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Reef ريف

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Ministry of Environment Water & Agriculture

Reducing losses in coffee in KSA through better harvest, postharvest management and processing VAL/051/2022/1

Strengthening MoEWA's Capacity to implement its Sustainable Rural Agricultural Development Programme (2019-2025) (UTF/SAU/051/SAU)

Food and Agriculture Organization of the United Nations

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Contents

Acronyms

BGR	Blacks, Greens or Rancids
CAGR	Compound Annual Growth Rate
CONACAFE	National Council of Coffee
FAO	Food and Agriculture Organization
FAOSA	Food and Agriculture Organization, Saudi Arabia
FDA	Fayfa Development Authority
ICO	International Coffee Organization
ISO	International Standard Organization
ITC	International Trade Center
IHCAFE	Honduras Coffee Institute
JMDA	Jazan Mountain Development Authority
KPIs	Key Performance Indicators
KSA	Kingdom of Saudi Arabia
MARD	Ministry of Agriculture and Rural Development
MoEWA	Ministry of Environment, Water and Agriculture
R&D	Research and Development
SMEs	Small and Medium Enterprises
CONACAFE	Honduras Coffee Institute
SR	Saudi Riyals
SRAD	Sustainable Rural Agricultural Development
SWOT	Strengths, Weaknesses, Opportunities and Threats
KPIs	Key Performance Indicators
SRADP	Sustainable Rural Agricultural Development

Acknowledgments

This report has been prepared with the support of FAO Saudia's Sustainable Rural Agriculture Development Program (SRADP), to improve the efficiency of target commodities' value chains including Arabian coffee. The current practices of harvesting, postharvest handling, and processing of coffee lead to both quantitative and qualitative losses thereby incurring economic losses to the small holders. Proper harvesting, postharvest handling and processing which have significant room for improvement, can lead to a reduction of these avoidable losses. It is in this background; the report on "Reducing losses through better harvesting practices, postharvest handling, and processing" is compiled to serve as a guideline and reference material for training MoEWA staff and coffee growers.

The support of all the FAOSA colleagues is highly acknowledged.

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Executive Summary

The vision 2030 of the government of Saudi Arabia, is aimed at expanding its economic base beyond the oil-based economy and ensuring food security. The Saudi government through its ministry of water, environment and agriculture and FAO jointly formulated a program 'Sustainable Rural Development Program (SRAD)" for developing the agriculture sector of the kingdom with particular emphasis on certain identified commodities through a value chain approach.

Coffee has been grown for centuries in Saudi Arabia. There are two coffee species i.e. *Coffea arabica* and *Coffea robusta*. The coffee plantation in Saudi Arabia is of *Coffea arabica*, which due to its superior taste is the predominant coffee specie and contributes to more than 60% of global coffee production. The changing lifestyle and purchasing power, have increased the demand for coffee and its cultivation and international trade have also been increasing. The *Coffea arabica* has enormous economic potential in both domestic trade and international markets. Thus, *Coffea arabica* is one of the target commodities of the SRAD program,

The success of the coffee sector in KSA to emerge as a global player, however, depends on transformation from traditional cultivation to modern agricultural technologies to increase not only the production but also the quality. It also requires adopting proper harvesting, postharvest handling, and processing technologies to meet the global standard of quality. The current production practices, postharvest handling, and processing result in a loss of quantity and quality. The existing production system is limited by the unavailability of quality planting materials and poor agronomic practices.

Harvesting and postharvest care is essential to reduce quantitative and quality losses of coffee. Harvesting care such as harvesting at proper maturity stage, harvesting by selective or strip picking methods, and gentle handling can reduce the losses during harvest significantly. Similarly, appropriate postharvest handling such as sorting of coffee cherries before drying to remove defective cherries, drying to 11.5-12% moisture content at optimum temperature of 40-45°C, hulling with minimum damage, and post-hulling sorting to eradicate defective beans can decrease the physical losses. Sorting also helps in separation of dark, sour and mold affected beans, Different processing technologies such as wet, semi-wet and dry processing are used for processing of coffee beans in the world with each method having some merits and demerits. Since, the wet method requires abundant water, which is a scarce resource in KSA, so only dry processing is practiced. The losses in coffee beans are aggravated by improper bags (gunny bags), storage temperature (higher than 30°C), and high relative humidity (more than 60%). Proper harvesting, postharvest handling and processing can be instrumental in decreasing the losses and retaining the quality of coffee. Its only then, that the coffee sector can be upgraded to produce coffee products that are competitive in both domestic and export markets.

The current assignment was carried out to evaluate the current scenario of harvesting, postharvest handling, and processing in KSA. The study focused to find the gaps at the levels of harvesting, postharvest handling, and processing of coffee, and propose measures at each level to reduce the losses and retain the quality throughout the postharvest chain. Since, the coffee is predominantly grown by smallholders lack the resources and skills of high-tech. postharvest techniques, low input and readily adoptable technologies are proposed.

The role of extension staff MoEWA is of crucial importance in changing the outlook of coffee growers from traditional to commercial coffee farming, driven by market demand and consumers' preferences. Training of both the Extension Staff of MoEWA as well as coffee growers can be helpful in promoting better postharvest management of coffee. With properly trained human resources, coffee growers can adopt low-input technologies to reduce postharvest losses in quality and quantity.

SECTION 1: AN OVER VIEW OF THE REPORT

1.1 Background of the Study

The Kingdom of Saudi Arabia (KSA), with a total area of about 2.15 million km^2, is by far the largest country in the Gulf Cooperation Council. It is bordered in the north by Jordan, Iraq, and Kuwait, in the east by the Persian Gulf with a coastline of 480 km, in the southeast and south by Qatar, the United Arab Emirates, Oman, and Yemen, and in the west by the Red Sea with a coastline of 1,750 km. Despite being the largest country, in the Arabian Peninsula, the total agricultural land is 173595.9 thousand hectares of which the crop land is only 3595917 hectares. The total area equipped for irrigation is 3178.9 thousand hectares. The government initiative on organic farming has led to 26.63 thousand hectares of land used for organic farming and crop certification.

Historically, agriculture in KSA has been limited to date farming and small-scale vegetable and fruit production. However, the coastal strip in the southwest and adjoining mountainous terrain is famous for rainfed cereals, subtropical fruits, and coffee cultivation. In KSA, about 88% of farmers are small holders lacking the necessary resources to adopt modern agricultural technologies. As a result, the smallholders use traditional agricultural practices, which do not achieve the potential yield of different crops grown in the KSA. Further, improper harvesting, postharvest handling, and processing cause significant losses in food commodities.

In 2016, The Kingdom of Saudi Arabia launched a roadmap to achieve sustainable economic growth and development. The program, “Vision 2030” aims to put KSA as the world’s best model for economic development and shift in reliance merely on oil to other economic sectors including agriculture. To achieve this, the flagship program of the Sustainable Rural Agricultural Development (SRAD) Program (2019-2025) has been jointly formulated to have a diversified agricultural production base, improving the income and living standards of small-scale farmers, strengthen food security and social stability, and preserve the environment and natural resources.

Prime beneficiaries of the FAO SRAD project are small-scale, rural farmers. It is generally acknowledged that rural agricultural SMEs are not only about farming, but it’s also an all-inclusive system of on-farm and off-farm activities and their linkages with the value and supply chain of commodities. Rural agriculture SMEs provide a major source of income and employment; particularly for youth and women. These are part of an extended supply chain along with large-scale farmers, aggregators, retailers, traders, importers/exporters, processors, government entities, markets, R&D organizations, and agricultural cooperatives. The inefficiencies along the value chain mar their competitiveness at the local level, which contributes negatively to the national competitiveness. The inefficiencies, broadly speaking, include reliance on old-fashioned inputs and production systems, low access to technologies appropriate for small-scale farming, lack of innovation, poor infrastructure and service delivery, poor marketing systems, low digitization, and scarce skilled human resources.

In the green sector of SRAD, besides other crops, coffee was selected because of its potential in the livelihood improvement of smallholders. Quite a large room exists for improving the practices at harvest, postharvest, and processing levels of the coffee value chain, through

optimizing postharvest management and processing practices and technologies. The farm produce needs to be properly and efficiently handled in the commodity supply chain to assure quality on arrival in markets. The inherent inefficiencies in the coffee production chain lead to poor quality, a high levels of food losses that adversely affect food availability, productivity, and the environment (SOFA 2019).

1.2 Cultivation of Coffee Crop in Saudi Arabia

Coffee has traditionally been grown in Saudi Arabia for the last more than three centuries. However, the coffee sector has not received the attention, it deserved, to develop as an important sector that can promote the livelihood of coffee growers. The coffee sector of Saudi Arabia could not keep pace with the growing domestic and international demand for coffee. As a result, Saudi Arabia imported 54,081 tonnes, worth 173,993 thousand US$ in 2020 (FAO, 2020). Whereas Saudi Arabia exports a small quantity of coffee (1,303 tonnes), it is a net coffee importing country,

The annual coffee demand in Saudi Arabia is about 80.07 thousand tons. It has been reported that Saudi Arabia can expand coffee cultivation in the south and southwest regions to about 2861.78 hectares to meet the increasing local demand and to increase its share in export markets (Al-Abdulkader *et al*., 2017). If Saudi Arabia increases its yield to the global average of 0.968 tonnes/ha, it can produce 2769.714 tonnes of coffee green worth USD 8.92 million.

However, the benefit of increased production can only be realized by reducing the losses during harvesting, postharvest handling and processing. The sustainable development of the coffee sector requires considerable attention to the full spectrum of activities from production through harvesting, postharvest management and processing to meet the quality requirements of high-end and export markets (Minten *et al*., 2014). Hence decreasing postharvest losses and improving quality are central to the sustainability of the coffee sector in KSA (Amamo, 2014).

1.3 Objectives of the study

a. Provide an insight into the coffee sector of KSA, and its economic importance.
b. Elaborate on the current status of harvesting, postharvest handling, and processing of coffee in KSA.
c. Identify the gaps in the harvesting, postharvest handling, and processing of coffee.
d. Propose postharvest handling and processing practices and technologies to minimize postharvest losses in quantity and improve the quality of coffee.
e. Suggest value-addition measures to enhance the income of smallholders of coffee growers as per global best practices.

1.4 Methodology

Assessment of postharvest handling and processing was carried out by adopting several different approaches including:

a. **Review of Project Documents**: A review of the SRAD project documents i.e the coffee situation analysis, coffee value chain, and implementation plan as well as documents from the MoEWA on the coffee to have a general perception of current postharvest management of coffee in KSA.
b. **Meetings with coffee experts**: Meetings with the coffee component experts of FAOSA as well as the value chain and marketing experts were held to appraise the overall status of the coffee crops and postharvest management and processing in KSA.
c. **Interviews with growers**: Interview questions were developed and the farmers/processors were interviewed from various parts of Jizan from different production strata. The interview covered a range of questions concerning production practices, time and methods of harvesting, and postharvest handling techniques i.e. harvesting maturity, methods, drying methods, packing, transport, processing methods, and storage techniques adopted for the coffee beans (Annexure 3).
d. **Field Visits**: Visits to the production regions, coffee nurseries, and orchards (Fayfa Development Authority and their Nursery (coffee) were conducted to witness and evaluate the different facilities currently being used for harvesting, postharvest handling, and processing of coffee in the target areas of KSA.
e. **Visits to Markets**: Several markets (Riyadh and Jazzan) were visited to get information about product handling, product storage, packing, packaging, quality and pricing in different markets and the market demand for coffee and its products. Visits were also made to the local transporters and processing facilities.
f. **Meeting with representative of the Ministry of Environment, Water, and Agriculture (MoEWA):** Meetings were held with the extension and research staff of the MoEWA working for coffee in the target areas to get an update on their version of problems and prospects of target crops.
g. **Review of literature**: A review of literature on coffee (*Coffea Arabica*) in KSA and elsewhere where agro-climatic conditions and processing processes are comparable to the coffee-growing areas of KSA was made. Besides scientific literature, information from various international organizations working to promote the cultivation and postharvest management of coffee were reviewed.
h. **Validation Workshop**: In order to have the findings and recommendation aligned with the adoptability by the coffee value chain actors, the findings and recommendation were presented to the coffee growers, processors and experts from MoEWA in a validation workshop. The findings were thoroughly discussed and the recommendations were deliberated upon in the socio-economic background of smallholders of KSA.

Limitations of the study: The methodology is limited by the fact that a detailed socio-economic survey could not be conducted due to the short time of the assignment. Hence, the survey questions were addressed through interviews with stakeholders. The data presented represent the mean values. However, this limitation was rectified by the methodology (a-h) adopted.

SECTION 2 THE COFFEE SECTOR

2.1 Global Scenario and the Coffee Sector

Coffee beans are one of the most traded commodities around the globe. The coffee crop is of enormous economic importance for several countries (FAO, 2015). Globally, the coffee crop is cultivated over about 10 million hectares of area in nearly 50 nations where it is a source of livelihood for about 125 million people (Ponte, 2002). The coffee crop was grown over 9.93 million hectares in 2011, which increased to 11.04 million hectares by 2020. During the said period, the production of coffee increased from 8.93 million tonnes to 10.49 million tonnes. The yield of coffee also increased by only 0.12 $t.ha^{-1}$ (Figure 1).

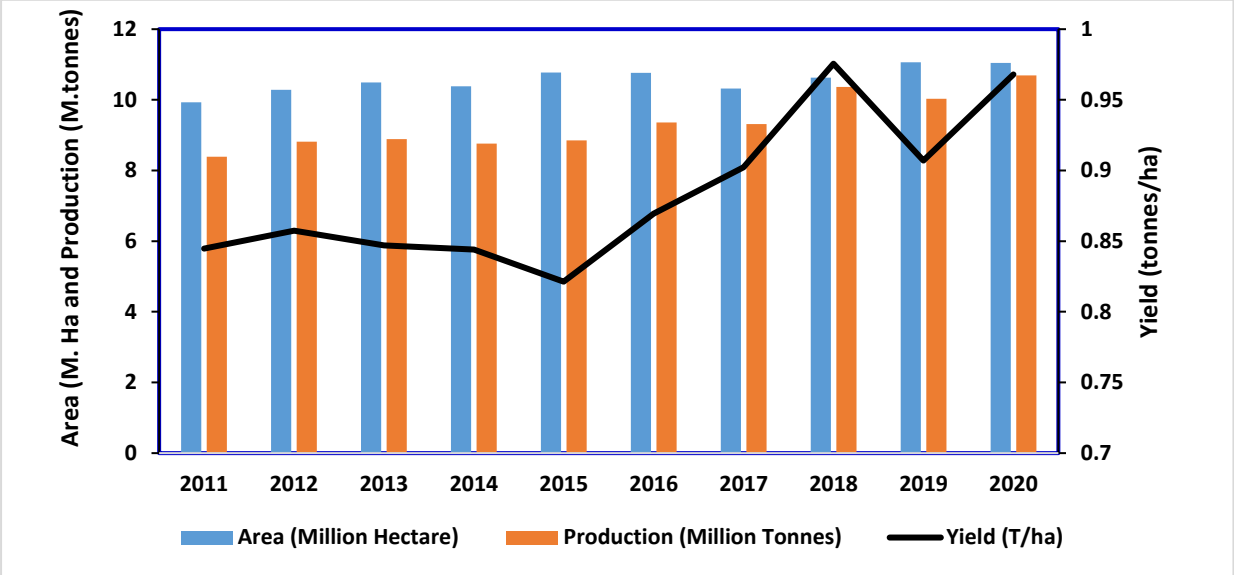


Figure 1. Global trends in coffee cultivation, production, and yield (FAOSTAT, 2020)

2.2 Top Producers and Exporters of Coffee

The global production of coffee was 10,688,153 tonnes. Brazil is the world's leading coffee-producing country with 3,700,231 tonnes, followed by Viet Nam and Colombia with 1,763,476 and 833,400 tonnes, respectively of coffee production. Guatemala, with 225,000 tonnes of coffee production, stands 10th among the top coffee producers in the world (Table 1).

Table 1. Top 10 Coffee producing countries

S.No	Country	Export (MT)	S.No	Country	Export (MT)
01	Brazil	3700231	06	Peru	376725
02	Viet Nam	1763476	07	Honduras	364552
03	Colombia	833400	08	India	298000
04	Indonesia	773409	09	Uganda	290668
05	Ethiopia	584790	10	Guatemala	225000

Globally, coffee is traded in a variety of forms including green coffee beans, roasted coffee, coffee extracts, coffee husks and skins, and coffee substitutes containing coffee. Although

coffee is produced in nearly 80 countries, it is traded in over 160 countries and consumed across the globe. Coffee export plays an important role in the economic growth of coffee-producing countries, especially in developing and least-developed countries (Yifru, 2015). The total global export of green coffee beans was about 7,718,744 tonnes (FAOSTAT, 2020). Brazil is the top producer as well as the top exporter of coffee (2,652,000 tonnes) followed by Vietnam and Columbia with the export of 1.650,000 and 810,000 tonnes export. Guatemala is the 10th largest coffee exporter with 204,000 tonnes (Table 2).

