Opportunities for robusta variety innovation

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AbacusBio is a genetic-improvement consultancy found at the intersection of science and business. AbacusBio fills expertise gaps so our collaborators can quickly and confidently execute programs that respond to market needs. abacusbio.com

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World Coffee Research (WCR) is a global, non-profit, collaborative agricultural research organization working to ensure the future of coffee. WCR is supported by over 175 coffee companies in 29 countries, working to drive science-based agricultural solutions to urgently secure a diverse and sustainable supply of quality coffee today and for generations to come. worldcoffeeresearch.org

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Key takeaways

This white paper examines current and likely future trends for robusta supply and demand, as well as existing resources given to robusta genetic improvement, in order to examine possible roles for a collaborative, global robusta breeding program. Below are the key takeaways of this paper.

- Taking into account rising consumption trends and the negative impact of the climate crisis on production, the world may face robusta shortages in 2040 of up to 35 million bags.
- Production of robusta has become increasingly concentrated among a small group of six countries, which are responsible for 95% of output by volume, while other countries have decreased production. This concentration represents meaningful production risk and potential further exposure to the impacts of climate change.
- As robusta is increasingly being substituted for arabica, the supply of higher-quality robusta must also increase, or else the perceived quality of blends will decrease and may face consumer rejection.
- Globally, current levels of investment in robusta research and breeding are not sufficient to meet projected shortages or the evolving quality needs of the market.
- Roasters are predominantly interested in securing the continuous availability of robusta as a lower-priced ingredient without declining quality, while farmers are primarily focused on improving yield, drought tolerance, and disease resistance, along with quality as a pathway to improved prices. Driving innovation to produce gains in yield (and other yield-impacting traits like climate resilience) is likely to be a win for farmers and roasters.
- Overall, existing robusta breeding programs are positioning themselves for innovation. A global, collaborative effort aimed at enhancing interaction and sharing of genetic resources could lead to faster advancement of breeding programs. Different strategies of support need to be employed in different countries, to aid in variety innovation and release.

Background

For commercial crops worldwide, breeding and variety innovation are critical inputs for securing long-term supplies and ensuring sustainable agriculture goals can be met. Coffee is one of the most important cash crops in the world, generating significant foreign exchange and supporting the livelihoods of millions of people globally. Over the last 30 years, demand for coffee has grown steadily, leading to an expansion in production and exports driven primarily by increased efficiency of coffee production in two countries: Brazil and Vietnam. In particular, there has been significant growth in the production of *Coffea canephora*, commonly known as robusta, after the emergence of soluble coffee in the 1950s. Robusta production has expanded from 28% to 44% of total production over the last 30 years (ICO, 2023a) and, if current trends continue, could overtake *Coffea arabica* as the dominant commercial species of coffee in production in coming years.

Despite its global economic importance, a recent analysis found that "the world is shockingly underinvested in coffee agricultural research and development (R&D)" (Maredia and Martinez, 2023). The current global investment in coffee agricultural research is estimated to be $115 million per year, with 90% of this investment coming from the public sector and 10% from the private sector. The coffee sector requires $452 million per year of additional investment over the next decade to meet rising demand in the face of yield and land area losses expected due to climate change if buyers wish to secure supplies of coffee from diverse origins. This analysis did not specifically calculate the investment gap for robusta vs. arabica, but given the magnitude of the innovation investment gap and the fact that robusta makes up 40% of global supplies, it is safe to assume that current investments in robusta research are insufficient to meet global demand for the product in the coming decade.

This white paper examines current and likely future trends for robusta supply and demand, as well as existing resources given to robusta genetic improvement, and examines possible roles for a collaborative, global robusta breeding program to support existing breeding programs to address key gaps. To be successful, any such program must identify priorities shared by farmers, countries, and roasters, to help leverage private sector support and to drive public funding to national breeding programs.

Global robusta landscape | PRODUCTION AND CONSUMPTION

Robusta expansion since 1990

Global production of both arabica and robusta coffee has increased significantly over the last 30 years, from over 93 million 60-kg bags of green bean equivalents (GBE) in the 1990-91 crop year,[1] to 167 million bags in 2021-22 (Figure 1). Over the 31-year period, this is equal to a compound annual growth rate of 1.9%. The individual growth rates for arabica and robusta are 1.1% and 3.4%, respectively, though robusta has grown at 1.8% for the last ten years (ICO, 2023a).

The higher growth rate observed in robusta reflects its growing importance in the global coffee landscape. In 1990-91, it accounted for 28% of production; in 2021-22, that share had increased to 44%. Overall, total coffee production has kept pace with consumption increases; however, short-term imbalances can be and have been at times sustained for a few years by drawing from coffee inventories built up during surplus years.

