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Selected post-harvest and processing technologies for small scale rural producers in the Kingdom of Saudi Arabia VAL/051/2021/1

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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Acronyms

AHP	Analytical hierarchy process
FAO	Food and Agriculture Organization
FL	Fuzzy logic
FLW	Food losses and waste
IT	Information technology
KPI	Key performance indicator
MCDA	Multi criteria decision analysis
MoEWA	Ministry of Environment, Water and Agriculture
MW	Microwaves
PHL	Postharvest losses
R&D	Research and development
SAR	Saudi Arabian Riyal
SMEs	Small and Medium Enterprises
SRAD	Sustainable Rural Agricultural Development
USDA	United States Department of Agriculture
WHO	World Health Organization

Executive Summary

The flagship program of Sustainable Rural Agricultural Development (SRAD) Program (2019-2025) jointly formulated by Food and Agriculture Organization of the United Nations (FAO) and the Ministry of Environment, Water and Agriculture (MoEWA) within the context of the Saudi Vision 2030. The SRADP aims at diversified agricultural production base, improved income and living standards of small-scale farmers, strengthened food security and social stability and preserved environment and natural resources. The FAO technical cooperation in Saudi Arabia is providing support to MoEWA in implementation of the aforesaid flagship program through the project "Strengthening MoEWA's Capacity to Implement the Sustainable Rural Agricultural Development Program (2019-2025)". Prime beneficiaries of the FAO SRAD project are small scale rural SMEs. These rural SMEs are part of a larger supply chain including large scale farmers, aggregators, retailers, traders, importers/exporters, processors, government entities, markets, R&D organizations and agricultural cooperatives.

A large room for improvement exists in the postharvest/processing segment of the value chain where in various post-harvest management/processing technologies can contribute not only to reduce food losses, but by taking a systemic approach to reducing food losses, the quality and shelf-life of fresh produce can be enhanced and the profit margins for processors/producers increased.

It is understood that not all the technologies from harvest to post harvest to processing and storage can be comprehended for all commodities, hence this report gives a gist of some low hanging technologies in the SRAD target commodity components. Other technologies like storage, drying etc will be included later on. Most of the technologies mentioned in the report are commodity specific while some can be utilized for more than one commodity.

Background

The Kingdom of Saudi Arabia, with a total area of about 2.15 million km^2, is by far the largest country on 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.

Historically, agriculture in KSA was limited mostly to date farming and small-scale vegetable production in widely scattered oases, except in a small coastal strip in the southwest while cereals, and other fruits were grown wherever the agro-climate was congenial; livestock farming was scattered throughout the peninsula. Majority of the farmers in the Kingdom are small holders and as such face many problems in bringing their production up to the mark in terms of productivity. This segment of traditional agriculture producers constitutes around 88 percent of the Kingdom's total producers. The development of rural sector thus is dependent on holistic consideration from the efficient management of production resources, processes and systems, technologies, value chain and supporting institutions.

On the historic day of 25th April, 2016, The Kingdom of Saudi Arabia launched a roadmap to achieve sustainable economic growth and development of the Saudi nation. The program, "Vision 2030" aims at putting KSA as world's best model for economic development through three pillars: A Vibrant Society, A Thriving Economy and An Ambitious Nation. The program is based on The Kingdom's "Vision 2030" comprises 96 strategic objectives, governed by a number of Key Performance Indicators (KPIs), that will be achieved through a number of initiatives codeveloped and executed by different governmental entities alongside private and non-profit organizations within the respective ecosystems. The Council of Economic and Development Affairs has set up an effective and integrated governance model with the aim of translating "Vision 2030" into multiple VRPs working in parallel to achieve the strategic objectives & realize the vision. The National Transformation Plan to realize the vision 2030 was launched on June 06, 2016 with the aim to achieve Governmental Operational Excellence, Improving Economic Enablers, and Enhancing Living Standards by accelerating the implementation of primary and digital infrastructure, engaging stakeholders in identifying challenges, co-creating solutions, and contributing to the implementation of the program's initiatives. It has 08 thematic areas namely (1) Transform Healthcare, (2) Improve Living Standards and Safety, (3) Ensure Sustainability of Vital Resources, (4) Social Empowerment and Non-Profit Sector Development, (5) Achieve Governmental Operational Excellence, (6) Labor Market Accessibility and Attractiveness, (7) Contribute in Enabling the Private Sector, and (8) Develop the Tourism and National Heritage Sectors.

In this background, the flagship programme of Sustainable Rural Agricultural Development (SRAD) Program (2019-2025) has been jointly formulated by Food and Agriculture Organization of the United Nations (FAO) and the Ministry of Environment, Water and Agriculture (MoEWA) within the context of the Saudi Vision 2030. The SRADP aims at diversified agricultural production base, improved income and living standards of small-scale farmers, strengthened food security and social stability and preserved environment and natural resources. The FAO Technical Cooperation Programme in Saudi Arabia is providing support to MoEWA in implementation of the aforesaid flagship programme through the project "Strengthening MoEWA's Capacity to Implement the Sustainable Rural Agricultural Development Programme (2019-2025)". This project is consistent with the national development goals, fits within the Saudi Vision 2030, contributes directly to achievement of the objectives of the National Agriculture Strategy, the National Environment Strategy and supports fully the achievement of the development goal of the SRAD Programme (2019-2025). The project is being implemented by FAO through direct implementation modalities in full collaboration and partnership with the MoEWA Under-secretariats for Agriculture, Environment and Livestock.

Prime beneficiaries of the FAO SRAD project are small scale rural farmers. It is generally acknowledged that the rural agricultural SMEs are not only about farming, but it's also an all-inclusive system of on farm and off farm activities and its linkages with value and supply chain og commodities. These act as a shock absorber in case of any food supply chain fluctuations as well as keeping the prices at an equilibrium. The rural agriculture SMEs provide a major source of income and employment at rural level; 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 mars their competitiveness at local level which then contributes negatively to the national competitiveness. The inefficiencies, broadly speaking, include reliance on antiquated 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, scarce skilled human resources. Performance of the agriculture sector, on the whole, through MEWA and its various initiatives is not exclusive of other stake holders including sister government agencies.

Context

The farm produce must be properly and efficiently handled in the commodity supply chain to assure the quality on arrival in markets. The SRAD target commodities are of differentiated characteristics in terms of their consumption and use, in terms of their integration in supply chain as primary or processed form and in terms of their perishability. These factors bring to focus methods and technologies to be applied to the agriculture commodities distinctly to these characteristics. Additionally, inherent inefficiencies in the food production chain leads to poor quality, a high levels of food losses that adversely impact food availability, productivity and the environment. As per FAO definition (SOFA 2019) food losses refer to the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers. Food loss or Post- harvest loss takes place from harvest up to wholesale market

Food waste is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers.

FLW effectively represent the decrease in the mass, nutritional value and/or quality attributes of edible food intended for human consumption. Prevention and reduction of FLW through good post-harvest management and processing practices is not only a goal in itself but provides a means to contribute to improving food security and nutrition, poverty alleviation, health and safety, employment generation, gender equality and preservation of the natural environment.

SRAD-51 strives to achieve the goal of sustainable rural agricultural development and contribute to the sustainable conservation and management of natural resources of Kingdom of Saudi Arabia through the following six strategic objectives:

1. Diversify agricultural production base
2. Improve income and living standards of small holders
3. Create job opportunities
4. Contribute to food security
5. Reduce migration and contribute to social stability and settlement in rural areas and
6. Preserve natural resources and environment

Having a closer look at these strategic objectives, it can be inferred that value addition/processing/diversification activities in all of the SRAD target commodities contribute to all of these strategic objectives and can contribute to reduce FLWs which currently stands at 33.1% (4.066 million tons) with a value of 12,980 million SAR per year (Saudi Grains Organization, 2019). The report covers output 5.1 "Rural agribusiness enterprises promoted particularly among youth and women entrepreneurs" with activities 5.1.9 "Facilitate development of infrastructure and logistics needed for production and processing of rural agri-food and traditional commodities" and 5.1.12 "Identify and promote innovative, cost effective technologies for traditional/indigenous agri-food production among productive families and indigenous producers" and output 5.2 "Technical skills of small holders and agri-entrepreneurs and other value chain actors strengthened on agribusiness management and value chain development" with activities 5.2.4 "Identify and disseminate best coffee processing practices including cherry drying and hulling techniques", 5.2.6 "Introduce and disseminate post harvesting and processing technology for fishery" and 5.2.7 "Assess the need for fruit production and processing infrastructure including cold storage, value addition centre and drying facilities and develop plan to strengthen such facilities" while at the same time recommendations of the report are also contributory towards output 3.3 "Small agricultural producers ad agribusiness entrepreneurs integrated into markets".

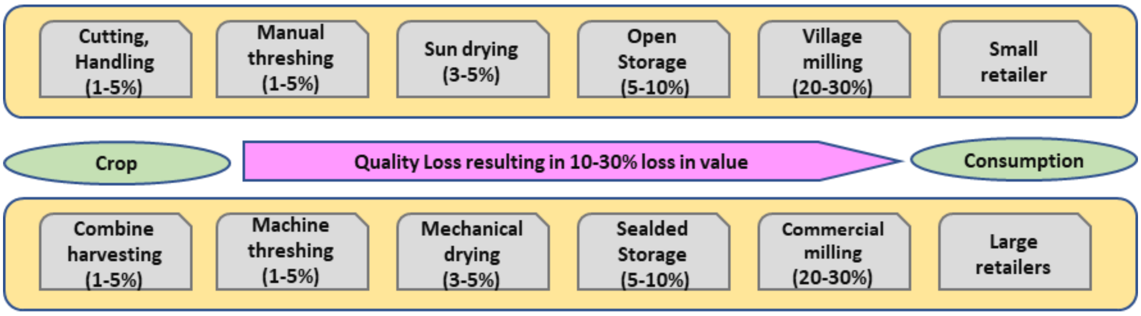
At the global level, postharvest losses have increasingly become a burning issue and consequently minimizing these postharvest losses continued to gain importance in the global food production systems (Affognon *et al*; 2015). These losses occurring in the postharvest stage of food chain are phenomenal; often exceeding 40% in some countries which not only cause huge burden on national economy but also leads to food insecurity and low nutritive value. With the increasing population, it has become even more important to reduce these food losses and waste through improving performance of food production systems. The major challenge faced by the food value chains is not only producing enough quantities of safe and nutritive food, but also to realize that agrifood production will continue to remain under pressure if these losses at postharvest level are not minimized and their shelf life as well as nutritive value not improved through processing and diversification (Aramyan and Van Gosh, 2014).

Understanding Postharvest losses:

Postharvest loss are referred to as any degradation in either quantity and/or quality of a food production from harvest to consumption. Quality loss refers to deterioration in nutrient composition, consumer acceptability and its preference for edibility while the quantity losses infer towards the losses occurring in amount of any product due to moisture loss, inappropriate handling, excessing bruising, high temperature etc. (Kader, 2002). FAO (2019) has elaborated quality food loss and waste as a decrease in food attributes that reduces its value in terms of intended use. It can result in reduced nutritional value (e.g. smaller amounts of vitamin C in bruised fruits) and/or the economic value of food because of non-compliance with quality standards. A reduction in quality may result in unsafe food, presenting risks to consumer health. Qualitative food loss refers to the decrease in food attributes that reduces the value of food in terms of its intended use – it results from decisions and actions by food suppliers in the chain. Qualitative food waste is the same but results from actions by retailers, food services and consumers.

Quantitative food loss and waste (also referred to as physical food loss and waste) is the decrease in the mass of food destined for human consumption as it is removed from the food supply chain. As such, quantitative food loss refers to the decrease in the mass of food destined for human consumption from decisions and actions by food suppliers in the chain. Quantitative food waste is the physical decrease in food mass resulting from decisions and actions by retailers, food services and consumers.

Both qualitative and quantitative food losses in the postharvest system comprises of interconnected activities from harvest including processing, marketing and food preparation till consumption. These losses occurring due to a plethora of reasons in the postharvest chain can occur at any link. With the increasing emphasis on global food supply chains and increasing their efficiency and food safety has resulted in a major shift of considering post-harvest system to be an integrated value chain linking



Estimated losses (weight and quality) from the postharvest chain for rice in South Asia. Source: Hodges *et al* (2011)

producers and consumers through trade, instead of being individual segments in a given food value chain.

On a wider scale, the food commodities can be divided in two broader categories based upon their perishability; Non perishable food crops and perishable food crops. The physiological behavior of both these groups is different and hence determines their usable life. Some distinctive features between the two are mentioned in the table below:

Perishable food commodities	Non perishable food commodities
Harvest spread over comparatively longer periods of time	Mainly seasonal harvest concentrated in a time window

Shelf-life extension generally possible after harvest through dehydration	Easier in field or off farm drying for storage
Products have generally higher moisture content (50-80% or even more)	Products have low moisture content (10-15 % or even less)
Voluminous and heavy fruits, vegetables, livestock and fish	Generally smaller in size
Higher respiration rate with higher heat induction and moisture losses	Low respiration rates and heat of respiration
Soft tissue, vulnerable to mechanical damage	Hard tissues
Early product disposition if not stored properly	Longer disposition of the product
Both intrinsic (respiration, transpiration, moisture etc) and extrinsic (insects, rots, rodents) factors responsible for losses	Generally extrinsic factors responsible for losses

Impacts of postharvest losses on agri-food supply chains

In almost all of the cases food losses occurring in any agri-food supply chain are either due to malfunctioning in the value chain or due to the inefficiency of the value chain actor in the supply chain. These malfunctioning in the value chain may be a result of absence of facilities and infrastructure or the market imperfections. There can be many reasons for these losses.

a. **Premature harvesting** in developing countries and, sometimes, developed countries, food may be lost due to premature harvesting as the poor farmers sometimes harvest crops too early due to food deficiency or the desperate need for cash during the second half of the agricultural season. In this way, the food incurs a loss in nutritional and economic value, and may get wasted if it is not suitable for consumption.

b. **Poor storage facilities and lack of infrastructure** cause post-harvest food losses in developing countries. Fresh products like fruits, vegetables, meat and fish straight from the farm or after the catch can be spoilt in hot climates due to lack of infrastructure for transportation, storage, cooling and markets..

c. **Unsafe food is not fit for human consumption** and therefore is wasted. Failure to comply with minimum food safety standards can lead to food losses and, in extreme cases, impact on the food security status of a country. A range of factors can lead to food being unsafe, such as naturally occurring toxins in food itself, contaminated water, unsafe use of pesticides, and veterinary drug residues. Poor and unhygienic handling and storage conditions, and lack of adequate temperature control, can also cause unsafe food.

d. **Lack of processing facilities** causes high food losses in developing countries. In many situations the food processing industry doesn’t have the capacity to process and preserve fresh farm produce to be able to meet the demand. Part of the problem stems from the seasonality of production and the cost of investing in processing facilities that will not be used year-round (FAO. 2011).

With increase in population, food demand, understanding about food quality and decrease in natural resources, the postharvest systems in the last century continued to gain more and more complexity as compared to the previous centuries. The major change in the postharvest system was to cover the entire system instead of focusing on a part of it. In the developing countries with postharvest systems not fully developed, the postharvest losses start at the farm, particularly for the perishable commodities (Van der

Vorst and Snels, 2014). A gist of the trends and impacts thereof on the agri-food supply chain and postharvest system are presented in the following table.

Global trend	Impact on agri-food supply chain and Postharvest systems
○ Global population growth, urbanization	▪ Scaling up and optimization of food supply chains, necessary in order to increase productivity and efficiency in output ▪ Exodus of population from the rural areas endangers the capacity to produce sufficient food for the cities, and requires new integrated concepts of food and biobased production (i.c. agroparks, metropolitan food clusters) ▪ Expanding cities with poor infrastructures offer challenges to distribute food in the cities
○ Growing middle class	▪ Increasing welfare and hence changing dietary patterns increase demand for high protein products (i.e. meat, dairy) ▪ Consumers become more demanding and critical, asking for good quality food products.
○ Scarcity of resources	▪ The decreasing availability of land and water per capita requires to invest in improved agri-food production systems ▪ Limited availability of fossil energy will require innovation in new (renewable) energy, specifically for cold chain development ▪ Valorization of waste streams from agro and food production require redesign of supply chain concepts (circular economy)
○ Safety, quality and sustainability of food	▪ Consumers become more critical towards safety and reliability of food products. Tracking and tracing systems increasingly affect product acceptance in markets ▪ Sustainability issues in supply chains become more important as consumer demand fair products and corporate social responsible conduct by actors in the supply chain (carbon footprint / food miles, water foot print, animal welfare, fair trade / fair employment,) ▪ Governments impose stringent requirements to minimize environmental effects to combat climate change
○ Internationalizations of trade and markets	▪ Increase of price volatility of raw materials ▪ Increased standardization of IT systems and data sources, as well as containerization allows virtual doing possibly resulting in global sourcing and distribution of long complex chains as a result ▪ An ever-increasing number of smaller (international) companies in every link of the chain dominates the market ▪ Increased focus on sustainability, however, also leads to regionalization, buying products from the region preferably produced on a small scale and close to nature.

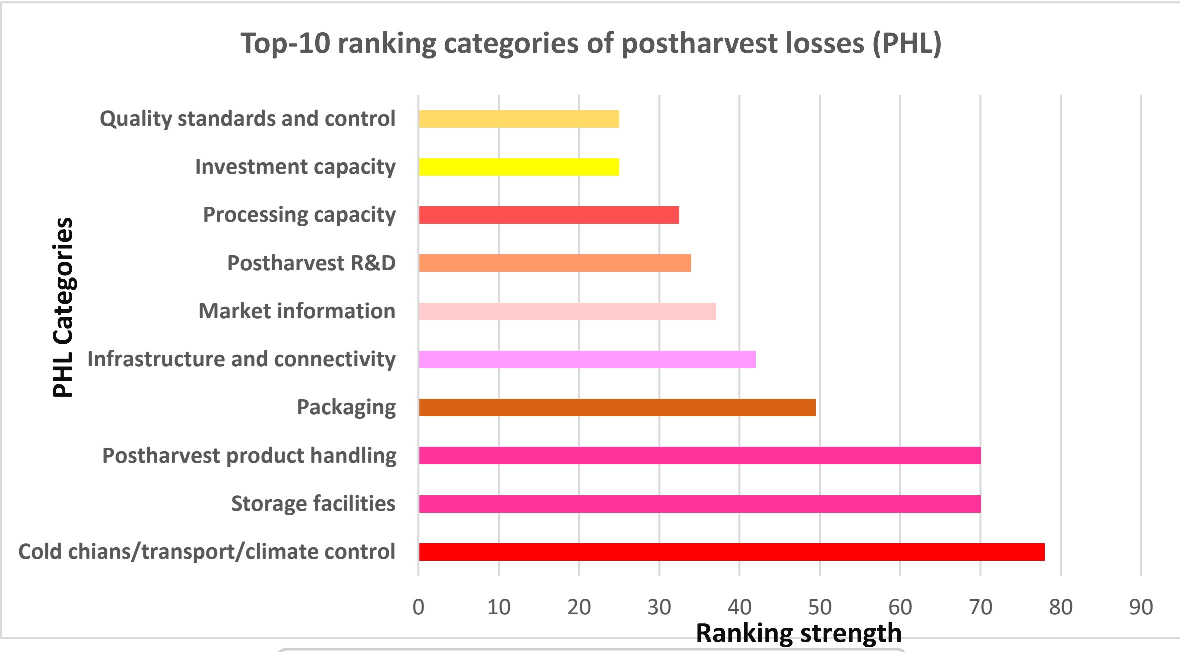
Categorizing postharvest losses:

To further understand the losses arising out of inefficiencies in the postharvest chain either due to the infrastructure malfunctioning or issues in management of the chain, Aramyan and Gogh (2014) categorized these causes into a wide series. Some major categories are listed below:

a. Cold chain transport: For perishable commodities, it is very important to immediately bring their core temperature to the lowest optimum to reduce respiration and moisture loss and hence increase shelf life. Fresh produce transport modalities, interruptions in chain of storages (at processing, transportation or at display), and absence of pre-cooling (field heat removal), if not designed to meet this purpose result in increasing postharvest losses.

b. Storage facilities: Absence of insufficient cold storage rooms, suboptimal performance and poor monitoring of product quality before subjecting it to storage may lead to spoilages.
c. Postharvest product handling: Most of the perishables are delicate in nature and require specific handling to avoid physical damage that results in increased postharvest losses. Rough handling of the produce, absence of grading and sorting, and absence of proper equipment leads to increased inefficiency in the postharvest chain.
d. Packaging: Developing countries using traditional packaging made up of poor material with designs not congruent with the postharvest physiological requirements of the product cause damages at handling, storage and transportation. Besides the design, overfilling of the produce and wrong stacking also leads to bruises in the produce as well as mixing of the product.
e. Infrastructure and connectivity: Poor quality roads, underdeveloped and unreliable energy networks create obstruction in the old chain.
f. Market information: Information pertaining to product demand, supply, existing prices, predicted supplies and market gluts result in below par paybacks
g. Postharvest R&D: Capacity of workers operating in the postharvest chain and their awareness about the protocols arising out of low education level or low skills also lead to non-adoption of new technologies and innovations which ultimately result in increased postharvest losses.
h. Processing capacity: Lack of inadequate processing facilities causes a shortage of outlets for second and third grade product, leaving the produce unused and spoiled. Another important factor under his category is usage of processing equipment with low technical efficiency that generates high waste and food loss.
i. Investment capacity: Lack of access to capital, collateral and high interest rates are an impediment to investment in postharvest technology. Low investment levels in rural areas due to small-scale production, makes it difficult to achieve improvements in efficiency and economies of scale.
j. Standards and quality control: If the produce does not meet the minimum requirements of the target market (particularly for export market), this can lead to rejections at destination. The issues in this category arises out of unclear standards, low enforcement of standards, mixing of good and damaged products or absence of infrastructure to test the products for compliance.
k. Chain length: The time taken to get the produce from harvest till the final consumer in any logistics chain and marketing chain for perishables is complicated with dominant role of middlemen and other actors. This not only cause delays but also adds costs and losses this decreasing margins.