Table 2. Top Coffee Green exporting countries

S.No	Country	Export (MT)	S.No	Country	Export (MT)
1	Brazil	2652,000	6	Honduras	348,000
2	Vietnam	1,650,000	7	India	348,000
3	Colombia	810,000	8	Uganda	288,000
4	Indonesia	660,000	9	Mexico	234,000
5	Ethiopia	384,000	10	Guatemala	204,000

2.3 Situation Analysis of Coffee Cultivation in Saudı Arabıa

2.3.1 Cultivation of Coffee in KSA

Globally, there are two major coffee species i.e. *Coffea arabica* L. and *Coffea canephora* (Robusta coffee). The specie *C. arabica* requires comparatively cool temperatures for growth and warm temperatures for flowering (Pohlan and Janssens, 2010). Hence, it is mostly cultivated in regions with altitudes higher than 1000 m. In KSA, the *Coffea arabica* is cultivated in the southwestern highland terraces of the provinces of Jazan, Asir, and Al Baha.

The Coffee farms in KSA are located at elevations between 1000 and 2000 meters above sea level, with an average annual temperature of 18 to 30°C, and annual rainfall between 200 to 500 mm (Fayfa Development Authority, 1993) (Figure 2). The available precipitation is not sufficient to meet the water requirements of coffee. Thus, coffee growers make up for the shortage of water with additional irrigation water during periods of drought (Hussain, 1990).

The estimated arable cultivation area of coffee is about 6884.7 ha in Jazan region, followed by the Aseer region (4589.9 ha), and Al Baha (674.1 ha) regions (Al-Abdulkader, 2018).

According to Jazan Mountain Development Authority (JMDA), there are about 78,000 coffee trees in the region of which Al-dayer district in Jazan alone covers 84% of the total plantation. These trees produce around 335 tons of coffee beans every year. There are about 1,600 smallholder coffee growers with 700 coffee farms that range in size from less than 100 to more than 500 trees (Interview with farmers and MoEWA Staff at Jazan, 2022). As per ministry's statistics the total production of coffee in KSA was about 800 tons in 2017. Some of the salient features of coffee cultivation and governmental support to promote the coffee sector of Saudi Arabia are summarized below.

Figure 2. Coffee plantations (Hada Mountain, Aseer region, Southwest of KSA

2.3.2.The Soil and climate of coffee growing regions in KSA

Soil: The coffee growing area has several types of soil and a wide variety of vegetation. The most significant type of soil is “soft soil” at low altitude regions. This soil can retain water longer than soil uphills in Aseer and Albaha regions. These soils receive rainwater from the mountains and have good nutritional status.

Temperature: Jizan, being a coastal area, has a relatively warm winter but slightly cooler summer due to south-west winds. The hottest months are from May to September, when the mean monthly temperature can reach 39°C. (Annexure 2). Coffee growing areas in Jizan are at a higher altitude with mean annual temperatures of 18–22°C which is optimal for growth. Temperature higher than 25°C accelerates fruit development. Hence, the climatic conditions of south western Saudi Arabia, especially the mountains of Faifa, the highland of AsSrawat mountains from Jazan province south to the Shada mountain in Al-Baha north are suitable for the cultivation of coffee (Figure 3). The relative humidity is also high especially in the low-lying areas of Jazan, which could potential promote disease incidence in crops.

Precipitation: Jazan receives relatively low annual rainfall (146 mm) as compared to Asser (444 mm) and AlBaha (631mm). The monthly mean precipitation in Jazan, Aseer, and Albaha is 12.17, 36.96, and 52.58 mm, respectively (Annexure 2). However, the relatively high rainfall is less effective to satisfy the water demand of coffee plants in the uphill regions due to rapid run-off and low water holding capacity of the soil.

Figure 3. Coffee flowering, mature cherries, and collection of ripe cherries.

2.3.3 Trends in Coffee Markets in Saudi Arabia

The Saudi Arabian coffee market is dominated by Arabia coffee. However, increased reliance on imported coffee allows *C. Robusta* to increase its share in Saudi Arabian markets. The coffee market size during the year 2020 was USD 3.4 billion which is expected to increase to 5.25 USD at a compound annual growth rate (CAGR) of 6.48% by 2027 (SMR, 2020). Hence, Saudi Arabia, besides increasing production, needs to promote quality to international standards.

However, increasing temperatures due to global warming, and depleting water resources are serious threats to coffee production, especially in low-altitude areas (Martins *et al*., 2014). Hence, it is desired to take appropriate actions to sustain coffee production in these regions.

a. Grafting *C. arabica* on *C. robusta* or *C. canephora*, enhance coffee tolerance to high temperature and water deficiency. Thus, coffee plants, especially at low altitude areas need such interventions (DaMatta and Ramalho, 2006).
b. Develop varieties of coffee resilient to climate changes and have high productivity (Rodrigues *et al*., 2014). The Fayfa Development Agency (FDA) has collected about 20 germplasm accessions from different coffee growing areas of the southwestern KSA. The germplasm collected from such an area where stressful conditions prevail could provide base materials for developing cultivars tolerant to environmental stresses.
c. Promote the use of natural sequestering agents such as well rotten farm yard manure for incorporation into the soil to improve soil water holding capacity.

Saudi Arabia grows only *C. Arabica,* which is, generally, considered of superior quality and fetches a higher price than *C. robusta*. A major part of Saudi Arabia coffee is grown under organic cultivation practices, without using any pesticides, herbicides, or chemical fertilizers (Al-Asmari *et al*., 2020). This factor also contributes to the premium price of *C. Arabica* in domestic markets.

2.3.4 Inputs Sourcing

The coffee growers generally raise their own coffee seedlings from seeds picked up from trees that have shown consistently better production. Some coffee growers procure coffee seedlings from fellow farmers while others buy the saplings from local nurseries which may cost SR 10-50 per sapling. The Fayfa Development Authority (FDA), a government organization, manages a large coffee nursery in Jazan and supplies the seedlings to local farmers. In 2016, it supplied over 40,000 coffee seedlings free of cost to farmers (Figure 4 A). MoEWA aims to make Jazan an important source of coffee and to meet the local market needs by planting over 200,000 coffee trees. The overall target is one million coffee trees producing 2,000 tons of clean coffee by 2030. The average production per tree in KSA averages to be 5.0 kg of coffee cherries. Recently, MoEWA has signed a 15-years deal with the Agricultural Cooperative Society of Baljurashi to plant more than 300,000 arabica coffee seedlings in Mashuqa, Al-Baha, and extend facilities such as a model farm, and nursery for the production of coffee seedlings as well as an industrial area containing processing and roasting facilities (Anonymous, 2021).

Additionally, the government of Saudia consistently provides subsidies to the farmers and processors to promote agriculture in the kingdom. A number of governmental organizations e.g. Agriculture Development Fund, provide interest-free loans to farmers.

2.3.5 Production practices and management

In KSA, coffee is grown either on the border of the field or as regular orchards. Since coffee cultivation is mostly in hilly terrain and slopes, tree/orchard management is always a challenge. The coffee growers are, generally, engaged in the production of several other crops such as cereals, fruits, and vegetables. Moreover, the coffee plantation is spread over difficult-to-access and uneven mountainous terrains, which makes cultural practices more challenging.

a. **Lack of pruning**: Regular pruning of coffee trees results in bright red cherries, and improves the bean size and flavor (Wintgens, 2004). The coffee growers of regular coffee orchards practice some degree of pruning, but the trees growing on field borders are not pruned. The presence of older coffee trees without pruning adversely affects both the equality and quantity of coffee harvested.
b. **Irrigation**: Coffee is a high water-consuming plant and drought spells reduce the yield and quality. Proper irrigation promotes the size and flavor of the coffee bean (Cheserek and Gichimu, 2012). In the coffee growing areas of KSA, rainwater is the primary source of water for irrigation. The coffee plantation experiences water stress at midday during the dry season. Hence, water for irrigation is extracted from dug wells in some areas of Jizan. The coffee growers, generally, use high-frequency irrigation (at 2 days intervals), which is a serious threat to local artesian water reserves. The dug wells cost SR 30,000-45,000 per dug well and some wells have gone dry in some areas due to low rainfall in the past 10-15 years and excessive water extraction for irrigation. Some of the coffee growers, who can not afford the dug wells are constrained to buy water for irrigation. Some coffee farmers have constructed rainwater harvesting systems for coffee irrigation requirements (Figure 4 B). Rainwater harvesting and efficient irrigation and mulching (Gole et al., 2015) may help to ensure water conservation and the sustainability of coffee cultivation in the region.

Figure 4. FAO-SA Mission visit to MoEWA supervised nursery coffee plantation in shade cloth (A) house and rain water harvesting system (B)

c. Fertilizers and Other Chemicals: The coffee growers were using fertilizers and other chemicals for coffee production. According to the agriculture census 2015, by the General Authority for Statistics KSA, 22 percent used chemical fertilizers while 28 percent used organic manures. About 19 percent of coffee growers used insecticides. However, there is an increasing tendency for organic production, without chemicals application and sheep/goat manure is the primary source of fertilizer.

d. Pests and Diseases: The presence of diseases and pests decreases the yield and quality of coffee (Wintgens, 2004). The growers, generally, do not use chemicals to control pests and diseases. However, physical practices such as the removal of disease-affected branches is practiced by some growers.

2.3.6 Yield of Coffee in KSA

The yield of coffee varies significantly with the age of the plant, cultural practices adopted, and the location of the plantation. There is no exacting official data available on the area and production of coffee in Saudi Arabia. However, the interview with coffee growers indicated that the yield of coffee cherries/tree ranges from 3.8-6.2 kg/tree, which is relatively higher than the coffee yield in other countries.

2.3.7 Postharvest Losses in Coffee in KSA

There are no authentic estimates of postharvest losses in coffee cherries in KSA. The coffee beans are prone to postharvest losses in both quantity and quality during the postharvest stage. In Ethiopia, the total postharvest losses are estimated to be about 7.57% of which 4.54% and 3.03% are losses in quantity and quality respectively (Table 3).

Table 3. Postharvest losses of coffee beans

Quantitative Losses	Ethiopia	Saudi Arabia			PH Losses
Stage of losses	Percentage	Minimum	Maximum	Mean	(Tonnes)
Harvesting	3.03	4	6	5.00	40
Drying	0.43	3	6.5	4.75	38
Hulling	0.10	2	5	3.50	28
Bagging	0.78	2	4	3.00	24
Storage	0.10	1	2	1.50	12
Transport to market	0.08	0.5	1	0.75	6
Marketing	0.02	0.5	1	0.75	6
Total Quantitative Losses	4.54				
Total Qualitative Losses	3.03				
Total Losses	7.57%	13	25.5	19.25	154

Source: Postharvest losses in Ethiopia, https://pdf.usaid.gov/pdf_docs/PA00Z2TS.pdf
Source for KSA: Interviews with coffee growers and processors + Samples analysis of hulled beans

2.3.8 Postharvest Management and Processing

The coffee growers, generally, follow the traditional methods of harvesting, postharvest handling, and processing by employing unskilled workers. However, some growers at Ad-Diyyar have adopted proper cherry drying facilities. One company in the region (Al-Jabalia) has hulling and dehusking machines, proper packing, and value addition to ensure the quality of coffee.

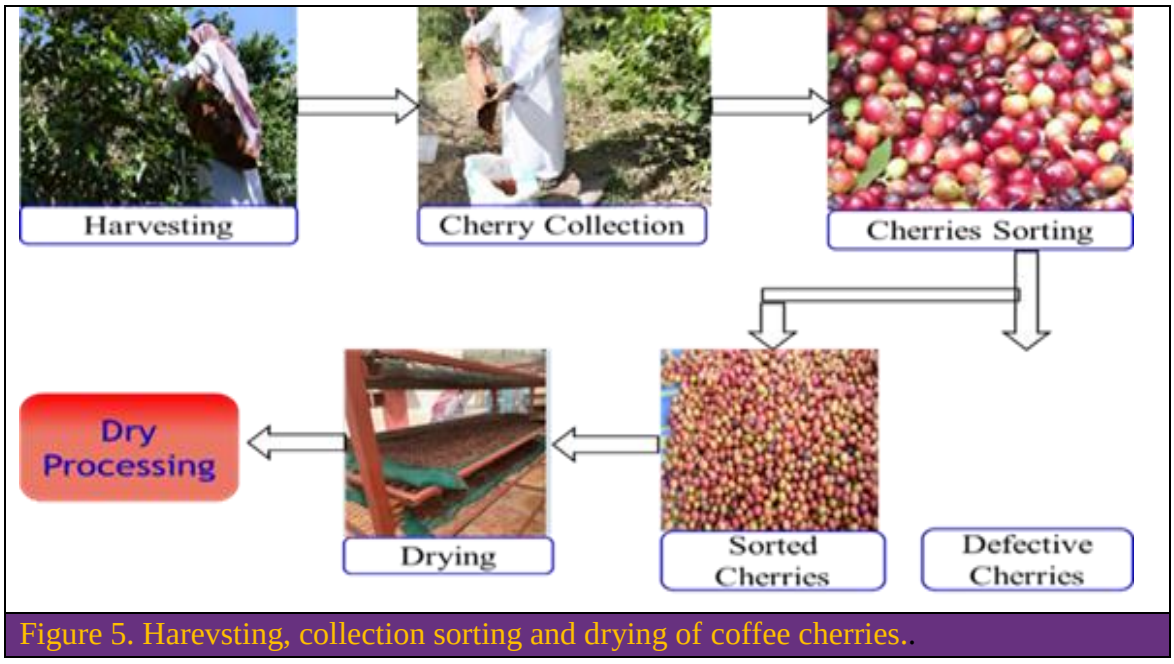


Figure 5. Harevsting, collection sorting and drying of coffee cherries..

The recent agreement between MoEWA and the Agricultural Cooperative Society of Albaha to establish coffee development centers in the Al-Baha regions of Mashuqa and Al-Qara governorates, with a model farm and nursery, and develop an industrial area equipped with packing, processing, and roasting facilities (Anonymous, 2021) will help in promoting the postharvest management of coffee in the kingdom of Saudi Arabia. Besides this MoEWA is also supporting several capacity-building initiatives for farmers and other stakeholders to improve postharvest practices.

2.3.9 Extension Service

The extension services seem technically weak in regularly visiting and providing on the site technical guidance to the coffee growers. The technical competencies of majority of MoEWA staff are confined to primary production with very little competencies in postharvest management of crops. The MoEWA has been organizing trainings for growers and extension staff in coordination with FAO-SA. These trainings will help in developing their skills, especially in postharvest handling and processing of coffee.

There is a lack of coordination between the coffee growers and Extension staff. The extension staff needs to reach out to the coffee growers to solve their problems concerning soil testing, pest identification, irrigation management, and postharvest handling.

2.3.10 Field Workers

The local farmers generally employ expatriates from Sudan, Yemen, Egypt, Pakistan, and Bangladesh for field management. The hired staff, generally, reside on the farm and the cost of Iqama (SR 600 per staff per year), visa fee (SR 2000 per staff), boarding and food expanses are the owners' responsibility. The field laborers are paid a monthly salary of SR 1200 to 2000. The high labor cost has resulted in the tendency of employing unskilled casual labor, which may compromise the production of quality produce as well as poor postharvest management practices.

2.3.11 Marketing of Coffee in KSA

The coffee is available in the local markets in different forms such as green beans, roasted beans, soluble powder mixed with spices such as cardamom, clove, and saffron, branded instant packaged coffee, substitutes, and coffee skins/husks. There is a well-established network of coffee supply chain in KSA. The coffee farmers use different channels to market their produce (figure 6). These channels include:

i. The produce is sold directly to retailers/roasters and consumers, through traders.
ii. The produce is sold directly to wholesalers, retailers, and coffee houses.
iii. The produce is marketed through branded retail chains that make local brands.
iv. The produce is marketed through global coffee house chains who also have their procurement system to import coffee beans.