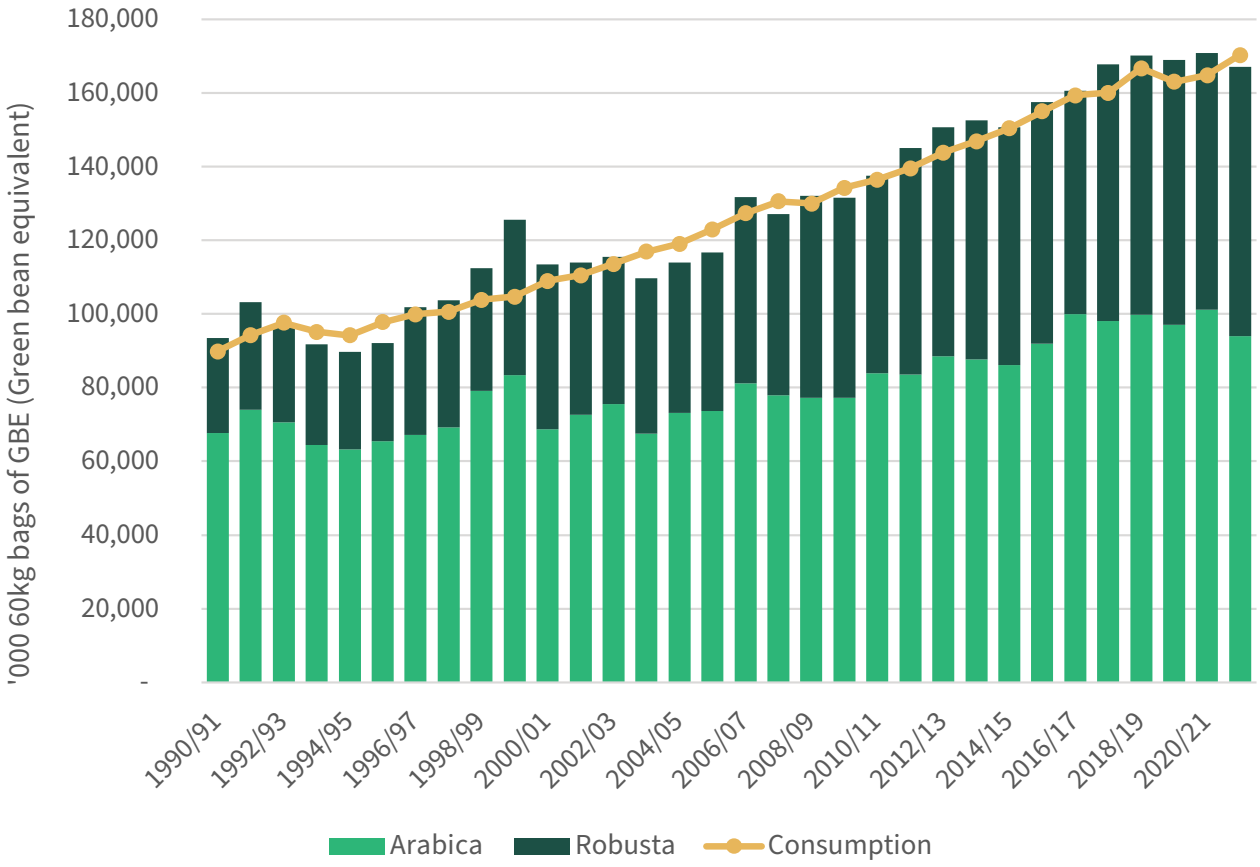


Figure 1. Global arabica and robusta green bean production and consumption, by crop year, from 1990-91 to 2021-22. Data source: ICO, 2023a.

The absolute increase in robusta production over the last 30 years (47 million additional bags per year, or 183%) has been driven overwhelmingly by Brazil and Vietnam (Figure 2, pg. 7). In 1990-91, Brazil and Vietnam accounted for 23% of global production. By 2021-22 this figure had increased to 68% as a result of 330% and 2,100% increases in robusta production in Brazil and Vietnam, respectively. In general, over the last 30 years, production of robusta has become increasingly

[1] Crop years represent the 12-month growing season in a given country, beginning on the first day of April, July, and October. These are aligned by the ICO for reporting output as explained in the Explanatory Note for the Coffee Production Report of Crop Year Production by Country report (ICO, 2021, p. 3).

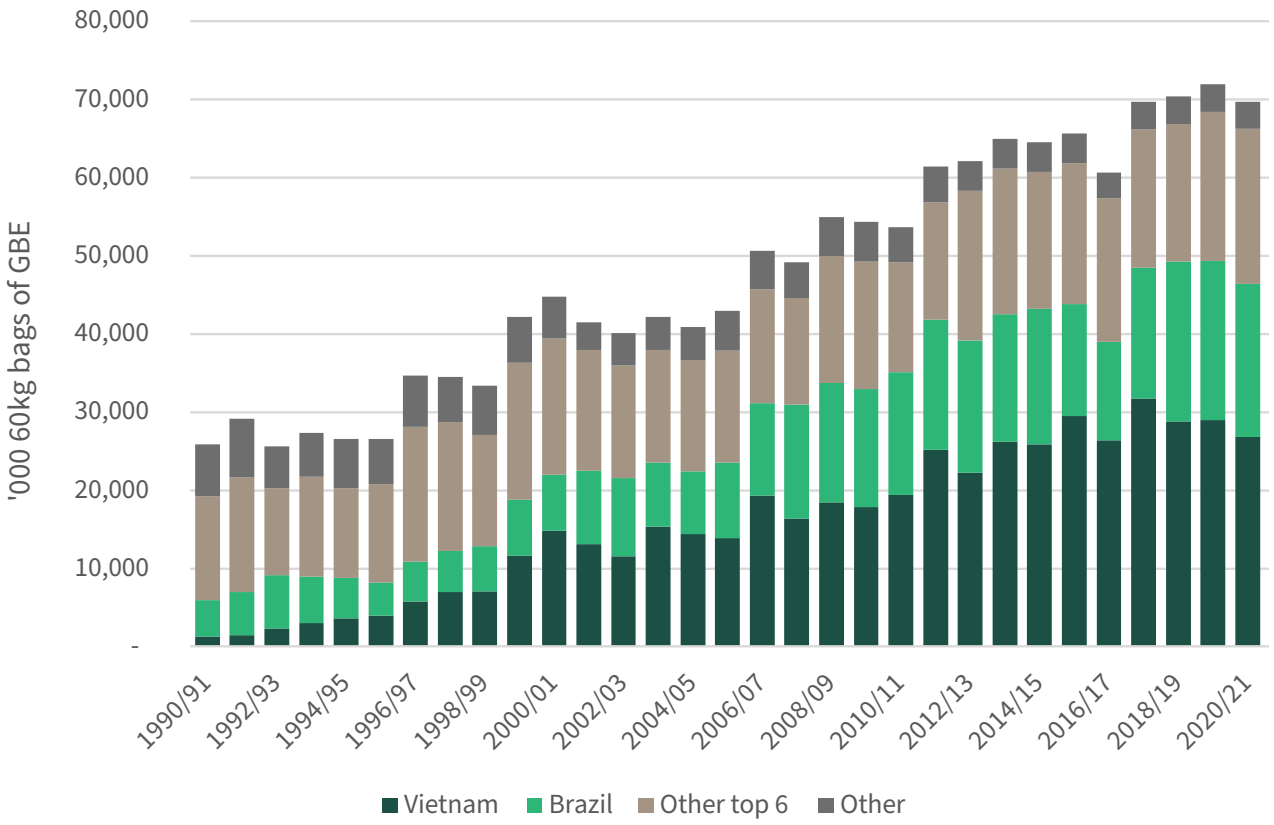


Figure 2. Global green bean production, by crop year, from 1990-91 to 2021-22. Data source: ICO, 2023a.

concentrated among a small group of countries. The top six producing countries (by volume) are responsible for 95% of output (Table 1), in contrast to arabica, where the six largest producers are responsible for 78% of global output.

Concentration among fewer producing countries is not only due to increased output from top-performing nations. Other countries have seen absolute declines in robusta output. For example, a group of small African countries that formerly produced 4% of global robusta supplies have seen their production fall by half since 1990-91. Interviews with roasters

Table 1. Average robusta production (60-kg bags), yield, and area planted (2019-20 to 2021-22) for key countries.

Country	**Area**[1] (ha)	**Yield**[1] (bags/ha)	**Production** ('000 bags/yr)	**Share of output** (%)	**Cumulative share** (%)
Vietnam	598,079	47.7	28,506	39.8%	-
Brazil	471,086	42.5	20,007	27.9%	67.8%
Indonesia	929,408	10.0	9,272	13.0%	80.7%
Uganda	473,941	10.4	4,922	6.9%	87.6%
India	220,586	17.9	3,948	5.5%	93.1%
Côte d'Ivoire	766,613	1.9	1,447	2.0%	95.1%
Remaining top 10[2]	147,861	11.9	1,754	2.5%	97.6%
Remaining top 15[3]	174,032	6.6	1,153	1.6%	99.2%

[1] Methods for estimating robusta yield and area planted are in Appendix 1.[2] Remaining top 10 producers: Laos, Tanzania, Madagascar and Thailand. [3]Remaining top 15 producers are: Cameroon, Democratic Republic of Congo, Ecuador, Philippines and Mexico.

and traders suggested three factors contributing to the loss of production in parts of Africa: low prices and profitability contributing to a lack of incentive to produce coffee, competition from other crops, and lack of reliability in the supply chain.