The most important underlying causes for postharvest losses in perishables are related to the absence of the cold chain along with poor transport climate control. The absence or poor quality of storage facilities in the chain and improper handling of the produce is also a major underlying cause of postharvest losses. Relative standing of each category is given in the below graph:



Adopted from Aramyan and Gogh (2014)

With the advances in science and technology, the past century witnessed an exponential increase in the productivity of many agricultural crops, livestock and other allied industries. This was made possible due to breeding of new cultivars, breeds alongwith their respective technology package to get higher outputs. In the 3rd and 4th quartile of the preceding century, it was increasing felt that the challenge to feed the world with a nutritive food that is accessible to all at all the times does not lie only in producing enough for the increasing population. It is equally important to apply a systemic approach to manage quality and reduce postharvest losses to avoid undue damage and come up with sustainable processing and packaging technologies that help in increasing shelf life and nutritive value of the perishables.

Determining good postharvest/processing technologies best suited for small producers:

It is interesting to note that the technologies to reduce postharvest losses need not be so high tech or complex. In fact the best postharvest/processing technologies are those that have the ability to fit well within the existing system or at least does not significantly distort the existing systems. There are different methods being used in making decision to select an appropriate technology including postharvest/processing technology by the small-scale producers. Technology selection remains a big question for small farmers when other economic and social factors must be considered (Giordano and de Fraiture 2014, Namara *et al*. 2014). Some techniques being used for determining technologies for small rural farmers include Analytical Hierarchy Process (AHP), Fuzzy Logic (FL) as part of Multi Criteria Decision Analysis (MCDA). It is an established fact that producers choose postharvest methods suited to their region and existing practices in the production unit. They also consider post-harvesting cost and technology adoption capacity. The other criteria including profit, price, social environmental and cultural considerations cannot be ignored either (Scheffler *et al*, 2014). The MCDA in our case shall follow the following criteria for selecting a good postharvest/processing technology best suited for small producers and it should contribute to:

1. Reduce losses: There are generally two kind of losses in a postharvest chain; quantity loss and quality loss. Quantity loss is a decrease in the amount of a product while the quality loss refers to the decrease in food attributes that reduces the value (nutritional and economic) of food in terms of its intended use. The losses may occur due to adverse effect on the appearance, flavor, food safety, texture and nutritional quality of the produce.
2. Reduce economic loss: The prime objective of any producer is to improve its profitability. This can be achieved through a number of means including increasing production, quality, decreasing post-harvest losses etc. A post-harvest/processing technology, to be selected, has to result in reduction of economic losses.
3. Increase efficiency: The inefficiencies arising out of infrastructure or capacities of postharvest chain actors lead to increase postharvest losses. This forms another criterion for technology selection if that technology increases efficiency at any level from harvesting, field heat removal, transportation, storage, value addition, packaging, etc.
4. Social and cultural acceptability: The technology needs to be in coherence with the existing social and cultural norms. Some of the processing or value addition technologies at postharvest level under use in the western countries may not be appropriate for KSA.
5. Gender friendly: Women constitute around 50% of the population and without a gender inclusive approach no value chain can achieve better efficiency. At small rural holders' level, postharvest technologies that are gender friendly are most easily adopted on a wider scale and results into higher margins.
6. Innovation: Innovation can be either minor or major with the objective to improve efficiency and reduce losses or increase marketability of the product.
7. Adoptability: Adoption at the individual small holders' level is the degree of use of new technology in long run when they have full information about the new technology and its potential. Generally, rural small producers tend to adopt those technologies earlier that have a better fit in their existing production or postproduction system.
8. Environment friendly: Any technology that contributes positively to the environment besides contributing to the above cited other criteria, can be selected.

The process:

Identification of best postharvest/processing technologies is an essential strategy for increasing food security, alleviating poverty and ensuring sustainability amongst the small holders. It is quite understandable that not all the suitable technologies can be mentioned here. Effort was made to confine only to a very few that are easiest and comply with the selection criteria are mentioned in each of the commodity component of SRAD51. The process of selection of any postharvest/processing technology for SRAD51 target commodities, the following sequence was followed:

a. Discussions with the commodity component team, visit field and discussions with stake holders about the existing technologies in vogue and problems thereof.
b. Analyse the gaps and areas of improvement in the existing postharvest/processing practices
c. Identify appropriate postharvest/processing technologies for each commodity of SRAD which is compliant with the determining factors mentioned above at any stage after harvest.
d. Validate the identified technologies form the sector experts

The next section mentions the brief of recommended low hanging one or two post-harvest technologies in SRAD51 target commodities while giving a brief account of the commodity and then trying to elicit the technology/ies with illustrations wherever possible.

1. Coffee

Coffee is one of the commodity components of the SRAD project as the agroecological and climatic conditions in south-west regions of KSA are conducive for the Arabica coffee production. The coffee tree, genus Coffea, family *Rubiaceae* (Madder family), is native to Ethiopia (Davis *et al*, 2007). The name coffee also refers to the fruit (beans) of the tree and to the beverage brewed from the beans. Coffee is one of the world's most valuable agricultural crops. There are about 30 species of Coffea, but only two species provide most of the world market for coffee. *Coffea arabica* is indigenous to Ethiopia and was the first cultivated species of coffee tree. C. arabica provides 75% of the world's supply of coffee. *Coffea robusta*, also known as *Coffea canephora*, is a native of equatorial forest of Central Africa. This species was not domesticated and cultivated until the turn of the twentieth century, and now supplies about 23% of the world's coffee. *Coffea liberica* is also an important source of coffee beans but is mostly consumed locally and does not enter the world market in great quantity. Arabica coffee is the most preferred although with technology good quality coffees are being prepared from Robusta coffee (Davis, 2001).

Coffee is considered to the king of beverages at global level by providing a revitalizing effect owing to the caffeine presence in it with numerous ways of presentation (Miron-Merida et al., 2019). In terms of commodity trading, only crude oil surpasses coffee. Coffee has a global turnaround of USD 100 billion per annum with a production volume of 10,538,820 metric tons during 2020 (Reference). The global coffee market, which was valued at approximately USD 102.15 billion in 2019 is expected to climb to USD 155.64 billion by year 2026 with a cumulative average growth rate of nearly 6.2% (Businesswire, 2020).

In KSA, coffee production and processing play a major role in the economy of rural coffee growers besides being considered as a status symbol and epitome of cultural hospitality. What sets KSA apart from other regions is its rich coffee traditions that evolved much before the European coffee cultures and are still existent today. In fact, "qahwa", the Arabic word for coffee, is the root of the word "Coffee" or "Café" used today.

In KSA, coffee is grown in the south-west region, the Fayfa mountains in the south to AlShada mountains in the north covering the regions of Jazan regions of Jazan, Aseer and Al Baha where the agroclimate is suitable for the Arabica cultivation.

Coffee production and harvesting

The coffee plants come into bearing during 3rd or 4th year of planting and into full production from year 5 onwards. The coffee plants come into bearing 2-3 times a year after each rain shower following a period of drought, then matures over seven to nine months from flowering to ripeness. Coffee fruit called cherry does not mature uniformly and as such the harvesting period may extend over months. The use of immature cherries in the production of coffee is associated with poor quality coffee. Therefore, it is important to harvest coffee cherries that are fully mature. In fact, coffee harvesting is the first step of coffee processing and quality assurance.

The most important indicator of coffee cherry ripening is its color. The coffee cherry starts green then fades to yellow, and then turns a rich orange, and finally becoming a deep, dark red (other varities the cherry becomes deep yellow). This is the time when it is considered fully mature and ready to harvest. This colour change is dependent upon the temperature and exposure to sun. Generally, the cherries located on the outer canopy of the plant mature earlier than the ones inside the canopy or in shade. Similarly, the cherries facing sun front mature a bit earlier than the ones located away from the sun f.

Picking of immature coffee cherries give rise to blackening during the drying process and coffee made from immature cherries has undesirable taste characteristics. This further adds up time during drying of coffee at harvest. At the same time, over mature coffee cherries are prone to fungal attack which may give rise to ochratoxins-A contamination (Bucheli and Taniwak, 2002). OTA contaminated coffee is not fit for human consumption.

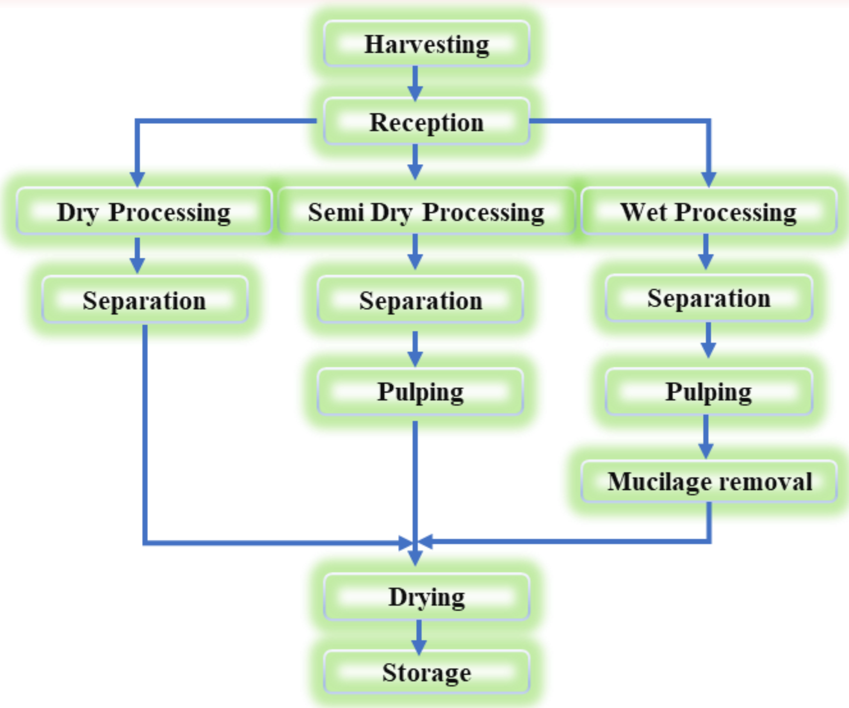
Several harvesting methods are used worldwide depending upon the agroecology and cultivars planted. These are strip picking, machine picking, and hand picking.

a. **Strip Picking:** This picking method is mostly utilized by small rural holders with fewer number of plants as this method does not require any modern machinery and is also quickerIt is more practiced in robusta coffee production where more uniform ripening is attained.
b. **Mechanical picking:** This picking method is very limited as it requires a plain area with large plantations for the operation of harvesting machines. The initial cost of harvesting machines is high that gets compensated by low labor utilization. Therefore, in major coffee producing countries, like Brazil, where larger plantations exist in plain areas, this method of machine picking is extremely efficient.
c. **Hand-picking:** This type of picking takes comparatively more time consuming and utilized in specialty coffee processing. The trained labor in this method only picks the fully mature cherries while leaving the unripe for later harvesting when these reach maturities. This expands the harvest span of cherries. However, the resultant coffee cherries are of highest standard.

Drying and processing

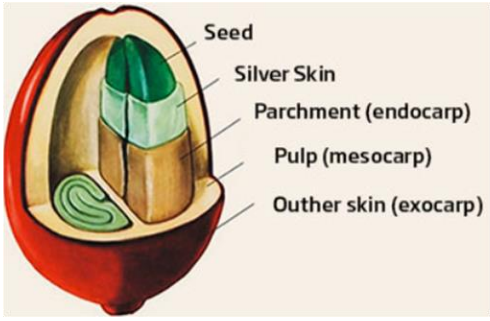
Irrespective of the drying method, mixing of overripe and immature cherries should be avoided as this adversely affects the quality of the final product. There are two main methods of processing: wet and dry. In KSA, due to scarcity of water only the dry processing method is utilized which is simpler and comparatively less expensive. Before processing, sorting of harvested cherries is done through separating overripe, immature and damaged cherries besides removing dirt and other inert material by winnowing, which is commonly done by hand with a large sieve.

Coffee drying in KSA is carried out in the shade with sufficient air flow to remove moisture for 10-15 days (depending upon ambient temperature) with daily turning of beans. Slower drying due to lower temperature and high humidity may lead to formation of molds and ochratoxins. Rarely sun drying is also done but requires regular monitoring and tilting 2-3 times a day. Sun drying requires 3-5 days. In case tilting is not regularly done and only one side of the beans gets exposed to sun, the may get discolored and too brittle for dry processing. Mechanical drying is not practiced in KSA. It is important to know that a very slow drying is as detrimental as a too quick drying methods as these can harm the quality of the processed product. Generally drying is preceded by sorting of off types or foreign materials from the harvest before subjecting to drying.
The simplicity and complexity comparison of both the processes is presented in the following figure. It is evident that in the Dry Processing (Natural Process) the cherries are being dried; while in the Wet Processing (Full Wash Process) the skin and pulp of the bean has been removed with only the parchment left covering the “green coffee beans” inside. In addition, in Wet Processing, after pulping the parchment beans or pulped beans undergoes mucilage removal by allowing it to ferment up to a couple of days and then rinsing (before it goes to drying). A variation of the Wet Process is the removal of the mucilage after pulping using a demucilager.



General Scheme of coffee processing and preparation of green coffee beans.
Adopted from Ghosh and Venkatachalapathy, 2014.

For dry processing, prevalent in the KSA, the cherries after initial drying and reaching to a moisture level of 10- 12%, are subjected to hulling where the entire dried husk (i.e. pericarp consisting of outer skin(exocarp), pulp (mesocarp) and parchment or hull (endocarp)) is removed through a mechanical hulling machine comprising of a steel screw with an inversely increasing pitch to remove the pericarp. In KSA, coffee farmers and traders generally use hulling machines whose speed and design is not so efficient for coffee hulling. This translates into smashed green beans lowering coffee quality and ultimately eroding profitability of the farmer.



After hulling, the winnowing is done to clean the coffee for removal of small debris. Defective beans are also removed at this stage. In major coffee producing countries chroma sorters are employed to detect any off colored and off type bean. While in KSA, no cleaning, sorting or grading is done. Sorting and grading offer the quickest method of value addition.

The green coffee beans may be packed and stored in good storage conditions at low relative humidity and away from light for either sales as such or for roasting as a next step. The traditional method of roasting in KSA transforms green coffee into the aromatic brown beans at a temperature of about 550 degrees Fahrenheit. The beans are kept moving throughout the entire process to keep them from burning. When they reach an internal temperature of about 400 degrees Fahrenheit, they begin to turn brown and the caffeol, a fragrant oil locked inside the beans, begins to emerge. This process called pyrolysis is at the heart of roasting — it produces the flavor and aroma of the coffee we drink. Such chemical reactions modify the coffee beans' chemical composition and produce the coffee compounds associated with the brewed coffee's flavors and aromas.
After roasting, the beans are immediately cooled. Roasting is generally performed in the importing countries because freshly roasted beans must reach the consumer as quickly as possible. Time duration

and temperature adjustment are the key to develop good taste and aroma at this stage. Various kinds of roasting mechanisms are employed globally in the coffee producing countries.

a. Coffee roasting machines: These roasting machines use electricity to heat up the drums to the desired temperature ranging from 370^{o}F to 550^{o}F, while continuously rotating the beans in a circular motion for even roasting.
b. Fluid bed roaster: This kind of coffee roaster utilizes and column of hot air to agitate and roast the green coffee means. These are also known as Sivetz roaster.

This is the final step with subsequent processes like grinding and brewing being done at the consumer level are optional.

Gap analysis

1. **Harvesting:** The current method of harvesting i.e. manual harvesting of mature coffee cherries by trained labor is good for specialty coffee. However, at the same time, it has additional cost associated with it in terms of labor costs spread over larger period of time notwithstanding the fact that trained manpower to harvest only the mature cherries is even more costly. Rising labor wages and their availability is yet another issue. More and more young labor is moving to the urban areas in search of better paying job thus leaving behind a smaller number of labors. Adequate skilled labour to selectively pick the coffee
2. **Drying:** Drying on the ground has a number of flipsides.
    a. The sandy soil or the gravel/stone segments within the soil, or the stoned floor have the ability to absorb and reradiate solar energy thus exposing some part of the cherry to higher solar energy than the others. This leads to either non uniform drying of a beans within the lot which results in quality compromises.
    b. The produce is exposed to dust and dirt which pose another health hazard besides lowering the quality of the produce.
    c. The time taken for drying varies from 10-15 days
    d. It requires a lot of space to spread the harvested cherries in case of larger plantations. Generally, the layer should not be more than 4 cm.
    e. The problem of ochratoxins-A[1] can potentially arise which, beyond permissible limits described by WHO (WHO, 2001), makes the product unfit for human consumption (FAO, 2006.,Van der Stegen *et. al*., 1997).

3. **Hulling:** Majority of small rural coffee producers in the coffee producing areas of KSA are utilizing hulling machines that are not specially designed for coffee. The damage caused by either over dried beans and/or the use of these machines results in smashed and broken beans which not only lead to loss in quality but also invites microbial infections. Ultimately, the profit margins of the producer get compromised as well as his reputation in the market becomes vulnerable.

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[1] The occurrence of Ochratoxin-A (OTA) in green co�ee was first found in 1974 (Levi *et al.* 1974) and later in commercially roasted coffee beans in 1988 (Tsubouchi *et al*. 1988). The earlier consideration for this class of mycotoxins was that these get decomposed during roasting and as such do not pose health risk. However, later studies revealed that OTA in soluble as well as roasted form are detrimental beyond permissible limits. (MAFF 1996, Pittet *et al.* 1996, Koch *et al.* 1996).
The name Ochratoxin-A comes from *Aspergillus ochraceus* (van der Merwe *et al.* 1965) with six species of ochratoxin producers: *A. ochraceus, A. alliaceus, A. sclerotiorum, A. ostianus, A. melleus and A. sulphureus* were reported (Ciegler, 1972).
European Commission's Scientific Committee for Food (SCF) declared OTA to be a hazardous contaminant (European Commission SCF, Working Group on Contaminants 1995). Many European countries have introduced national limits on green coffee or coffee products e.g. Italy 8 mg /kg, Finland 10 mg/kg, Greece 20 mg/kg and Switzerland has 5 mg/kg. (Patel *et al*. 1997, Bresch *et al*. 2000)

Options of Suitable technologies

Based upon the gaps identified at various postharvest stages of coffee, the following technologies with their comparative advantage are suggested:

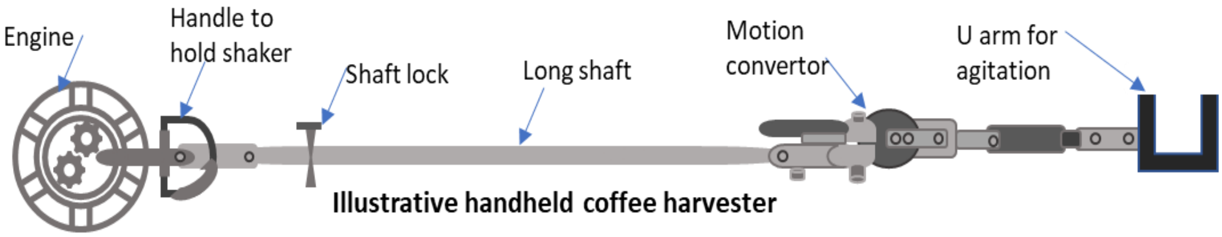
A. **Harvesting:** In order to overcome the shortfalls present in the existing manual harvesting and considering the landholdings of small rural coffee producers, terrain of the coffee producing area, adoptability and other indicators, the best option seems to be the handheld mechanical harvester. The comparative advantage against the selection criteria is given below:

Criterion	Current method compliance	Proposed method compliance
Reduce losses (Quantity, Quality)	Partial	Full, avoids damage to the cherries being harvested
Reduce economic loss	Partial	Full; quality of harvest is better, labor costs reduced
Increase efficiency	Partial	Many times more efficient that the total manual harvesting.
Social and cultural acceptability	-	Acceptable
Gender friendly	No	Yes, as it does not require much of the human energy and can harvest with upto 8 times efficiency.
Innovative	Conventional	Yes
Adoptability	-	Yes. Being low cost, efficient, easy to handle, and efficient, fitting within the existing system.
Environment friendly	Yes	Yes

Specifics of handheld mechanical harvester

Why mechanical harvesting? Determining how to pick the fruit depends on multiple factors including cost of labour, time required to harvest, area to harvest and above all delicacy of the product. Many fruit harvesting methods utilize reciprocating vibrations to separate mature fruit from plant. It acts on the fact that the peduncle of mature fruit develops abscisic acid that creates a layer of abscessed cells thereby weakening the join of fruit with plant (Setha S., 2012). Towards the maturity, cherries develop a layer of abscission at the attachment point. The abscission layer leads to easy detachment of the cherries. A little shaking helps detach the mature fruit only while aggressive shaking might lead to harvesting of unripe cherries which may cause quality loss. The proposed handheld mechanical harvester for coffee is designed to pick fruit with low labor intensity and as such incurs less cost under this head. The larger harvester work on the principle of agitating the plant and collect the harvested fruit in a canvas spread beneath the canopy of tree installed with the harvester connected to a storage trolly via a conveyor belt.