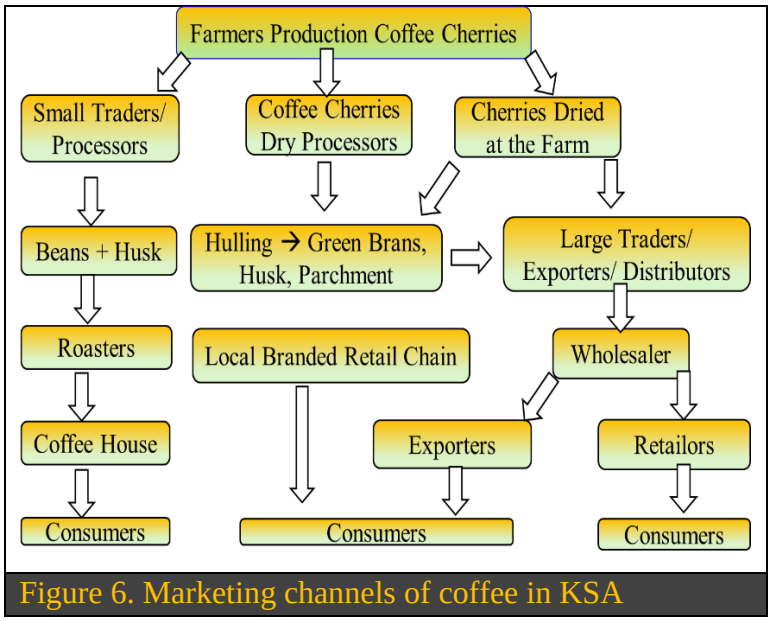


Figure 6. Marketing channels of coffee in KSA

2.3.12 Domestic Consumption

The per capita consumption of coffee is 2.78 kg in KSA. The changing lifestyles and increased purchasing power of consumers have increased coffee consumption. To meet the domestic demand, Saudi Arabia relies on the import of coffee. The coffee import bill during the year 2020 was about 173.99 million USD.

2.3.13 International Trade of Coffee by KSA

Despite the favorable soil and climatic conditions for coffee cultivation, Saudi Arabia is a net importer of coffee. Saudi Arabia stands 89th among the coffee-exporting countries, while it

ranks 28th among the coffee-importing countries. During the years 2011 to 2020, the coffee import of Saudi Arabia increased by 18,455 tonnes as compared to the 48 tonnes increase in export of coffee. The average import price of coffee by Saudi Arabia was 3,750 USD /tonne as compared to the export price of 2,770 USD/ tonne (Table 4). Interestingly, the price of local green coffee beans is four to five times higher than that of imported green coffee beans, indicating the domestic consumers' preference for locally produced coffee. Improving harvest, drying, hulling, storage and roasting practices will reduce losses as well as improve the quality and shelf life of the product. These improvements will further support fetching premium prices for Saudi coffee in domestic and export markets.

Table 4. International trade of coffee green beans by Saudi Arabia

Year	Import			Export		
	Import (Tonnes)	Import Value (000USD)	Price / Tonne	Export (Tonnes)	Export Value (000USD)	Price / Tonne
2011	35626	157948	4433.50	1255	2610	2079.68
2012	42178	184116	4365.21	1099	2125	1933.58
2013	38253	137289	3588.97	1526	3027	1983.62
2014	42575	162818	3824.26	1961	3294	1679.76
2015	50464	164313	3256.04	1614	2947	1825.90
2016	44108	139624	3165.50	711	1959	2755.27
2017	52398	191013	3645.43	895	2115	2363.13
2018	55176	169707	3075.74	1406	3574	2541.96
2019	48694	144666	2970.92	32	248	7750.00
2020	54081	173993	3217.27	1303	3592	2756.72

Source: FAOSTAT

2.3.14 Gender role in Coffee Sector

The coffee fields are, generally, located away from city centers and residential areas. Cultural norms and traditions limit women's access and participation in farm-based activities. During the visit to different fields, no presence of women in the fields was witnessed. Similarly, the role of women in the harvesting, postharvest handling, and processing of coffee could not be observed. However, women's presence as coffee house workers, coffee sales personnel and customers/consumers is gaining momentum.

2.3.15 The Challenges and Prospects of the Coffee Sector in KSA

A. The Challenges/ PROBLEMS of the Coffee Sector in KSA

a. **Water and High Temperature**: Water deficiency and high temperature are the main climatic limitations for coffee production, especially in the low-altitude coffee-growing regions of KSA. Low water stress in the coffee plant reduces cherry filling thus reduction in total production as well as loss of quality. Similarly higher temperatures also lead to higher respiration and transpiration which leads to a reduction in phloem unloading and thus results in reduced total production and compromise on quality. Interventions such as grafting on *C. robusta* to produce plants resistant to high temperatures and breeding varieties of coffee resilient to climate change can be the way forward for the sustainability of the coffee sector. Similarly, practices like improving the water-holding capacity of soil through soil amendments and reducing water losses from the soil, and organic mulching may also be considered.
b. **Improper production practices**: Most of the coffee plantation in KSA is not in the form of regular orchards. This makes the orchard operations difficult, time-consuming and costly. The presence of weeds competes with soil nutrients and moisture but may also harbor pests. Similarly, improper irrigation in unplanned irregular orchards is difficult to carry out. Pruning allows to develop the framework of the tree, promotes the growth of productive branches, and allows sunlight penetration and air circulation which allows better quality cherries. Noncompliance with good production practices leads to reduced quality and quantity of produce.
c. **Poor postharvest handling**: The harvesting and postharvest handling of coffee are conducted manually by unskilled laborers, which increases the postharvest losses in quantity and quality. The fruits are generally harvested irrespective of their physiological maturity with the conventional hand-picking method thus leading to quality losses. Further, improper drying and storage also add to these losses and reduction in quality.
d. **Independent Processing**: Most coffee growers are involved in small-scale independent processing. Hence, the quality may vary greatly which hinders the development of internationally accepted quality and branding; and risks sustainable growth in the coffee sector. Coffee processing driven by international standards and consumer preferences is the way forward for the coffee sector in KSA.

B. The Prospects of the Coffee Sector in KSA

a. Superior Quality: Saudi Arabia produces Arabica coffee, which is superior in aroma, strong body, and pleasant acidity as compared to Robusta coffee (Zewdu, 2016).

b. **Favorable Climate:** The favorable environments especially the temperature for the growth and development of coffee in South-Western Saudi Arabia (mountains of Jizan, Aseer and Abha) coupled with the centuries-long experience of coffee production in the coffee growing regions indicate opportunities to maximize coffee cultivation.By the end of 2021, around 400,000 coffee trees were planted, which will increase coffee production by about 800 tonnes. The government plan to plant as many as 1.3 million coffee trees by 2025 to boost the production of coffee (Annonymous, 2022). The provision of saplings by the government is a

standard practice to promote perennial culture throughout the kingdom. Besides this, the government also provides various subsidies to the farmers on their produce and plantations.

ii. Farmers Cooperatives: The government of KSA has encouraged farmers' cooperatives since 2008, such as Baljurashi Agricultural Cooperative, at Albaha and Honey Cooperatives at Aseer. The farmers' cooperatives were formally affiliated with formally International Cooperative Alliance (ICA) in 2016. There are over 240 agriculture cooperatives societies in KSA. However, only a small number of coffee growers are part of these cooperative societies due to limited awareness, especially among smallholders. These societies provide agricultural inputs to members. The coffee growers, generally, work individually but collaborate to hire a transport vehicle to take agricultural produce to the markets.

iii. Access to finance: There are ample opportunities for formal financing through the Agriculture Development Fund and commercial banks. The regional offices of the Directorate of Agriculture facilitate crop-specific financial support to small farmers through the Agriculture Development Fund. Any farmer willing to start coffee production can avail agricultural loan from the ADF. Agricultural loans (up to 85% of project cost) below SR 1 million are interest-free with a 10 years repayment period. Loans (up to 75% of project cost) above SR 1 million at an interest rate of 2% for repayable in 10 years. A maturation period of 3 years is also provided, giving agri-preneurs effectively 13 years for repayment of the loan. However, there is little awareness among small producers about formal sources of finance.

With the favorable climatic conditions, the superior flavor of *Coffee arabica*, long experience in coffee cultivation, high demand for local coffee, hospitality, tradition, and support from the government, the coffee sector of KSA has enormous untapped potential (Alemseged, 2012).

iv. Subsidies Extended: In an effort to promote the coffee sector of KSA, the government is offering subsidies of SR 31 per kg of green coffee beans produced and SR 47 for a fully grown productive coffee plant on the drip irrigation systems. For the drip irrigation system, 50% of the cost is covered by the government. These subsidies are a regular feature of the Saudi agriculture sector for which the government is consistently providing support for its expansion and diversification.

Despite, very good prospects and full support of the government to the coffee sector of KSA, the share of the coffee sector of KSA in the global coffee trade is negligible. This can be attributed to inefficiencies in production, postharvest handling, and processing, which adversely affect the coffee sector in several different ways but lead to decreased income. The inefficiency of pre and postharvest management results in lower quality, and losses during postharvest harvest handling and processing. Hence, the gaps analysis and benchmarking are conducted to identify the gaps and suggest measures for improvement in the coffee sector of KSA.

SECTION 3: GAPS ANALYSIS AND BENCHMARKING COFFEE HARVESTING, POSTHARVEST HANDLING AND PROCESSING

Despite centuries old history of coffee production in the kingdom, many challenges are still limiting the development of a profitable and sustainable coffee sector. The first step for improvement would be gap analysis and benchmarking against best performers to help in identifying the areas of improvement and suggest possible practical improvements to promote the coffee sector in KSA.

The sustainable development of the coffee sector requires optimizing a broad spectrum of activities of the coffee supply chain, from production through postharvest handling and processing to domestic or export marketing. However, the gaps analysis and benchmarking in this report are limited to the postharvest handling and processing of coffee. Identifying the gaps in harvesting, postharvest handling, and processing and adopting appropriate technologies accordingly will help in decreasing the postharvest losses in coffee produce (Minten *et al*., 2014) and increase the growers' income.

3.1 Gap Analysis

There are several gaps in the harvesting, postharvest handling, and processing of coffee in the kingdom of Saudi Arabia. The major gaps in the existing system of coffee production, postharvest handling, and processing are presented below, so that effective intervention can be suggested/ adopted to promote the coffee sector of KSA.

3.1.1 Increasing Yield and Enhancing Quality: Coffee production is economically viable only when grown on more than one dunums ($1/10^{th}$ hectare) or having more than 200 plants. Hence, the calculation of cost and profit is based on a farm comprising a minimum of 200 coffee trees (Table 5). The total cost incurred on coffee production (excluding land resources and building) is about 31,585 SR. With an average yield of 1,020 kg, containing 75 and 25% A-grade and low-grade coffee cherries, the net income of the farm stands at SR 51,035, with a BCR value of 1.62. However, in the subsidized scenario, the net income increases to SR 101,020 with a BCR value of 2.2. While subsidies extended to the growers are needed at this stage to promote the coffee sector in KSA and make it at par with the other economic sectors, efforts should be made to increase the yield, reduce losses and enhance quality to increase the market returns. It will contribute to the sustainability of the coffee sector over longer periods of time once the subsidies get drawn in future.

Table 5. Cost and Profit of coffee farm with 200 coffee bearing trees.

Costs	Mean (SR)	Earnings	Mean (SR)
Manure and Compost	2850	Cherries Produced (kg/tree)	5.1
Cost of water for irrigation	4600	Cherries Produced (kg/200 trees)	1020

Permanent Laborers @2000/month for 12 months	24000	A Grade Cherries @ 85%	867
Cherries Drying Mesh	115	Low Grade Cherries @ 15%	153
Harvesting Bags	20	Market value A Grade Cherries @ SR 75/Kg	76500
Total annual Cost	31585	Market value low Grade @ Cherries SR 40/Kg	6120
		Total Income/200 trees	82620
Income from the coffee crops	51035	BCR (unsubsidized Scenario)	1.62
Subsidies by Government (in practice)			
Subsidy on Irrigation with drip system			9400
Subsidy on bearing plants @ 45/plant			9000
Gross Income (Crop + Subsidies)			101020
Net Come (Crop + Subsidies)	69435	BCR (Subsidies Scenario)	2.2

3.1.2 Harvesting of non-uniform coffee cherries: The coffee cherries are harvested by selective picking at the cherry stage when it has developed red color. However, the untrained harvesting laborers may harvest both immature and over-mature cherries along with cherries at the optimum maturity, which causes non-uniform color and poor quality.

2.1.3 No mechanical harvesting: The coffee cherries are harvested manually by selective picking, a time-consuming and labor-intensive operation, that increases the cost of production. Further, the pickers are least vigilant in observing the proper maturity stage for harvesting.

3.1.4 Collection of fallen cherries: It is estimated that about 10–20% of coffee cherries fall on the ground due to rains, wind, pests or disease infestation (Santinato *et al*., 2014). Hence the picker tends to collect such cherries and mix them with the cherries harvested. These "ground cherries" can be used as ground coffee if collected on a tarpaulin sheet below the canopy of the tree. Such beans can be used to make "sweeping coffee".

3.1.5 Improper drying in sun or shade: The smallholders do not have proper drying facilities. The harvested cherries are dried either on tarpaulin sheets or steel racks or in some cases even on the ground. The growers prefer drying in shade, but the harvested cherries remain exposed to sunlight due to a lack of proper overhead covering. Some growers in the Ad-Dayer area, however, conduct drying on steel racks with overhead covers.

3.1.6 Non-uniform Drying: The coffee cherries require regular turning for uniform drying. The growers, usually, do not practice regular turning-over of coffee cherries, which causes non-uniform drying and poor coffee quality.

3.1.7 Little protection from dust contamination: Drying coffee cherries over tarpaulin on the ground is prone to contamination by dust and mold. Even the coffee-drying steel racks are not protected from dust. It causes contamination by dust.

3.1.8 Risk of Ochratoxin A contamination: The non-uniform drying along with exposed beans to pathogens can cause pathogenic infection causing Ochratoxin A contamination.

3.1.9 Improper Hulling: In the absence of mechanical hulling, the hulling and winnowing are carried out by locally developed techniques. It causes the non-uniform quality of beans.

3.1.10 Improper sorting and grading and lack of mechanical grading: There is no proper sorting and grading machinery available to the small growers. Consequently, the grading is based mostly on locally developed tools (sieving structures), which causes poor grading.

3.1.11 Small and independent processors: Most of the smallholder coffee growers process the coffee beans on small-scale operations. Small-scale processors do not have access to modern technologies. It results in non-uniform quality.

3.1.12 Large scale processors: The coffee processing seems to offer little benefits. The cost of dry processing 10,000 kg of coffee cherries is about 952,000 SR, while the net profit is about 544,000 SR with a BCR of 0.57 (Table 6). This can be attributed to the relatively small-scale processing and traditional technologies of drying and processing. It may be the reason why large-scale coffee processing has not flourished much in KSA. The relatively small supply of the locally produced coffee cherries and the availability of imported coffee may also hinder large commercial-scale processing. Interestingly, most of the coffee growers in KSA act as one-man value chain where the producer is the aggregator, processor and market person at the same time. However, some Small and Medium Enterprises (SMEs) (Al-Jabaliya for example) are involved in producing various coffee value-added products in the kingdom. These processing companies process the coffee cherries on a relatively larger scale and, hence, use mechanical processing technologies for coffee beans. However, the evaluation of coffee beans in a processing unit revealed considerable broken beans (3.5%) and variations in bean size after dehulling and dehusking.

Table 6. Cost Benefits of Coffee by Dry Processing of 10000 kg capacity	
Expenditure/ Earning	Cost/Profit (SR)
Coffee Cherries procurement @ SR 75/kg	750,000
Electricity Cost	120,000
Labor Cost per year @ 2000/month	24,000
Boarding/ Food @ 500/month	6,000
Rental cost	24,000
Packing Cost	12,000
Hulling Equipment	10,000
Marketing Expenditure Variable	6,000
Total Cost	952,000
Weight loss due to drying @ 20% (Kg)	2000
Dried coffee cherries (Kg)	8,000
Green bean produced (Kg/10000 coffee cherries)	6,400
Coffee Husk produced (Kg/10000 coffee cherries)	1,600
Average price of green beans (SR 225/kg)	1,440,000
Average price of coffee husk (SR 35/kg)	56,000
Total Income	1,496,000
Net Income	544,000
BCR	0.57

3.1.13 Little consideration for export markets requirements: Since the coffee is mostly sold locally at a very good price; quality enhancement is not in the priority list for growers and small-scale processors.

3.1.14 Minimum product diversification and Value Addition: Product diversification increases the growers' income by producing other commercial products from the primary products are other parts of the coffee plants. Some parts of the coffee beans or other parts of the coffee plant can be made into different products of commercial value. However, there is very limited product diversification and value addition of coffee in KSA.