The first two points are directly related to low yield and the flow-on effect of low productivity on farmer incomes. Importantly, it suggests that increasing yields can also activate additional supply by making coffee production more attractive.

Consumption in importing regions

Over the last 31 years, total coffee consumption of arabica and robusta has grown at an annual rate of 2.1%,[2] maintaining that same level of growth for the last 10 years. However, the average rate of growth obscures large regional variation (Table 2). Asia has easily seen the largest growth over the last decade, though still has very low consumption per capita.

Roasters view future growth of robusta production as being driven by expanding middle classes in low- and middle-income countries in Africa and Asia, specifically the soluble market in these regions. Like variation in regional production growth rates, there is substantial variation in the preference for robusta in different parts of the world. In North America, robusta accounts for only a small percentage (13%) of coffee imports, in line with what we'd expect given North American consumer preferences. However, in Africa, robusta represents nearly 70% of green coffee imports. European coffee imports are around 30% robusta. This may be due to the importing of green beans for manufacture and exporting to other parts of the world. If so, this would indicate that European preferences for robusta are slightly lower, while Asian and African preferences for robusta are higher than suggested based solely on the share of imports. Domestic production in Brazil would also indicate South American robusta preference is higher than reported here.

Table 2. Average robusta consumption and preference (2019-20 to 2021-22) for key consumer markets.

Region	**Population**[1] (millions)	**Consumption (R + A)** (Bags/ person/yr)[2]	('000 Bags/yr)	**10 yr growth rate** (%)	**Robusta preference**[3]
Africa	1,394	0.49	11,424	2.1%	69.4%
Asia & Oceania	4,739	0.49	38,947	4.2%	30.3%
Central America & Caribbean	222	1.45	5,375	0.5%	10.0%
Europe	745	4.30	53,380	1.0%	31.1%
North America	374	4.96	30,929	2.0%	13.1%
South America	434	3.59	26,000	1.5%	49.3%
World	**7,908**	**1.26**	**166,054**	**2.0%**	**28.8%**[4]

[1] Source: List of continents and continental subregions by population, 2023. [2]Per-capita consumption based on population and consumption (ICO, 2023a). [3] "Robusta preference" is the percentage of all coffee imports (ICO, 2023b) that are robusta (see Appendix 2). [4] Global robusta preference understates actual robusta consumption (44% of all coffee consumed is robusta; ICO, 2023a) because imports exclude robusta that is domestically produced and consumed.

Understanding the manufacturing of green beans is important to understanding the role of robusta in the global coffee system. Manufacturing coffee involves transforming raw green beans into either roasted or soluble coffee products, and the robusta/arabica composition of roasted or soluble coffee varies significantly. Roasted products can be pure or blended, but are generally higher quality than soluble products, and contain higher proportions of arabica. Soluble tends to be cheaper and as a result contains more robusta; it is not uncommon for soluble products to be 100% robusta.

[2] This figure differs slightly from the compound annual growth rate observed in coffee production (1.9%), due to surplus production in 1990-91 and a shortage of production in 2021-22.

Over a third of imported coffee (measured in GBE, not raw volume) has already been processed as soluble or roasted products (Figure 3), which means the majority of imported coffee is for domestic manufacturing (i.e., processed into roasted or soluble products internally). Around 70% of roasted and soluble coffee imports are re-exports, which means they're imported from countries that themselves import and then process the coffee (usually European), rather than countries where the coffee is actually grown. This makes it difficult to determine country or regional preferences for roasted or soluble coffee based on trade data. However, because robusta is used more commonly for producing soluble, we can approximately infer preferences based on green robusta imports (Table 2, pg. 8).

Africa stands out as having the highest preference for robusta, which also suggests a lot of soluble coffee is consumed there (this aligns with what we heard from interviews; three-in-one soluble packets—single-use packets containing milk, sweetener, and soluble coffee powders—are among the most popular ways of consuming coffee). The preference for soluble coffee raises two questions: will this preference remain as incomes in the region rise? And would growing demand for soluble products require more coffee with any particular characteristics?

Given the lower preference for robusta in Asia, for example, it's plausible that as incomes rise countries will shift consumption more towards arabica as they develop a more "Western" coffee culture. This would likely involve moving away from cheaper soluble coffees with higher robusta content, however, there is still room for considerable variation in the blends and composition of products consumed higher up the income distribution. Underlying taste preferences in these countries would remain (for example, Northern African countries are known to prefer more bitter flavors, and thus consume more robusta, all else being equal).