The proposed harvester for coffee is a miniature handheld version of the same and works on the same principle of agitating/shaking the branch to get the mature cherries shed off the tree and collected in canvas spread beneath the canopy to collect the fallen fruit. *Coffea arabica* cherries mature at different times as compared to *Coffea robusta*. The shaking allows mature/ripe cherries to drop and get collected for further processing. As mentioned earlier, care must be taken not to agitate too aggressively to avoid harvest of immature fruit. The equipment is composed of a motor that is run by either DC electricity or by a gasoline engine to produce electricity and run the motor (both options are available), a long adjustable handle with a shaking clamp type structure at the end which is engulfed in soft rubber to avoid physical damage to the branches. The motor provides the agitation force to shake the branches and get the fully mature cherries harvested. The same machine has been tested and used in olive and almond harvesting.



Illustrative handheld coffee harvester

This handheld harvester with a weight of around 13 kg with a rated no load speed of 900 beats per minute and electric power source of 12 volts with a power usage of 80-100 W.

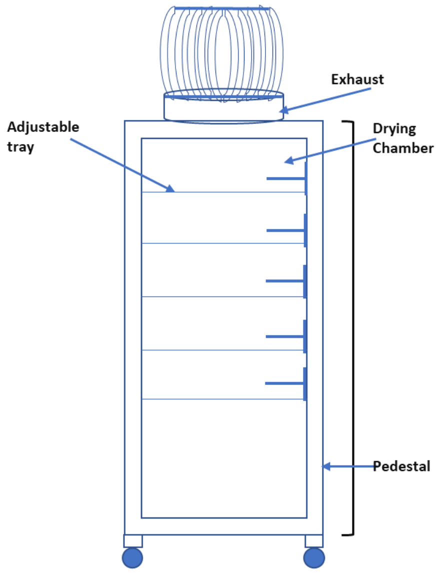
B. **Drying:** The gap analysis of currently employed drying technology by the coffee farmers reflects quite a number of gaps that needs to be a abridged for increasing quality, efficiency and hence profitability of the farmers. Coffee drying is important for stabilizing this otherwise unstable product.
    a. A number of technologies are existent for mechanical drying of coffee cherries with varying energy requirements and costs. However, utilizing the nature's free energy gift of sun cuts down energy costs for drying purpose. Cherry drying in the sun requires energy to the extent of about 17000 KJ/kg of fresh coffee cherry at a layer thickness of 4-6 cm (FAO, 2006).

A multitude of techniques are being employed by coffee producers across the world depending upon their farm size, agro-climate and the target market requirements. But sun drying is considered to be the most economical one. However, the flipside of it comes into play when this drying is done on concrete floor or on field floor or on roofs with no detachment from the ground and no covering on top. This leads to a number of problems including quality deterioration due to uneven drying, dust and dirt, as well as ochratoxin-A infestation.

The other drying methods include (i) mechanical drying including static bed or silo drying where hot air is forced through a bed of coffee, (ii) Contra-flow or vertical dryers where the coffee is cycled from bottom to top and allowed to flow downward through a stream of hot air, and (iii) horizontal dryers where the hot air is introduced through a central shaft and forced outward through a rotating, perforated cylinder oriented horizontally. However, mechanical drying also requires some kind of pre-drying that to some extent, is done under sun.

The thorough gap analysis and the existing drying system in the coffee growing areas lead to proposing two kinds of drying: though both acting on the same basic principal of using moving air for taking out moisture from the cherries. It needs to be considered here that the conventional solar dryers raise the temperature inside the drying tunnel to an extent which can potentially deteriorate the composition of this specialty Arabian coffee.

(i) **Simple drying on multilayered drying structures:** These structures can be made locally without any hassle with wood having multiple slidable perforated trays at a height distance of around 20-25 cm from each other while a ground clearance of 25 cm from the ground. The perforated trays allow better air circulation thus allowing the produce to dry quickly. However, the cherries need to be tilted after every 3-4 hours to facilitate even drying of cherries on all the sides. These tables are covered by the mesh to protect from dirt and dust. The addition of small exhaust fans on top or sides induces air circulation to increase efficiency of the structure. It is better to have a movable structure to move inside the building or a covered place in case of rain or during night.

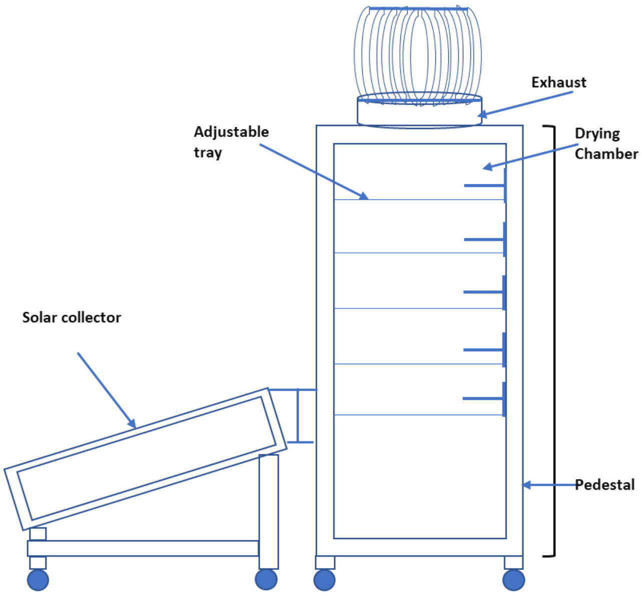


Schematic diagram of coffee multilayered dryer

The cost in this case is very minimal as the wood panels (or aluminum panels) and making perforated trays can all be done locally without much of the cost. It is easy to handle and environment friendly and gender friendly as well.

(ii) **Hybrid Multilayered structure:** At higher elevations during winter period when temperature is low and the moisture carrying capacity of air or moisture diffusivity gets low (Varadharaju *et al*, 2001), it becomes useful to have the similar kind of structure with a modification to add a panel to trap solar heat and utilize it for the same purpose of drying cherries. The same structure can be used for drying fruits and vegetables if covered with polythene sheet to increase solar insolation.

The connection between the drying structure and solar heat generating structure can be made through polyethene sheet. The hot air generated in the solar structure goes into the drying structure, rises up through perforations and on the way out takes moisture with it on its way out. Both the structures stay movable for ease of usage. This structure is also easy to handle, low cost, gender and environment friendly. For larger capacities, the same principle can be applied in the plastic tunnels having above ground drying tables with perforated cloth (or mesh) for better air circulation and moisture exchange.



Schematic diagram of Movabel Conjugated Coffee dryer

Criterion	**Current drying method compliance**	**Proposed method compliance**
Reduce losses (Quantity, Quality)	Partial	Full, avoids damage to the cherries being harvested, particularly ochratoxins and coffee composition
Reduce economic loss	Partial	Full; quality of harvest is better, labor costs reduced
Increase efficiency	Partial	Being movable, can be shifted to shade or sun depending upon requirements. Additionally, the conjugated dryer version can also work for fruits and vegetables
Social and cultural acceptability	-	Acceptable
Gender friendly	No	Yes, as it does not require much of the human energy and can be handled easily as well as occupies less space
Innovative	Conventional	Yes
Adoptability	-	Yes. Being low cost, efficient, easy to handle, and efficient, fitting within the existing system.
Environment friendly	Probability of Ochratoxin A and other contaminations	Yes, minimizes the contamination chances.

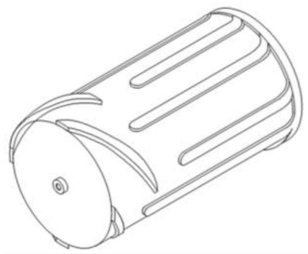
C. **Hulling:**

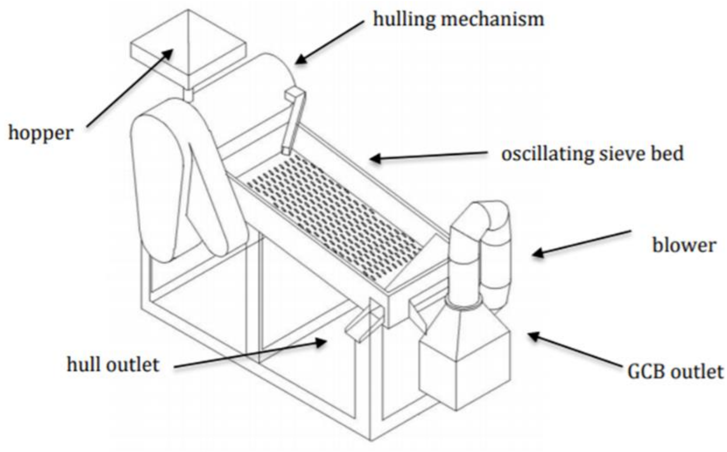
Removal of thin parchment around the coffee is called hulling. Majority of small rural coffee producers in the coffee producing areas of KSA are utilizing hulling machines that are not specifically designed for coffee. The objective of hulling is to remove the dry pericarp and get the green bean through coffee hulling machines. Having right kind of huller as well as its setting is as important as having the dried coffee at optimum moisture content. Incorrectly set huller or the overdried beans may result in damaged coffee beans (FAO, 2005). Similarly, if the beans have higher moisture content, these will get crushed in the huller thus causing losses to the farmer.

In order to reduce postharvest losses at hulling stage and maintain the coffee quality without incurring much of the labour costs as well as meeting with international standards, mechanical hulling is required. There were different hulling machines being used by the coffee farmers but since most of these dehulling machines are primarily designed to be used for cereal grains, they somehow damage the beans thus lowering the produce quality. The performance efficiency of a huller can be judged by the quality of coffee beans delivered at the end of operation. A good hulling machine does not have a percentage breakage exceeding 3% (Dibaba *et al*, 2019).

A good hulling machine for small rural farmers should be affordable yet efficient. It should have a close ended rotating shelling cylinder with adjustable speed with round bar welded on 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.

Based upon the comparative advantage of these hullers as opposed to other in the market, the following mechanized coffee huller is suggested.





Simple coffee huller with components
Adopted from Bureau of agriculture and fisheries standards, Philippines (2017).

The machine has a power usage of 30KW with machine body and other parts made of corrosive resistant stainless steel of grade 316 or 304.

Criterion	**Current hulling method compliance**	**Proposed hulling machine compliance**
Reduce losses (Quantity, Quality)	High losses	Losses less than 3% as it avoids damage to the beans during hulling
Reduce economic loss	Partial	Full; quality of hulled produce is better with less damaged beans, labor costs reduced
Increase efficiency	Partial	Increased efficiency in terms of less damaged beans hulling
Social and cultural acceptability	-	Acceptable
Gender friendly	-	Yes, being electric power driven it does not require much of the human energy to operate and can be handled while fitting within the house.
Innovative	Conventional	Yes, adjustable speed and distance between the hulling arts.
Adoptability	-	Yes, although the initial cost might seem a bit higher but it is specifically designed for coffee and as such is more efficient, easy to handle, and efficient, fitting within the existing system.
Environment friendly	-	Same as existing cereal hulling machines being used for coffee hulling.

Recommendations

For coffee harvesting, in comparatively larger plantations where the harvesting costs are high, small rod shaped mechanical harvestor is recommended as it is economical, easy to operate, suitable for the coffee growing terrain and has better efficiency. Care must be taken to adjust the speed of shaking to avoid injury to branches and at the same time avoid harvest of immature cherries. However, for smaller plantations where harvesting costs and time to harvest are not an issue, small farmers might keep utilizing manual picking.

For drying cherry beans, the multilayered dryer with removable trays is recommended with a possibility of its hybridization with a solar heat generator for usage to dehydrate other commodities too. For larger plantations, the plastic tunnel working on the same principle and having elevated drying trays (beds) with perforated mesh to allow efficient air flow and hence moisture exchange may be utilized. While for hulling purpose, the motorized huller with speed adjustment is recommended that will help increase efficiency and reduce damage to beans.

2. Beekeeping and honey production

Production and utilization of honey is as old as human history. Honey has been used since ancient time due to its nutritional and therapeutic values. There had been varied ways of consumption honey including its use as a sweetener and flavoring agent. The most important ingredient of honey is carbohydrates present in the form of monosaccharides, fructose, glucose and disaccharides, maltose, isomaltose, maltulose, sucrose and turanose and the sweetness of honey is due to presence of these ingredients. It also contains oligosaccharides including the anderose and panose and enzymes including amylase, oxidase peroxide, catalase and acid phosphorylase. Furthermore, honey contains amino acids, trace vitamin B, Vitamin B6, Vitamin C, niacin, folic acid, minerals, iron, zinc and antioxidants (David, 2007, Fatimah *et al.*, 2013). Honey is commonly used as an anti-inflammatory, anti-oxidant and anti-bacterial agent (Noori *et al*., 2014).

Honey is highly valued by users for therapeutic purposes as an alternative medicine. However, its use has been controversially discussed in the literature, whether treatment with honey bee product is safe or not especially for metabolically compromised people. It is also strong believed that honey bee is a main source of nurturing and dynamism. The health promoting characteristics of bee are mainly due to the presence of multiple metabolites including folic acid, thiamine, biotin, niacin, tocopherol, polyphenols, phytosterols besides enzymes and co-enzymes. The favorable facts on the anti-oxidant, anti-bacterial, anti-fungicidal, hepato-protective are recurrently available in the scientific literature. In principle, honey is a valuable supplement for healthy population (Denisow and Denisow, 2016). Recent advances in research, literature highlighted that honey has potential biological activities with promising health promoting properties (Muhammad et al., 2016).

The honeybee and thus honey is well distributed over the globe except in the severe cold of the polar regions. The Kingdom of Saudi Arabia has most of its area as lowland plain and deserts however there are also extensive hills, mountains chains and associated fertile valleys which are best used for beekeeping than other agricultural activities (Al-Ghamdi and Nuru, 2013). The Sarwat Mountains which range in altitude between 800 and 3 000 meters above sea level and stretches for more than 1 000 km is one of the dominant and extensive land features in the southwestern parts of the country. These mountains have diverse climates and receive relatively better rainfalls in summer, winter and early spring and support the growth and flowering of a great diversity of plant species that are rich in nectar and pollen for bees. These Mountain chains and their associated valleys are relatively beekeeping potential areas of the country. Because of its potentiality more than 70 percent of the bee colonies in the country are exist in the regions of Al-Baha, Jizan, Mekkah, Aseer, and Al-Medinah (Al-Ghamdi, 2007).

For the small rural farmers, it is even more important in terms of providing high nutrition to combat malnutrition as well as a source of income. FAO in its Agri Service Bulletin 68/6 (FAO, 1990) mentioned the importance of honeybee farming for small rural farmers for the following reasons:

- Rural traditional level apiculture is cheap as it does not involve mass feeding of bees, because the insects can provide their own food all year round, and there is no over-wintering bee management.
- Inputs for traditional beekeeping e.g. pollen and nectar from flowering plants are available locally.
- Limited funds are required to initiate honey production.
- It is a self-reliant business.
- Local improvisation of technologies is already there.

- It improves the ecology. It helps plant reproduction. Bees do not over-graze as other animals do.
- The honeybee produces honey, beeswax and propolis. These are non-perishable commodities that can be marketed locally or abroad.
- The honeybee provides pollination service. This is an indispensable activity in the food production process.
- The honeybee is the only insect that can be transported from crop to crop.
- Honey and beeswax can be produced in semi-arid areas that are unsuitable for any other agricultural use.
- The beekeeper does not need to own land in order to keep bees.

Rural areas of the kingdom of Saudi Arabia has centuries old tradition of beekeeping and honey production. However, the beekeeping practices are generally traditional with migratory pattern of management and more than 70 percent of the bee colonies are kept in local hives with recent trend of shifting to modern hives with higher yield potentials.

Honey seems to be the only product that is currently being utilized by the small rural farmers while the second most important product of the same farming i.e. bees wax is generally neglected. Beeswax is an important by-product used in many different ways to make candles, polish, cosmetics, food, engineering and other industry (MAAREC, 2005). Beeswax, in certain instances, depending upon its quality, can provide an appreciable income in addition to honey. In KSA, most of the wax is either not utilized or is extracted in a non efficient way that leads to compromises on its quality, as well as price.

Beeswax rendering

Wax comes from the honeycombs for which this wax secreted by honeybees is used as a construction material. Major constituents of wax are carbohydrates, honey sugars fructose, glucose and sucrose. The raw products for wax manufacture are old combs and capping, particularly from the traditional log hives. The beeswax production and processing practices use traditional and inefficient techniques that leave significant amount of beeswax resource unutilized (Ayalew, 2008). Although it is a nonperishable commodity, but the methods of its processing and handling greatly influences the quality and quantity. The efficiency of manual beeswax rendering method is very low, only 50% efficient compared to mechanical presser and other methods. Improving the beeswax extraction technique can lead to more wax extraction of better quality and this adding to the profitability of honeybee farmers.

Beeswax rendering technologies

With the development of industrial sector in 19th century, demand for beeswax increased and new methods of beeswax rendering were invented. These methods involve a combination of melting and filtering the beeswax.

The following methods are most commonly used:

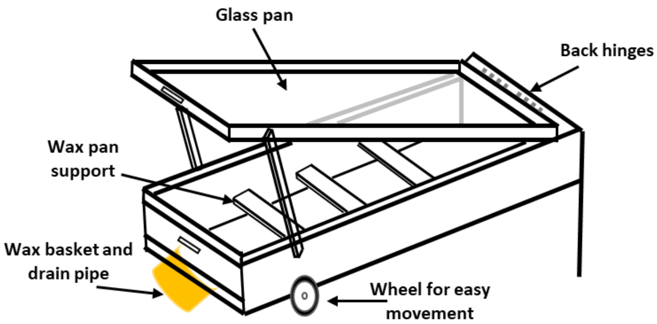
1. **Hot water extraction using immersion method:**

This is also called the manual extraction method for beeswax. The collected combs put in a cheesecloth are first immersed into water for dissolving any remaining honey and dirt etc. After this straining, the wax is melted in boiling water as the wax has a boiling point of 67°C. The boiled mixture is let to cool so that the wax comes on the surface and is removed from there. This utilizes manual force to extract wax and has its own limitation. Besides, for boiling purpose, the fire wood or other fossil fuel is used that is not environment friendly.

Source: Montanahomesteader.com

2. **Extraction with boiling water and a wax press:**
   In this methods, honeycombs are placed into a big size water container. The mixture is then boiled and wax melts. When all the wax has melted, the content is poured in jute-lined press, then for pressing and getting rid of excess water. After obtaining wax, it is put into various moulds for further marketing. The method utilizes fossil fuel for heating and is not environment friendly.

3. **Extraction through solar wax melter:**
   The bee combs collected from various sources are put into this simple structure that raises the internal temperature of the melter to above 70oC which is required for melting wax. The heat trapped under the principle of green house in the melting chamber does the melting from where the melted wax melts down the base leaving most of the dross behind it as it gets strained through a mesh screen. The collected wax is solidified in various molds for further disposal (Meseret, 2019).
   The solar extractor is a simple box having a chamber to trap solar irradiation and raise the internal temperature of the chamber to above 70°C for melting the wax. This structure is made of wood lined with a galvanized metal plate, having a glass or plastic sheet to cover it and trap the solar energy for heating purpose. The top is slanting so that the hinged top lid has a more favorable. The base is kept airtight to disallow any air circulation that can adversely affect the heating efficiency of heating chamber. Some extractors even paint the chamber black to absorb more and more heat.



   This method of beeswax extraction is not only efficient but is highly environment friendly. Besides, the small-scale rural honeybee farmers can easily take it as it is very easy to dismantle and carry along to places (FAO, 1990).