3.2 Benchmarking Harvesting, Postharvest Handling, and Processing of Coffee

3.2.1. Parameters for benchmarking

For improving the efficiency of the harvesting, postharvest handling, and processing, the following indicators were identified for benchmarking with comparators:

a. Cultivation and utilization of *Coffea arabica*
b. Improved harvesting techniques
c. Utilization of maturity indices
d. Dry processing method utilization
e. Improved processing methods' utilization
f. Product diversifications and byproducts
g. Identification of quality attributes
h. Quality control systems
i. Traceability mechanisms
j. R&D activities
k. Government support
l. Cooperatives involvement
m. Organic production
n. Branding
o. Utz certification (good inside)
p. Common code for the coffee community 4C
q. Third-party certifications for boosting consumer confidence
r. Fairtrade certification

3.2.2 Selecting the comparators

There are two main coffee species grown in the world; Arabica and Robusta. Since our focus is on *Coffea arabica*, so the comparators that utilize the same species shall be considered. Similarly, in KSA dry processing of coffee is utilized due to paucity of water, hence the countries which have the same processing method (in addition to the wet method) shall be considered.

Brazil: Brazil is by far the largest producer and exporter of coffee with a production of 69,000 thousand 60 kg bags during the year 2020 and also stood as the top coffee exporter in the world by exporting 3280 thousand 60 kg sacks of coffee (Source: International Coffee Organization data as on Feb 2021). Brazil has a well-developed and fully integrated value chain for coffee right from primary production to processing and ultimately to marketing and consumption. The country is cultivating both C. *Arabica* and C. *Robusta* and utilizes mechanical harvesting techniques (tree agitators as well as small mechanical agitating sticks) to harvest properly mature coffee cherries for which maturity indices are well defined. The harvested cherries are later sorted by machines to remove unripe cherries and trash as one of the quality control measures Although much of the processing is done through wet processing, an appreciable quantum goes to dry processing by the smallholders and their cooperatives. The cooperatives for small farmers are active in coffee production, processing, and marketing. The drying techniques are well-defined to roast to the desired color and temperature by continuous tilting

and auto temperature control of the roasting machines. The country is not much into organic production. With modern brewing methods such as drip machines becoming more common in Brazilian households over the last decade, specialty coffee has become an increasingly relevant and lucrative crop. According to the latest Brazilian Coffee Industry Association (ABIC) survey, specialty coffee represented 12% of total coffee retail sales in 2018. Meanwhile, the number of coffee shops in the country has increased by 3.2% over 12 months (Worldcoffeeportal.com). The country has developed several coffee brands for which the quality attributes are well-defined with a traceability system utilizing bar codes (and QR codes). The government invested in and supported R&D activities in the sector for long while the ABIC (Brazil Coffee Industry Association), developed in 1973 also invests in coffee production, processing, innovation, and marketing (thebrazilbusiness.com). Besides these indicators, Brazil has also ventured into several certifications including Utz (Utz.org, Slob, B. 2003), adopted 4C i.e. Common Code for the Coffee Community (4C Association), Fair Trade Certified Coffee as well as goes for third-party certifications for boosting consumer confidence. Brazil also utilizes coffee to make many secondary value-added products including making fertilizers.

Vietnam: Vietnam is the second-largest exporter of coffee after Brazil and exported 1,900 thousand 60 kg sacks of coffee while at the same time it produced 29,000 thousand 60 kg sacks of coffee in 2021 (ICO 2021). There are two main types of coffee (Robusta and Arabica) grown in the country with Lions' share going to Robusta. The total area covered by coffee cultivation is estimated at 600,000 ha. Coffee is mostly cultivated in the Central Highlands, including Dak Lak 190,000 ha, Lam Dong 162,000 ha, Dak Nong 135,000 ha, Gia Lai 82,000 ha, and Kon Tum 13,500 ha (vietnamcredit.com). The Vietnam coffee industry is primarily an export-oriented industry with over 60% of the produce going to exports. The country has developed quality attributes of both arabica and robusta coffees (http://www.ico.org/documents/cy 2018-19/icc-124-9e-profile-vietnam.pdf). Coffee harvesting at small farms is done usually by hand by stripping both ripe and unripe cherries together and then sorting these later for maturity. The processing method utilized is the dry method where the cherries are either sun-dried or mechanically dried by small farms while large farms utilize the wet processing method. Mechanical roasting and processing of coffee is *in vogue* to ensure quality. For small farmers, the relevant associations are involved in the production, processing, and marketing of coffee. The government is heavily involved in the R&D of the coffee sector through the Ministry of Agriculture and Rural Development (MARD). Vietnam has a coffee quality assurance program in place by the government with a traceability system.

Honduras: Honduras is the 4th largest exporter of coffee and exported 642 thousand 60 kg sacks of coffee with a production of 6100 thousand 60 kg sacks (ICO 2021). Honduras has a developed coffee value chain from production to consumption including exports and processing while producing both arabica and robusta. The country developed its coffee policy in 2003 that focused on coffee development from production, harvesting, and exports. The government also established a National Council of Coffee (CONACAFE) as well as Honduras Coffee Institute (IHCAFE). Government supports R&D activities in coffee. Honduras utilizes both dry and wet processing methods of coffee. The country has a manual harvesting system at the small farmers' level while mechanized harvesting at the large commercial level. The

country has developed its quality control system. Small farmers get knowledge sharing, marketing benefits, and other advantages of economies of scale through their farmers' association. Organic production is not much prevalent. While the country does follow 4C and the fair trade regime of coffee.

Germany: Germany although is not among the leading coffee producer, rather does not grow coffee, but is still the second-largest exporter of roasted coffee after Brazil (independantaustralia.net). Germany is Europe's second-largest roasted coffee exporter, with a market share of 23% in 2019. Exports of roasted coffee beans from Germany amounted to 236 thousand tons in 2019, at a value of € 1.3 billion. Between 2015 and 2019, Germany's exports of roasted coffee beans registered an annual average growth rate of 3.7% in volume and value. The main destinations for German roasted coffee in 2019 were Poland (16%), the Netherlands (11%), and France 8.9% (cbi.eu). German coffee roasting industry is increasingly improving in the processing of organic coffee. Germany excels in the production and sales of coffee single-serve machines as well as espresso machines. Germany has strict quality control measures for all of its food products including coffee with traceability systems in place. Germany also has Fair Trade certification, German Rainforest Alliance-certified coffee brands, UtZ certifications as well as certification for German Organic Coffee importers.

Table 7. The parameters for benchmarking and practices in KSA

Parameters	Brazil	Vietnam	Honduras	Germany	KSA
Cultivation and utilization of *Coffea arabica*	✓	✓	✓	-	✓
Improved harvesting techniques	✓	-	-	-	-
Utilization of maturity indices	✓	-	-	-	-
Dry processing method utilization	✓	✓	✓	-	✓
Improved processing methods	✓	✓	✓	✓	-
Product diversification and byproducts	✓	✓	✓	✓	-
Identification of quality attributes	✓	✓	✓	✓	✓
Quality control systems	✓	✓	✓	✓	-
Traceability mechanism	✓	✓	✓	✓	-
R&D activities	✓	✓	✓	✓	-
Government Support	✓	✓	✓		✓
Cooperative's involvement	✓	✓	✓		✓
Organic production/processing	-	-	-	✓	✓
Branding	✓	✓	✓	✓	✓
Certifications	✓	✓	✓	✓	-

3.3.3 Harvesting, Postharvest Handling and Processing in KSA

The harvesting, postharvest handling, and processing is of coffee in KSA are traditional in nature. There are several inefficiencies in postharvest management and processing that can cause significant losses of coffee.

Interviews and discussions with growers and processors revealed that the maximum losses at harvest are caused by harvesting mixed mature cherries. The coffee cherries drying is another major cause of postharvest losses because some growers dry the coffee cherries on the ground or raised mesh and no regular tilting of beans to ensure uniform drying. Hulling and poor bagging also contribute significantly to postharvest losses (broken beans) because the machine used for hulling is not coffee specific. Coffee beans are either bagged in jute bags instead of hermetic bags or stainless steel containers also 1.5% to the postharvest losses of coffee beans (Table 8). The mean postharvest losses in coffee in KSA, as determined by interviews with coffee growers and processors are about 19.25%. With 800 tonnes of coffee production, it accounts for 154 tonnes. The import price of coffee for the year 2020 was 3220 USD/tonne. Thus, reducing the postharvest losses of coffee by 50 - 75% and its utilization to reduce import can save as much as 247,940 – 371,910 USD annually to the coffee sector of KSA (Table 8).

There is a wide gap in existing postharvest handling and processing to that of the standard procedures adopted in better performing coffee producing countries. Hence, the coffee growers in the Kingdom of Saudi Arabia can improve their coffee harvest, postharvest, and processing practices by adopting some of the practices used in the above mentioned countries. It requires that best harvesting, postharvest handling, and processing practices are adopted in KSA.

Table 8. Economic impact of postharvest management and processing

Postharvest Losses	Mean Losses (%)	Total Losses (Kgs)		Quantity Recovery through PHM			Values based on import Price (3.22/kg)		
			Losses Value	25%	50%	75%	25%	50%	75%
Harvesting	5.00	40	128800	10	20	30	32200	64400	96600
Drying	4.75	38	135063	9.5	19	28.5	30590	61180	91770
Hulling	3.50	28	99520	7	14	21	22540	45080	67620
Bagging	3.00	24	85303	6	12	18	19320	38640	57960
Storage	1.50	12	42651	3	6	9	9660	19320	28980
Tranpsort to Markts	0.75	6	21326	1.5	3	4.5	4830	9660	14490
Marketing	0.75	6	21326	1.5	3	4.5	4830	9660	14490
Total Losses	19.25	154	547361	38.5	77	115.5	123970	247940	371910

3.3.4 Best Harvesting Practices, Postharvest Handling, and Processing of Coffee Cherries

Harvesting and postharvest handling of coffee cherries in Saudi Arabia is limited to harvesting, minimal sorting, undefined grading, sun-drying, and marketing. It is desired to adopt the best harvesting, postharvest handling, and processing practices to reduce the postharvest losses in coffee and increase growers' income.

3.3.4.1 Harvesting of Coffee Cherries

Harvesting is a critical step that influences the quality of coffee and economic returns for producers. As the coffee cherries mature, the coffee fruit attains desirable chemical compositions which lead the fruit to the best quality (Pimenta *et al*., 2008). The volatile compounds, responsible for the aroma and flavor of coffee, are present in a very low amount at the early stage of the coffee cherry, but increase as the coffee cherries reach the fully mature stage (Pimenta *et al*., 2008). Hence, for optimum quality attributes, the coffee cherries should be harvested at the proper stage of maturity i.e. physiological maturity (Figure 7).

i. Maturity and Harvesting of Coffee Cherries

The coffee plants (*Coffea Arabica*) continue to flower especially during wet seasons. As a result, the coffee cherries at the plant are at different developmental and maturation stages (figure 7) ranging from immature to green, mature, ripe, to dry berries (Dalvi1 *et al*., 2017). It necessitates repeated harvests to ensure that coffee cherries are harvested at optimum maturity, with the desired quality traits and minimum defects in the quality (Bertrand *et al*., 2002).

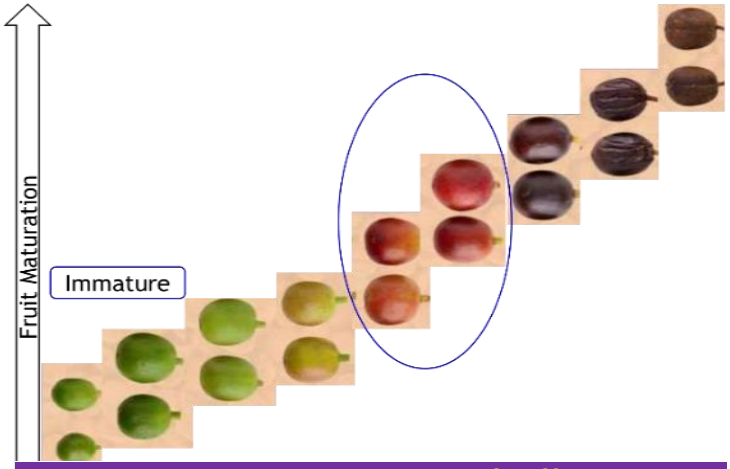


Figure 7. Growth and development of coffee chrries

The mature berries can be plucked by hand. Harvesting by hand (selective picking) is labor-intensive and hence expensive in Saudi Arabia. Mechanical harvesting is not practiced due to the non-availability of such machines. The mechanical harvesters use a vibrating force to release the coffee cherries from a branch. A handheld mechanical harvester can be used for small-scale operations. Mechanical harvesting saves time and is economical, but it may harvest immature or over-mature berries if the correct agitation speed is not calibrated. Hence it necessitates proper sorting to separate the berries that are not at the optimal stage for processing into superior-quality coffee.

ii. Maturity stages of coffee Cherries

The coffee cherries are classified into 9 different stages with 08 stages of maturation. These include the unripe, green, green cane I, green cane II, cherry I, cherry II, post cherry, Raisin, and dry stage. The cherry I and cherry II stages are considered the ideal stages for the coffee cup and the physical quality of *C. arabica* (Bertrand *et al*., 2002) (Figure 8). Thus, it is desirable to harvest cherry I and cherry II stages and avoid mixing the early or over-mature cherries to achieve optimal coffee quality.

Unripe	Green	Green-cane I	Green-cane II	Cherry I	Cherry II	Post-Cherry	Raisin	Dry

Figure 8. Developmental stages of coffee cherries

iii. Effects of Harvesting Immature Cherries

a. Decreased final yield: The final yield of dry beans decreases due to greater weight loss during further processing (drying). The immature beans lose 30% more weight than the mature beans.

b. Non-uniform drying: The beans harvested at the early mature stage do not dry down uniformly.

c. Lower Quality: The desirable composition and volatile compound causing the peculiar aroma of the coffee are present in a very low quantity at the early stage and increase as the coffee cherry reaches the optimal maturity stage (Pimenta *et al*., 2008). The beans from such early mature cherries are prone to blackening during the drying process and coffee made from immature cherries has an undesirable taste.

d. Low Caffeine Content: The caffeine content is lower than beans harvested at optimal maturity (Endale *et al*., 2008).

e. Quantitative Losses: The unripe berries produce beans that break easily, are of inferior quality, and are small and usually eliminated along with the husks during milling, resulting in qualitative and quantitative postharvest losses.

f. Poor Taste: The immature beans give a bitter taste to the coffee.

iv. Effects of Harvesting Over-Mature Cherries

Harvesting coffee cherries at the over-mature stage is also undesirable because it:

a. Decrease the coffee quality
b. Increase the incidence of defects such as blacks, greens, or rancids (BGR).
c. Overripe cherries that have already fermented on the tree lead to off-flavor.
d. Ripe cherries take too long to be processed and cause over-fermented beans.

Harvesting Methods

The coffee can be harvested by either strip picking or selective picking. The coffee cherries are harvested manually by selective picking. Generally, red-colored cherries are picked. However, the growers/ pickers may sometimes, harvest the cherries that have not developed to the fully mature stage. It is particularly a problem when harvesting is done by hired labor, who are paid based on the weight of cherries harvested.

a. Strip picking: Strip picking can be done by machinery or by hand. The whole coffee cherries are harvested at one time. Since the picked cherries have a mixture of coffee cherries at different maturity stages, the harvested coffee may not have the desired quality (Ventureli *et al*., 2016). Strip picking is not common in KSA.

b. Selective picking: Most coffee growers in KSA, however, harvest the coffee by hand and generally by selective picking. On an average coffee farm, the pickers may gather between 50 and 100 kg of coffee cherries per day. In this harvesting system, the ripened coffee cherries are harvested selectively by hand. It involves several pickings and is labor-intensive, but ensures uniform maturity of cherries and superior quality coffee (Pimenta *et al*., 2018).

c. Mechanical Harvesting: Both strip and selective have certain limitations. The strip picking is limited by non-uniform cherries, while the selective picking is labor-intensive and time-consuming. Therefore, hand-held mechanical harvesting, which is more efficient, can offer a cost-effective solution (Figure 9). While mechanical harvesting by shaker harvested some premature cherries but selecting the branches for harvest with maximum cherries at the cherry stage I and II and adjusting the shaker speed can minimize the removal of immature coffee cherries (Santinato *et al*., 2016).