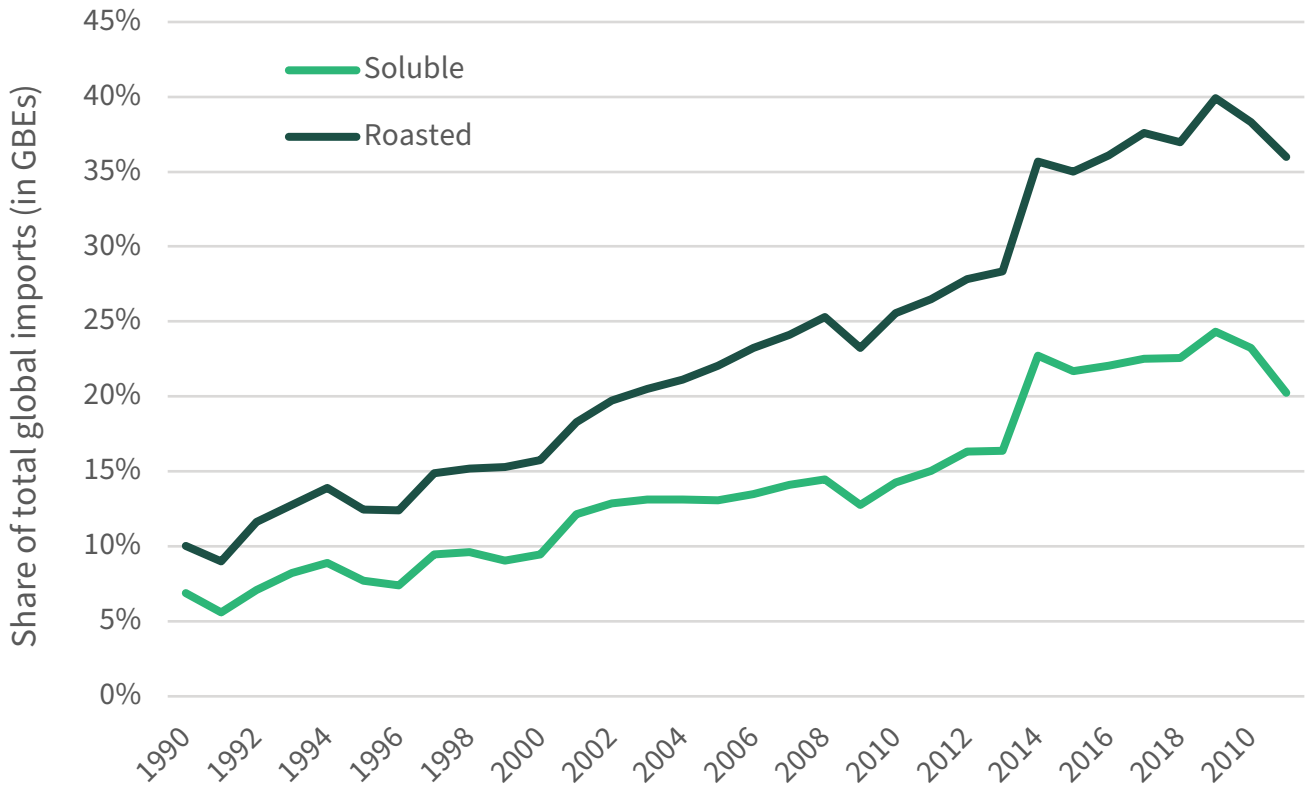


Figure 3. Additive share of soluble and roasted imports of global coffee consumption by year. Data source: ICO, 2023b.

Although soluble and roasted manufacturing processes differ, in no discussions did roasters suggest they looked for robusta with particular traits for soluble. Roasters uniformly prioritized price and consistency for robusta, and in fact, as soluble products are more price-sensitive than roasted ones due to their positioning at the lower end of the market, achieving a certain price point for a given quality threshold is even more important for robusta used in soluble products.

FUTURE PRODUCTION OUTLOOK

Production challenges

A key theme emerging from interviews with breeders, roasters, and farmers was that a lack of profitability in coffee farming is a threat to long-term production. Contributing factors include increased competition from other crops and increasing labor costs (from scarce labor, due to better opportunities in urban centers), leading to farmers exiting robusta. In other words, less robusta is supplied at lower levels of profit, and because lower yields result in less profit per area planted, lower yields can also decrease production indirectly, by shrinking supply (and vice versa).

The climate crisis is the other major, separate challenge to robusta production, and it has the potential to both reduce yields and reduce the land suitable for planting each species of coffee. Because less coffee is supplied at lower yields, the effect of climate change on yields is likely to exacerbate the effects of climate change on the area planted. Furthermore, pest and disease outbreaks–often induced by higher temperatures–are expected to intensify along with the impact of floods, droughts, and saltwater intrusion. These factors contribute to a higher risk of crop failure, loss of income for farmers, and price volatility for consumers. Given the specific resilient characteristics of robusta compared to arabica, robusta production may be able to replace, in part, the losses in arabica production. However, recent research is revealing that robusta may be more sensitive to climate change than previously thought. For example, it thrives in climates with minimal intra-seasonal variations, restricting its cultivation to lower altitudes; if the climate not only becomes hotter but also exhibits increased variability, this could worsen the impacts of climate change on robusta production (Bunn et al., 2015). Robusta may also be far more sensitive to heat than previously thought, and its production potential could decline considerably as temperatures increase under climate change (Kath et al., 2020). There is a general lack of large-scale research on aspects of robusta production, such as climate-sensitive flowering and growth phases, that would enable deeper understanding of its climate resilience potential (Bilen

et al., 2023). Nevertheless, both species appear to be affected by climate change and all interview participants expressed concerns about climate change variability on the future of robusta production. While robusta is easily substituted for arabica for consumption, it cannot be easily substituted at the production level. Currently, the main driver for farmers to grow robusta instead of arabica is location and elevation, and farmers typically specialize in one species of coffee only. Farmers cannot easily switch between growing arabica and robusta.

In Table 3, we consider the effects of climate change and yield on land use to forecast future robusta production in 2040 from key markets, based on underlying changes in yields and area planted under two scenarios, treating major producing countries as separate from smaller ones:

- Status quo (with climate change impact) scenario:
  For Vietnam, 1% per year growth in yield[3], and no change in area planted
  For Brazil, 2% per year growth in yield[4], and no change in area planted
  For all other countries, no change in yield, and a 5% decrease in area planted

- Supply activated (through price mechanisms) scenario:
  For Vietnam, 1.5% per year growth in yield, and a 10% increase in area planted
  For Brazil, 3% per year growth in yield, and a 10% increase in area planted
  For all other countries, 0.5% per year growth in yield and 10% increase in area planted

Under the status quo scenario for most countries, where total production has been stagnant, we assume that climate change will place some negative pressure on the amount of land available for growing robusta, decreasing acres planted

Table 3. Forecast robusta production (60-kg bags) in 2040 under status quo and additional supply-activated scenarios.[1]

Country	*Status quo*		*Supply activated*	
	Production ('000 bags/yr)	**Change** (absolute %)	**Production** ('000 bags/yr)	**Change** (absolute %)
Vietnam	34,439	20.8%	41,609	46.0%
Brazil	29,146	45.7%	38,591	92.9%
Indonesia	8,809	-5.0%	11,213	20.9%
Uganda	4,676	-5.0%	5,953	20.9%
India	3,751	-5.0%	4,775	20.9%
Côte d'Ivoire	1,375	-5.0%	1,750	20.9%
Remaining top 10	1,666	-5.0%	2,121	20.9%
Other	1,643	-5.0%	2,091	20.9%
World	**85,506**	**19.4%**	**108,104**	**51.0%**

[1] Expanded details of each scenario (e.g., acres, yields, share of output) are in Appendix 1.

by 5%, and yields will stay constant. In Vietnam and Brazil, we assume that yield improvement will continue, but be slowed by climate change (1% per year in Vietnam and 2% in Brazil, vs. recent historical growth of 1.9% per year), and that higher yields will activate some additional land for planting coffee, mitigating the decrease in available land from climate change effects, and holding acres planted as constant. Growth projections for Brazil are greater than those for Vietnam because experts we spoke to were more optimistic about Brazil's capacity for yield growth.

[3] Over the last ten years, yields in Vietnam (combined robusta and arabica) have increased 1.9% per year, though sustaining this rate for the next two decades is more optimistic than any of our projections.

[4] Estimates for yield projections in Brazil were based of feedback from regional experts.

Under the supply activation scenario, we assume that increasing profitability in all countries can activate additional land for growing robusta. This is plausible if robusta prices were to increase in addition to increasing yields, mitigating the effect of having less suitable land for planting due to climate change. The price of robusta (relative to arabica) is likely to increase if climate change effects are more severe for arabica than robusta[5] or if global market preferences change to become more favorable toward robusta (see below). We therefore assume a 10% increase in area planted for all countries and assume a 1.5% per year growth rate in yield for Vietnam and 3% for Brazil, and a 0.5% per year growth rate in yield for everywhere else (a 0.5% growth rate in yields is somewhat optimistic, given stagnant recent production).