Gap analysis

Honey beeswax in the kingdom is a highly neglected area throughout the honeybee farmers in KSA despite it being the major by-product of beekeeping and honey production. A very few farmers who are extracting beeswax utilizes the manual extraction method. The method is not efficient enough and consumes a lot of time to attend to the wax rendering. For heating purpose, the burning of wood is a bit risky too as wax itself is an inflammable commodity and requires utmost care. The fire sparks and coal flakes flying around can get added to the wax thus negatively affecting its quality.

Recommendation for Beeswax extraction

Based upon the gap analysis of the current wax rendering practices which are almost non existent, the method of solar extraction is recommended on the following grounds:

1. It is highly environment friendly
2. It does not require much space
3. It is mobile and can easily fit into the existing system of honeybee farming
4. Construction of this solar extractor is highly economical, hygienic and sanitary.
5. The operations are very simple and does not require much of the high-tech trainings

Honey dehumidifier

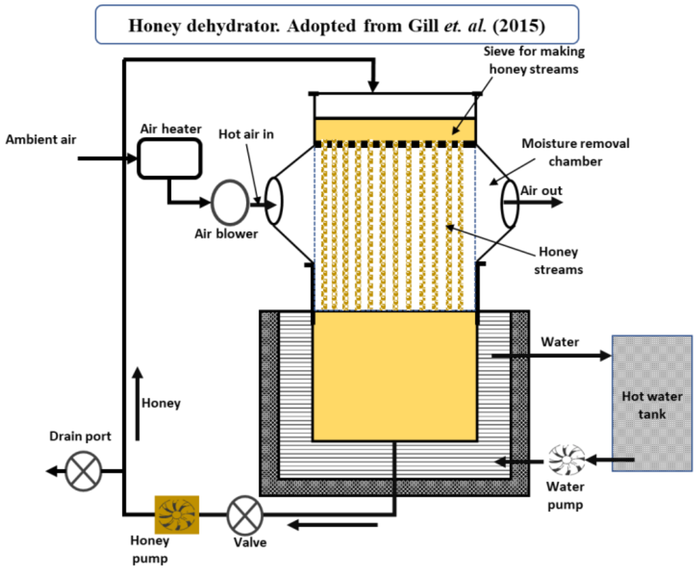
Honey wide utilization throughout the world calls for its storage to widen its availability period. One of the problems associated with honey storage while still maintaining its quality is the moisture content of honey which is practically the most important quality parameter in affecting its storage life. If moisture content of honey is more than 19 %, it starts to ferment, to spoil, to lose flavor, to granulate irregularly and to separate into two layers during storage, thus, reduces its shelf life (Dustmann 1993). At a moisture content of below 17%, honey fermentation gets appreciably reduced thereby adding to its shelf life. The simplest process seems to be heating the honey and get rid of excess moisture. But heating the honey directly negatively affects its quality through the loss of thermolabile and aromatic substances. Heating process also darkens the honey (Subramanian *et al*., 2007), and decreases its enzyme activity (Nurhadi *et al*., 2012). The adverse effect of heating on quality of honey is proportional to the temperature and the duration for which heat is applied to it (White, 2000) and hence in order to maintain the quality of honey, it should not be heated above 45^{o}C for dehumidification purpose.

Existing methods of dehumidification and gap analysis

The current methods of dehumidification are either nonexistent or utilize the higher temperatures to get rid of excess moisture which adversely affect the quality of honey. Direct heating is carried out in most of the instances. Direct heating removes most of the enzymes and aromatic compounds that have low boiling points. This also leads to reduced nutrition of honey. This heated honey gets lower price in the market as compared to the honey that is not heated and have enzymes and aromatic compounds intact.

Recommended method:

A mechanical dehydrator with temperature controls and honey recirculation system, moisture removal chamber, air heating and circulation system can effectively serve the purpose. The process initiates at honey loading to a container placed below the moisture removal chamber. Heating of the system is done through a circulating hot water bath to desired temperature level. At this temperature, honey is pumped to the top of the moisture removal chamber where a sieve is placed to break the honey in to streams. These honey streams are allowed to fall through the moisture removal chamber in the honey container. At the same time, drying air at desired temperature is passed across honey streams for moisture removal. The honey collected in honey container is then re-circulated through moisture removal chamber for further dehydration to achieve desired moisture content. The parts of the dehydrator that come in contact with honey are made up of stainless steel grade 304 or 316.



Other configurations of the same system are also available in the market that utilizes hot air blowing over the honey which is spread on rotating discs in a closed environment. The hot air takes the excess moisture while the honey with low moisture content is collected on gravitational method.

This method is suitable for establishing a business at the rural level as Many beekeepers need to get services to reduce the moisture content of their honey. This help them to harvest the honey in short period of time without waiting their honey to be fully ripe and they can use their bees to collect other honey. It contributes to increase the shelf life of honey. The equipment can be managed by the honeybee keepers' association to provide services on business grounds to make it a sustainable activity.

Both solar honey wax extractor and dehumidifier fulfills the selected criteria

Criterion	Current method compliance	Proposed method compliance
Reduce losses (Quantity, Quality)	Partial	Does not overheat and ensures maximum extraction of wax. For dehumidifier, no overheating is there, and quality is maintained.
Reduce economic loss	Partial	Full; quality of harvest is better, labor costs reduced
Increase efficiency	Partial	Being movable, can be shifted with the movement of honeybee colonies
Social and cultural acceptability	-	Acceptable
Gender friendly	No	Yes, as it does not require much of the human energy and can be handled easily as well as occupies less space
Innovative	Conventional	Yes

Criterion	Current method compliance	Proposed method compliance
Adoptability	-	Yes. Being low cost, efficient, easy to handle, and efficient, fitting within the existing system.
Environment friendly	-	Yes, minimizes the contamination chances.

3. Rose

Rose is truly acclaimed as queen of flowers with a long a colorful history. Rose has over many species and thousands of cultivars for different uses such as cut flowers, ornamental purposes, perfumery, medicinal and other aesthetic purposes (Damania, A.B. 2010). Out of the many species, *Rosa damascena* is considered most suitable for perfumery purpose. Cultivation of roses in KSA is a centuries old practice, largely pursued in Taif governorate of Makkah region and is traditionally recognized for making rose oil and perfumery products. The rose farming has distinct features and its specialized cultivation is undertaken in the variable altitudes of the mountains (>1200 meters above sea level) in the North, West and South of Taif city, concentrated within a diameter of 50-60 km. There are 480 rose farms with nearly one million rose plants spread in about 270 hectare area.

The rose cultivation in Taif is integrated to its processing for rose oil and related by products such as rose water. Thus, rose sector needs to be identified from the cultivation along with 72 local processing factories. The rose oil is a high value product, and this small sector produces about 400 kg of rose oil per year with estimated revenue of 54 million SAR (about 15 million USD). The rose oil is almost entirely used in the domestic market for perfumery industry which later enters the export market. This apparently small sector in terms of area cultivated has relatively high potential of employment, and it is estimated that more than 8000 people are employed in all the supply and value chains of the rose sector.

Having an agro-climate congenial for the cultivation of rose in Taif, the oil-rich, 30-petal damask rose (*Rosa x Damascena trigintipetala*), commonly known as "Arabia's Rose," is under cultivation for centuries and processed into precious attar of roses and its popular—and even older—counterpart, rose water. In fact, the word "attar", which is today a synonym for rose oil, comes from the Arabic 'itr, meaning "perfume" or "essence." The first description of the distillation of rose petals was written by the ninth-century philosopher al-Kindi, and more sophisticated equipment was described in the 10th century by al-Razi. Later, in the 13th century, rose water was produced widely in Syria, and the name of the oil-bearing rose genus *Damascena* may trace its origins to the city of Damascus. But true attar—rose oil as we know it today—was not produced until the late 16th century, when the double-distillation technique was developed.

Today, Taif's production, though high in quality, is modest when compared to the quantities produced by larger, export-oriented operations in Turkey, Bulgaria, Russia, China, India, Morocco and Iran. But the market is not oversupplied, for, now as always, attar is painstakingly obtained, and both its potency and its price remain so high that a gift of this precious oil is one of the highest compliments that can be paid to anyone.

Some two centuries ago, the rose flower producers used to pack their produce and take their produce on camels to Makkah for processing. Later, the distillers brought their craft to Taif itself, closer to the rose fields, improving efficiency of rose oil extraction.

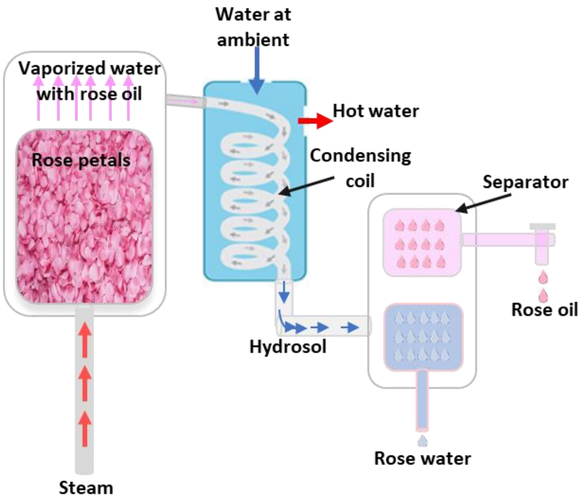
Rose oil extraction methods

Rose oil is extensively used as the primary fragrance ingredient in rose perfumes, creams, soaps and other value added products. The rose oil, being an essential oil[2] is a complex of terpenoids and aromatic compounds (Mondello *et al.*, 2005). The oil extraction method is of key interest as it determines the quality of oil, quantity of extraction as well as the associated costs to determine the profitability of rose

[2] : Volatile compounds synthesized by the plants with the capacity of solubilizing in fats and fatty oils. These are viscous and hydrophobic.

oil extraction businesses. Many rose oil extraction methods are being utilized across the globe including Hydro-distillation, Microwave aided hydro distillation, Solvent-solvent extraction and Super critical CO_2 extraction.

Existing system: There are a number of rose oil extraction methods being used worldwide. However, the most commonly used rose oil extraction method in KSA is water distillation also called hydro distillation or steam distillation. The same is used in the rose oil distilleries in Taif. This is the first and the oldest method of obtaining essential oils, still being used in many areas. Nowadays, this kind of distillation is done in a still, usually made up of high-grade stainless steel[3] (grade 304 or 316), but in Taif almost all of the distilleries are using copper stills. The rose oil extraction process starts with the arrival of rose petals at the factory where these petals are sorted and rose hips and other inert material/debris are removed. The whole flower petals are soaked in the container, which has water for preventing overheating and charring of the plants, and then heating water with plants till the steam comes out. The oil comes out and it goes to the condenser where the oil and water are collected in separation flasks. The oil collected in the top layer of hydrosol can be isolated. In this method, the extraction temperature always is below 100^{o}C to avoid the evaporation of water and oil together. Heating systems in the extraction of essential oils using water distillation are direct fire, steam jacket, closed steam jacket, closed or open steam coil.



Rose oil hydro distillation schematic

Gap analysis

Although this method is conventional and widely utilized throughout the kingdom for being comparatively less expensive and easy to operate as well as ease of movement from one place to other place for smaller units, it still has quite a few disadvantages as well. For example:

(i) Complete oil extraction is not possible and after removal of top layer of oil, the remaining rose water still has some precious rose oil and is subjected again to the distillation process with the next batch.

(ii) Some of the oil ingredients like esters are sensitive to hydrolysis while other compounds like acyclic monoterpene hydrocarbons and aldehydes are susceptive to polymerization, some phenols have a tendency to liquify in the distilled water and the distillation unit is not able to remove them completely.

(iii) Some of the essential oils are heat sensitive and at higher temperatures, might change their chemical composition.

(iv) A huge amount of heat energy is required to boil water for the extraction process utilizing fossil fuels or woods. This is not environment friendly.

(v) At the initial phase of essential oil extraction, some vapors are left to escape in order to avoid vacuum pressure. These first vapors also contain low boiling point essential oils and aromatic

[3] In Taif, almost all the distilleries are using copper instead of stainless steel.

compounds which if lost, can incur economical loss. Also, poor cooling of the condenser makes some of the aromatic substances escape.

(vi) The method is time consuming.

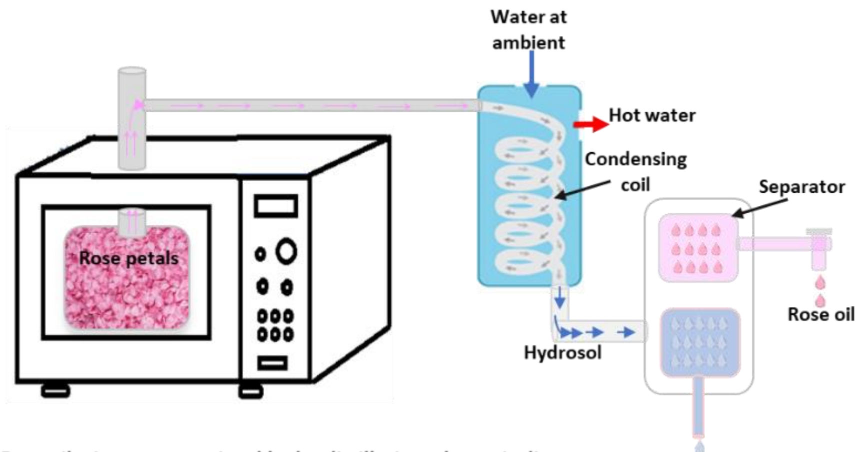
(vii) The stills are made of copper which although is a good conductor of heat but is not recommended for high quality extractions and also for food processing. For which stainless steel of 304 or 316 grade are preferred.

Suitable technologies

Based upon the gap analysis of the current rose oil practices in the kingdom prevalent in the rose production areas and considering the important facets like extraction efficiency, economic benefits, environmental impacts, gender friendliness, ease of operations, adoptability within the existing system, etc, the following rose oil extraction methods were analysed:

1. **Microwave aided hydrodistillation:** Microwave assisted extraction (MW) is comparatively a new addition to the array of essential oil extraction techniques, dating back to mid-80s of the last century (Ganzler *et al*. 1986). Since then microwave aided hydrodistillation gained popularity for essential oil extraction for being comparatively efficient than simple hydrodistillation in terms of efficient heating and shorter extraction time. It does not depend upon burning fossil fuel to generate heat and is thus more environment friendly. The microwaves, being nonionizing radiations have the ability to activate the rotational energy of molecules.

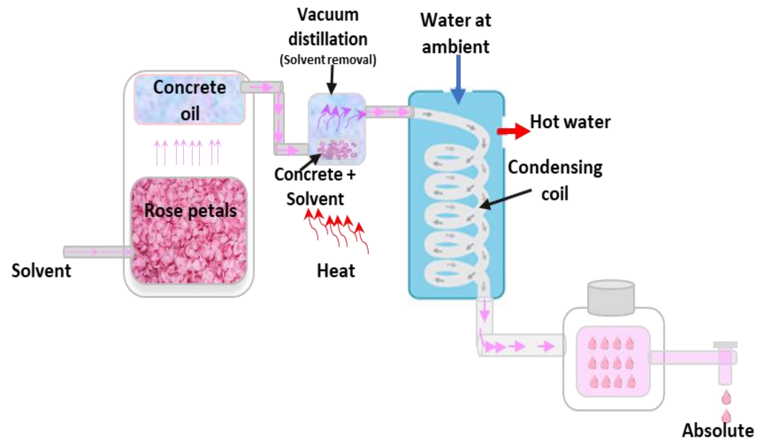
   The principle of microwave heating is based on the effects of dipole rotation and ionic conduction that microwaves exert on dipolar and charged molecules. The alternating electric field which continuously changes its polarity makes the molecules rotate at exceptionally high speed. The friction caused by these high-speed rotating molecules results in quick heating (Dean J.R. 2012). In this case bulk heating is more efficient and uniform as compared to heat transfer from the surface inwards (Chemat *et. al*., 2006)



Rose oil microwaves assisted hydro distillation schematic diagram

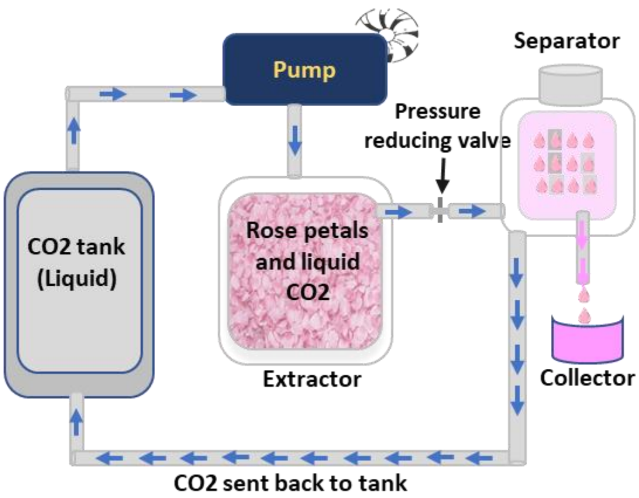
   The system of microwave aided hydrodistillation in fact has an additional component of microwaves generator put around the collector still which has to be made essentially of microwave safe glass material. Stainless steel (and other metals too) is not usable in this case as it has high quantity of dipolar molecules that can easily heat up due to the changing polarity of alternating current. The other process remains the same as for simple hydrodistillation. The method however is limiting in nature as the temperature sensor and hence control is not easy as well as the electron generator generates variable powers at different voltages.

2. **Solvent-solvent extraction:** This method utilizes the principle of differential solubility between two immiscible[4] solvents. Solvent extraction is most commonly used on flowers that cannot withstand higher temperature often maintained during steam distillation. This method produces absolutes, which may have both aromatic and non-aromatic chemical constituents. Generally, less polar compounds (such as pentane or hexane) or alcohols (such as methanol or ethanol) are used as solvents. The type of solvent used can alter the absolute, so it is important to choose a solvent that will make minimal alterations to the unique fragrance and beneficial properties of the absolute. The apparatus assembly used for solvent extraction utilizes the Soxhelt's extraction apparatus process (Gopalasatheeskumar, K. 2018). This method is particularly useful for Jasmine oil extraction in Jizan region (Jasmine oil is more sensitive to heat) To extract the jasmine oil, the jasmine petals are put on a porous thimble placed in cylinder where desirable solvent (N-hexane, ether etc.) in vaporized form is allowed to fall into the thimble and extract volatile compounds. The resultant product is called concrete oil which is then further processes to get the jasmine oil completely free from the solvent.



Rose oil solvent-solvent extraction schematic diagram

3. **Supercritical CO_2 extraction:** This is one of the most effective, and environment friendly method of essential oil extraction as it does not contain any solvent and the operations of extraction of essential oils are carried at ambient temperatures. Essential oils derived through this method do not have altered qualities as no application of heat is there unlike steam distillation. In this method CO_2 acts as a solvent. Any compound above its critical temperature and pressure is called supercritical. At supercritical stage, neither liquid nor gaseous form exists; rather an intermediary of both as a fluid with the properties of both liquid and gas exist. Supercritical carbon dioxide extraction is a commonly used method to separate various components from the plant due to it producing a pure, clean, and safe product. Carbon



Rose oil supercritical CO2 extraction flow diagram

[4] Immiscible liquids are those that remain in separate phases. Generally organic solvents with low polarity are immiscible with water which is highly polar. Diethyl ether, toluene and hexane are common solvents that are immiscible and less dense than water.

dioxide reaches a supercritical state at 1071 psi and 31.1°C. A molecule in a supercritical state has properties of both liquid and gas (Xu *et. al.*, 2011). When it comes in contact with the target product through a pressure pump mechanism, its sudden expansion while in contact with the target product burst the product molecules thus releasing volatile compounds first as they have low boiling point.

For the extraction purpose, CO_2 under high pressure and in a supercritical state is injected into the chamber containing rose petals. Since the CO2 is in a supercritical state here, it acts as a solvent due to its liquid properties. The tissues containing aromatic compounds burst under this pressure thus releasing these compounds. This is followed by product recovery in the separation section, whose temperature and pressure is adjusted in order to optimize the extract amount. The solvent is then recycled and pumped back to the extractor. The final product separation cane be achieved either by depressurization while maintain the same temperature in which case mechanical energy is provided to the system to increase the CO_2 pressure from the separator to the extractor conditions (Pourmortazavi and Hajimirsadeghi, 2007). The extract separation from CO_2 can also be done by increasing the temperature in which case thermal energy is provided to the system.