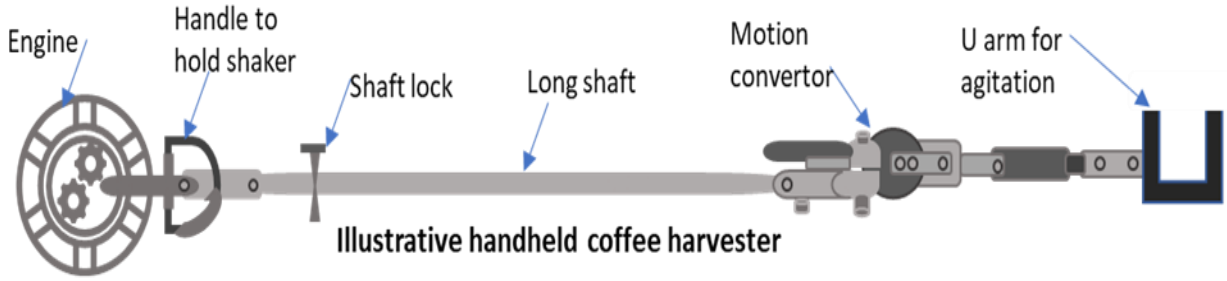


Figure 9. Mechanical harvester for coffee cherries

d. Care during Harvesting: Dried cherries, either on the tree or fallen down on the soil should not be picked. Especially fallen cherries as they pose a health risk of bacterial infection and the development of molds and Ochratoxin A; a potent carcinogen (Kuit *et al*., 2004).

3.3.4.2 Best Postharvest Handling Practices

The primary aim of postharvest handling is to minimize the losses during harvest, postharvest handling, and processing as well as maintain the quality. The postharvest chain in KSA is fragmented into growers, traders, processors, whole sellers and retailers, and roasters. However, proper management at each stage contributes to quality, adding to consumers' preference, and hence paying a premium, that ultimately benefits all the postharvest chain actors.

The smallholder, by following proper harvesting and postharvest handling can enhance their coffee income by (1) reducing the losses and (2) provision of superior quality cherries/ beans for onward processing. Similarly, coffee processing can get a higher income by reducing postharvest losses during processing and offering superior quality products.

3.3.4.2.1 Sorting of Harvested Coffee Cherries

After harvesting, the coffee cherries are sorted by washing with water to separate floaters. The sound and mature berries have a higher density than defective berries. Hence flotation or winnowing is used to physically separate defective berries based on density.

3.3.4.2.2 The Coffee Quality and Processing

Quality is described as the possession of a set of inherent characteristics of a product to fulfill

consumers' requirements (ISO, 2000). The quality of coffee is affected by multiple pre and postharvest factors (Wintgens, 2009). The pre-harvest factors set approximately 40% of the sensory attributes and physical and chemical properties of the coffee beans and the remaining 60% of the coffee quality is established by the post-harvest processing (Musebe *et al*., 2007). The coffee quality is linked to bean size, lack of defects, and physical characteristics. At the roaster level, coffee quality depends on moisture content, stability of the characteristics, origin, price, biochemical compounds, and organoleptic quality (Leroy *et al*., 2006). With proper processing, the market value increases at each increasing step of processing (Figure 10)

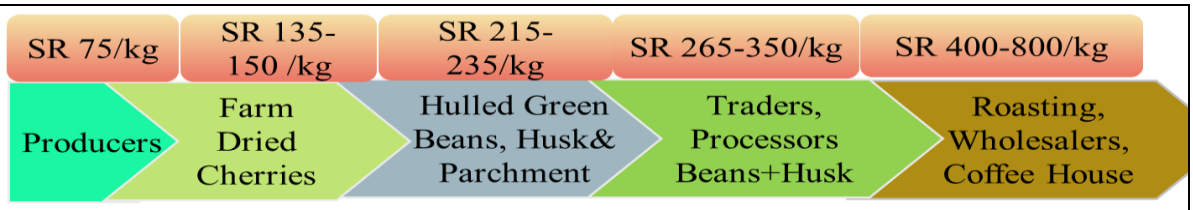


Figure 10. Price escalation at different levels of postharvest and processing

3.3.4.3.Coffee Processing Methods

The processing method has a significant effect on the flavor and quality (chemical composition) and hence gets a high price (Dalvil *et al*., 2017). After harvesting, the coffee cherries are processed by three different methods i.e. dry, wet, and semi-dry processing to get the green coffee beans (Teixeira *et al*., 1995) (Figure 11). In Saudi Arabia, coffee is processed by dry processing only.

3.3.4.3.1 Wet Processing Method

Wet processing ensures the inherent quality of coffee beans and produces uniform green coffee beans with minimum defects. Hence wet processing gives a very high-quality coffee (Wanyonyi, 1999).

In wet processing, the pulp is separated from the parchment. In this way, slippery mucilage is exposed which is commonly removed by a process called fermentation. This is followed by drying and washing the beans in the parchment. Removal of parchment by hulling gives the clean coffee.

Limitations of Wet Processing

a. Wet processing requires a high amount of water (15–20 l/kg of the coffee bean), which causes an extra burden on scarce water resources (Dadi *et al*. 2018).
b. The wet processing system uses a large volume of water and, therefore, generates a high volume of polluted effluent, which necessitate treatment of the coffee effluent (Cardenas *et al*., 2009).

3.3.4.3.2 Semi-dry processing

Semi-dry processing is an intermediate method between dry and wet coffee processing methods. In this method, the coffee cherries are dried after pulping without a long time of fermentation. The semi-washed processing is similar to wet-processing in the first step as the cherries are pulped, but it is dried with mucilage clinging to the outside of the parchment (Stump Town, 2011). The mucilage is later on removed from the parchment. The coffee beans that have been processed with the semi-washed method are somewhat similar to wet-processed coffee and exhibit a bright clean cup with a bit less body than dry processed coffee (Espresso and coffee guide, 2008). This method gives a cleaner and more constant flavor to the final coffee.

Among the different methods of coffee processing, dry processing is the traditional method of coffee processing in KSA. While each method has certain merits and demerits, wet processing methods do not suit water resource-scarce countries like KSA. Hence, efforts are needed to develop dry processing on a scientific basis.

3.3.4.3.3 Dry Processing Method

The drying operation is one of the most important steps in coffee processing for the final quality of the coffee (Correa et al., 2006). The drying removes the excess moisture to a level that is safe for long time storage without detrimental effects on the aroma or taste of the final beverage (Ciro-Velásquez *et al*, 2010). The critical factors of the coffee drying process include the drying method, drying temperature, relative humidity, drying air velocity, and drying time (Correa *et al*., 2006).

The dry method is a simple method that requires less labor. The whole cherry is dried and the pulp and parchment are removed in one single operation. The cherries are sun-dried with the outer fruit intact until the fruit gets a moisture content of 10-12%. After drying, the cherries are de-hulled mechanically to produce beans that are less acidic, sweet, smooth, and more complex in flavor than wet-processed coffee cherries (Wanyonyi, 1999).

Limitations of dry processing

a. Failure in proper drying causes the fruits to be more susceptible to fungal and bacterial growth and subsequent deterioration.

b. Poor drying also increases the imperfect beans with a musty, earthy, and greenish color.

c. The over-dried cherries are brittle and get defective (broken) during hulling.

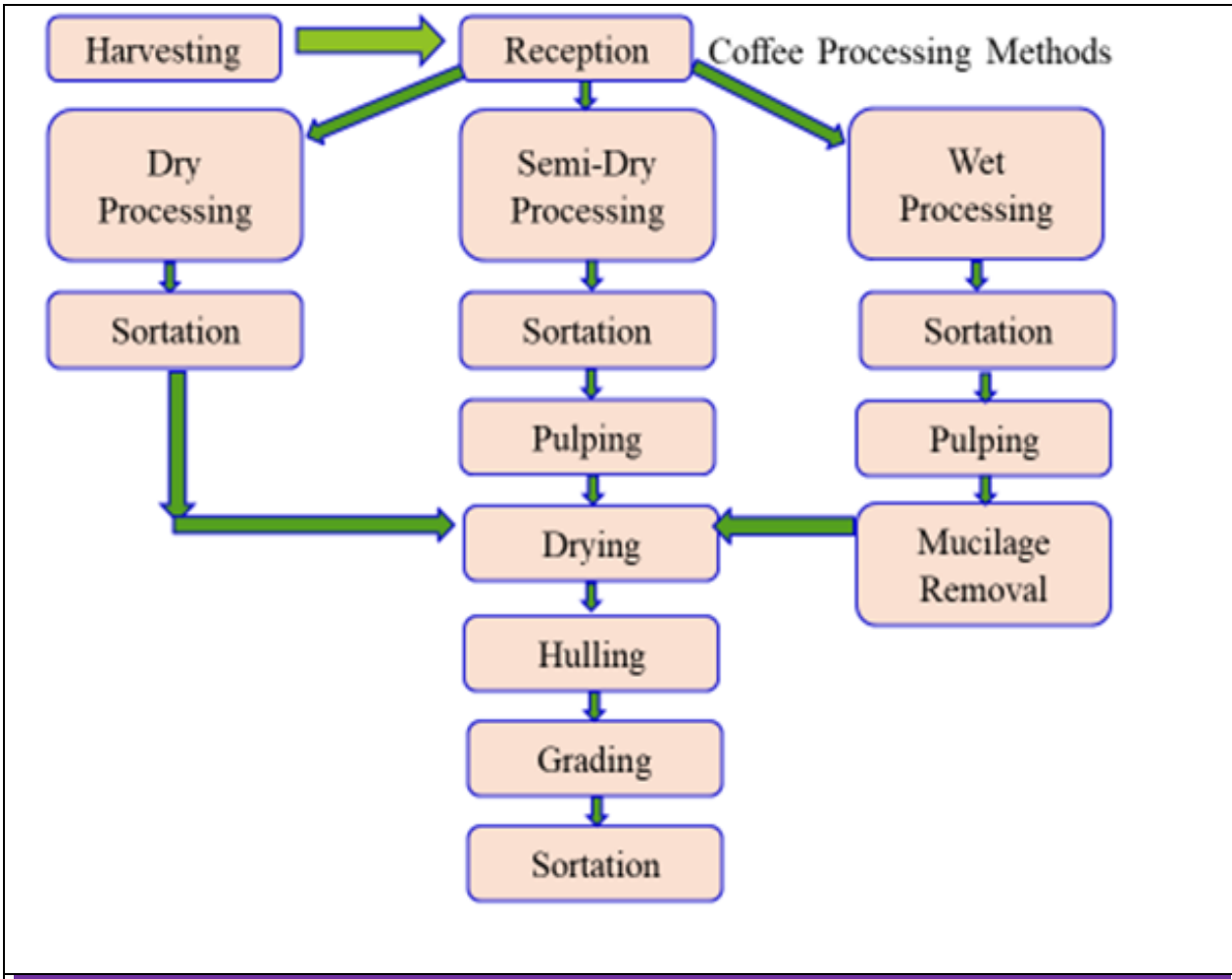


Figure 11. Coffee processing methods

3.3.4.4 Drying of Coffee Cherries

Drying is one of the most important steps in coffee processing. It is aimed at decreasing the moisture content to 11.5-12%. The traditional sun drying takes 7–15 days, depending on the weather conditions. However, it may take 3-4 days when the drying temperature is kept 40-45°C. Drying to less than desired levels promotes mold growth on the beans. Similarly, excessive drying causes the beans to become brittle (Ghosh and Venkatachalapathy, 2014).

Progressive coffee growers understand the importance of drying in the shade and its relation to coffee quality. They try to ensure shade during the drying process. However, in most instances, the coffee cherries may remain exposed to sunlight during the drying, which can deteriorate the quality of the final product (Muschler, 2001).

Some small growers conduct the natural sun-drying process of coffee in terraces. Still, other growers dry the coffee cherries by placing them on a steel rake. In shade drying, the cherries are dried for several weeks in shade, usually provided by an overhead structure. Since the cherries are dried in shade, it takes longer than sun drying. Yet, it requires repeated turning over of the beans to develop uniform color. Drying either by the sun or in shade requires more

labor, and time, and depends on the climatic conditions. In addition, sun-dried cherries do not develop good-quality beans. Sun-drying also has a high risk of secondary fermentation because of the mucilage, which is very hygroscopic and remains with the coffee cherry.

The quality of coffee depends on homogenous drying to obtain the proper color, and size and to get rid of pests for longer storage life. The coffee beans can be stored for 8-9 months, if dried properly (Ghosh and Venkatachalapathy. 2014). Coffee cherries are dried by spreading them on tarpaulin (Figure 12) or racks (Figure 13). However, drying on racks is preferred because it helps in avoiding contamination from the ground. Racks are also more exposed to wind; which removes saturated air and shorten the drying time.

Figure 12. Harvested coffee cherries

Figure 13. Drying of coffee cherries

3.3.4.4.1 Enhancing the Drying Process

Tunnels with light wooden or metallic structures covered with plastic can further enhance the drying process as it can increase the temperature by 10-15°C. If drying racks are kept in plastic tunnels, and an exhaust fan installed to remove the saturated air, the efficiency of drying can further be enhanced. In such conditions, the coffee is sheltered from rain, dew, and dust.

a. Solar Tunnels: A solar tunnel heated either passively by the sun or by a solar heater. The solar tunnel can be equipped with a hygrometer, and with an inlet, and exhaust fans to remove the extra humidity (Figure 14). Drying temperatures of 40 – 60°C can be achieved. It takes about 50 hours to reach the final moisture content below 12.5% while open sun drying required 75 hours (Abdullah *et al*., 2001). Solar tunnel drying can be a low-cost alternative to minimize contamination and ensure uniform drying in a relatively short time than shad drying.

b. Mechanical Driers: The current system of sun/shade drying will become more time-consuming with increasing coffee production. Hence, switching over to mechanical drying will be needed in the future not only to enhance the rate of drying but also to retain the quality desired in international trade for commercial-scale processing (Cunha *et al*., 2003). In mechanical drying, the beans are heated by passing hot air (40-45°C), which removes the moisture of cherries and air (Rolz *et al*., 1969) (Figure 15). There are mainly 2 types of dryers, static and revolving. The revolving dryers allow the proper turning of beans and are less prone to heating coffee beans to excessive temperatures (Finzer *et al*. 2007). However, rapid drying at high temperatures lowers the coffee quality (Sivetz and Foote, 2004). Further, mechanical

drying has not been evaluated in relation to the quality attributes of *Coffea arabica*.

Figure 14. Solar drying tunnel of coffee cherries

Figure 15. Mechanical drying tunnel of coffee cherries

Box 1: Degree of dryness test: Degree of dryness can be tested by two methods

Dental: The dental method involves peeling the parchment of an individual bean and biting it with incisors. If it is easily dented or even cut by the bite, it is not dry. If a hard bite hardly dents the bean, it is dry.

Digital: The digital method relied on a digital coffee moisture meter (tester), when correctly calibrated; it is the best method to determine moisture content of coffee.

3.3.4.4.2 Dehusking and Hulling

Dehusking: The process of removing husk either from the dry parchment coffee or dry cherry in order to give the commercial green coffee.

Hulling: This is the next step after drying. The dried coffee cherries (dry-processed) or parchment coffee (wet-processed) is hulled to remove the covers and get the coffee beans out of it. When the coffee gets to this stage, all intrinsic quality (moisture content, color) has already been obtained. Hulling is achieved by creating friction among the beans lying along the screw of the machine. It is crucial not to heat the beans during hulling otherwise it will affect the final color and taste of the coffee. There is another final layer closest to the bean, called silver skin, which may or may not be removed during the hulling process. For the removal of silver skin, separate equipment, a polisher, is needed. The green bean received is then subjected to sorting according to density, size, and color (Wanyonyi, 1999). The hulling is followed by sieving and winnowing. The sieving is carried out manually to remove the small and broken beans. Winnowing is conducted by passing the hulled beans in front of an electrical fan which separates the husk from the beans (Figure 16).

Figure 16. Hulling, sieving and winnowing of coffee beans in KSA

3.3.4.5 Sorting of Hulled Coffee Beans

It is desirable to sort the hulled coffee beans and remove the defective beans before storage. Some defects such as mold and moisture damage can deteriorate the sound beans in the storage. While, other defects such as damaged, immature, sour, or black adversely affect the coffee quality. Hence, all defective beans should be eradicated at this stage to minimize the risk of losses in quantity and quality during storage (Figure 17). The sorting of hulled coffee beans can be done by machine or hand. Hand sorting is most widely used, but requires more labor for sorting the coffee beans based on size, color, and density. Floatation in water is another handy way to remove defective beans. The defective beans float on the surface while good quality beans tend to sink. The floaters are removed and used for producing low-quality coffee.