Table 4: Forecast robusta demand (60-kg bags) in 2040 under status quo and faster growth scenarios.

Region	*Status quo*		*Faster growth*	
	Growth (%/yr)	**Demand** ('000 bags/yr)	**Growth** (%/yr)	**Demand** ('000 bags/yr)
Africa	1.9%	16,365	2.5%	18,421
Asia & Oceania	3.8%	78,868	5.0%	99,213
Central America & Caribbean	0.5%	5,859	0.6%	6,030
Europe	0.9%	63,386	1.2%	67,099
North America	1.8%	43,327	2.4%	48,415
South America	1.3%	33,395	1.8%	36,274
World (all coffee)	**2.0%**	**241,200**	**2.7%**	**275,452**
Robusta consumption	-	105,617	-	120,615
Robusta share	**-**	**43.8%**	**-**	**43.8%**

We estimate global robusta production in 2040 will be between 85,000 and 108,000 bags per year. The status quo scenario sees increased production from Brazil and Vietnam compensate for lower production from the rest of the world and equates to a 0.7% annual growth rate. In the supply-activated scenario, total global production increases by nearly 51%, equal to a 1.7% annual growth rate (this is on par with recent trends—robusta production/consumption has increased by 1.8% for the last ten years).

Future robusta shortfall

Considering the differing consumption profiles of different regions, which vary with respect to the proportion of robusta and arabica imported and the mix of soluble and roasted products consumed, it's plausible that continuing current consumption growth trends would lead to very different demands for robusta than currently observed.

To estimate the future demand for robusta in 2040, we considered two scenarios (Table 4):

- Status quo growth:
  Growth for ALL coffee in each region grows at 90% of the annual growth rate observed in the previous ten years.
- Faster growth:
  Growth for ALL coffee in each region grows at 120% of the annual growth rate observed in the previous ten years

The rationale for having slightly lower-than-historical growth rates under the status quo scenario was simply diminishing marginal returns, which may make sustaining high growth rates challenging. In the faster growth scenario, we assume this

[5]This perception is grounded in the sensitivity of arabica to heat, implying challenges in a warmer climate. Robusta thrives in climates with minimal intra-seasonal variations, restricting its cultivation to lower altitudes. If the climate becomes hotter and exhibits increased variability, this could worsen the impacts on robusta.

Table 5. Forecast shortages (in thousands of bags of GBE, and percentage of forecast demand that is met) for robusta under different demand and supply scenarios.

		Forecast supply scenario	
		Status quo	**Supply activated**
Forecast demand scenario	**Status quo**	-20,111 (81%)	2,487 (102%)
	Faster growth	-35,110 (71%)	-12,511 (90%)

isn't the case, and that rising incomes translate to 20% faster growth in consumption than observed recently. It is of course plausible that developed countries with more mature coffee markets will exhibit slower growth, while developing markets may see faster growth in line with the faster growth scenario prediction. In each scenario, we estimate the growth in total coffee consumption (robusta and arabica) and assume the global share of robusta consumed remains unchanged.

When we subtract forecast robusta demand (Table 4, pg. 12) from forecast production (Table 3, pg. 11) three of the four scenarios result in shortages, ranging from 12.5 million to 35.1 million bags GBE (Table 5). Under the status quo demand scenario, where each region grows at nearly the same rate observed over the last ten years, total production only exceeds demand (by 2%) when additional supply is activated (where supply grows, on average, by 2.5% each year, driven by Brazil). The average of all four scenarios is a shortage of 16 million bags of GBE.

The scenarios where additional robusta supply is activated assume higher prices for robusta, due to price pressure as roasters substitute away from relatively more expensive arabica (assuming arabica is more impacted by climate change). For substitution to take place, the supply of higher-quality robusta must increase, or else the quality of blends will decrease, but for this to occur, breeding goals now must address this future requirement.

In scenarios where additional supply is activated, the result is a 21% increase in production from all smaller countries by 2040 (Table 3, pg. 11), and yet projections still range from a surplus of only 2.5 million GBE to a shortage of 12.5 million GBE.

In short, there is a likely and potentially substantial supply gap for robusta in the coming two decades, highlighting the need for significant increases in robusta production. Yield growth and extensification in Vietnam and Brazil have been primarily responsible for meeting global robusta demand increases over the past three decades, but it is not likely possible for those two countries to sustain future global growth on their own. Even if it were, it would lead to even further consolidation of supply, which presents significant supply risk and climate exposure for coffee companies.

If breeding can deliver sustained yield increases in any or many other countries beyond Brazil and Vietnam, particularly among the top six producers that already have resources deployed in robusta (i.e., land and labor) then the potential impact would be significant. For this reason, investment in countries with currently stagnant yield growth may have the potential for greater returns, albeit at higher risk, whereas investment in already successful countries may only lead to incremental improvement upon already successful breeding programs.

What buyers want

In order to gain perspective on the needs of the robusta supply chain, interviews were carried out with 11 major commercial buyers of robusta beans, including coffee roasters and exporter/trader companies. Robusta is generally considered a commodity crop and is often used in blends with arabica by roasters. The main driver when sourcing robusta is price. Volume and consistency of supply are the other key drivers. Overall, large commercial roasters are incentivized to use as much robusta in coffee blends as consumers will tolerate, with an emphasis on avoiding the negative qualities of robusta (bitter, rubbery, and muddy taste).

Distinct market preferences. The choice to source robusta versus arabica is greatly determined by the markets. North American and European markets favor arabica, but Eastern Europe, Asia, and Africa are more comfortable with a higher blend of robusta, on average. However, while there is variation across geographical markets, there is much greater variation within markets, where coffee blends may range from 0 to 100% robusta, depending on the price point and specific market.

Blend consistency. Roasters are reluctant to change their blends because their brands are associated with particular flavor profiles, which they want to maintain. The extent to which roasters can substitute robusta for arabica is limited by consumer tolerance for low-quality robusta on the one hand and availability and price of higher-quality robustas on the other. As arabica becomes more expensive, consumers may shift buying behavior towards cheaper products, which tend to have a higher robusta content.

Despite being a commodity crop, there are minimum thresholds for quality, where quality is defined by fewer defects or less contamination (rather than the coffee possessing special characteristics or favorable cup profile qualities). Consistent bean size and not-too-big bean sizes are important. Given the role of robusta in blends, the need for neutral flavors was also emphasized. Overall, the roasters see little differentiation of robusta on product cup profile.

