



Agronomic Interventions for Global Market-Driven Pursuit of Coffee

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Coffee is one of the most traded agricultural commodities globally. As a woody perennial, it serves as a major cash crop and a vital source of foreign exchange for many producing countries. In India, coffee holds a prestigious position among plantation crops, being the most significant cash crop grown in tropical regions. Predominantly an export-oriented commodity, India exports 65 to 70% of its coffee production, earning substantial foreign exchange, especially from its highly sought-after Indian Robusta known for its excellent blending quality.

Rich in caffeine, coffee owes much of its widespread popularity to this stimulating compound. With over 1,000 years of consumption history, coffee has become the most consumed beverage worldwide and is the second most traded commodity after oil. As one of the top-traded commodities, coffee supports the livelihoods of millions, from smallholder farmers to baristas in urban coffee shops. This article explores the agronomical interventions that are transforming the coffee industry to meet global market demands.

Global Scenario of Coffee Production

In the 2022-23 period, the global area under coffee production reached 12.2057 million hectares, yielding a production of 10.7823 million tons and a productivity rate of 0.8834 tons per hectare. Brazil stands as the leading coffee producer worldwide in both area and production, while Vietnam boasts the highest coffee productivity. Brazil is also the top coffee exporter, accounting for 33.28% of global exports, followed by Vietnam, which holds a 23.20% share. The European Union emerges as the largest coffee importer, comprising 30.13% of total global imports. India is the seventh largest producer of coffee with a 3.23 % share in global production and is the fifth largest exporter of coffee with a 5.14 % share in world export of coffee.

Types of coffee beans

Although there are over 100 species of coffee, Robusta (*Coffea canephora*) and Arabica (*Coffea arabica*) dominate the commercial coffee trade, accounting for 99% of it. Among the main varieties of *Coffea arabica*, several are noted for their excellent cup quality, including Typica, Bourbon, Caturra, Catuai, Pache Comum, Pache Colis, Catimor, Kent, Mundo Novo, Maragogype, Amarello and Blue Mountain. Additionally, some *Coffea robusta* varieties, like Indonesian Kopi Luwak and Philippine Kape Alamid, are renowned. Other notable varieties include Barako coffee and *Coffea liberica*, but only *C. arabica*, *C. canephora* (with *C. robusta* as a major variety) and *C. liberica* are of significant commercial importance. Different coffee varieties contribute unique aromatic compounds, specific to their type or origin.

Arabica beans are known for their sweeter, softer taste, with high amounts of sugar, fruit, and berries, and a higher acidity that imparts a wine-like flavor. In contrast, Robusta beans have a stronger, harsher taste with a grain-like overtone and a peanutty aftertaste. They contain twice as much caffeine as Arabica beans and are generally considered to be of inferior quality. However, some high-quality Robusta beans are valued, especially in espressos, for their deep flavor and good aroma. Arabica coffee is more valuable because it produces a better-tasting beverage, making it more expensive than Robusta coffee. The cultivation of coffee requires meticulous practices, from selecting suitable varieties to implementing advanced farming techniques.

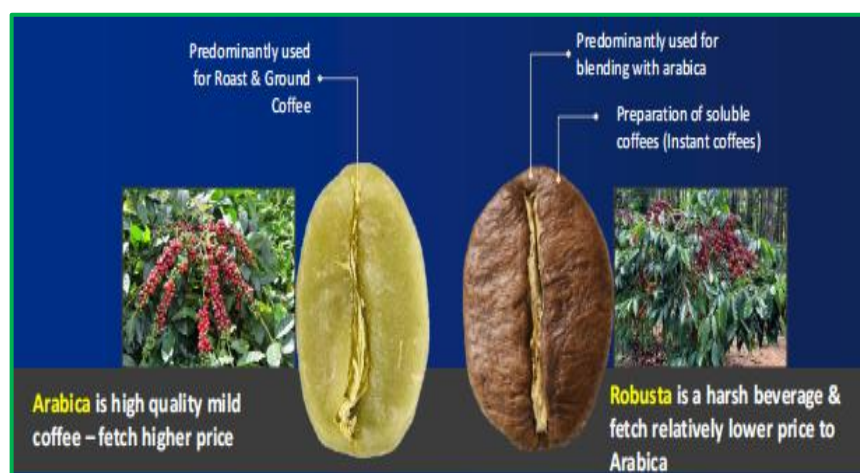


Fig. 1 Types of Coffee

Major Challenges in Coffee Cultivation

One of the major challenges in coffee cultivation is climate change. It significantly impacts the coffee industry by altering temperature and rainfall patterns, and increasing the prevalence of pests and diseases, all of which affect coffee quality and processing. Arabica coffee is particularly sensitive to temperature changes, thriving best within the range of 18-22°C. Coffee plants are also vulnerable to various pests and diseases, such as coffee leaf rust (*Hemileia vastatrix*) and the coffee berry borer (*Hypothenemus hampei*). These threats can devastate crops, leading to substantial economic losses. Additionally, the genetic diversity of commercial coffee is relatively limited, making it more susceptible to diseases and environmental stresses. Developing new, resilient coffee varieties is essential for sustaining production.

