerilla fighters trained to now grow Robusta coffee [9–13] would reintegrate these people into society. The achievement of higher incomes and safety compared to illicit crops was an essential part of the peace agreement signed between previous combatants and the national government. Likewise, Robusta coffee represents a chance to introduce on-farm small scale mechanization which would help all areas of agricultural productivity, another reason for the promotion of this "new" crop for Colombia.

A reasonable question for potential investors in the Orinoquia is the following: How profitable would the production of Robusta coffee be compared to current products and production systems? An approximate answer is given by Leibovich and Llinás [9]. Coffee generates more income than corn and soybeans, although it is much less than palm oil, with palm being more attractive from an income point of view. However, it is important to bear in mind that this crop in the Altillanura is not profitable in small areas of land, while coffee is (Table 5).

Table 5. Comparison between coffee and the representative productive systems of Orinoquía.

Productive System	Yield (Mt/ha)	Producer Price, 2011 (USD/Mt)	Income (USD/ha)
Robusta Coffee (DPC)	0.91	4225	3845
Maize/Corn	4.50	434	1953
Soybeans	2.40	632	1517
Palm oil	3.1	1148	3100

Source: Leibovich y Llinás [9]; DPC = dry parchment coffee; USD = United States Dollars.

Therefore, under the current regulatory framework and given the current debates on land tenancy, deforestation and farmland holdings in Colombia overall and more specifically on the Caribbean and Pacific coasts or in Orinoquía, it is very likely that palm expansion will be restricted while Robusta coffee planting will grow in the region. Oil palm is a strategic product for areas near processing plants but has been severely affected by phytosanitary problems such as bud decline. Likewise, in the areas where lack of commercial plantation crops or coca production are issues, the Robusta coffee crop could become an alternative to diversify agricultural production.

A breeding program to address the specific needs of each major area of possible production for Robusta coffee in Colombia is recommended [2]. For this, knowledge of diversity in the species is needed especially as there are different groups of *C. canephora* in the primary centers of origin in West and Central Africa [3,21] along with additional germplasm of interest in secondary centers of diversity where the crop has a tradition of production such as in Brazil [22,23] and India [24]. A breeding program will have to consider adaptation plus current abiotic, biotic, climate-related and edaphic stresses [25]. Adaptation is suggested to be better for Robusta coffee production in Equatorial regions such as Colombia than in Central America, another Arabica growing region [26]. South–south technology transfer and technical exchanges from Indonesia and Vietnam in Asia may be useful for fertilization recommendations and agroforestry methods involving shade trees that may adapt to Colombian conditions [27,28]. Use of shade trees has also been studied in India and Uganda [29–31]. In the Americas, Brazil and Mexico, are also looking

at growing Robusta in lower elevations. Wild Robusta coffees seem to have high diversity and adaptability [32–34].

6. Conclusions

Robusta coffee is originally from West Africa (DR Congo and Guinea) but has potential as lowland and heat stress environment germplasm for South America, especially in the equatorial areas that include most of warm-season Colombian agriculture. The crop is of interest in tropical regions where climate change is increasing temperatures at mid-elevations and pushing out highland Arabica coffee. Colombia is prominent in production of quality Arabica coffee and could also become a major producer of Robusta coffee. Compared to Arabica that is typically grown in central Colombia, Robusta can be grown along the Caribbean and Pacific coasts or in the Eastern lowland region of Orinoquía and the Altillanura. Robusta coffees have higher caffeine levels than Arabica and some organoleptic properties that could complement the high-quality beans grown in the country. This review discussed the benefits and limitations that Robusta coffee may have in Colombian production regions. Overall, the ecological adaptation of this "new" type of coffee makes them ideal for drought tolerance and they have natural resistance to some of the major pests and diseases of Arabica coffee allowing them to thrive under harsh conditions of drought or hotter-temperatures. Climate change is likely to further induce disease epidemics and insect spread. As a result, Robusta coffee is a promising new crop for production in Colombia. Like other countries in equatorial regions of Africa, Asia or the Americas, Colombia could have significant production for the domestic and foreign market of Robusta coffee given it has large areas suitable for this crop.

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