Comparative analysis of rose oil extraction technologies

Criterion	**Current hydrodistillation**	**Microwave assisted hydrodistillation**	**Solvent-solvent extraction**	**Supercritical CO_2 extraction**
Reduce losses (Quantity, Quality)	Low	Medium	High	High, as no heating is involved, and the quality is of highest standard
Reduce avoidable economic loss	Low	Medium	Medium	High[5]
Increase efficiency	-	Yes, lesser time compared to conventional method	Medium[6]	High
Social and cultural acceptability	In practice	Yes	Yes	Yes
Gender friendly	No	Yes	Yes	Yes
Innovative	Conventional	Yes	Yes, in context of KSA rose extraction	Yes
Adoptability	In practice	Partial, as it requires a lot of modifications to gel with existing system	Easy to operate and hence adoptable	Easy to operate, and can be used for a variety of other crops to extract essential oils
Environment friendly	Uses fossil fuel or wood for energy,	Yes, uses electricity for heat generation	Yes	No heating required; no harmful solvents being used. CO_2 being

[5] Since the availability period of rose crop is for around 2 months, enhanced efficiency of this extraction system requires other crops to be included in the list of essential oil extraction. Cultivation and oil extraction from other aromatic plants like jasmine, lavender may be encouraged. The same equipment can be used to extract oil from a lot of other crops too like condiment crops.

[6] Of the many solvents used, N-hexane has proved to be more efficient compared to ether or ethanol.

Criterion	Current hydrodistillation	Microwave assisted hydrodistillation	Solvent-solvent extraction	Supercritical CO_2 extraction
	not environment friendly	through microwaves		recycled again and again for extraction
Initial investment	-	Medium	Medium	High

Recommendations

Based upon the comparative analysis of these oil extraction techniques, the two technologies are proposed in the order of priority:

1. Solvent-Solvent extraction for Jasmine oil extraction
2. Improved hydrodistillation method for rose oil extraction
3. Solvent solvent extraction for rose oil

Solvent-solvent extraction is recommended as first choice for jasmine oil extraction as it is quite efficient when compared to the existing extraction methods of hydrodistillation because Jasmine oil has higher thermal sensitivity. The method is also less expensive in terms of initial installation; through the colvent recovery cost is a bit high. It is easy to operate and does not require much of capacity building. Its efficiency for time taken to extract essential oils and the %age of oil extracted is way better than existing hydrodistillation The method is environment friendly and the extractant can be reused again and again with no damage to the environment.

The existing traditional hydrodistillation method being used in Taif region for rose oil extraction offers a lot of room for improvement. Improvement in heating systems to make it more efficient, utilization of stainless steel stills, better glass condensing systems with regular cold water circulation in the inner tubes and better separation systems as well as avoiding over filling of stills to allow movement of petals and steam can improve the efficiency of the system. The market appetite for the traditionally extracted rose oil through hydrodistillation is very high.

Despite the fact that supercritical CO_2 extraction is very efficient its initial installation cost is quite high as compared to traditional hydrodistillation or solvent-solvent extraction method.. Besides, supercritical extraction is highly environment friendly as it operates on ambient temperature and no harmful solvent is released. In terms of efficiency, it can be termed as super-efficient as the processing time is very short as compared to all other techniques, the extract quality is very high as no heating is involved and resultantly almost all of the aromatic substances are extracted in their original form and color. Its initial high cost, some delicacy in operations, requirement of continued large quantities of roses (not available beyond 2 months period) excludes it from the list of preferred choices.

One point to ponder is the business efficiency of both technologies, and for that matter the conventional technology too. The operational time of these extraction equipment is spanned over a couple of months only which leaves rest of the year unused. It is suggested that other aromatic crops like Jasmine, Lavender etc may be cultivated and included in the oil extraction list. Besides this a number of other crops like mint and cinnamon might be added to expand the operational time of these extraction equipment.

4. Sub-Tropical Fruits

SRAD51 project has three commodities under this component namely Grapes, Fig and Pomegranate. At the moment, to start with, the grapes is discussed in this document as the findings related to grapes are applicable to other perishables too.

Grapes (*Vitis vinifera*)

The history of grapes production probably goes hand in hand with human civilization since centuries. Today, grape is one of the most widely cultivated plant on earth with a wide range of varieties grown for different purposes (McGovern *et al*, 1996). Grape belongs to family *Vitaceae* with 12 genera and thousands of varieties but the most dominating species in this group is *V. vinifera* which is used for table, drying or wine purposes (Jackson and Looney, 1999). Majority of grapes grown in KSA are for table purpose belonging to *V. vinifera*. Grapes are grown in many parts of KSA with Tabuk having highest population of grape plants while the total number of grape plants in the kingdom were 5,014,178. A total production of 117,638.8 tons was obtained from the productive plants during the year 2018.

MoEWA, Agricultural statistics- Agricultural production survey 2019

Total number of grape trees, fruitful grape trees, total production and total sold production by administrative region in the Kingdom, 2018

Administrative Region	Total number of trees	Number of fruitful trees	Production (ton)	Sold production (ton)
Riyadh	130,174	122,735	2,789.4	2,324.5
Makkah	76,635	68,516	2,327.4	1,947.5
Madinah	169,508	158,386	6,790.6	5,760.8
Qassim	1,009,677	733,866	18,785.7	18,314.2
Eastern Region	16,516	14,156	582.8	554.4
Asir	80,411	67,381	2,834.5	2,628.4
Tabuk	2,280,376	2,155,665	53,757.9	52,591.5
Hail	706,377	640,230	17,844.1	17,065.9
Northern Borders	6,493	6,263	219.2	193.2
Jazan	154	146	2.9	1.2
Najran	53,114	47,766	1,650.5	1,469.9
Al-Baha	34,338	31,174	968.1	847.0
Al-Jouf	450,406	430,542	9,085.7	8,247.3
Total	**5,014,178**	**4,476,827**	**117,638.8**	**111,946.0**

Grapes are non-climacteric in nature and its physiological maturity usually coincides with the edible maturity. So, it is imperative that the grapes are harvested when they are fully mature. The maturity indices include sugars or total soluble solids measures in ^{o}Brix, sugar acid ration, color development, bunch compactness (Crisosto *et al*. 1994). But in any case, it is the consumer acceptance that is the determining factor for determining right maturity indices (Crisosto and Crisosto, 2002).

Like other fruits and vegetables, grapes are also a living entity and as a living entity even after harvest, they keep on respiring, loosing moisture, can get disease and even die. However, respiration rate is low when compared with many climacteric fruits. Decreasing the temperature to an optimum level without freezing reduces respiration rate of the grapes and enhances its shelf life. One important aspect to consider here is the time delay between harvesting and removing the field heat to the minimum permissible temperature without freezing. Earlier the field heat is removed, and the harvest is put into the cold chain, the chances of retaining product quality, its shelf life and hence its profitability for the producer and other value chain actors remains high. Delayed precooling increased moisture loss decreases tissue firmness and leads to an elevated state of metabolism in these respiring entities and a serious damage in the appearance of fruit too (Finger *et al.*, 2007). As a general principle, at higher temperature, the respiration rate also increases which generates heat of respiration, loss of sugars and moisture. Precooling is also called field heat removal. This field heat removal is possibly the first and most important step in determining the future life of the product (Baird and Gaffney, 2001).

Research on perishable commodities has confirmed the role of precooling in retaining the nutrition composition, product freshness, avoiding chilling injuries and reduce pathogenic activities thereby slowing down the decaying process (Thompson *et al.*, 1998). Precooling also considerably reduces heat load[7] in the later parts of the cold chain. It also provides marketing flexibilities by giving producer a window to adjust his harvest at the best paying time.

Current method of field heat removal or precooling in KSA

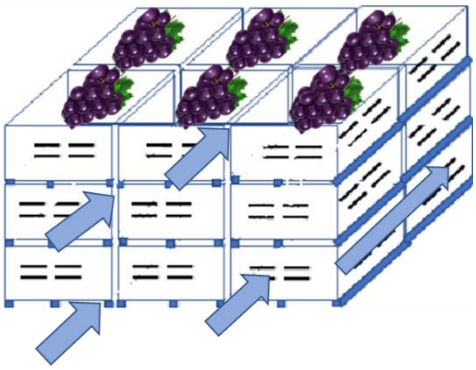
The grapes harvesting starts in the month of July and August in Saudi Arabia in various regions of grape cultivation. The temperature during this period is generally high even in the otherwise moderate areas. The harvesting is carried out manually early in the morning to avoid excess mid-day heat to the produce. The harvest is done manually using manual clippers. The harvest in the field is collected first in the plastic bins from where it is moved to a shady place in the field where the harvest is brought in the harvesting bins and then packed then and there in corrugated boxes for dispatch to the different destinations. No other precooling techniques except early harvesting and putting the harvest in the shade are being practiced[8]. Apparently no refrigerated vehicles are being used for Innately, farmers do possess this knowledge of protecting the produce from excessive heat as it leads to reduction in quality and hence in economic returns. This method is about protecting the grapes from getting more heat and does not efficiently remove the field heat from the grapes.

Different methods of precooling

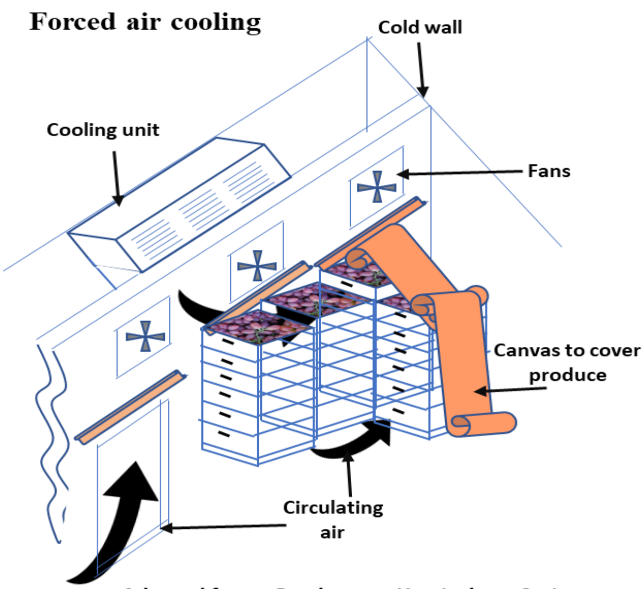
A number of methods are being utilized depending upon the initial installation costs, operating expenses and the postharvest physiology of the crop and its tolerance to various techniques, market requirements, available time to market, kind of packaging to be used, cost of energy, maintenance costs and above all the intended benefits. (Gaffney and Baird, 1991).

[7] Energy removed from one ton of water, so it freezes in 24vhours; equivalent to 3.5 kW.
[8] Personal discussions with Mr. Hani Saylani, a grape grower in Taif.

1. **Room cooling:** This is the most common type of cooling to remove field heat for the produce which is small in quantity and does not deteriorate quickly (Boyette *et. al.*, 1990) and those do not need to go to zero-degree Celsius. In this method, the harvest is brought into the room fitted with thermal panels, and refrigeration equipment. The cold air generated is allowed to exchange heat from the product through conduction. Most commonly the cold air is discharged into the room near ceiling and it sweeps past the produce containers to return to the heat exchangers. This method requires a uniform air distribution, proper staking of the produce with ample space within to allow free air flow to aid heat exchange (Mitchell and Crisosto, 1994). The efficiency in terms of cooling time in this case is not high enough to quickly remove product heat due to lack of forced air circulation. The air velocity of the refrigeration fan is not enough to equally spread the cold air to the farther areas of room. The slow cooling rate makes it difficult for the produce to reach its desired minimum temperature in a short span of time. Another problem with this kind of cooling mechanism is that it can not go beyond certain low temperature due to icing on the refrigeration coil. For grapes that require appreciably low temperature, this system would require additional installation of defrosting system on the refrigeration coil (Gameiro, 1994). This kind of cooling removes humidity from the air which in turn gets compensated by moisture from the produce making it unsuitable for products that need to retain internal moisture for maintaining their shape.



2. **Forced air cooling:** This kind of cooling is a modification of room cooling and is also known as pressure cooling. The cooling air in forced air cooling method is forced to run through and around the stacked produce through the vent holes in the packaging that are placed in the direction of the cold air. This is comparatively a faster cooling method than room cooling (Winrock Intl., 2009). This method is used when the produce is in large commercial quantities and needs early cooling down to the desired level. The cooling rate, though, is affected by the cold air throughput, bulk of the commodity, type of commodity and its thermal properties, packaging type, staking orientation, carton vent areas, relative humidity etc. The temperature is brought down by either direct expansion refrigeration system of by water cascade cooling system. To generate air velocity, centrifugal or axial fans are used. The temperature of he cold air can not be brought down below a certain safe point to avoid chilling injury. The simplified version of forced air cooling involves a canvas sheet that is rolled on top



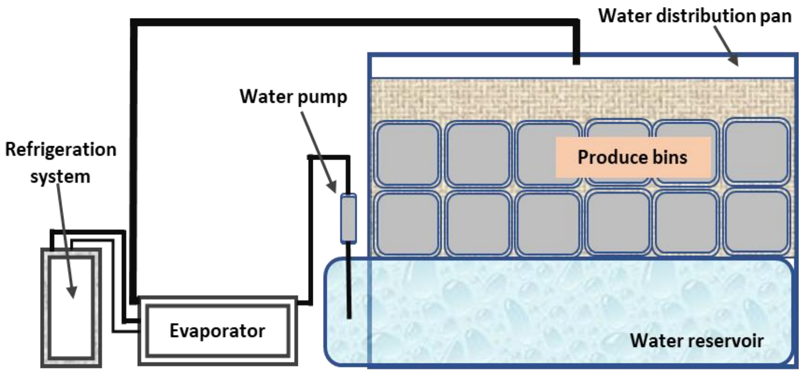
Adopted from: Postharvest Horticulture Series No: 8E, University of California, Davis.

of the product boxes down to the back of boxes till the floor and sealing off the unit. The cold air is then pulled through the vents of the packaging (Parson and Kasmire, 1974). The air can be channeled to flow either horizontally or vertically. In horizontal flow system, the air is forced to flow horizontally from one side of the pallet to the other side through holes in the sides of the pallet bin or containers. Only two sides that are opposite can be open in the pallet bin or containers in stacked containers. All the containers' sides must be lined up in a way to allow air to pass from one side of the stakes to the other. In this system the top and bottom of the pallet or containers must be sealed to prevent air from passing the produce. In the vertical flow system the air is forced to flow vertically from the bottom to the top of the pallet through holes in the bottom of the pallet and containers if used then out to the top in this system so the sides must be sealed to prevent the air from bypassing the produce. The holes in the tops and bottoms of the containers must line up so the air can travel vertically from one container to the next. This method is faster than room cooling because of flow of chilled air is in direct contact with the produce in these systems. Condensation on the produce is controlled through a cover placed on top of the stack of container which prevents the entry of ambient air during handling. Most of the modern day refrigerated trucks too utilize this method. The leeway of this method is that the floor with ducts and holes to allow vertical airflow needs to stay clean to allow free air movement.

The key to forced air cooling is moving the cold air through the container and its content. important factors in container ventilation or location of container vents stacking of containers and size of the winds container vents need to be aligned whether the containers are straight across to minimize airflow through the containers if vents are too small or too few, airflow is slowed. This is the recommended method for grapes.

3. **Hydrocooling:** This method utilizes water or chilled water to decrease the temperature of the produce. This is achieved by flooding, spraying or immersing the product in chilled water. Different hydrocooling mechanisms differ in their efficiency and choice of product. The flood type hydrocoolers cools the packaged product by flooding as the product moves through a cooling tunnel. While in spraying method, the chilled water is sprayed on the product for certain period of time to bring its temperature down. In immersion types, the product is immersed in the water to lower the product temperature. This type of hydrocooler has a smaller capacity but are less expensive too. The produce subjected to this hydrocooling method should be tolerant to being wet; grapes are intolerant, so not suitable for this method.

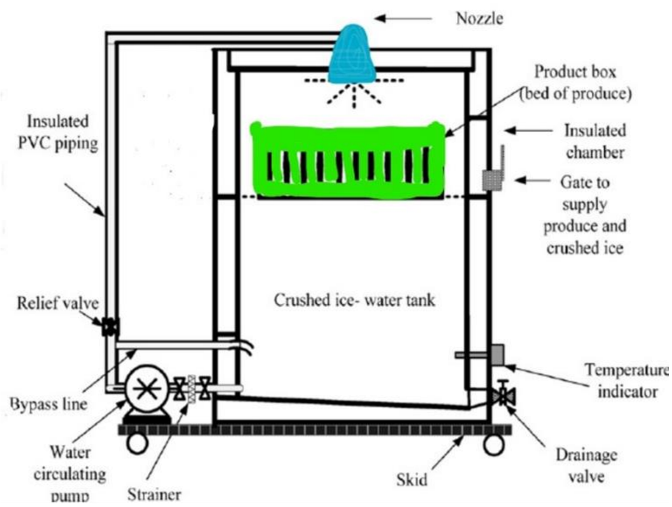
Batch type hydro-cooling shower



Adopted from: Postharvest Horticulture Series No: 8E, University of California, Davis.

Another bottleneck associated with hydrocooling is the possibility of recirculation of decaying microorganisms that get accumulate din the system during usage of each batch. To avoid this, disinfectants such as chlorine etc are added which, if the concentration goes beyond certain limit, becomes toxic (Reid, 2000).

4. **Ice cooling:** This type of cooling utilizes the coldness of the ice to absorb heat of the produce while melting itself. A number of different methods are used to remove heat from the product depending upon the nature of product, packaging and the time available. The crushed ice, ice flakes of fine granules of ice are packed around the produce in plastic cartons. This method though may lead to uneven cooling as the ice remains at the place where it is put until it has all melted away. This problem is partially overcome by using an ice slurry injected into the packaging. This liquid ice or slurry distributes throughout the packaging thus achieving better contact and hence better and uniform cooling of the produce. Primarily, this method of cooling is used to supplement any other cooling method but is not recommended for corrugated card board cartons due to their sensitivity to water. Water proof containers are more expensive and the method is also not suitable for produce sensitive to wetting, like grapes. One advantage, however, of this method is that the produce does not loose moisture as it is cooled and maintains low product temperature as it is transported to shorter distances (Gillies and Toivonen, 2000).

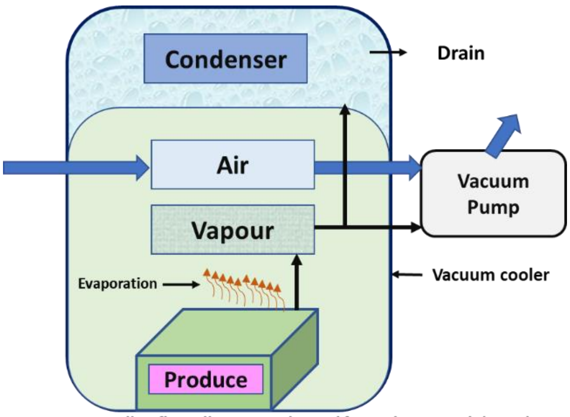


Crushed ice cooling. Adopted from Atef Elansari (2008)

5. **Vacuum cooling:** This method of cooling is achieved by the evaporation of moisture from the produce and utilizes the water latent heat[9] function for this purpose. In order to change the state of water from liquid to vapor state, the latent heat of vaporization needs to be provided by the vacuum cooling equipment. The process is done in two phases. First the pressure in the vacuum chamber is reduced to about 20 mbar with slow evaporation and little cooling until the saturation pressure is reached. This is followed by a phase when the moisture in the produce starts to vaporize, produce begins to lose moisture (high kinetic energy molecules leaving the produce making overall energy of the produce low and thus reduction in temperature) and start cooling (Deng *et. al*., 2011). This cooling is continued until a pressure corresponding to the desired final saturation temperature is reached which generally is above 0ºC to avoid extra cost and freeze injuries.

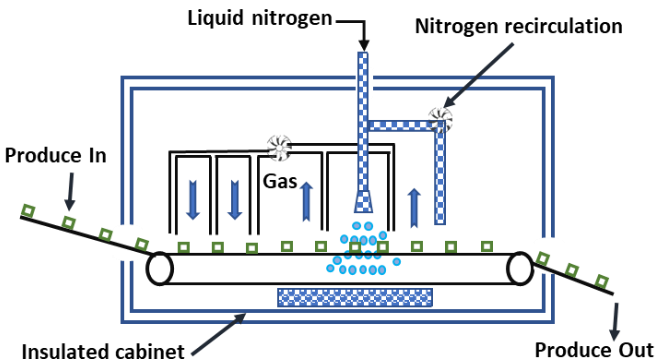
[9] Latent heat is the heat required (measured in calories burned) to convert a solid into a liquid or vapor, or a liquid into a vapor, without a change of temperature. As water cools it will reach 32°F (or 0° C) and will stay at that temperature until all the water freezes.

Since the cooling is carried out by vaporization of moisture form the surface of produce, cooling rate or heat mass transfer is dependent upon exposed surface area of the produce and the strength of surface tissues. This cooling is better for the products having high surface to volume ratios (Apai *et. al.*, 2007). This method requires water misting of the produce before putting it into the vacuum chamber to avoid excessive weight loss by the product. Some of the vacuum coolers have built in misting system to avoid moisture loss from the product. At the same time, to avoid freeze injuries and avoid temperature going below 0^oC, vacuum pump is regularly stitched of and on to stay above freezing point. This method provides rapid cooling and uniformly removes heat from the produce.