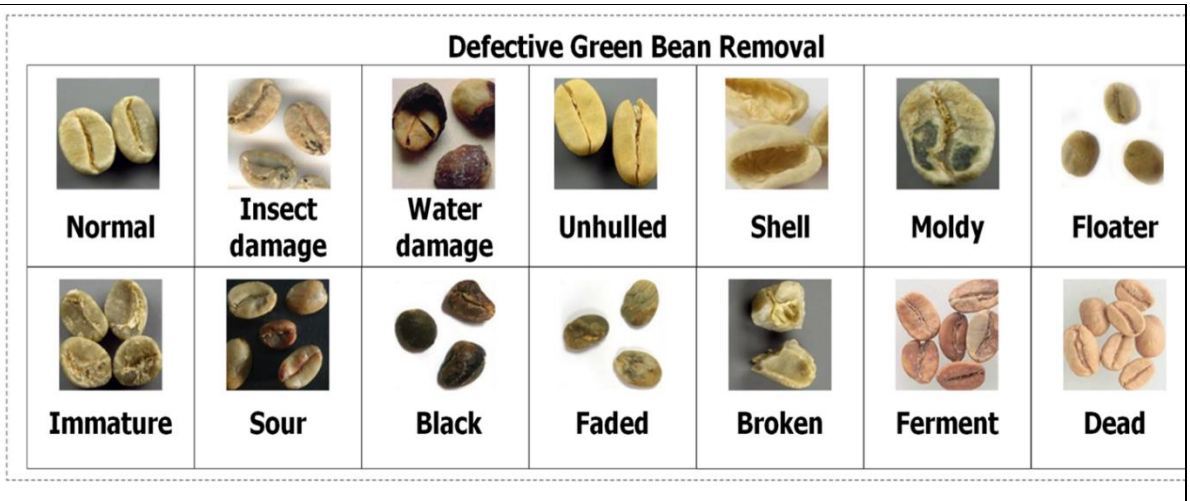


Figure 17. defects in hulled coffee beans. Source: Yung-Chien *et al.*, 2019.

3.3.4.6 Size Uniformity

The uniform size and larger coffee beans get a premium price in the market, while a high percentage of defects may lead to a lower grade and lower price (Mutua, 2000). Size uniformity can be ensured by sieve machines, with a vibrating bed, to separate the coffee beans according to their size. The larger and uniform coffee beans get a premium price in the market. By contrast, a high percentage of defects may lead to a lower grade and lower price. The coffee beans are classified according to the size of the beans. The beans are passed over a sieve plate of different sizes and the size is approximated by retention at each sieve size (Brasil, 2003).

a. Small Sieve: 13 – 14

b. Medium Sieve: 15 -16

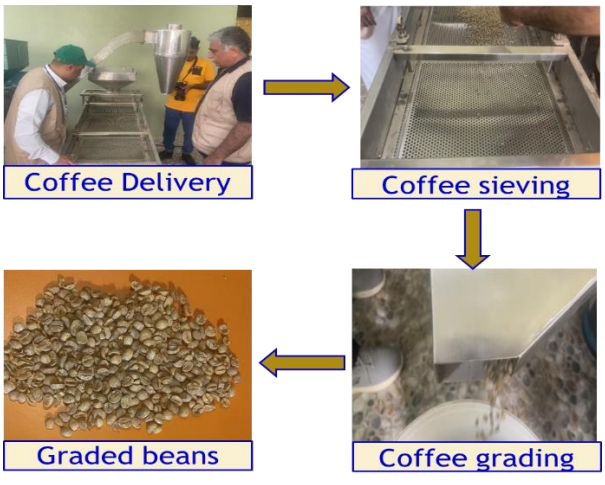
c. large Sieve: 17-20

The bean size in screens 16 and 17 is an important quality attribute as this formation has greater acceptance, especially on the international market (Clemente *et al*., 2015).

Size, shape, and color are used to grade beans after they have been dried to an even moisture content for storage. Electronic devices, called Chroma sorters, are also used to separate coffee beans by their colors. However, this is not always sufficient to detect and separate the good and bad coffee beans. Dry processing of coffee beans escalates the price from SR 75/kg to as high as 215-235/kg. However, extreme care is needed at each stage of processing especially post-hulling sorting to ensure uniform quality and a price premium (Figure 18).

Figure 18. Grading of coffee beans.

The coffee is delivered into the coffee grader, which role the coffee beans over a sieve plate. The vibrating sieve plate separates the coffee beans by size and delivers it through three different openings according to the size of the beans.



3.3.4.7 Packing of Green Beans

Smallholder farmers pack green coffee beans in jute sacks or polypropylene (PP) sacks as these are more affordable. Many smallholders store the coffee in empty plastic buckets. The coffee beans as is done in the international market are sold in gunny bags of 50kg and 60kg as the

global standard though is 60 kg pack. However, smaller packing is also used depending on the demand. Several types of container bags can be used to pack the coffee for storage. However, it is best to pack the coffee beans in hermetic bags or stainless steel airtight containers.

a. Gunny Bags: Fresh and clean gunny bags are, generally, used for storing coffee beans (Figure 19 A). However, such bags allow moisture uptake and are more prone to damage by insects.
b. Value bags: These are sealed bags that protect the beans from moisture. Being opaque, value bags also protect against light.
c. Airtight containers: Stainless steel containers that protect against moisture uptake.
d. The plastic bags impermeable to CO_2, called GrainPro^{TM}, which coat the jute bags, are a low-cost alternative to the storage of coffee beans.
e. Hermetic bags: Multilayered bags protect the beans from moisture uptake and modify the atmosphere within the bags, which kills the insects in the bag (Figure 19 B).

Figure 19. Storage of green coffee beans in gunny (A) and hermetic bags (B)

3.3.4.8 Storage of Coffee Beans

The storage of coffee beans is an important aspect of postharvest handling of coffee. Storage is needed to store the graded or packed coffee beans for shipping or selling in the market. The coffee bean can be stored for about 12 months under optimum storage temperature and relative humidity. Ensuring proper storage temperature and relative humidity are critical factors in retaining the coffee quality and physical and chemical traits of coffee beans. It is desirable to store coffee beans at a temperature below 20°C and 60% relative humidity to retain the quality and commercial value of coffee beans (Anwar, 2010). The coffee beans can absorb moisture if stored at high relative humidity (Tharappan and Ahmad, 2006). Similarly, storage at high temperatures and relative humidity can increase the incidence of molds and Ochratoxin-A development (Kuit *et al*., 2004). High relative humidity and warm conditions increase bean

moisture content and reduce quality by causing poor appearance and liquor quality (Woelore, 1995). Some of the primary considerations in the storage of coffee beans include (Figure 20):

a. **Temperature**: The green coffee beans should be stored at a temperature below 20°C.
b. **Relative Humidity**: The relative humidity should be about 60%. High relative humidity promotes moisture uptake by beans. Too low relative humidity may cause excessive drying (less than 11% moisture), which decreases the taste of coffee.
c. **Light**: Green coffee beans lose taste with prolonged exposure to light during storage. Therefore, light should be avoided as much as possible.
d. **Pests**: Storage pests such as rodents and insects such as psocids, small soft insects of seeds, is a serious threat to the stored beans. Pests cause physical loss of weight and contaminate the product, thereby, causing quality deterioration.
e. **Pathogens**: Because coffee beans have a porous, spongy texture, they can easily be contaminated by fungi, giving rise to off-flavors, or can pick up strong odors, and deteriorate rapidly if allowed to become too moist.
f. **Strong Smell**: The coffee beans may absorb small from other commodities. Hence, it should not be exposed to smells emitted from other commodities during storage.
g. **Proper Stacking**: The beans should be stacked on a firm platform with the lowest about 15 cm high above the ground. The bags should be protected from excessive light and sources of heat (Figure 21).

Figure 20. Protection needed during storage


Figure 21. Stacking of coffee bags in storage

3.3.4.8.1 Storage losses of Coffee Beans

The coffee beans can be stored for one year under optimum storage conditions. However, a considerable quantity of coffee beans can be lost when stored in improper conditions. Some of the major causes of losses during storage include:

a. Poor shape: The poor shape of beans is caused by high relative humidity.
b. Storage Pests: While the coffee beans are relatively less damaged by storage pests such as birds and rodents, yet significant damage can be caused by coffee weevil, which attacks the dry beans. Storage in hermetic bags can control the insect problem of coffee beans in storage.
c. Toxic substances: High moisture content of the beans or high relative humidity promotes the development of mold and toxic substances during storage.

d. Undesirable flavor: The dried coffee beans can absorb the odors of other commodities.

3.3.4.9 Coffee Quality Standards

The quality standards for Arabia Coffee are well documented and are registered and certified by the Saudi Arabian Standards Organization (SASO). This paves the way for international certification by International Standards Organization and will help in brand recognition through a number of ways including geographical identification to get better returns and control adulteration.

For export quality, ISO (2004a) defined a standard for green coffee quality (ISO 9116 standard) as, it requires several pieces of information, like the geographical and botanic origins of the coffee, the harvest year, the moisture content, the total defects, the proportion of insect-damaged beans and the bean size. These ISO standards define methods of measurement for several of these qualities such as defects, moisture content, bean size, some chemical compounds, and preparation of samples to perform cup tasting.

The assessment of defective bean count is done by hand picking all the defects from a specified weight of coffee then grouping similar defects counting, weighting them, and finishing up with one number representing the total amount of defects.

Defective (triage) coffee beans are beans rejected after separating the graded ones according to their size and color. Generally, according to SCAA grades which include:

a. Specialty grade 1: No more than 5 full defects/300 gm, no primary defect, and Quakers are not allowed,
b. Premium grade 2: No more than 8 full defects/300 gm, primary defects are permitted and 3 Quakers are allowed),
c. Exchange grade 3: Having 9 to 23 full defects, 5 Quakers to the maximum are allowed).
d. Below standard grade: Having 24 to 86 defects/300gm
e. Off grade: Having greater than 86 defects.

Thus, based on one or more of these criteria each coffee-producing and exporting country has its national coffee grading system that fulfills the minimum standard for export (ITC, 2002).

Classes of Coffee Beans

For the highest price, green coffee must be graded and classified by internationally accepted standards. Although there is no universal coffee grading and classification system, however, some common grading criteria can be adopted to enhance the market value of coffee in Saudi Arabia.

Minimum Quality Requirements

The minimum quality requirement refers to the quality attributes that should be present in

coffee beans. However certain provisions and tolerance limits are given for different classes.

a. Wholesome;
b. Dried to a moisture content not exceeding 13%;
c. Clean, practically free of any visible foreign matter;
d. Sound, free of defects and deterioration in quality that may make it unfit for brewing –
e. Practically free of physical damage;
f. Practically free of abnormal external moisture;
g. Free from mycotoxin-producing mold;
h. practically free of pests and damage, affecting the general appearance of the produce;
i. Free of any foreign smell and/or taste.

Each of these defects is permitted within certain limits, depending on the importing country. In export markets, coffee beans are classified into three classes i.e. extra class. Class I and Class II, depending on the quality and absence of the defects. For the sizing and classification, ASEAN standards are given as an example in annexure 5.

3.3.4.10 Roasting, Grinding, and Brewing

Roasting release the aroma, an operation that many coffee lovers insist on performing themselves. During roasting, continued tilting must be ensured for uniform roasting all around the beans. Well-roasted coffee should be brown, of varying degrees of darkness, but never black. Both traditional and modern roasters are used, but to get better uniform quality of roasted beans, modern (electric) roasters with temperature control and automatic tilting are preferred.

The roasting process causes the selling of coffee beans and increases their size by over 50%, but greatly reduces the weight due to loss of moisture (Hicks, 2002). Temperature and time are two critical considerations during roasting for superior-quality coffee. During roasting, the coffee beans are heated at 200-240°C for about 10-15 minutes depending on the degree of roasting required, which is mainly evaluated by color. The longer the roasting the greater is the oil drawn to the surface of the bean due to the caramelization of sugar and carbohydrates inside the bean increases proportionately to the length of roasting time.

a. Light roast

The lightly roasted coffee develops light brown color, and it is preferred to make a coffee with a mild body. It has light fragrant, floral or fruity coffee notes. In this roasting condition, the coffee beans should not develop oil on their surface. It is also characterized by pronounced acidity and high caffeine content. During light roasting, the internal temperature of the coffee bean reached approximately 204°C (Figure 22A). According to Almohanad Almarwai, the co-founder and CEO of the Arabian Coffee Institute (ACI), Saudi consumers, generally, prefer lighter roasts compared to most other Middle Eastern countries. Hence, a light roast (that is roasted to just before the first crack) is preferred. The Saudi Arabians also have a tendency of

drinking flavored coffee, which necessitates processing by adding raisins, dates, other dried fruits, dark chocolate, and spices such as cardamom and cinnamon (Anonymous, 2022).

b. Medium roast

Medium roasted coffee developed medium brown color, and the surface of the coffee beans should not have oils. It is characterized by a balanced aroma flavor and acidity. Traditionally this is the most preferred roasting condition. It has medium caffeine content (Figure 22 B). To achieve this roasting condition, the internal temperature of the coffee beans reached approximately 215°C.

c. Medium-dark roast

Medium-dark roasted coffee has a dark brown color, and the surface of roasted beans developed oils. It is characterized by fully bodied deep flavored and little spicy notes. It has low caffeine content. This roasting condition is attained when the internal temperature of the coffee bean reached nearly 229°C (Figure 22 C). Overall, roasting coffee in medium to dark conditions causes an increase in ketones, esters/lactones, aldehydes, aliphatic acids, and aromatic acids, but a reduction in caffeine content is observed.

d. Dark roast

It has nearly a dark color and produced oils on the surface of the coffee beans. The darker the coffee beans, the less is the acidity. It is also characterized by very low caffeine content with a heavy mouthfeel, strong flavor, bitter, and burnt or smoky notes. When the coffee is roasted in the dark 22 D).

Figure 22. Levels of roasting coffee beans

3.3.4.11 Packing of Roasted Beans

After roasting, coffee does not keep its aroma for long and should be held in airtight packaging to prevent light, heat, and moisture ingress (Deoju and Manandhar, 2004). The aroma is quickly lost from ground coffee (Hicks, 2002). Therefore, the coffee should be ground just before brewing. After sorting is properly done, the coffee beans should be packed in stainless steel airtight containers. Roasting holds a very important step before consumption by the final consumer. Roasting determines the final quality of coffee and is of four types.

3.3.4.12 Storage of Roasted beans

The roasted beans are prone to losses and require careful handling. Moisture is the most serious threat during the storage of roasted beans. The best strategy is to store in airtight containers. For this purpose airtight, food-quality stainless steel containers, with a capacity of 30 kg of coffee can be used to minimize the losses of roasted coffee during storage.

3.3.4.13 Product Diversification and Value Addition

In addition to the green beans, the other parts of the coffee plant and cherry can be utilized in making different products which will increase the income of coffee growers, reduce wastage and offer new products such as coffee candies, coffee blossom tea, coffee leaves tea, coffee pulp in Jam, juice, flour for bread, cookies, and brownies, etc. The coffee husks can be used to make tea, while the silver skin can be suitable for bakery products. The coffee parchments can be used as food preservatives and as a source of anti-oxidant. However, there is little, if any, value addition at the smallholder level. However, most small coffee producers lack the skills and knowledge to embark on product diversification and value addition. Training for capacity building are needed for smallholders to identify and develop value added products. It will not only decrease the losses during postharvest handling but will also enhance the income of smallholders in KSA.

There are some commercial-scale processing units, that process coffee into different value-added products such as s green beans, roasted coffee beans, capsules, Saatchi and coffee husk, etc. In addition value addition in the form of coffee bars, powder and capsules can diversify the processed products and promote the coffee sector of KSA.

Figure 23. Value added products of coffee in KSA

3.3.4.14 Organic Production and Value addition

Organic production is an economically viable value-addition strategy especially for small holders (Van der Vossen, 2005) and organic produce, generally, fetches a price premium of as much as 25 percent over conventional coffee (Anonymous, 2010). A research study of a study of conventional and organic coffee production revealed that the cost of physical input of organic coffee per hectare acre was 45% lower than that of conventional coffee (Harold, 2013).

Saudi Arabia has been promoting organic agriculture and supporting environmentally friendly farming systems. Saudi Arabia introduced the first National Regulation & Standards for Organic Agriculture in 2011, which shows its commitment to developing a strong organic sector. At present, organic farming is among the priorities of the Ministry of Agriculture. The Department of Organic Production and Saudi Organic Farming Association (SOFA) promotes organic production and certification in the country by providing technical and financial support to farmers and bearing the cost of certification. Farmers are encouraged to follow organic practices and are supported to sell organic produce directly to consumers. A number of supermarket retail chains have exclusive organic segments in their stores and they are interested to procure directly from farmers.

3.3.4.15 Waste management and Value added Products

Coffee processing generates a considerable amount of waste, which can become serious pollution and environmental concern. The waste generated during coffee processing can be converted into value added products of industrial and economic importance (Figure 24).