Agronomic Interventions and Innovations

Breeding new coffee varieties is a critical intervention in coffee cultivation, combining traditional breeding methods with modern genetic techniques. Researchers are developing cultivars with enhanced traits, such as disease resistance, higher yields, and improved cup quality. Hybrids like those in the Catimor and Sarchimor groups merge the desirable characteristics of Arabica and Robusta, offering both disease resistance and appealing sensory profiles. Recent hybrids such as the H1 Centroamericano are becoming increasingly popular due to their robustness and superior bean quality. Advancements in genomics have enabled the identification of genes associated with desirable traits, allowing for the selection of parent plants with optimal genetic profiles. This speeds up the breeding process and enhances the precision of developing new cultivars. Improving coffee genotype quality is a primary goal in coffee genetic improvement programs. Genomic progress offers new tools for analyzing coffee quality at the molecular level. A significant milestone is the sequencing of the genomic sequence for robusta coffee (*Coffea canephora*). However, a reference genome sequence for the genetically complex Arabica coffee (*C. arabica*) is also necessary to fully understand the molecular determinants of quality in this high-quality coffee species. Genes controlling the levels of major biochemical components in coffee beans, which are crucial in determining coffee quality, can now be identified through association analysis.

Incorporating agroforestry practices into coffee cultivation offers numerous benefits. Shade-grown coffee, for example, not only improves bean quality but also supports biodiversity and enhances ecosystem services. Agroforestry systems can mitigate the effects of climate change by maintaining cooler microclimates and protecting soil health. Maintaining soil health is also crucial for robust coffee production. Practices such as composting, mulching, and using organic fertilizers can enhance soil fertility and structure. Recent research highlights the benefits of biochar—a carbon-rich material produced from organic waste—in improving soil properties and sequestering carbon, contributing to climate change mitigation. Effective water management is also critical in coffee farming, particularly in drought-prone regions. Precision irrigation methods like drip irrigation ensure efficient water distribution, reducing waste and improving plant health. Additionally, rainwater harvesting and using cover crops can enhance water availability and conservation efforts.

The journey from coffee cherry to green bean involves several post-harvest processes that affect quality. Innovations in processing methods, such as controlled fermentation and the use of specific yeast strains, can enhance flavor profiles and consistency. Improved drying techniques, including solar dryers and mechanical drying, ensure uniform moisture content and reduce the risk of mold. Advanced coffee cultivation technologies increase yield, operational efficiency, and the quality of the final product. They also enhance the competitiveness of coffee cultivation within the global agricultural landscape. Remote sensing is another technology utilized in precision coffee farming, contributing to the sector's development since its early research efforts. Additionally, the advent of remotely piloted aircraft (RPA) has opened new possibilities. Brazil's role in advancing scientific knowledge on precision coffee farming is significant.

The global coffee market is dynamic, with constantly evolving consumer preferences and industry standards. There is a noticeable shift towards sustainable and quality-oriented practices, increasingly shaping the interventions in coffee production. The rise of specialty coffee has shifted the focus towards quality over quantity. Specialty coffee commands premium prices and is characterized by unique flavor profiles and high production standards. Agronomic practices that enhance bean quality—such as selective harvesting, precise fermentation, and careful drying—are critical in producing specialty-grade coffee. Consumers are increasingly interested in the origins of their coffee and the practices behind its production. Blockchain technology and digital traceability tools are being used to provide transparency in the coffee supply chain. These tools enable consumers to trace their coffee from farm to cup, ensuring ethical practices and high-quality standards.

Global Coffee Success Stories

Vietnam: Vietnam boasts the highest coffee productivity worldwide, primarily attributed to Robusta coffee, which constitutes 97% of the country's production. Surpassing its initial output of fewer than two million bags annually in the early 1990s, Vietnam has ascended to become the world's second-largest coffee producer and exporter. Presently, its average annual output exceeds 25 million 60-kg bags. To foster the expansion of the coffee sector, the government has offered farmers subsidies and agricultural planning guidance.

Ethiopia: As the origin of Arabica coffee, Ethiopia is home to a diverse range of coffee plant genetics. Traditional farming practices in the country, such as cultivating coffee under the shade of native trees, result in unique and complex flavor profiles. Recent initiatives in Ethiopia aim to conserve coffee genetic resources and promote organic farming methods to safeguard the country's rich coffee heritage.

Brazil: Brazil holds the title of the world's largest coffee producer, with a notable focus on mechanization and extensive-scale farming practices. Nevertheless, Brazil has made considerable advancements in sustainability and enhancing coffee quality. The cultivation of

drought-resistant varieties and the adoption of sophisticated irrigation methods have facilitated Brazilian farmers in confronting climate-related adversities. Furthermore, the nation's commitment to research and technological advancements has fostered innovations in processing techniques and quality management.



The Future of Coffee: Challenges and Opportunities

The future of coffee is characterized by a blend of challenges and opportunities. Climate change stands out as a significant threat, demanding ongoing research and adaptation efforts. The cultivation of resilient coffee varieties, alongside the adoption of sustainable farming methods, will play a pivotal role in mitigating the impacts of climate change.

Exciting prospects also emerge through technological advancements within the coffee industry. Precision agriculture, which incorporates drones, sensors, and data analytics, has the potential to optimize farming techniques and enhance overall efficiency. Furthermore, biotechnology, including CRISPR and other gene-editing tools, holds promise for developing coffee plants with improved characteristics.

Consumer preferences will continue to steer the direction of the coffee market. There is a growing demand for transparency, sustainability, and distinctive flavor profiles, which will shape the future of coffee production and marketing strategies. Embracing these trends through innovative agronomic practices will be crucial in meeting market demands and ensuring the longevity of the coffee industry.

Conclusion

Agronomic interventions are at the heart of the coffee industry's evolution, addressing challenges and seizing opportunities in a global market-driven landscape. From breeding resilient varieties to implementing sustainable farming practices, these interventions enhance both the quality and quantity of coffee production. As the world continues to appreciate the complexities and nuances of coffee, the role of interventions will only grow in importance, ensuring that coffee remains a beloved beverage and a vital economic commodity for generations to come. By focusing on scientific research and adopting innovative practices, the coffee industry can navigate the complexities of the global market and ensure a sustainable and prosperous future for all stakeholders involved.

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