Supply volumes vs. quality. Although perception about quality exists based on sourcing countries, the volume of supply is regarded as more important than the source of the robusta. While Uganda is perceived as having the highest quality of robusta, Vietnam—which is considered mid-tier quality—is the most preferred location for sourcing. Although roasters expressed concerns about supply being consolidated in Vietnam and Brazil, the major challenge in sourcing from smaller robusta-producing countries is the lack of assurance in the volume of supply.

While roasters are very aware that the climate crisis is a threat to arabica and that robusta is part of the solution, they are still focused on volume and price for robusta. There is therefore some clear tension in their long-term goals because higher

quality, higher priced robusta would be required to shift blends towards robusta (unless consumers are willing to tolerate higher robusta blends at higher price points than they would currently expect).

There is more interest in reducing robusta's negative rubbery, skunky, sulfury, and musty characteristics than improving cup profile attributes of robusta. Overall, roasters are driven by the need for a lower-priced ingredient that meets base quality thresholds and doesn't bring negative features to blends.

Specialty robusta. Specialty (also called "Fine") robusta coffee is a very small part of the roaster market, but these roasters are interested in unique attributes and demand higher cup quality. This niche roaster segment wants to compete with arabica, and change perceptions of robusta, noting its many positive attiributes (higher caffeine content, more body—known as "crema"). Specialty coffee buyers require "clean coffee" (grade with the fewest defects).

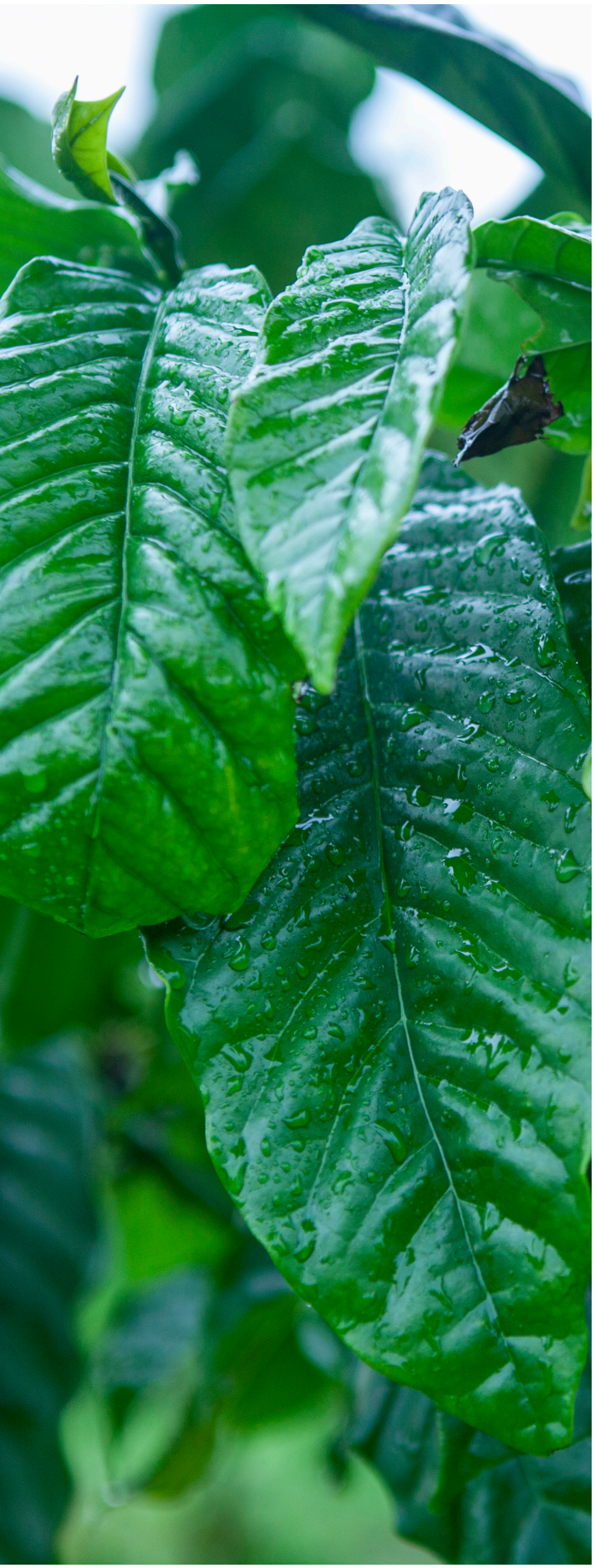
Sustainability regulations. There is increasing demand among buyers for deforestation-free products and reduced chemical inputs. The requirement for deforestation-free products suggests that more yield needs to be delivered from the existing if not a smaller robusta production area, while chemical input regulations suggest that disease and pest resistance are important breeding targets.

Other concerns among buyers include the profitability of farmers, competition with more profitable crops, and aging farming populations.

Robusta variety innovation

Understanding future supply needs and buyer demands are critical aspects of evaluating the potential importance and impact of a global breeding collaboration for robusta. Equally important is understanding the current variety innovation landscape and whether current sources of supply for agricultural innovation (encompassing breeding, trials, and propagation systems) are likely sufficient to stave off supply shortages, avoid further consolidation, and deliver the quality needed by the market. For this section, interviews were conducted with seven organizations representing or carrying out research to support coffee farmers in their respective countries. This included two farmer representatives and five breeding/research groups.

The current variety innovation landscape for robusta, similar to arabica, is dominated by public breeding programs operated by coffee-producing countries where robusta is an important



economic driver of the agricultural economy. A 2023 survey of coffee R&D investments concluded that current global spending on coffee R&D, for both arabica and robusta, is estimated at only $115 million per year (inclusive of 45 countries and the private sector), an extraordinarily low number given the $200 billion farm-gate value of coffee (Maredia and Martinez, 2023). The total value of green coffee makes up about 4.8% of the total value of agricultural output in the 45 countries included in Maredia and Martinez's analysis. However, in these countries, coffee only received 1.8% of total agricultural sector investment. This suggests a threefold increase necessary to merely align investment into coffee with coffee's contribution to agricultural output.

In interviews, breeders and farmer organizations from multiple countries agreed greater opportunities exist to improve robusta performance through breeding, particularly given that robusta is relatively unimproved compared to arabica. In general, interviews suggest that breeding programs, farmers, and buyers have shared priorities, with some key exceptions.

Yield. In interviews with breeding programs across all major robusta-producing countries, yield ranked as the most important plant characteristic for breeding. Disease resistance and abiotic/drought tolerance also ranked high. These are also critical traits for farmers and important for buyers' goals of sustaining supplies without significant price changes and without substantial increases in extensification (e.g., on maintaining production on current or reduced land area) in order to avoid deforestation and increased carbon emissions from land-use changes. Yield is currently the primary target of all breeding programs interviewed.