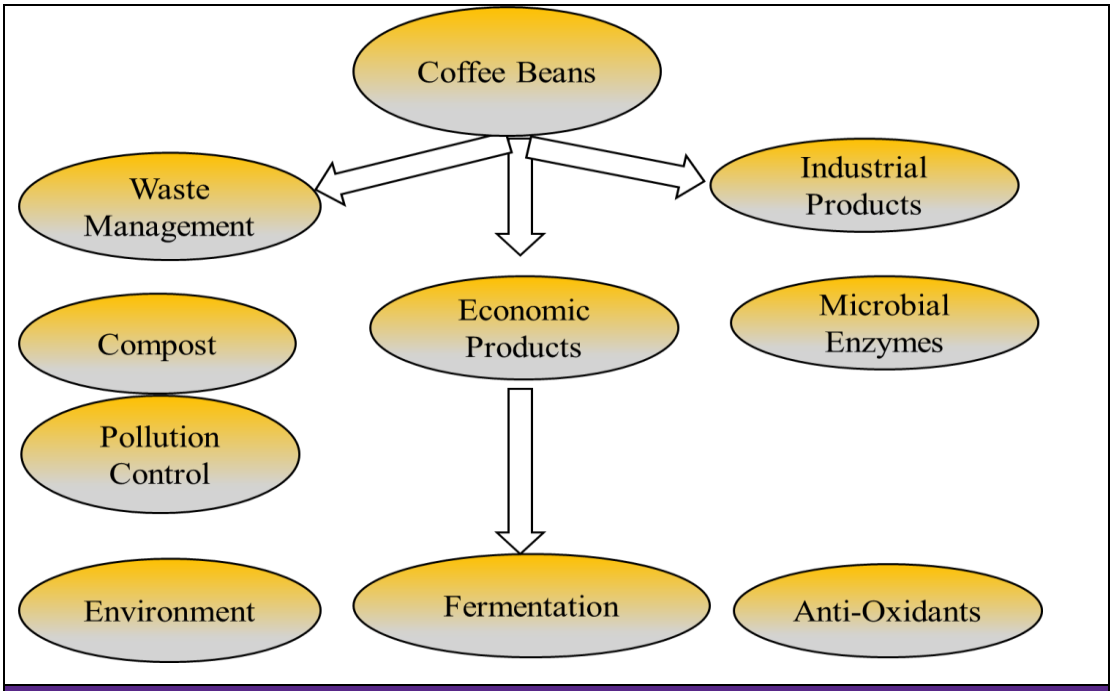


Figure 24. Waste management of coffee beans and value added products of commercial importance

Dry processing of coffee generates coffee cherry husks as a major residue. The husk comprises the outer skin, pulp, and parchment, and represents about 12% of the berry on a dry-weight basis. About 0.18 tons of husks are released from 1 ton of fresh coffee fruits (Murthy and Naidu, 2012). The coffee husk contains 58-85% total carbohydrates, 8-11% protein, 0.5- 3% lipids, and small amounts of bioactive compounds such as caffeine and chlorogenic acids (Murthy and Naidu, 2012). The coffee husk can be utilized as a substrate for biogas and alcohol production, bio- sorbents in the removal of cationic dyes from aqueous solutions, or extracted for bioactive substances recovery (Murthy and Naidu, 2012). However, the most cost-effective utilization can be as a substrate for edible mushroom production or composting (da Silva *et al*., 2012). Both products can be easily adopted by smallholders in KSA and add in pollution control measures.

3.3.5 SWOT Analysis of the Coffee Sector in KSA

The SWOT analysis of the coffee sector is resented in Table 9 to understand the challenges and possibilities of postharvest management in the overall background of the coffee sector in KSA.

Table 9. SWOT analysis of the coffee sector in KSA.

Strengths	Weaknesses
a. The cultivation of Arabica coffee is highly preferred and valued. b. Long experience in coffee cultivation c. Increasing urbanization helps in the growing demand for specialty coffee. d. Coffee is considered a priority crop by the government of KSA to expand the non-oil-based economy. e. Facilitation of coffee promotional events such Coffee festival Jazan, by the government. f. The constantly increasing number of visitors i.e. Hajj and Umrah pilgrims and tourists visiting the kingdom increases the demand for coffee. g. Awareness of coffee growers/processors of the postharvest losses and the need of diversifying the coffee produce. h. Business liberalization and direct purchases from growers	a. Coffee farms are in hilly terrains and poorly developed link roads make cause less access to the farms. b. The area under cultivation of coffee is decreasing due to the cultivation of other fruits and vegetables. c. High labor costs increase the cost of production. d. The yield is low e. Quality attributes of local coffee not documented f. Large-scale commercial interventions are limited by smallholders and less organized communities. g. Lack of proper grading in green coffee sold by small producers. h. The coffee growers lack knowledge of proper sorting, drying, and packing practices for retaining the quality of coffee after harvest. i. The Smallholders hardly avail financing opportunities for improving the postharvest handling and processing of coffee. j. A relatively weak extension system, that is less effective in postharvest management and processing of coffee on a commercial scale.
Opportunities	Threats
a. Increased domestic production and minimized postharvest losses. b. Land area available for coffee cultivation. c. Engagement with the private sector (roasters, importers, traders) d. The growth of global coffee house chains motivates local entrepreneurs to develop specialty coffee matching the taste profile of the local population.	a. Local coffee is not price competitive and may not compete in the global and domestic markets. b. High price variation adversely affects buyers' confidence and long-lasting business relation. c. Frequent droughts, hot weather, limited rains, and other climatic changes are detrimental to the growth and quality of coffee.

e. Significant potential for improvements in postharvest handling and processing of coffee. f. The government provides incentives for organic coffee production that can promote organic coffee and capture premium in the health-conscious market. g. The coffee sector can generate jobs for youth in rural areas.	d. Improper postharvest management increases the risks of losses, quality deterioration, and contamination. e. Shifting to the cultivation of other high-value crops undermines the coffee sector of KSA. f. Farmers are not aware of preventive practices for disease management. g. The unorganized small coffee producers are unable to reach economies of scale h. Loss of quality in postharvest handling threatens sustainable growth in the coffee sector.

3.3.6 Action Plan for Coffee Postharvest Management and Processing

Some of the actions required for the development of the coffee sector especially the harvesting, postharvest management and processing are summarized in table 10. Harvesting at proper maturity, sorting, drying and processing can be optimized by training growers and MoEWA staff. Some small tools and equipment are also required so that traditional handling practices can be improved on a scientific basis. Organic certification will further improve the quality and ensure higher returns to the smallholder coffee growers.

Table 10. Action Plan: Coffee postharvest management and processing

Actions	Responsibility/ Support	Outcome	Methodology
Harvesting at proper maturity and method	Growers/ FAO Technical Staff & MoEWA Staff	a. Coffee cherries harvested at Cherry stage I or II b. Enhanced coffee quality	Training of MoEWA staff and coffee growers
Cost Involved: No Cost to the growers		Benefits: of the 40 tonnes lost during harvested, 10000-30000 kg coffee cherries can be recovered with 25-75% reduction in losses, which is worth 32,200 to 96,600 USD based on import price, 2020.	
Mechanical Harvester	FAO, MoEWA	Save Time and Labor	Adopting mechanical harvesting of coffee
Cost	280-380 USD	Benefit: Save harvesting laborers cost by 60%.	
Adopting solar tunnel drying technology	Growers/ FAO & MoEWA Staff	a. Uniform ripening and color development. b. Superior coffee quality c. Minimize mold or aflatoxins incidence.	Training of growers and provision of mechanical harvester

		d. Minimize dust or birds excreta contaminations	
Cost: Variable depending on the size of the tunnel.		a. Benefits: Minimum contamination by dust and pathogens. b. Uniform drying and superior coffee quality c. Of the 38000 kg lost, 3000, 6000, or 9000 kg can be recovered with a 25, 50 or 75% loss reduction. It is worth 30,590, 61180 and 91,770 USD with 25, 50 and 75 reduction in losses during drying of coffee cherries.	
Dry Beans Mechanical Hullers	Processors/ MoEWA Staff	Separation of husk and obtaining coffee beans	Training of growers and facilitation in the provision of mechanical harvesters
Cost: 1000-5000 USD		Benefits: Variable depending on marketing options. a. Save labor hours and retain beans' quality. b. Minimized broken beans	
Coffee polishers	Processors/ FAO	Removal of silver skin	Training of growers/ processors and provision of mechanical harvester
Cost: USD 1800-2000 by MoEWA		Benefits: Save labor hours and retain beans' quality.	
Coffee Grading Machine	Growers/ FAO & MoEWA	Separate coffee beans in uniform sizes	Adopt mechanical grading
Cost: 3200-5000 USD by MoEWA		Benefits: Save labor hours, Enhanced efficiency, Access to high-end markets	
Air-tight and moisture-resistant packaging. i.e. Hermetic Bags	Growers/ FAO & MoEWA	a. Protection from light, heat, and moisture ingress. b. Preservation of aroma	Adopting proper packaging technology for roasted beans.
Cost: Hermetic bags 3.5- 4.0 USD/ bag		Benefit: Of the 24000 kg beans lost, 18000 kg can be recovered with 75% efficiency, which is worth 57,960 USD based on import price.	
Storage	Growers/ FAO & MoEWA	Benefit: Of the 6000 kg losses during storage, storage in hermetic bags, moisture protection and minimum insect damage, 75% recovery will be worth 4980 USD.	
Cost: Hermetic bags 3.5- 4.0 USD/ bags		Of the 6000 kg lost during storage 1500 to 3000 Kgs can be recovered with 25 to 50% efficiency.	
Dry cards and hygrometers 5 USD/ Card	Growers/ FAO & MoEWA	Ensure proper moisture content of coffee beans	Use of dry cards and hygrometers to ensure proper moisture content
Value added products	Growers/ FAO & MoEWA	Processing of coffee into different value added products	Installation of value addition facilities
Cost: Variable depending on which products are developed		Benefits: Variable depending on which products are developed	
Waste management	Growers/ FAO & MoEWA	a. Utilizing waste materials for different purposes	Promotion of waste management strategies in the coffee industry

		b. Decreased solid waste	
Cost: Variable depending on the products generated from coffee waste		Benefits: Variable depending on the usage of waste products.	
Organic Certification	Growers & MoEWA	Certified organic produce and higher returns	Simplifying the certification process
Cost: No Charge to growers		Benefits: Enhanced access to high-end and export markets.	
Note: The losses and benefits are estimated based on reports of the total coffee production of 800 tonnes. As indicated, the government of KSA intends to increase coffee production; the total losses will increase with increased production. Hence, increased production is of little benefit of it cannot be preserved through proper postharvest management. Hence, training and capacity building of growers and extension staff in harvesting, postharvest handling and processing of coffee should be the primary focus to realize the benefits of increased coffee production.			

Since MoEWA provides financial support for most of the tools/ equipment recommended in the action plan, the postharvest handling and processing can be optimized with almost no cost to the growers at this stage. The total benefit with a postharvest handling system, at 75% efficiency can be as high as 371,910 USD based on import price.

SECTION 4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The coffee sector of KSA has enormous potential to uplift the livelihood of smallholders and add to the environment and biodiversity. Despite several problems in production and postharvest handling, the coffee sector of the KSA is strengthened by the production of coffee in organic conditions. However, Saudi Arabia satisfies its domestic coffee demand by importing coffee beans from different countries. While Saudi Arabia also exports a relatively small quantity, the higher import price of coffee as compared to the export price indicates the untapped potential of the coffee sector in KSA. The government of Saudi Arabia has been promoting the coffee sector for the last serval years and is recently reflected as one of the target commodities for "Sustainable Rural Agricultural Development Program (SRADP)".

The cultivation of coffee in KSA is more of traditional nature than modern crop husbandry. There are several problems in the production, harvesting, postharvest handling, and processing of coffee, which can adversely affect the chemical compositions and physical properties of coffee beans and limits the realization potential of the coffee sector in KSA.

Improper harvesting and postharvest handling and processing can cause significant losses in quantity and quality, which decrease the market value and growers' income. The identification of problems in harvesting, postharvest, and processing and adopting appropriate technologies to reduce postharvest losses and retain the intrinsic quality, will ensure access to high-end domestic and export markets. Decreased postharvest losses and retaining quality will increase the growers' income and contribute to the sustainability of the coffee sector in KSA.

The quality of coffee is largely dependent on the stage at which the coffee cherries are harvested. Hence, identifying the proper maturity stage and harvesting accordingly, and avoiding a mixture of cherries at different stages of maturity sets the basis for a superior quality coffee. While selective picking is desirable to ensure uniformity of coffee cherries maturity, it is limited by the non-availability and skills of harvesting. A handheld mechanical harvester can be used for harvesting coffee cherries, which decreases the cost of harvesting. However, it should be followed by proper sorting to remove the early mature or over-mature cherries before further processing.

Postharvest handling technologies are adopted to decrease the losses in quality and quantity. Postharvest techniques such as sorting, drying, grading, packing, and processing are used to enhance quality and marketing opportunities. However, in KSA postharvest handling is limited to drying and dehulling and minimal grading and packing of beans in Jute or polypropylene (PP) sacks and storage in a room with no temperature or humidity control. The inefficient postharvest handling can result in 9.175% losses. With a total production of 800 tonnes, the losses in coffee are 73.4 million tonnes and cost about 15.78 million SR at the dry bean levels. If the postharvest losses are reduced by 50%, it can save as much as 7.89 million SR annually.

Coffee processing generates significant waste, which can turn into an environmental issue if not addressed. At present, there is no proper waste management system for coffee processing. The problem of waste produced during coffee processing can be minimized by converting

coffee husk into useful products such as a substrate for mushroom production and compost as a soil conditioner.

Establishing a proper postharvest management and processing system requires efficient extension staff, and growers and processors ready to adopt new interventions. For most smallholder coffee growers, coffee cultivation is primarily a tradition rather than a business. It is needed that the coffee production, postharvest handling, and processing are driven by markets and buyers' preferences. For this purpose, both the coffee growers and processors as well as the extension staff of MoEWA need extensive training, for which the primary materials are provided by this report.

4.2 Recommendation

Smallholder coffee growers should take practical steps in production, postharvest management, and processing system of coffee plants. The selection of promising cultivars resilient to climate change, planting healthy saplings, regular pruning, rejuvenation of old trees, efficient irrigation, and orchard management are some of the factors that can increase the yield and promote the quality of coffee cherries. The benefits of increased yield can not be realized, without reducing losses in the postharvest chain. Hence, it requires a holistic effort to increase yield and quality and realize the potential of the coffee sector.

4.2.1 Pre-harvest Stage:

a. The coffee growers should plant recommended seedlings obtained from reliable nurseries.
b. The smallholder should adopt regular pruning for canopy management, better air circulation of air, and proper light penetration which will ensure higher yield and superior quality of the coffee cherries. Further, all old, weak, and diseased branches should be removed.
c. The aged coffee trees should be rejuvenated by stumping to minimize pests' incidence and safety of produce.
d. Composting and manuring should be promoted to ensure enough organic fertilizers. Apply the organic fertilizers at least 1-2 months before the spring season.

4.2.2 Harvesting Stage

a. The harvesting practices such as picking immature or over-mature cherries affect the drying rates and ultimately lower the quality. Hence, care should be exercised to harvest the optimally mature berries by selective picking. Alternately weather stripping or using mechanical shakers, branches with maximum mature berries must be selected for harvesting.
b. Sorting after harvest is essential to remove any immature or over-mature cherries and any disease or pest-damaged cherries from the lot destined for processing.
c. The collection of fallen berries from the ground can be a source of contamination. Therefore, such cherries should not be mixed with harvested cherries destined for drying even if it appears to be sound.
d. Improve harvesting practice by harvesting red ripen cherries by hand-picking from the tree.

e. The growers should focus on quality instead of quantity only at the time of harvesting, which will help in enhancing the reputation, and the price.

2.2.3 Postharvest Handling

a. Sorting: Practice sorting after harvesting before drying, to avoid moisture variation due to mixed coffee harvesting and drying problem.

b. Uniform Maturity: Select uniformly and optimally matured cherries for drying, to avoid moisture variation and loss of quality during the drying process.

c. Drying Racks: Ensure the drying of coffee cherries in shade over a rack at least 30 cm high from the ground to avoid contamination by dust and moisture.

d. Uniform Drying: Ensure regular turning over of coffee cherries on the rack to avoid partial drying and encourage uniform drying.

e. Avoiding moisture: Avoid all sources of water in the drying areas to avoid mixing water and soil with coffee beans.