Vacuum cooling flow diagram. Adopted from Liana *et. al.* (2014)

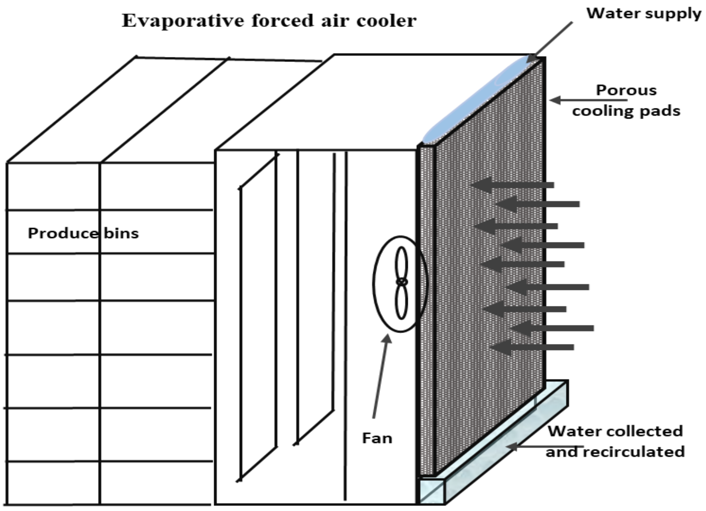
6. **Cryogenic cooling:** Cryogenic[10] cooling technique in super rapid cooling and is getting popularity in different aspects of food preservation. In this method, the produce is cooled by conveying it through a tunnel where the liquid nitrogen or solid CO_2 is evaporated to immediately bring down the temperatures to much below freezing points. However, the major shortcoming of this procedure is the thermal damage to the fresh produce as the produce will quickly freeze rendering it unfit for the fresh market. The issue can be controlled by careful control of evaporation rate and speed of conveyer belt carrying the produce (Cristian et. al., 2008). The associated costs of liquid nitrogen and sensitive handling makes it a difficult preposition for this technique. However, this technique is employed in locking the freshness of the produce through individually quick-frozen (IQF) method for frozen horticulture products.



Cryogenic freezing flow diagram. Adopted from Fellows, P. (2000)

[10] Cryogenic is a branch of engineering where production and application of low temperature from absolute zero (-273.15^oC) to -150^oC is done using liquified nitrogen or liquid oxygen or solid CO_2 as cryogen.

7. **Evaporative cooling:** Evaporative cooling method is considered as the most inexpensive of all cooling methods in areas where relative humidity is low. The method uses the evaporation of water to produce cool air as it changes from liquid to vapor state, it absorbs heat from the air thus lowering the temperature. However, the temperature reduction gradient is not much as it drops temperature to only 5-10ºC. The method is only suitable for warm season crops that do not require lower temperatures for storage. A simple evaporative cooler has a blower which has a blower fan installed in front of water soaked cooling pads. The air pushed by the blower passes through the moist cooling pads and on the way gets cold and humidified. This cold air passes through the produce and lowers its temperature by a few degrees Celsius.



Adopted from: Thompson and Kasmire, 1981.

Comparison of typical product effects and relative cost for six common cooling methods (adopted from Kitinoja and Thompson, 2010).						
	Room	**Forced air**	**Hydro**	**Electric evaporative**	**Passive evaporative**	**Package ice**
Cooling time (h)	20-100	1-10	0.1-1.0	20-100	40-100	0.1-0.3
Moisture loss (%)	0.1-2.0	0.1-2.0	0-0.5	No data	No data	No data
Water contact with produce	No	No	Yes	No data	No	Yes
Potential for decay contamination	Low	Low	High	Low	Low	Low
Capital cost	Low to medium	Low	Low	Low	Low	High
Energy efficiency	Low	Low	High	High	High	Low
Portability	No	Sometimes	Rare	No data	Possible	Yes
Limitations and concerns			*	**	**	***
* Recirculate hydro-cooler water must be constantly sanitized to minimize buildup of decay organisms						
** Evaporative cooling to a few degrees only above the ambient is possible						
*** Melting ice can cause physical hazards during transport and unloading; packages need to be moisture proof and therefore expensive.						

Gap analysis

The existing method of field heat removal of harvesting grapes early in the morning and packing them under shade in the field is an effort by the farmers to somewhat reduce the core temperature of the produce immediately after harvest. Unfortunately, temperature under shade and temperature under sun does not have much of a gradient and is not efficient enough. Even reaching at a heat equilibrium state with this shade method does not help much as the core temperature stays high enough. This results in produce moisture loss as well as quality loss thereby compromising on the profits. There are no temporary cold storages available for the farmers in their vicinity. Large cold stores are away from the farms and storing there is not only cumbersome but a bit costly for the small rural farmers too. Additionally, farmers lose their bargaining power and have to send off the produce as soon as possible at the offered price.

Based on discussions with the farmers, it was found that they are not converting to the recommended methods of field heat removal due to one or more of the following reasons:

i. Do not have information about these technologies
ii. Do not have access to these technologies
iii. The initial cost is considered to be on a higher side by the farmers
iv. Simply wanted to stick to their traditional system
v. Fear of unknown for adoptability.

At the moment no visible gender involvement is there at the postharvest level because the farms are situated away from houses. The packing, packaging etc is all done by male labour.

No temporary storage structure exists at the village levels by the small rural farmers for holding the produce for a day or two. This is primarily due to unavailability of information about modern technology and false fear of high cost associated with the suitable technology to economically convert domestic air-conditioned room to act as a temporary small cold store.

Recommended technology/ies for precooling

Considering the agro-climate, terrain of the grape growing areas in KSA, affordability of small-scale producers, and post-harvest physiology of grapes, the following technologies are recommended for consideration at field level and at temporary storage level. This needs to be kept in mind that bringing the core temperature of grapes to 0-4^{o}C as early as possible after the harvest, the shelf life of the produce can appreciably get enhanced. Ideally, the cooling process should begin immediately after harvest and the grapes should be cooled to their recommended pulp temperature without any delay. After precooling (field heat removal) is completed, the grape containers should be moved to a holding room designed for short-term storage for later dispatch to the destined market or loaded directly onto a refrigerated vehicle for distribution to market.

1. **Portable forced-air cooling units (Porta-cooler):**
   The recommended method of cooling for grapes is forced-air cooling which pulls are pushes air through the produce placed in containers. This method reduces cooling time of the produce. The portable version of these units is called porta cooler and is most efficiently used for field heat removal/precooling of the produce at the field level immediately after harvest. This brings down the temperature to the desirable range (before subjecting it to cold transport or temporary storage. The first porta-cooler was designed by United States Department of Agriculture (USDA) which can be carried on traditional small-scale transport vehicles and moved in the field. This has a capacity of 700 kg (in a small, insulated box of 3.5m3) and diesel/petrol powered generator of 2 kW.
   These porta-coolers can bring down the produce temperature down to 10^{o}C. Lower temperatures result in ice buildup on the cooling coil of air conditioner (USDA, 1993).

The cold air generated by the air conditioning unit installed on side of this cooler is pushed through the produce using a pressure fan. The air after passing through the produce comes back to the air conditioners via a false floor. The produce immediately after harvest in the field is put in the plastic cartons in a palletized manner. To compensate for the moisture loss, the inner side of the porta cooler is lined with misting.


A small-scale porta cooler for grapes. (Source: Writer; during implementing a USDA funded project in Pakistan)

Since majority of grape growers are not in the vicinity of a cold storage and many precious hours are spent before their harvest reaches either cold store or to the refrigerated vehicles for cooling. Porta-coolers provide an excellent solution to this problem as these are small scale and are not much expensive, these are movable and can easily be towed with any vehicle and finally are easy to operate and can contribute appreciably in reducing the post-harvest losses in grapes by efficient field heat removal immediately after harvest within the field thus not only contributing to controlling avoidable food loss but also aiding to increasing profit margins by maintaining quality and quantity of marketable produce. The technology is environment friendly as it does not use any fossil fuel and the current day refrigerants use permissible environment friendly gases. Its operation is quite simple yet innovative and as such can be easily adopted.

2. CoolBot technology:

Farmers have been facing this problem of temporary storage of their perishable produce for few days before sending it to the target market. cost of constructing a conventional cold storage on a higher side for common farmers as it has to have the refrigeration equipment, insulation paneling and proper building design for these stores. This financial inability to go for these larger cold stores erodes the opportunity of temporary storage for small scale produce.

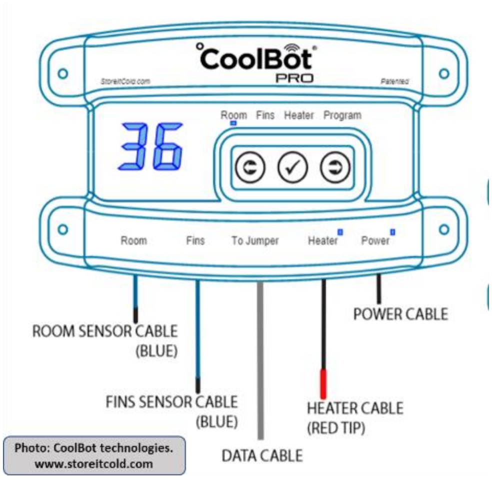


Photo: CoolBot technologies. www.storeitcold.com

a The is

However, another method was developed to modify the dometsic air conditioning units at home to perform the cooling function to an extent that the small room in the house can become a temporary cold store (Boyette and Rohrbach, 1993). The conventional air conditioning does not allow to go below 10-12^{o}C as below this temperature the ice deposition starts on the cooling coil that restricts airflow and stops cooling.

A device with the name of CoolBot was developed recently that does not allow ice build up on the cooling coil without modifying the domestic air conditioning system. The system returns back the moisture condensed on the cooling coil to the cold room air. This not only allows domestic air conditioner to keep cooling below the normal range of its cooling but also restricts moisture loss from the produce. The room, of course has to have insulation panels on walls, roof and floor besides a sealing insulated door fitted with controls.

This technology enables farmers to convert a common room fitted with domestic air conditioner it turn into a temporary cold storage through putting insulation panels and some controls. No additional construction is required. This not only adds to the bargaining capacity of the farmer but also enable shim to act as a small cold storage for the village level market. The CoolBot can get most walk-in coolers down from ambient temperature to 7°C in about 20 minutes. However, it can take longer (about another 30 minutes) to reach 4.4°C and will take increasingly longer the farther you go down in temperature.

Since there is no hi-fi additional equipment installation involved, its operation is quite easy and fits well within the existing system. The cold room can be within the house making it a lot easier for the women to operate it thus being highly gender friendly. The system is highly environment friendly and reduces the postharvest losses besides adding to producers profit margins.

Grape Raisin production

Grapes are classified as berries and have higher juice content making them highly perishable in the postharvest period thus reducing the marketability period if not stored properly or subjected to drying. High level of moisture and sugar present in the berry makes fresh grapes prone to various physical damages and quality deterioration. (Khiari, Zemni, & Mihoubi, 2019). The most efficient and convenient way of fresh grapes preservation is removal of water which leads to prevention of fruit deterioration (Farias *et al.*, 2020). This, despite being the oldest method of food preservation, is also considered as a major value addition in grapes in most of the countries (Adiletta *et al.*, 2016).

The process flow of grapes raisins starts with harvesting the grapes when they have attained a brix level of 18-22 at ambient and stored/transported at low temperature. Proper physiological maturity of the grapes is important to have the best sugar acid ratio. The higher sugar content leads to better raisin yield. The TSS in brix can be measured through a hand held refractometer in the field. Harvesting of grapes with high TSS (Brix^{o}) is followed by cleaning, washing and sorting. The berries are then subjected to drying. The grapes are dried in three stages; in the first stage most of the moisture gets removed leaving the remaining moisture to 40-50% leading to shrinkage of berries, in the second and third stage partially dried berries are cleaned again and subjected to further drying to reduce the moisture to 13-15% moisture content. This is followed by further sorting, cleaning, packaging and then storage (Sharma and Adulse, 2007).

Since the outer epidermis of grape berries is covered by a waxy material which is hydrophilic in nature, efficiency of water gets decreased due to its presence (Esmaiili, Sotudeh-Gharebagh, Cronin,Mousavi, and Rezazadeh, 2007). For increasing drying efficiency, it is very essential to get rid of this waxy layer before drying. This is generally achieved by utilizing two different categories of pretreatment techniques namely chemical and physical.

A. **Chemical Techniques**: This method utilizes the specific chemical solutions in specific concentrations at a favorable temperature over a specific period of time. The major objective of using these chemicals is to make the waxy layer soluble and quickly remove the same thus making the drying efficient. Any overdosage or overexposure may lead to compromised taste and aroma of raisins thus reducing the quality. Some of the chemicals used for this purpose include:

Sodium hydroxide (NaOH) which is abundantly used at commercial scale as it improves the color of dried grapes at a concentration of 0.25% at 82^{o}C for 5-10 seconds. However, due to creation of microcracks, use of NaOH is generally done at the first stage drying only (Zemni *et. al.*, 2016).

Potassium Carbonate (K_2CO_3) is also utilized at industrial scale raisin production at a concentration of 5% with increased drying rate (Vazques *et al.*, 2000).

Sulfur compounds (Sodium metabisulfite and sulfur dioxide) treatments have shown to not only increase the drying rate but also reduce both enzymatic and non-enzymatic browning by reducing pH of the material and inhibiting action of polyphenol oxidase thereby reducing Maillard reaction resultantly having a low discoloration during and storage of raisins (Feminia *et al.*, 1998).

B. **Physical techniques**: Since excessive use of chemicals is bound to create food safety problems, the better option is to go for the alternative non-chemical methods. This physical method utilizes mechanical force, thermal energy and/or nonthermal methods such as water blanching, abrasion, microwave heating etc.

Water blanching technique utilizes the principle of hot water that dissolves the waxy epidermal material besides softening of skin and hence increase drying rate. This is the simplest of all methods and can easily be adopted at small scale with no biosafety hazards (Xiao *et. al.*, 2017). However, some compromise is made on the color of the final product as the coloring pigments also gets blanched during the process (Cabrera and Moon, 2015).

Abrasion involves mechanical shearing of grape berries' walls in a shaker with abrasive wall coating. Although the drying efficiency gets increased in this method, but resultant raisins have a comparatively darker color probably due to enzyme activation resulting in the formation of brown pigments (Selvi *et al.*, 2014).

Microwave heating results is rapid evaporation of moisture existing inside the berries through change in polarity of dipolar molecules thus generating heat. Raisins color and appearance is not affected as the browning enzymes are partially deactivated by microwaves (Kostaropoulos and Saravacos, 1995).

Drying techniques for making raisins:

The word raisin has become synonymous with dried grapes. Drying of grapes increases their shelf life, availability period and offers better economical returns at all levels. Various techniques are in vogue for drying grapes some of which are mentioned below:

Solar drying: Since ancient times, solar energy is being utilized to dry food products for preservation. The process employs spreading of grapes in a room under the shade with abundant airflow. It is more practical in areas with high temperature and low relative humidity. Drying in open sun results in unnecessary discoloration. Although very convenient and economical method but time taken for drying is comparatively much longer. The room for drying needs to have nets on the sides to keep the birds away. The method is good at micro level household drying but not so at commercial scale as it takes a lot of time (Wang *et. al.*, 2016). However, a simple modification of having a plastic solar tunnel or a chimney dryer can increase drying efficiency to make it sustainable. A more modified version of conjugated solar dryer is explained under coffee section.

Hot air drying: This method is considered a good alternate for direct sun drying as the method retains many quality attributes of raisins (Coklar and Akbulut, 2017). The method utilizes air heated through an electric heating plate which moves upward through the perforated trays having grape berries to be dried. The hot air takes moisture from grapes leaving them dry. The part close to the fruit surface dries up earlier and the interior part a bit later as the moisture within the berry moves through capillary action. The rate of drying varies with time and temperature.

Microwave drying: This method utilizes the molecular oscillations through change of polarity in the alternating current by using a magnetron or microwave generator. The friction increase temperature of water molecules inside the grape berries which then evaporates in the environment leaving the berries dry. This method has better drying time and retains both ascorbic acid as well as color of the produce. The shrinkage is also low thus adding to the cosmetic value of the final product (Lokhande *et. al.,* 2017).

Vacuum drying: In this method, the air surrounding the product is removed within a closed chamber through a vacuum pump resulting in lower pressure thereby creating a gradient with the internal pressure. This results in easy removal of unbound water molecules. Since no heat is utilized, heat sensitive constituents of food remain intact. This technology is used only at commercial scale for high end markets.

Some other technologies that have recently emerged include infrared drying, pulsed vacuum drying, microwave assisted air drying and microwave vacuum drying; all mostly used at large commercial scale for high end markets.

Based upon the efficiency of the method, being environment friendly, ease of operation and adaptability for the small-scale rural farmers, the non-chemical pretreatment method of water blanching is recommended followed by solar drying method preferably utilizing solar tunnels or simplified solar chimney dryers with food safety and hygiene care maintained all along.

5. Aquaculture and Fisheries

A large number of postharvest technologies are existent in fisheries and aquaculture. However, at the moment, the focus is kept only on improving shelf life of the catch through temperature management.

The Kingdom of Saudi Arabia occupies 80 percent of the Arabian Peninsula land surface with a unique geographical location, with the length of its coastal belt along the Red Sea and the Gulf exceeding 2,400 km. Of the Kingdom's total of 7,572 km coastline, roughly 2,400 km is available for fisheries and aquaculture development along the Red Sea in the west and the Arabian Gulf in the east. This makes the country a rich source of a wide range of fish and other marine products suitable for commercial exploitation, particularly marine species, attributed to favourable climate conditions, availability of water, good land and suitable environment.
Aquaculture in Saudi Arabia dates back to the early 1980s when Nile tilapia was reared in inland water bodies. The kingdom is currently both importing and exporting different species of fish.

Fish has a short shelf life if not handled properly and kept chilled before consumption. The quality can deteriorate rapidly after harvesting the fish which depends on factors such as controlling of temperature, relative humidity of air, hygiene and handling. Fish spoilage is mainly due to enzymatic activity, microbial growth and lipid oxidation resulting in loss of positive sensory attributes (Valtysdottir et. al., 2010). Furthermore, rough handling, mechanical or physical damage results in poor external appearance and hence early spoilage as well as less returns in the market. Rough physical handling causes some cells to rupture, leaving the enzymes free to react with other substances. Mechanical damage, therefore, gives good conditions for some enzymatic activities. The micro-organisms come into the fish flesh and allow faster spoilage of the fish. Enzymatic and microbiological activity are significantly affected by temperature; thus, temperature control is of crucial importance in fish post-harvest handling (Huss, 1995). Temperature plays a vital role in the deterioration of the fish quality after harvesting. Usually, the temperature during transportation to the processing plant should be lower than 4°C in order to slow down the microorganism multiplication which can cause fish spoilage. It is imperative to maintain low temperature immediately after harvest till consumption to avoid spoilage and food waste and losses. If the temperature is beyond the optimal level, fish spoilage rate will be accelerated (FAO, 2014).

Methods for short terms preservation

Small artisanal fishermen in many countries are constrained of resources and can hardly afford to have much post-harvest losses in their catch or harvest. To reduce these post harvest losses, a number of strategies are used in order to reduce the losses. These strategies include immediate freezing, quick selling, smoking, salting and sun-drying etc (Tesfay and Teferi, 2017).

a. <u>Salting:</u> Preserving food by salt has been in practice for centuries. The principle is based on the fact that food-spoiling bacteria cannot live in salty conditions and a concentration of 6–10% salt in fish tissue will prevent bacterial activity, thereby impacting a longer shelf life. Traditional methods of using salt usually involve removing the guts and gills and cutting the flesh into pieces before rubbing salt into the flesh or making alternate layers. The recommended levels of salt usage are 30–40% of the prepared weight of the fish. However, uniform application of salt is necessary to avoid spoilage. An alternate solution to this problem is brining, where the fish is immersed into a pre-prepared solution (36% salt; as 36 gram salt in 100 ml of water at 26^{o}C). The method, though very useful in terms of controlling spoilage is not market oriented as in the context of KSA, the consumers do not like slated fish. Additionally, the slated fish with higher concentrations of salt can be deleterious for persons suffering from high blood pressures.

b. Sun-drying: The process utilizes sun energy to remove moisture form the fish with the aid of air movement leading to preservation at a moisture concentration of less than 25%. The simplest form of drying involves exposing whole small fish or split large fish to heat from the sun by placing products either directly on the ground, roofs, nets, and mats placed on the ground or on racks. It may take three to ten days before the fish gets dried to desirable level of moisture (Tiwari and Sarkar, 2007). Some of the problems associated with this method are:
   i. No control over drying time
   ii. Exposure to attack by insects
   iii. Higher probabilities of contamination by dirt etc.
   iv. Compromised protein quality due to exposure to high temperature for extended period of time
   v. Skin dries first, locking the internal moisture thus requiring more time.

c. Smoking: Smoking dries the fish, melts some fat out of the fish, and reduces microbial growth and hence extending its shelf life to several weeks. Besides extension in shelf life, the specific taste of smoke also gets added to the fish. The principle behind this method of fish preservation involves heat that causes drying thus controlling bacterial growth and enzyme activity and therefore preventing spoilage (Essumang, 2013). Depending upon the type of kin, it can be categorized into two types:
   i. Cold smoking, where the temperature is not raised high enough to completely cook the fish. It is not usually higher than 35 °C.
   ii. Hot smoking, where the temperature is high enough to cook fish. Hot smoking is often the preferred method. Traditional kilns are used in this method with a temperature between 300 and 700 ^{o}C using wood or fossil fuel to attain this temperature. Shelf life in this case is longer because the fish is smoked until dry. Hot smoking consumes more fuel than the cold smoking method. The method is not environment friendly and the processors when exposed to higher temperatures and smoke for years and years become prone to many lungs problems.

d. Freezing/chilling: This method involves the principle of utilizing low temperature to arrest microbial and enzymatic activities that cause the spoilage. Most of the mid-level fisherman utilize this method with having a freezing compartment at the base of their boat. The compartment is either filled with ice to store the catch immediately after harvest and washing. Larger boats have their own freezing rooms. The temperature of the fish needs to be brought down to -2^{o}C immediately after harvest.
   The most common means of bringing down temperature for small fishermen is through the use of ice which can preserve the fish for some time. Freezing reserves the fish for longer periods of time as compared to chilling. The use of ice for preserving fish and fishery products has proved to be an effective handling method on board fishing vessels for the following reasons:

- Ice is available in many fishing areas or ports.