Quality. The introduction of fine robusta standards in the last decade has ushered in a new niche for high-quality robusta. This high-quality robusta can achieve higher prices, like arabica, but only a small portion of the market is demanding this higher-quality product. Nevertheless, this shift seems to be leading to increasing farmer demand for higher quality. For non-specialty markets, there may also be a need to increase the supply of higher quality robusta as robusta is increasingly substituted for arabica, or else the perceived quality of blends will decrease leading to consumer rejection. Breeding programs so far have not significantly responded to these demand signals for enhanced robusta quality. This may be in part because increased cup quality may come with some trade-offs in terms of yield and/or disease/pest resistance (for example, some pest-resistant clones have been reported to be of poorer cup quality).

Bean size. While roasters do not currently pay a lot of attention to robusta bean sizes, farmers are demanding varieties with bigger beans. However, high-yielding cultivars tend to have smaller bean sizes. To meet current market demands, farmers need to focus on achieving uniformity in bean size (rather than bigger beans).

However, if robusta continues to substitute arabica, market demand may gradually shift to bigger beans for robusta due to arabica having bigger beans. To address this trade-off and projection, robusta breeding programs may need to be positioned to select for bigger beans and improved yield simultaneously.

Farmer acceptance. Farmers are generally willing to accept new varieties of robusta, but breeding programs appear to have several factors impacting deliveries, such as access to improved seeds/clones and slow varietal release.

Gaps and challenges. Interviews with breeding programs suggest many common challenges and gaps in the global ecosystem for robusta variety innovation. These challenges include but are not limited to low farmer profitability, increasing biotic and abiotic pressures due to climate change (particularly water availability, flooding, heat, and rain), lack of regulations to support new variety releases, technical/scientific capacity limitations, lack of access to germplasm, low access to clonal planting material, severe funding limitations, lack of opportunity for global collaboration.

Global, collaborative breeding—insights and opportunities

Current production and consumption projections highlight the need for a significant increase in robusta production, not just in Vietnam and Brazil but in other robusta-producing countries too. The scenario where additional robusta supply is activated assumes higher prices, due to price pressure as roasters substitute away from relatively more expensive arabica (assuming arabica is more impacted by climate change). For substitution to take place, the supply of higher-quality robusta must increase, or else the perceived quality of blends will decrease. This needs to be accompanied by more research into the climate adaptability of robusta in flowering and growth phases to deliver robusta varieties that are resilient to climate change.

While large roasters primarily see robusta as a commodity and are not particularly demanding of a higher quality cup profile, it appears that farmers are more focused on improving the quality of robusta in addition to high-yielding, drought-tolerant, and disease-resistant robusta as a future strategy. This demand for higher cup quality robusta by farmers is being driven by higher prices for premium quality, although the market is currently a niche one, and yield is still their top priority. Despite the demand for higher quality robusta varieties by farmers, the current market trends present little incentive to prioritize quality by breeding programs in the short term. The farmer's focus on yield is entirely justified, given the drivers of the farming business.

There are some similarities that can be drawn between farmers and roasters. Farmers prioritize yield almost universally. Under various definitions (e.g., supply continuity, yield stability, bean size, screen size, farmers' yield) roasters did point to the importance of yield. While the focus on yield for farmers is about income, for roasters it is about ensuring consistent supply and volume.

A key factor of success, therefore, is aligning current and future sourcing needs of the market with robusta-producing country breeding and variety development strategies. This is complicated by current differences in the perception of roasters and farmers about the place that robusta occupies in the market. Furthermore, while the roasters see robusta as a substitute for arabica, the breeding programs and farmers see robusta as a product, in its own right, which does not necessarily compete with arabica in terms of production. This situation presents an opportunity to make improvements in robusta, but the successful delivery of these improvements in robusta breeding would require a re-orientation of the markets' perception of robusta in terms of potential and uniqueness. It is clear from production forecasting herein, and from the views of farmers and roasters, that driving innovation to produce gains in yield (and other yield-impacting traits like climate change tolerance/resilience) is likely to be a win for farmers and roasters.

Opportunity exists for smaller robusta-producing countries in Africa to return to robusta production. This would require initiatives in the form of partnerships between roasters/traders and farming cooperatives or through vertically integrated operations that involve farming. These types of initiatives can cater to the robusta soluble market for African consumers who have the highest preference for robusta, or more niche markets.

Overall, current robusta breeding programs are positioning themselves for innovation, although variation exists in their advancement stages, which is reflected in what they perceive as their limitations and needs. A global effort aimed at enhancing interaction, removing barriers to technology, and sharing of genetic resources could lead to faster advancement of the breeding programs.

Despite the potential positive impact of a global collaboration, a 'one-size-fits-all' approach is unlikely to be successful. Different strategies of support need to be employed in different countries, to aid in variety innovation and release.

Given a predicted supply gap, increasing sustainability pressures, and low existing investment, there is a compelling case to expand global robusta breeding efforts, and in particular for a global, collaborative program of genetic improvement.

Appendices

Appendix 1. Estimating robusta planting area

A complete understanding of the global robusta landscape requires estimates for yield and area planted, underlying production in each country. However, estimating these parameters for robusta is not straightforward, because FAO data on land use is not disaggregated by coffee species (total coffee area is reported; robusta and arabica combined). We calculated the yield and area planted, by country (Table 6), using the four following approaches:

1. For Brazil, where sources for robusta yields were available,[6] we determined acres planted based on yield and average production from 2019-20 to 2021-22.
2. For countries that only produce robusta,[7] aggregate FAOSTAT statistics for yield and area planted were assumed to be equal to robusta parameters.
3. For India, we assumed the total area of coffee planted is split equally between robusta and arabica,[8] and calculated yields for robusta based on this and average production.
4. For the remaining countries, we solved for the robusta area planted (HaR), by calculating the value which produced a given relative yield (Z=1.69)[9] which also determined yield:

$$Z = \frac{YLD_R}{YLD_A} = \frac{Bags_R}{Ha_R} \Big/ \frac{Bags_A}{Ha_{(R,A)} - Ha_R}$$

Table 6: Average robusta production, yield, and area planted (2019-20 to 2021-22) for key producing countries.

	Uganda	Indonesia	Brazil	Vietnam	Ghana
1	Yield	Yield	Yield	Yield & early berry	Yield
2	Drought tolerance	Bean size	Quality	Disease resistance	Early maturity
3	Disease resistance (wilt)	Cup quality	Maturation cycle (uniform)	Bean size	Plant height (shorter better)
4	Cup quality	Biotic stress tolerance	Plant height (taller better)	Growth rate	Abiotic resistance
5	Bean size	Low defect rate	Stem architecture	Cherry-to-bean ratio	Ease of establishment
6	Ease of multiplication	Ease of harvest		Ease of harvest	Cup quality

[1]Average of yields from 2019 to 2022 (FAOSTAT, 2023). [2]Average production from 2019-20 to 2021-22 (ICO, 2023a). [3]Area calculated based on yield and combined robusta/arabica output.

[6] Average yield in Brazil from 2019-2021 for robusta and arabica were 42.5 and 25.1 60-kg bags/ha (Statista, 2023).