2.3.3 Coffee Processing

i. Hulling and Winnowing

a. Avoid damage to the beans during hulling.
b. Sort the hulled beans for defects in the beans and remove all defective beans.
c. Winnowing can easily be achieved by sieving and finally general purpose fan. The husk is easily separated from beans due to mass variation.

ii. Sizing and Grading or Classification

a. Determine the market demand and size the beans accordingly. The berries can be sized on sieve plates or manually depending on the quantity and availability of size separators.
b. The coffee beans should be classified on the basis of quality and compliance with grade standards must be ensured.

3.3.4 Packing/Bagging and Labelling

The dried coffee beans can be temporarily stored in jute sacs or polypropylene bags. However, it is best to use hermetic bags, which offer good protection against moisture and minimize insect infestation.

Labeling: The packages should be labeled to give all relevant information such as the name of the produce, variety, grade, net weight, origin, processors/packers/ traders, Web site, E-mail or Phone number, etc. The label must also indicate any certification (Phyto-sanitory, organic, etc.) if acquired.

3.3.5 Storage of coffee beans

The coffee beans store best at a low temperature and low relative humidity. High temperature and high relative humidity increase the risk of mold growth and aflatoxin production. Hence, the beans should be stored at a temperature below 20°C and low relative humidity of less than 60%. In addition to the temperature and relative humidity, care should also be exercised to:

a. Stack the bags on steel racks at least 30 cm above ground level.

b. Protect the coffee bags from sources of water in storage.
c. Protect the coffee beans from order-transferring commodities.

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3.3.5. Recommended Tools and Equipment

Mechanical harvester: The current system of selective picking is a time-consuming and labor-intensive exercise. Since the pickers of coffee cherries are paid by the weight harvested, the pickers usually pick immature and over-mature cherries. Hence, the benefit of selective picking is lost. Hence, mechanical harvesters (shakers), which with vigilance in the selection of branches with maximum optimally mature cherries and proper adjustment of vibration force enhance the harvesting efficiency, and decrease time and labor costs.

Solar Tunnel Drying: The current system of cherries drying on the floor or racks should be upgraded to solar tunnel drying. It will ensure the uniform ripening and color development required for superior coffee quality. Further, it will minimize mold or aflatoxins incidence and decrease the risk of contamination by birds or dust.

Drying cards and Hygrometers: The excess moisture can be a serious cause of quality loss in coffee beans. It is recommended that drying cards and hygrometers are installed in the coffee cherry drying structures. It will ensure optimum drying and moisture content of dried cherries and retain the quality of coffee beans during subsequent handling.

Mechanical Hullers and Graders: Manual hulling and grading is neither an efficient nor cost-effective system. It is, therefore recommended that mechanical hullers and coffee graders are used to retain the grade and quality of coffee beans.

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Annexures

Annexure-1. References Cited

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Annexure-2 Climatic data of Jazzan, Aseer, and Al-Baha regions

Jazan	Temperature			Precipitation	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	20	31	25	14	3
February	20	32	26	4	1
March	20	34	27	6	1
April	22	36	29	16	2
May	24	39	32	8	1
June	27	38	33	1	1
July	27	39	32	11	2
August	27	38	33	27	4
September	25	38	33	10	2
October	24	37	31	19	2
November	21	35	28	14	1
December	19	32	26	16	2
Average	23	35.75	29.58	12.62	1.83

Source: https://en.climate-data.org/asia/saudi-arabia/jazan

Aseer	Temperature			Precipitation	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	10.7	21.1	15.6	10.67	2.45
February	12	23.1	17.4	13.94	3.27
March	13.6	24.5	18.9	29.12	6.64
April	15.6	26.1	20.7	69.54	13
May	18.5	28.9	23.6	76.34	14
June	19.9	31.4	25.7	15.69	5.27
July	19.4	30.5	25	44.83	8.73
August	18.8	29.1	24	105.38	18.73
September	18.1	29.2	23.6	26.43	7.36
October	15.5	26.6	20.8	18.67	5.45
November	12.9	23.5	18	24.2	7.82
December	11.2	21.7	16.2	8.75	2.45
Average	15.52	26.31	20.79	36.96	7.93

Source: https://tcktcktck.org/saudi-arabia/asir#t

Annexure 2. Continues.

Al Baha	Temperature			Precipitation	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	10.8	19.6	14.9	45	3
February	12.2	21.8	16.7	25	1
March	13.9	23.6	18.5	36	1
April	16.4	25.8	20.8	46	2
May	19	28.8	23.7	52	1
June	20.9	31.1	25.9	30	1
July	21.1	30.4	25.5	36	2
August	20.3	29.2	24.6	150	4
September	19.1	28.5	23.6	130	2
October	16	25.6	20.6	39	2
November	13.4	22.6	17.8	19	1
December	11.3	20.5	15.7	23	2
Average	16.20	25.63	20.69	52.58	1.83

Source: https://en.climate-data.org/asia/saudi-arabia/al-bahah-region/al-bahah-29914/

Annexure 3. Questioner for Coffee growers/ Processors

Coffee Growers Questionnaire/ Interview

The questionnaire is designed for the coffee growers of KSA. The objective of this questionnaire is to get an insight into the production, harvesting and postharvest handling of coffee crop. It attempts to understand the problems of small land holders of coffee. The questions are tailored so that environment friendly and easily

adoptable solutions can be offered in the form a training modules. The questionnaire can either be directly filled by the growers or it can take the form of interview/ discussion. In a brief introduction by the Interviewer to explain:

1. The survey is aimed at getting the general information about the harvesting, postharvest handling and processing of coffee and will not reveal the personnel information in any reports based on the response of the growers.

2. The respondents will be encouraged to ask questions regarding any confusion about any question.

3. If a grower feels not to reveal any information requested in this questionnaire, he/she is allowed not to respond to such questions.

A. General (Demographic) Information

Name of respondent		Region	
Male or Female		Governorate	
Age of respondent		Contact Info	

1. What is the size of your coffee orchard (Dunum/ Hectares)?
   _____
2. How much of your land (Percentage) is dedicated for the coffees farming?

Less than 25%	25-50%	51-75	100%

3. Do you grow any other crop in the coffee orchards?

No	1	2	3

4. Do you have any other job/business in addition to coffee farming?

Yes	No	If yes	Job/Business?	

5. How many youth / female workers are involved in coffee production_____%?
6. Are you part of any growers'/ farmers' cooperative in the region?

B. Production Practices

7. How much is your experience of coffee growing (years)?

Less than 5	6-10	11-15	16-20	More than 20

8. How many plants are there in your coffee orchard / hectare
9. Which variety/Varieties of coffee do you grow?

10. On what basis you select the plants of coffee for your orchards.

Early maturity	Higher Yield	Good Quality	High Market Value	Any Other

11. What kind of agriculture practices do you use in your coffee orchard?

Practices	Traditional	Modern	Both
Fertilizers Application			
Weeding			
Irrigation			
Diseases & Pests Control			

12. Which measure (s) do you ensure for getting high yield and quality of coffee?

Practice	Plowing	Fertilizers	Pruning	Irrigation	All
Frequency					

13. What is the coffee yield (fruits) per tree?

Upto 1 kg		Upto 2 kg	Upto 3 kg	Upto 4 Kg	More than 4 Kg

14. How severe is the pest and disease problem in your coffee orchard?

	Damage Estimate of the disease (%)					
Diseases	< 10%	11-20%	21-30%	31-40%	41-50%	> 50%
Fungal diseases						
Bacterial						
Viral Diseases						
Insects and Pests						
Physiological deriders						
Any Other						

C. Facilities and Problems

15. Which factor adversely affect the production of quality of coffee?

Lack of Fertilizers	Lack Irrigation	Pests and disease	Less Rain
Excessive Fertilizers	Excessive Irrigation	Excessive Rain	Winds/ Hailstorm

16. How much is the cost of production practices of coffee/ hectare

Practices	Cost	Laborer Cost	Services Cost
Fertilizers			
Manures			

Pest Control			
Irrigation			
Any Other			

17. Do you need any guidance in the following practices?

Advice/ Services	Yes	No	Advice/ Services	Yes	No
Help in site selection			Fertilizers application		
Selection of cultivar			Pests/ disease control		

18. In case of disease or insect problem, you get help from?

Experience	Extension Staff	Fellow Coffee Grower	Literature

D. Postharvest Management, Value addition and Marketing

19. How do you determine harvest maturity of Coffee?

Change in Position	Size	Color Change	Sweetness	TSS

20. Do you do selective or strip picking in your copy orchards?

Strip Picking		Selective Picking	

21. When do you, usually, start and the harvesting of coffee beans?

Start Time	Before 6:00 -7:00 am	7:00-9:00 am	10:00 am Onward
End Time	Before 9:00 am	Before 11: 00 am	After 11: 00

22. What is the level of uniformity in coffee cherries harvested by the pickers?

Uniform Mature (%)	Immature (%)	Over mature (%)	Damaged (%)

23. Who conduct the harvesting operation?

Family Labor	Local Skilled Labor	Unskilled Labor	Distant Skilled Labor

24. How do you harvest the coffee beans high in tree?

By placing a ladder on tree	Shaking the branches	Harvesting Rods	Any other

25. Which type of material you use for collecting the harvested coffee beans?

Harvesting bags	Plastic Buckets	Cloth Bags	Any other

26. Do you sort the coffee cherries immediately after harvest? If yes what percentage of berries is discarded.

Yes		No	No	
Not Discarded	1-5%	6-10%	11-15%	More than 15%

27. What percentage of harvested coffee beans are green in color? _____%.
28. How much of the coffee beans are spoiled / lost during harvesting? _____%.
29. Which of the following postharvest procedures are needed and adopted for coffee?

Activities	Yes	No	Needed	Not Needed
Harvesting with a rod				
Sorting and Grading				
Drying				
Packaging of dried cherries				
Storage				
Drying facilities				
Any other				

30. How much of coffee are spoiled / lost during postharvest handling at the farm? _____%.

31. The non-availability of which factor is the serious problems during harvesting season?

Harvesting tools	Experienced pickers	Packages	Efficient Transport	Storage	Drying Facility

32. Do you sort and grade the coffee beans, If yes on what basis?

Practice	Yes	No	If Yes Tick your options below		
Sorting			Size	Color	Freshness
Grading			Freedom from damage	Freedom from diseases	
			All of the above		

33. While grading coffee cherries, which of the following you consider as low quality Coffees.

Small Size	Color	Damage	Diseases	Any other

34. How do you dry your coffee?
35. If you are sun-drying the coffee cherries, how much time doe it take?_____ days
36. How often you turnover the coffee cherries during drying?
37. While sun-drying, how do you keep the coffee cherries?

Field	On a floor	On Tarpaulin	Floor +Tarpaulin	Raised Mesh

38. Do you take any special precaution to avoid contamination of coffee while drying?

Precautions	Yes		No	
Protecting from dust	Watching for rotting coffee	Protection form Birds	Protection form Pests	Any Other

39. Do you sort the coffee cherries after drying?
40. What types of packaging you use for packing the coffee beans?

Fiber Board Boxes	Plastic Package	Gunny Bags	Hermetic Bags

41. Do you grade the coffee after drying. If yes what is the basis of grading?

Yes		No		
Size	Color	Size + Color	Soundness	Any Other

42. What percentage of coffee beans is spoiled during the drying process _____ %.
43. What price you get for the best quality dried beans per Kg? _____.
44. How much coffee do you keep in a package?
45. How much of your coffee are lost during packaging?_____%.
46. Do you feel the need of trainings to improve the skills of harvesting and postharvest management? If yes which type of training do you need? Tick your choice

Training needed	Yes	No
	Identification of maturity stage for optimum quality	
	Harvesting techniques	
	Sorting & grading	
	Packaging materials, designs and packing	
	Cooling the produce	
	Good handling practices in Postharvest Management	

47. Which of the following activities you do to add value to your produce for higher returns?

Variety selection	Pests and disease Control measures	Harvesting at proper maturity	Proper Drying	Sorting of Beans

48. Is your produce, packaging and packing aligned with markets/ buyers requirements?
49. What percentage of your coffee production is distributed for?

Family use	Family Use	Marketing (Locals)	Marketing (High-end)

50. Indicate the vehicle used for transport of coffee

51. Do you store your coffee beans? If yes, what percent is stored?

Storage	Yes		NO	
Percentage	Less than 25%	25-50%	50-75%	100%

52. Are you satisfied with your coffee farming/ Processing? _____

53. Any Other question that may emerge during the interview

Annexure 4. Equipment and Accessories for Coffee harvesting, postharvest handling and processing

Hand held Mechanical Harvester: Since the coffee cherries of *Coffea Arabica* do not mature at the same time, harvesting becomes a laborious job. The hired labor tends to poach the branches and generally harvest red cherries, green cherries, and yellow cherries at the same time leading to both qualitative and financial losses. Physiologically, the red cherries at the ripe stage develop an abscission layer that weakens the attachment point. This allows the utilization of mechanical shakers/harvesters to harvest only the fully mature cherries and thus avoid losses.

Solar Drying: Plastic sheds are light wooden or metallic structures with plastic roofs and walls that can further enhance the drying process. If drying racks are kept in plastic tunnels, it can increase the temperature to 10-15°C. An additional exhaust fan should be installed to remove the saturated air. In such conditions, the b coffee is sheltered from rain, dew, and dust.

A solar tunnel is heated either passively by the sun or by the solar heater. The solar tunnel can be equipped with a hygrometer, and with an inlet and exhaust fans to remove the extra humidity. Drying temperatures of 40 – 60°C can be achieved. It takes about 50 hours to reach

the final moisture content below 12.5% while sun drying required 75 hours (Abdullah *et al*., 2001)

Hulling Machine: The traditional method of hulling utilizes hullers that are designed for cereal crops. These potentially lead to undesirable losses and give rise to broken beans. Having the right kind of huller as well as its setting is as important as having the dried coffee at optimum moisture content. A hulling machine with adjustable speed, appropriate blades, and blunt appendages having a close-ended rotating shelling cylinder with the adjustable speed with a round bar welded on a drum and made up of two circular plates. An adjustable concave clearance to synch with bean size to provide just enough abrasion, a blowing fan to blow off the debris and a collection tray to collect the hulled beans.

Grading Machine: Proper grading of coffee as per its volume is a must for high-end markets. A grading machine with adjustable speed and multistage sieves having soft-edged holes of appropriate size and a slope of 3-5 degrees and an oscillating movement is recommended.

Annexure-5. List of small tools and equipment for coffee harvesting, postharvest handling and processing

The following machinery and equipment are recommended for better coffee harvest, postharvest and processing:

1. Solar drying tunnels for cherry drying
2. Hand-held mechanical harvester/shaker
3. Hulling machine specifically for coffee
4. Grading machine
5. Automated roasting machine
6. Chromasorters
7. Moisture testers
8. Dry cards
9. Hyperspectral camera (Colorimeter)
10. Air-tight stainless steel container for storage of green beans.

Annexure 6. Classification and Grading of coffee beans

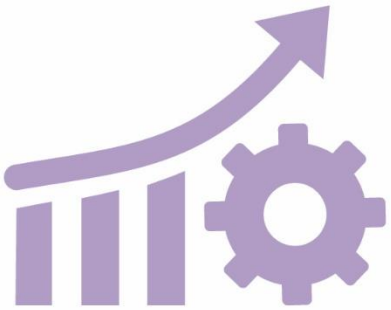
The ASEAN Standards for Coffee are given to indicate how the standards system works for the classification of coffee beans. So that the reader/ trainers could have a clear idea of the permissible levels of different defects.

Sizing Classification: The coffee beans can be classified into the following classes based on size (ASEAN Standards). The sizing requirements are not stringent, within certain limits. However, size contributes to market value.

Table Size grading (optional) of coffee beans						
Size Code	1	2	3	4	5	6
Bean Size (mm)	>7.0	>6.5-7.0	>6.0-6.5	>5.5-6.0	>5.0-5.5	4.0-5.0

Coffee beans Grading/Classification: The coffee beans can be classified into three classes, based on the minimum quality requirements and the limits of defective beans (Table 10) (ASEAN Standards). The graders and packers, thus, need to remain vigilant not to exceed the permissible limits and ensure packing uniformity for high market returns.

Table. Classification of coffee beans and provision of defects in each class.			
Quality Defects	Percentage of permissible defect		
	Extra Class	Class I	Class II
Black bean	<4.0	4.0-6.0	>6.0– 15.0
Moldy	<5.0	5.0-6.0	>6.0-8.0
Immature bean	<2.0	2.0-3.0	>3.0-8.0
Broken bean	<3.0	3.0-5.0	>5.0-10.0
Dried cherries	<0.5	0.5-1.0	>1.0-2.0
Foreign matter	<1.0	1.0-1.5	1.5-2.0
Total allowable defect	7.0	15.0	25.0



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