- Purchasing patterns can be varied according to need (e.g. block ice of different sizes is frequently manufactured, and crushed, small or fragmentary ice ready for use is sold by weight).
- Ice has a very high cooling capacity.
- Ice is harmless, and in general relatively cheap.
- Ice can maintain a very definite temperature.
- Ice can keep fish moist and as it melts it can wash surface bacteria from the fish.
- Ice can be moved from place to place and its refrigeration effect can be taken to wherever it is needed.
- Ice can be made on shore and used at sea.

Despite all of the above advantages, it is labour intensive and short living even in ice boxes on board hence limiting the time for small boats to spend in the sea (FAO, 2003).

Current practices and Gap analysis

The current practice of using ice for chilling of the catch to make it to the sale market in fresh condition utilizes ice cubes which are prepared in the ice factory located at the fishing port. Block ice is preferred by small scale artisanal fishermen in KSA like many other parts of the world because it will last longer and takes up less space in the fish hold. The fisherman purchases the ice box transported to the port in a small reefer container. From there these ice blocks are loaded on to the fishing boat to be placed in the ice boxes. The iceboxes are of varying sizes with outer casting made up of high density polyethylene, inner casing with a food grade liner while insulation within achieved through high density polystyrene foam to keep the ice for longer periods of time. After the catch the block is generally broken down and fish alongwith the ice pieces put into the box with a cover on it. The catch is then brought to the fish auction market for auction.

There are quite a few gaps in the entire process that erode the efficiency of cooling thereby negatively affecting fishermen's bargaining capacity.

a. The ice blocks are difficult to carry to the boats from the port and involves additional labour
b. The ice blocks, broken into pieces when required does not make good contact twith all of the fish and all parts of fish, leaving the unexposed parts vulnerable to spoilage.
c. The ice boxes are not maintained properly and generally, instead of covering with the same insulating material, the ice boxes after filling with fish are covered with common jute cloth which is neither hygienic nor thermally as good an insulator as the box lid itself made up of the same material.

d. At the auction material similar kind of ice boxes are used for temporary storage of fish which do not have high level of insulation and does not last long besides creating some hygienic issues due to rusting.

Recommendations

Having a closer look at the existing system, gap analysis, ability of the farmers to adopt, cost constraints and cohesion with the existing practices, the methods of salt brining, sun drying, or smoking does not seem to gel well with the existing eating habits, consumer demand and farmers' practices. The ice storage temporary storage with some modifications can improve the situation and appreciably reduce the fish post-harvest losses at temporary storage.

To address the issue of scale, a common facility center for fishermen and sellers can be established with the fisheries' sector cooperatives with the facilities of fish sorting, containerizing, auction and selling alongwith the conjugated facilities of ice making and ice flakes making. The facility having a cold store to protect unsold or excess fish on the same common facility center will help reduce the food losses. The existing reefer trucks can be utilized for further inland transport.

Ice flaking:

Flake ice has the advantage over block ice of being relatively easy to use since it does not need crushing before use. Because it is slightly subcooled during manufacture and can be packed well around fish, it may be more efficient in cooling fish than crushed block ice. However, because it has a higher surface area and holds a lot of air, it takes up more room in storage and melts more quickly than uncrushed block ice.

Ice flaker works on the same principle as is used for making ice cubes with addition of an ice crushing component for crushing the ice into flakes. The machine uses the same heat exchanging coils and a stream of water to build up a layer of ice. But in this system, the coils are positioned inside a large metal cylinder. To make the ice first, water is passed through the metal cylinder on both sides to build up into a column of ice. Once the ice is formed, the hot gases are released to the cooling coils for releasing the frozen ice column to drop on to the ice crusher below it that breaks the ice cylinder into smaller ice flakes.

A simpler modification could be a simple conjugation of a mechanical ice flaker alongside the existing ice block factories.

The ice flakes are packed into the thermal ice boxes with airtight insulating lids to minimize heat exchanges. In this case instead of taking the ice blocks onto the fishing boats, these ice box filled with ice flake are taken to the boats.

For the fish auction market, it is suggested that a small cold storage be established to temporarily store the fish and avoid spoilage.

6. Livestock (Small ruminants)

Saudi Arabia with a vast land, mostly arid and semi arid, with majority of farmers comprising of small rural strata, livestock in general and small ruminants in particular are an important source of living. Like elsewhere in the world, livestock remains a major driver of livelihoods, and productivity enhancement alongwith improved market access is a powerful catalyst for poverty alleviation in transition economies (FAO, 2012). The plays a vital role in the country with high economic, social and cultural significance. The share of agriculture sector (agriculture, forestry, animal and fishery sub-sectors) is only 4.2 percent of the overall non-oil GDP. The livestock sector in the Kingdom is predominant in rural and agriculture economy and its share in total value of agricultural output is impressive and is about 52 % (FAO Stat).

However, the most neglected part in the small ruminants value chains is the utilization of its by-products including skin hides which are produced in millions during any given year. Utilization of these skin hides for further processing into leather products requires proper deskinning without cuts and then its curing and short term preservation before it reaches the tanneries. Skin hides can add a good profit to the small farmers.

Current practices

The current practices in vogue are deskinning at various slaughter houses both mechanized and manual. The major shortcoming at this stage is the cuts inflicted upon the skin hides of small ruminants that appreciably reduces the quality of these skins as there utility in the processing segment gets reduced due to these cuts.

The skins after removal from the animal are put in a room and cleaned of from any visible large meat or fat chunks. Immediately after flaying[11], the skin has to be preserved as its deterioration process starts within 5–6 h after flaying; hence, there is a requirement for an effective preservative to protect the skin's matrix through arresting microbial attacks (Kanagaraj and Babu Chandra, 2002). Preservation is accomplished either by destroying active bacteria, by preventing bacterial activity or by preventing bacterial contamination (Covington, 2009).

The skins after flaying are spread on the floor and sodium chloride slat sprinkled on to these while adding layer after layer of skin hides. These skin hides when reaches a truck load, are sent to the processing industry for further processing. At times the salt is reused which is counterproductive on many fronts. Reused salt already contains a lot of bio load so that it can not sustain any additional bio load and can not stop microbial activity. Secondly, the salt utilized here goes into the environment when the skin hides are soaked and washed for processing thereby negatively impacting environment (Kannan *et. al*., 2010).

[11] Flaying is removal of skin hide from animal after slaughtering.

Gap analysis

The current method, although widely n practice throughout the kingdom has many inherent flaws in it which reduce the quality of raw hides and erodes the profitability. Some of the problems associated with this curing of raw hides through dry salting include:

Skin hides at a municipal slaughter house in Jazan

1. The salt must be in sufficient quantity to completely saturate the skin to avoid any bacterial growth. The raw hide needs to be salted with 40-50% salt in relation to skin weight equating more than one centimeter layer of salt on the flesh side of the skin. This is not the case and only a very thin layer of salt is spread leading to possibilities of bacterial growth and reduction in resultant leather quality.
2. The high quantity of salt required leads to environmental issues as these chlorides ultimately get into the ecosystem and cause harmful effects.
3. The skins are spread on the floor and are prone to attack by rodents as the salted skins are a favorite food for these.
4. The treated hides should not be kept in humid environments as these become a breeding ground for insects to lay their eggs on and resultant larvae feed on the skin deteriorating its quality.

Technologies for temporary preservation

Many methods are developed for short-term preservation of skin hides and can broadly be divided into physical and chemical ones.

A. **Physical methods:**

a. <u>Cooling</u>

In many countries industrial application of cooling system for hires and skins is being practiced at a temperature between +2 and + 5 ^oC is employed with satisfactory results. However, preservation time is limited and the quality of preservation depends on the temperature maintained during transfer of these hides to the tanneries. Cold hides and skins are kept in a well insulated store to avoid heat exchange from ambinet and in piles to get the best results. In practice one of the methods given below can be utilized to achieve this method of temporary preservation (1) cold air treatment, (2) addition of ice and (3) Carbonic dry ice addition (Vijaylakshmi *et. al.*, 2009).

Cold air treatment technology is suitable only for large slaughterhouses with fully automated functions and large quantities for processing. This method is effective to a maximum of five days with cold transport.

Addition of ice is also done to cool hides and skins in a continuous way in a mixer by using some ice cubes cakes or flakes just after flaying. Generally flayed hides are put in a cool tank and ice added to it to bring the temperature down to 10^{o}C. This is more economical method but requires efficient transportation to tanneries and is suitable for large processors only (Kanagraj and Babu Chandra, 2002).

The dry ice method has a better efficiency because of the lower temperature achieved due to dry ice that can reach -35^{o}C at a very rapid rate. The rewetting problems are not associated with this method. However, special care needs to be taken because of possibility of suffocation risk by the use of carbon dioxide. The initial cost is high and operations need higher levels of efficiency.

b. Vacuum method

As mentioned in the cooling method, lowering temperatures slows down the bacterial growth thereby reducing the rate of collagen and non-collagenous protein degradation. However, at times, for high quality processing, the freezing can result in undesirable changes in the skin. One of the alternative methods is storage of hide in vacuum under low temperatures in the similar fashion as used for foods. The vacuum does not provide oxygen to the microbes to allow microbial decay hence promoting its life before processing. This is a quick method with very little damage to the environment (Wen *et. al.*, 2007).

c. Irradiation

The irradiation processing is comparatively a lot environment friendly method that involves systematic exposure of materials to ionizing energy to effect specific chemical or biological changes. The high energy irradiation gets rid of the bioburden thereby reducing the chances of microbial decay in the skin hides. No toxic effluents are generated in this method. Previously gamma irradiations were used for the purpose that utilized radioactive source of radiation usually cobalt 60. As per international atomic energy commission, this needed approval by the commission for installation and was extremely costly. Now the method is utilizing electron beam for hide processing for reasons of efficacy, safety, versatility, speed and cost. Electron beams are superior to gamma rays as these do not require use of any radioactive material. Instead, a particle accelerator generates an electrical field through which electrons are brought up to near the speed of light targeted magnetically towards the exposed commodity, the resultant energy kills the microbes on the skin hides (Bailey *et. al.*, 2001).

The method requires high cost of initial installation and requires protection of operators. However, at the same time, the method is quick and highly environment friendly but suitable only for commercial large-scale operations.

B. Chemical methods:

Despite being environment friendly, highly efficient in operations, convenience, these methods are not suitable for small scale operations and require large commercial or industrial level set up to operate. The other chemical methods of preservations are more suitable for the small scale operations because of their ease of operations, no requirement for specialized equipment and low cost involved in setting up of operations.
Some of the chemical methods for short terms preservation are listed below:

a. Sodium Chloride+ Ethylene diamine tetra-acetic acid (EDTA): A combination of NaCl and EDTA called “Liricure” is used for the temporary preservation of skin hides. This is a mixture of 25% tetra-sodium ethylene diamine tetra-acetic acid (EDTA), 40% NaCL and 35% medium coarse sawdust (pine) to make the volume. This is applied directly to the flesh surface of hides and skins (Russel, 1998). The treated skin hides can be preserved for a period of around 6 weeks. The availability of EDTA is an issue and its utilization in warmer climates reduces its efficiency.

b. Sodium chloride + sodium meta-bisulphite: Sodium metabisulfite was originally used for preservation of processed foods in very low quantities as the higher concentrations become carcinogenic. The mixture applied to the flesh side of the skin controls microbial decay with lower pollution profile as compared to NaCl only (Kanagaraj *et. al*., 2005). The method is comparatively more environment friendly but utilization of sodium meta-bisulphite in the desired quantity and its availability is an issue and hence not suitable for small farmers.

c. <u>Potassium chloride:</u> Potassium chloride (KCl) is quite similar to the codium chloride but has a better effect in case of effluents as KCl provides potassium to the plants as one of the macronutrients. The effects and utilization manner is the same as NaCl and can effectively substitute NaCl. However, cost of KCl is much higher as compared to NaCl. KCl also has low solubility at lower temperatures thus posing a problem (Bailey and Gosselin, 1996).

Besides these a number of plant-based preservatives like neem oil are also available but due to their high cost are not recommended.

Recommendations

Having a look at various available methods, their impacts in the environment, cost implications, ease of operations and suitability to the small scale operations, the adoptability possibilities of integration within the existing system, the already existing system of NaCl salt usage is recommended with the following modifications:

- All the flesh and fats form the skin hides should be removed immediately after flaying.
- The room for keeping the hides should not be damp and be rodent proof to avoid any damage caused by rodents to the hides.
- The hides, after cleaning should be spread flat with flesh side up and the salt applied evenly to cover all areas of hide.
- Sea salt is better than rock salt in terms of its price and suitability for the purpose.
- The salt should be properly rubbed into the skin instead of just sprinkling it while covering even the seam sides if the hide
- Do not use salt on the hairy side
- After salt application, the hide may be rolled up and placed on an inclination to allow excess fluid drain out.
- Give ample time to settle down, say about 12 hours.
- Unroll the hide and shake all of the wet salt off.
- Then repeat the procedure with another layer of salt and wait for 12 hours.
- If the skin appears dry, it can be racked and stored temporarily in room for further transportation to the processing unit.

7. Rainfed Cereals (Sesame)

Under its component-7, Development of rain-fed cereals production, Sesame is included besides sorghum and millet for their tolerance to drought and adoptability by the farmers particularly small-scale rural farmers. Sesame (Sesamum indicum L.) belongs to family *Pedaliaceae*, is an important oil seed crop being cultivated in the tropics and the temperate zone of the world (Biabani, and Pakniyat, 2008). Its cultivation in KSA is spread over an area of 1663 hectares with a production of 3085 metric tons with an average of 1.86 MT per hectare (FAOSTAT, 2018). The economically important part of the sesame plant is its seed which is mostly used for oil extraction and the rest are used for edible purposes throughout the world (El Khier *et. al.*, 2008).

Leading Sesame exporters and importers (2020)						
	Export			Import		
Cereal	Country	Value	% global share	Country	Value	% global share
Sesame	Sudan	463.76 M$	14.8	China	1.3 B$	44.2
	India	448.57 MS	14.3	Japan	331.9 M$	11.5
	Ethiopia	312.00 M$	10	India	184.5 M$	6.4
Source: Tridge.com/intelligences/sesame-seed/production						

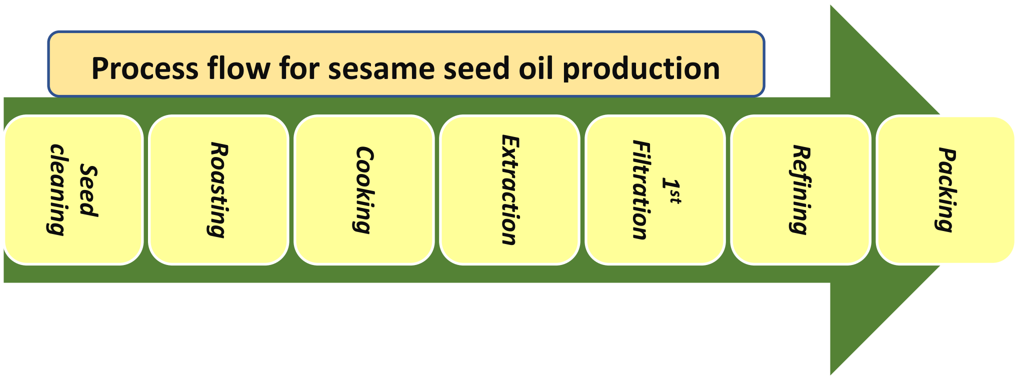
Globally Sudan continues to be the world leader in sesame production followed by India and Ethiopia. Quite a large number of varieties of sesame adopted to various agro-ecological regions exist in the world (Nzioku *et. al*., 2010).

Sesame oil, being the target product in sesame crop production activities has multiple uses. It is used as recognized gourmet oil because of its longer half-life, rich lignans content, presence of essential fatty acids, tocopherols and tocotrienols which are known to possess antioxidant, anticarcinogenic and antimicrobial activities (Ayyildiz *et. al*. 2015, Dar *et. al*. 2015, Pathak *et. al*. 2014). Sesame oil is also utilized in the industry level manufacturing of perfumery, cosmetics, pharmaceuticals, insecticides, paints and varnishes (Chemonics International Inc. 2002). After oil extraction, the remainder cake is fed to animals and nutrient additive (Elleuch *et. al*., 2007).

Sesame oil extraction, in the simplistic way, follows the following sequential steps:

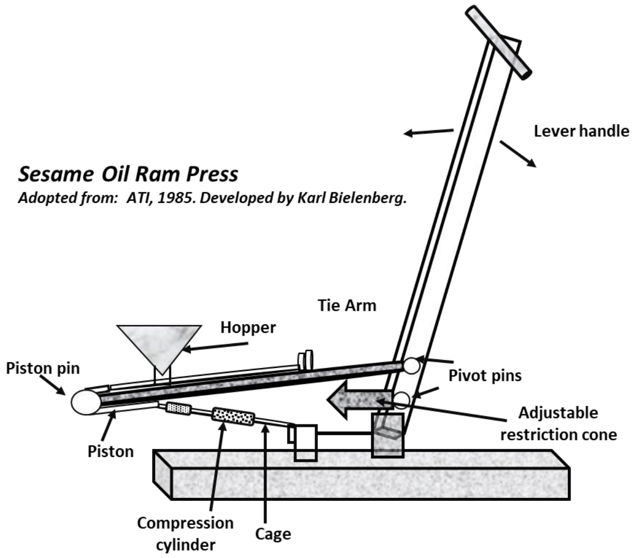
1. **Seed cleaning**:
   The first step after harvest and initiate oil extraction is cleaning of seed through washing for removal of unwanted products. This helps in sorting out the good seeds and cleaning them to remove dust, foreign matter, and stones and making the extraction easy and oil quality better.
2. **Seed Dry roasting**:
   Once the cleaning process is complete, the seeds are dried by gentle roasting after which these are subjected to crushing or any other extraction process.
3. **Oil extraction:**
   Once the seeds have been dried completely, they are ready for crushing or pressing or other methods. After extraction, the oil is given some time to settle with any impurities floating on top.
4. **Crude oil filtration:**
   After oil extraction some oil cakes that are mixed up with the oil needs to be removed. The process of filtration is done to separate the seeds from the oil. This makes the refining level easier to extract the final oil.

5. **Refining:**
For further cleaning, another step of refining is carried out before the oil is packed. Filtration ensures that the oil is fully pure and that it does not have any oil cakes in it.
6. **Packing:**
After passing through all of the above processes, the oil is then packed into bottles, small barrels, canes or any other suitable packaging for further consumption or marketing.



Sesame oil extraction methods:

Considering that sesame seed has a higher oil content (40-60%) as compared to many other oil seeds (Hwang, 2005), it is important to carefully select the extraction method that is efficient, economical, environment friendly and retains the properties of sesame oil. Of course, cost implications, adoptability by the farmers at rural level and environment friendliness can not be ignored while selecting a suitable sesame oil extraction method.