[7]This applied to Côte d'Ivoire, Madagascar, and Laos (where Laos output is 99% robusta).

[8]Based on USDA country report (Sood and Beillard, 2023). Table 2 shows approximately a 50/50 split. The implied yield for arabica (7.3 60-kg bags, or 440 kg/ha) aligns with reported yields for 2019-2020 from the same report (see Figure 3).

[9]Relative yields in Brazil, India, and Indonesia are 1.69, 2.45, and 0.92, respectively. Unusually, in Indonesia arabica yields are greater than robusta (Rahmanulloh, 2023). The raw average of these relative yields (1.69) was used for all countries except for Indonesia, where Z=0.92.

Appendix 2. Estimating robusta preference[10]

In Table 2 (pg. 8) we infer each region's preference for robusta according to the share of green bean imports that are robusta. To do this, the following steps were followed:

1. We calculated annual robusta imports, by country, based on ICO export data from the five biggest robusta producers[11] (where exports are reported by destination, which can be reversed to calculate robusta imports).
2. We then took ICO total import data by country (combined arabica and robusta), and then subtracted imports of robusta to calculate annual arabica imports.
3. For each country, imports of arabica = total imports – imports of robusta
4. The preference for robusta coffee is calculated as the proportion of robusta imports relative to the total import volume over the past three years and then aggregated by region.

Figure 4 (pg. 21) shows the time series of import shares for several countries. The robusta preference is based on an average of the three most recent years. It is clear there are diverse trends in coffee imports globally, with some countries demonstrating a definitive shift from arabica to robusta Coffee, while others remain with arabica preference.

In Algeria, China, Italy, Russia, and Spain, the ICO data suggests a significant change in coffee imports. Over the years, robusta has surpassed arabica as the preferred coffee variety to import. These shifts could be due to a variety of reasons such as changes in consumer preferences, pricing, manufacturing and re-exports, etc.

The case of Germany is particularly interesting. The country shows a declining trend in arabica imports and a simultaneous rise in robusta imports. If this trend continues, it is expected that in the coming years, Germany will join the list of countries where robusta is more popular than arabica and, thus, suggests a shifting preference among the German industry and/or consumers.

The United States and Japan present a contrasting picture to the aforementioned countries. They continue to hold their preference for arabica, indicating a strong favorability for this species. However, it is noteworthy that, despite their traditional inclination towards arabica, there has been a gradual yet discernible increase in robusta imports in both nations over the past eight years. This indicates that even in countries with a historically strong preference for arabica, the appeal of robusta is progressively gaining traction.

Lastly, the United Kingdom exhibits a more unpredictable pattern, fluctuating between arabica and robusta. This unpredictability needs further investigation but could indicate a more diverse consumer preference or could reflect the impact of external factors like import prices, or supply chain issues.

[10] Appendix 2 contains analysis of the following data sources: ICO 2023b

[11] The five largest exporters are responsible for 93% of robusta production (Table 1).

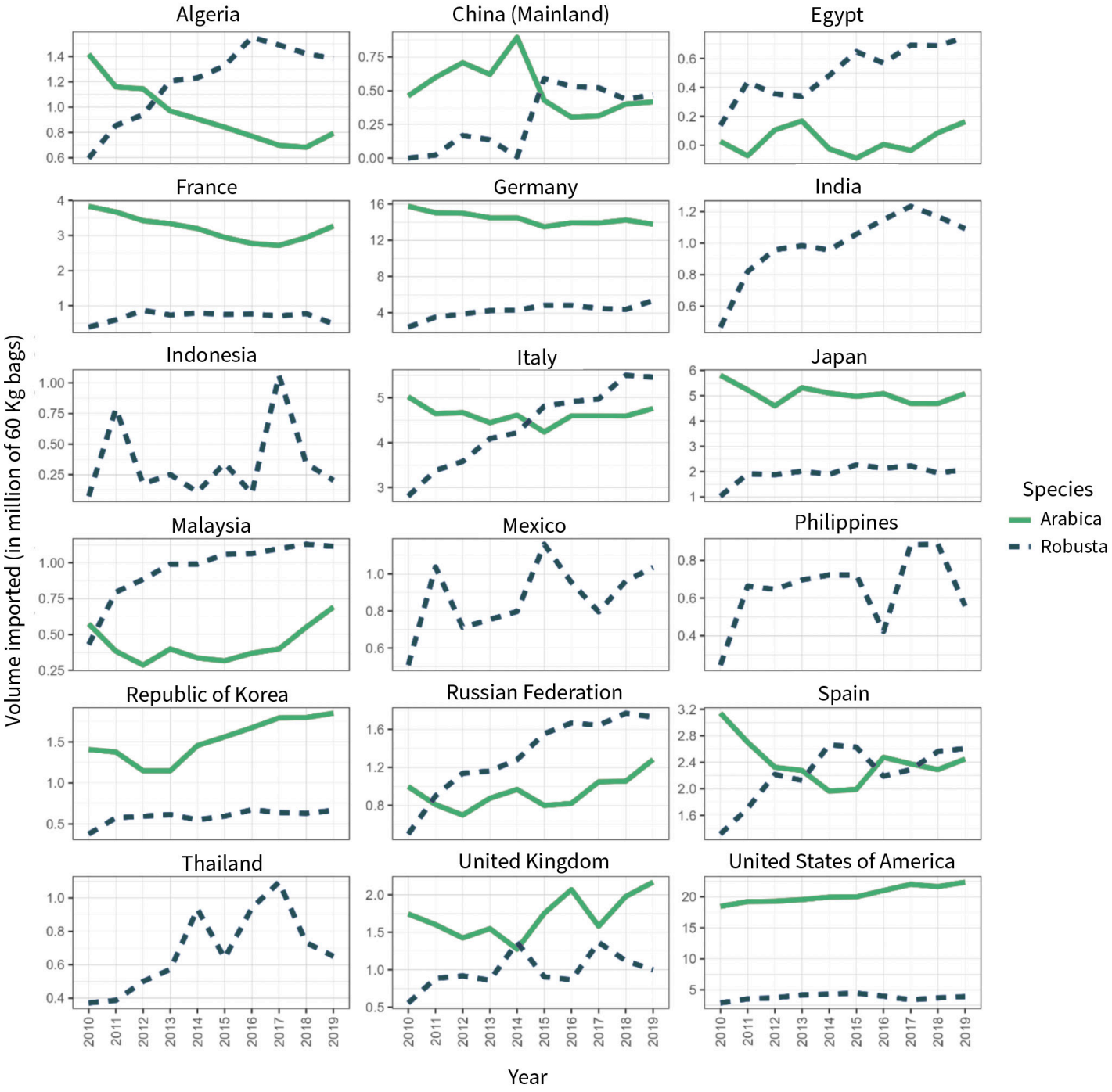


Figure 4. Change in volume of robusta and arabica imports by top 18 countries (2010-2019).

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