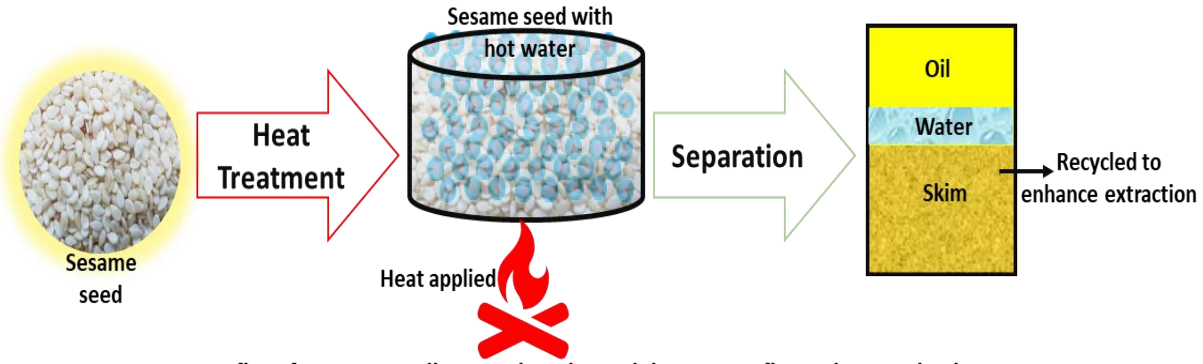


1. **The ram press method:** This method was originally designed by Carl Bienlenberg in 1985 (ATI, 1985). The press has a long, pivoted lever that moves a piston in forward and backward directions housed inside a cylinder that is placed in a cage type structure made up of steel bars for passage of oil. At one end of the piston's stroke an entry port from the seed hopper is opened so that seed can enter the press cage. When the piston moves forward, the entry port is closed, and the oilseed is compressed in the cage thus expelling oil. Remaining seed after compressing is pushed out. The design uses lever and function to act as a pseudo-hydraulic press to achieve pressing pressures which otherwise cannot be achieved manually. The ram press has a low seed throughput but has the advantage of continuous operation. The sesame seed does not require pre grinding; only a little preheating is required to improve extraction efficiency[12]. This Ram press can achieve an efficiency of 57.5% to 62%, depending on model, in terms of clarified oil (Uzaik and Loukanov, 2007). Simplicity of operation, minimal operation and maintenance cost, low

[12] Extraction efficiency (EE), an important quantity in oilseed processing, is the percentage of oil extracted in relation to the amount of oil present in the seed. Generally, commercial processing operates with an EE of over 90%, while in small-scale processing, EE is in the range 60-65% and rarely exceeds 80%.

initial investment and minimal requirement of operation skills make it suitable for small rural farmers for their own domestic use. However, since it does not have large throughputs, its viability for commercial purposes becomes questionable.

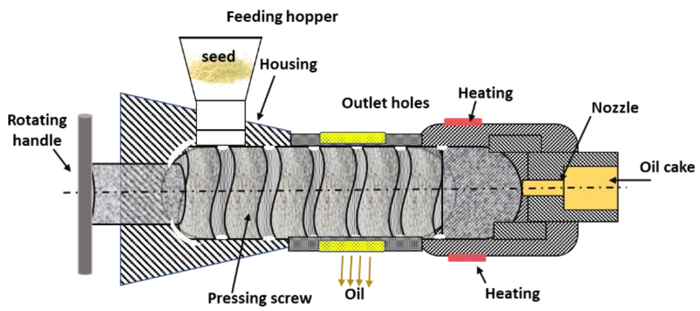
2. **Hot water floatation:** This method is traditionally used in many sesame producing countries by the small farmers at rural level; although not in KSA. The hot water floatation method is based upon utilizing heating and grinding of sesame seed by pounding in large size traditional pestle and mortar. After this vigorous grinding, the suspension is kept boiling for 30 minutes to



Process flow for sesame oil extraction through hot water floatation method

liberate the oil. If required, water is added to aid continued boiling for supporting oil floatation on the surface. The floating oil is then regular removed by scooping and reheated to remove water residues (Warra, 2011). This is a very simple method for small scale operation with only a few equipment required. On the flipside, lot of heat is to be produced either by burning wood or fossil fuel which is not environment friendly. The extraction efficiency is also low in the range of 40-45% (Kaviani *et. al.*, 2015) and the process itself take a long time to complete. The oil extracted through this method has shorter shelf life as compared to oil extracted from other methods where water is not used. The moisture in oil might leads to very mild hydrolytic rancidification[13] and at times making it aesthetically unsuitable for utilization though very little as sesame oil is considered to be a fixative oil.

3. **Bridge press extraction:** This method of sesame oil extraction utilizes the pressure mechanism for oil extraction. Sesame seeds are first ground to a paste using a powered mincer utilizing the screwing mechanism. Finer the grinding, better is the oil extraction with a seed moisture percentage of 11-13% and seeds preheated to 50^{o}C before pressing towards the end of the inner column. The design of a bridge press combines a pressing plate with small holes (2mm) at the end of a screwed tunnel which runs in a nut set in the 'bridge' of the frame that surrounds the extraction cage. The screwed rod is turned by a single cross-head bar providing two levers that



Bridge press extraction process flow diagram.
Method developed by Natural Resources Institute (1995)

[13] Rancidification is the process of complete or incomplete oxidation or hydrolysis of fats and oils when exposed to air, light, or moisture or by bacterial action, resulting in unpleasant taste and odor.

provides power. It is important to have square shaped screw pitch to allow maximum power transfer. The design incorporates a thrust bearing which allows the screwed rod to move onwards while rotating easily against the pressure plate (Natural Resources Institute, 1995). Efficiency of this method is around 70%.

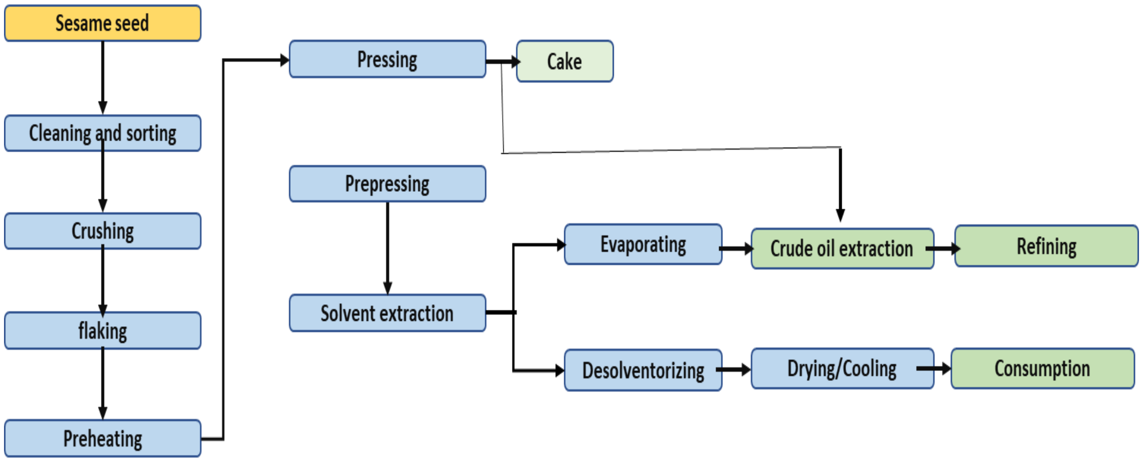
4. ***Ghani* press extraction:** This is one of the ancient methods of oil extraction from various oil seeds and now have been modified from simple mortar and pistil to camel driven *ghanis* and motor driven *ghanis* (Achaya, 1993). In the *Ghani* press oil extraction, oilseeds and subsequently the expressed oil are held in a scooped circular pit in the exact centre of a circular mortar made of stone, wood or steel. In it works a stout, upright pestle which descends from a top curved or angled piece, in which the pestle rests in a scooped-out hollow that permits the pestle to rotate, eased by some soapy or oily lubricant. With the advent of time, single angled piece took the form of two shorter pieces pinioned together. The bottom of the lower angled piece is attached to a load-beam; one end of the load-beam rides around the outside of the barrel, while the other is yoked to the animal. The load-beam is weighted down with either heavy stones or even the seated operator. As the animal moves in a circular ambit, the pestle rotates, exerting lateral pressure on the upper chest of the pit, first pulverizing the oilseed and then crushing out its oil (FAO, 1994).

Photo: Aleksey Morgunov, FAO KSA)

Depending upon the nature of oil seeds, there are large regional variations in *ghani* design (Patel, 1943;Chaudhuri and Selvaraj, 1985), requiring two animals yoked side by side and two operators, one for the animals and the other near the mortar. These *ghanis* have a life of four to five years, after which the pit is too worn to be useful. For oil extraction, sesame seed is put in the pit to its three fourth fill to be pulverized by the pestle with the circular movement of animal. Then some water is sprinkled around the chest. The material built up in the chest is raked using a crowbar, and the pieces are broken up by hand and cast into the pit. The operation continues till the oil starts coming out which is rained by unplugging the drainpipe located at the lower end of the pit (FAO, 1994).

Currently the same method is used in the rural areas of KSA for sesame oil extraction with some modifications and now instead of animal power, electric powered motors are being used. The method has an efficiency of around 70% with the seed cake having some oil which is then either fed to animals or utilized as a high-quality organic fertilizer additive.

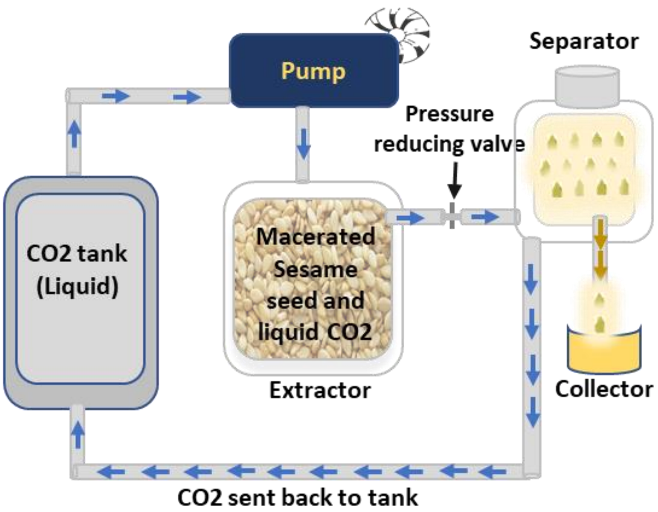
5. **Solvent extraction:** This method is a little different from the previous mentioned processes that utilize mechanical force to squeeze out the oil. Solvent Extraction involves extracting oil from oil-bearing materials by treating it with a low boiler solvent. The solvent extraction method can be applied directly to any low oil content raw materials. It can also be used to extract pre-pressed oil cakes obtained from high oil content materials. Because of the high percentage of recovered oil, solvent extraction has become the most popular method of extraction of oils and fats. Various solvents can be used for extraction but considering the low boiling point of N-hexane,



it is considered better than other solvents. The extraction process consists of treating the raw material with hexane and recovering the oil by distillation of the resulting solution of oil in hexane called miscella. Evaporation and condensation from the distillation of miscella recovers the hexane absorbed in the material. The hexane thus recovered is reused for extraction. For oil extraction, the cleaned seed is milled to the fine quality followed by heating to about 80^{o}C with open steam to temper and raise the moisture content to about 11-12% (Durmaz and Gokmen, 2010). The flakes thus formed are conveyed to the extraction equipment through the rotary air seal. The extractor consists mainly of a very slow moving articulated band conveyor inside a totally enclosed chamber. The band is lined with perforated sheets and porous stainless steel cloth. The mass of the material moving on this band forms a slow moving bed. During the movement of the bed through the extractor it is washed continuously with solvent in a counter current manner by means of sprayers kept in a line over the meal bed. The oil mixed with solvent percolates through the perforated bottom and collects in various hoppers kept below the bed. The material is discharged into an airtight chain conveyor, which conveys it to the desolventiser for heating upto 100^{o}C for solvent evaporation. The material is then cooled to get the oil while cake is filtered off (Saxena *et. al.*, 2011). This method is around 90% efficient for oil extraction but is mostly used at industrial scale or laboratory scales and seldom at the small rural level.

6. **Supercritical CO_2 extraction:** This method has the supremacy of retaining all the original traits of oil as it does not involve any high temperature heating or any hydrocarbon solvent. The heat sensitive compounds are not altered. This method has been used in many technologically advanced countries at industrial level (Ozkal *et. al*., 2005; Roy *et. al*., 1996). This is one of the most effective, and environment friendly method of essential oil extraction as it does not contain any solvent and the operations of extraction of oils are carried at ambient temperatures. Oils derived through this method do not have altered qualities as no application of heat is there unlike steam distillation. In this method CO_2 acts as a solvent.

Any compound above its critical temperature and pressure is called supercritical. At supercritical stage, neither liquid nor gaseous form exists; rather an intermediary of both as a fluid with the properties of both liquid and gas exist. Supercritical carbon dioxide extraction is a commonly used method to separate various components from the plant due to it producing a pure, clean, and safe product. Carbon dioxide reaches a supercritical state at 1071 psi and 31.1°C. A molecule in a supercritical state has properties of both liquid and gas (Xu *et. al.*, 2011). When it comes in contact with the target product through a pressure pump mechanism, its sudden expansion while in contact with the target product burst the product molecules thus releasing volatile compounds first as they have low boiling point.



Sesame oil supercritical CO2 extraction flow diagram

For the extraction purpose, CO_2 under high pressure and in a supercritical state is injected into the chamber containing macerated sesame seed. Since the CO_2 is in a supercritical state here, it acts as a solvent due to its liquid properties. The seed containing oil compounds burst under this pressure thus releasing these compounds. This is followed by product recovery in the separation section, whose temperature and pressure is adjusted in order to optimize the extract amount. The solvent is then recycled and pumped back to the extractor. The final product separation cane be achieved either by depressurization while maintain the same temperature in which case mechanical energy is provided to the system to increase the CO_2 pressure from the separator to the extractor conditions (Pourmortazavi and Hajimirsadeghi, 2007).

Gap analysis

The current method of sesame oil extraction in the rural areas of KSA is the ghani method where earlier camels were used to rotate the pestle in the oil extracting pit. Now, this method is modified to be run with electric power with rest of the process being the same. Only a little efficiency is improved as the electric motor rotates the pestle more efficiently and is not labor costly.

However, when compared with the other oil extraction method, the extraction efficiency is much below the improved methods of oil extraction whose oil extraction efficiency is above 50-70% (camel driven and electric motor driven) and which are not labour intensive. The current method, however, utilizes some water sprinkling at the sesame seed for pulverization purpose. This addition of water although eases the oil extraction process, but in certain cases may also lead to rancidity thereby reducing the shelf life of the extracted oil. The earlier camel powered *ghani* method would process only around 5-6 kg of sesame seed for oil extraction in an hour (motor extraction has increased it to around 6-7 kg/hour which is not enough) as compared to other processes like other methods that can process 40-800 kg/hour depending on the process.

The current method, however, is equally environment friendly and economical as the farmers do not need to keep camels now for this purpose and the feeding associated/husbandry costs are not incurred.

Criterion	Current method compliance	Proposed method compliance
Reduce losses (Quantity, Quality, economic)	Partial	Better as its oil extraction efficiency is lot higher as compared to traditional methods.
Increase efficiency	Partial	Many times higher as it can process more sesame seed for oil extraction in a day
Social and cultural acceptability	-	Acceptable
Gender friendly	Partial	Yes, as it does not require much of the human energy and can be run easily
Innovative	Conventional	Yes
Adoptability	-	Yes. Being low cost, efficient, easy to handle, and efficient, fitting within the existing system.
Environment friendly	Yes	Yes

Suitable technologies

Several technologies in vogue for sesame oil extraction utilizes different techniques. Although CO_2 supercritical extraction and solvent extraction are highly efficient in terms of oil extraction, but these technologies are suitable for industrial level extraction and are not suitable for small scale rural farmers due to their high initial investment, sophistication of operations and requirements of a continued supply chain with excellent integration at forward level too. However, press extraction method utilizing hydraulic press for oil extraction seems to be more suitable for the small-scale rural farmers in KSA. This is a modification of the ram press method that utilizes electric power to move hydraulic press in a cylinder having perforated sieve at the bottom. The piston in the cylinder moves with hydraulic force and presses the sesame oil for oil extraction. Cakes are removed regularly. The oil extraction efficiency of this method is above 90%.


Foto credit: Aleksey FAO KSA)

Hence this technology is recommended for the small-scale sesame farmers for oil extraction purpose.

Cereal grain drying and storage

The two target commodities under the rainfed cereals' component for grains (excluding sesame, as its oil content makes it a different commodity with special storage requirements) are sorghum and millet. These are generally considered to be commodities with longer shelf life as compared to the perishables like fruits and vegetables. This, however, is possible only when the moisture content of the grain is brought down to a suitable level in proper manner followed by its proper storage that protects the stored grain from exposure to excess moisture, insect attacks and rodent attacks.

Cereal grain storage has been in practice since centuries in one way or the other. The first step of this process is proper drying. Cereal grains drying has many advantages including that safer storage by reducing moisture content and thus eliminating possibility of degradation of germination resulting in prolonged storage without compromising the quality, Low moisture content reduces the risk of molds or aflatoxins which can have a detrimental effect on human health, less waste by reducing the risk of deterioration, maintain productivity and quality and finally, adding value and profits by inculcating flexibility to the farmer for having favorable price. Before putting the grains to storage, their moisture level must be brought down to around 10%. There are different methods of grain drying broadly categorized into two; natural drying and artifical drying. The natural drying is either done in the field conditions before harvesting, drying in shallow layers and exposing to sun and wind on a surface that prevents moisture from the ground from reaching the produce after the harvesting or later drying in, or on, a structure that has open sides to permit air movement through the mass. The artificial drying has shallow layer drying or deep layer drying; with hot air blown over the grains to remove moisture. Care, however, must be taken to avoid overheating as this can damage plumule. Another important aspect is to immediately cool down the grain after moisture removal in the continuous-flow dryers.

However, the choice of drying technique depends upon volume of the product, season of harvest, storage system that will be used, intended utilization and the cost of drying. However, under the scope of SRAD project, targeting the small-scale rural farmers, the natural drying system currently being utilized seems to be more practical as it is cost effect and due to manageable volumes of the crop, can be easily dried at ambient in shallow layers. The layers, however, may be tilted every few hours to swiftly get rid of excess moisture. This should be followed by winnowing to get rid of dirt and inert material and then proper packaging for storage purpose.

Storage structures

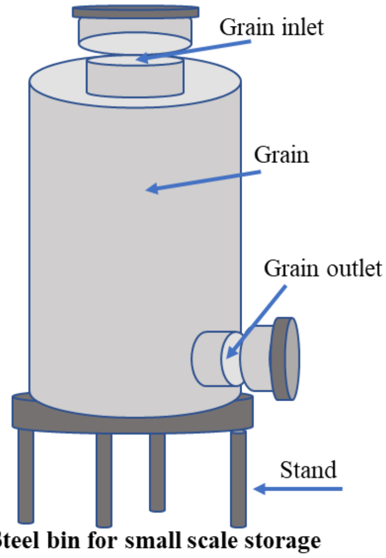
The most important objectives of grain storage for small scale rural farmers are to provide assurance for the producer that the grains will remain available for food and as seed beyond the harvest periods and gain some profits by timing the disposal of the produce with the market requirements and thus generate margins.

The existing system of storage for cereal grains is marred with a number of complications. In most of the cases the harvested grains after drying are put in the jute bags without any control measures or fumigation for controlling storage insects like weevils, moths or beetles. The bags are either directly staked on the floor in a room or in some instances placed on wooden planks with 3-4 inches elevation above the ground. This method exposes the stored grains to ground humidity, termites, and rodents. Rodents and the store grain insects coupled with moisture contact from the soil leads to huge losses. These factors make this method a compromised storage method for grain storage.

Other storage structures for small scale rural farmers as elaborated by FAO include improved traditional bin with some minor but meaningful improvisations for increased efficiency. These improvisations include raised floor to avoid moisture, supporting legs of the structure are high enough to get protected from rodents with baffles at the ends, mud replaced with cement/lime plaster, thatched roof for protection against rain and strong sun, and separate airtight and lockable inlets and outlets.

Bricked walled silos are yet another example of small scale rural level grain storage. The structure has Walls made of bricks, mud or cement that have the ability to absorb moisture from the ambient air. In areas with high relative humidity it is therefore necessary to protect the grain by adding a moisture barrier to the silo walls. The walls can then be painted with plastic paint or coal tar if better protection is needed. However if the structure exceeds certain size and holding capacity limits, it needs reinforcement which results in incurring of extra costs.

However, the most efficient one for the smaller farmers at rural level in terms of protection from the pests, protection of stored grains, longevity of structure etc. remains the miniaturized version of large silo bins. These steel bins in the shape of a conical drum have varying storage capacities varying form 5 metric tons to 20 metric tons. The structure itself is kept above ground on a stand at about 1-1.5 ft elevation and has a controlled opening at one of the lower sides for collection of grains while a sealable opening at the top to pour grains. The entire structure is generally kept airtight. The cost of this structure is a bit higher, but the structure life compensates for that cost escalation.



Steel bin for small scale storage

Based upon the efficiencies, longevity, protection from various pests, protection form rodents, and maintaining the desired condition of stored grains over longer period of time for continued availability as well as ease of handling, small scale steel bins with a capacity of 5-10 metric tons are recommended for small rural farmers for cereal grains storage.

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برنامج التعاون الفني بين وزارة البيئة والمياه والزراعة ومنظمة الأغذية
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