Reducing losses in rainfed cereals of KSA through better harvest, postharvest management and processing VAL/051/2022/2

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

Riyadh, Kingdom of Saudi Arabia

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Acronyms

BDS	Business Development Services
FAO	Food and Agriculture Organization
FAOSA	Food and Agriculture Organization, Saudi Arabia
FGDs	Focus group discussions
KSA	Kingdom of Saudi Arabia
MoEWA	Ministry of Environment and Agriculture
PHLs	Postharvest loses
PICS	Purdue Improved Crop Storage
QuickPhos	A phosphine gas releasing chemical
SALIC	Saudi Agriculture and Livestock Investment Company
SFDA	Saudi Food and Drug Authority
SRAD	Sustainable Rural Agricultural Development
SRADP	Sustainable Rural Agriculture Development Program
NPPO	National Plant Protection Organization
R&D	Research and Development
RFCs	Rainfed Cereals
Saudi GAPs	Saudi Good Agricultural Practices
SMEs	Small and Medium Enterprises
SR	Saudi Riyals
Sulait	The sesame oil extracted from sesame seed
SWOT	Strengths, Weaknesses, Opportunities and Threats

Acknowledgments

This report has been prepared with the support of FAO Saudia's Sustainable Rural Agriculture Development Program (SRADP), with a focus to improve the efficiency of target commodities including rainfed cereals (RFCs) i.e. sorghum, millets and sesame at the postharvest level. The current practices of harvesting, postharvest handling, and processing of target rainfed cereals lead to both quantitative and qualitative losses thereby incurring economic losses to the small holders. The existing harvesting, postharvest handling and processing have significant room for improvement, which can lead to a reduction of these avoidable losses. It is in this background; the report on "reducing losses through better harvesting practices, postharvest handling, and processing" is compiled to serve as a guideline and reference material.

The support of all the FAOSA colleagues is highly acknowledged.

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Executive Summary

Vision 2030 of the government of Saudi Arabia aims to expand its economic base beyond the oil-based economy and to ensure food security. The Saudi government through its Ministry of Water, Environment and Agriculture (MoEWA) and FAO jointly formulated a program 'Sustainable Rural Development Program (SRAD)" for developing the agriculture sector of the Kingdom with particular emphasis on certain identified commodities through a value chain approach.

The rainfed cereals i.e. sorghum, millet and sesame have been traditionally grown for centuries in Saudi Arabia. Sorghum is the predominant crop among the rainfed cereals followed by millets, while sesame occupies the least area among the rainfed cereals. Sorghum is a source of food as well as feed for domestic animals. However, millet and sesame are grown primarily for their grain and seeds.

The cultivation of rainfed cereals is a major agricultural activity in Southwestern Saudi Arabia, where it serves as a source of food and feed. Rainfed cereals, because of their tolerance to high temperatures and moisture deficit, are the ideal crops that coincide with the government of the Kingdom of Saudi Arabia (KSA) efforts in water conservation, especially in agriculture. The government of KSA is also extending subsidies to promote the cultivation of rainfed cereals. Despite enabling environments, domestic production is short of demand and Saudi Arabia has to rely on the import of sorghum and sesame. By contrast, the export of sorghum and millet is negligible. While Saudi Arabia is a regular exporter of sesame seed, it is a net importer because the import quantity has always been higher than the export quantity.

The agro-climatic conditions of southwestern Saudi Arabia are desirable for the cultivation of rainfed cereals. The production of sorghum, millets, and sesame in KSA is about 123,869, 11,701 and 4,012 tonnes, respectively. There are no published estimates of postharvest losses in rainfed cereals in KSA. Saudi Arabia by increasing its domestic supply can, not only decrease its import spending on rainfed cereals but can also emerge as a net exporter. However, increasing the production of rainfed cereals will be of little importance if the losses during harvesting, postharvest management and processing are not reduced. However, the postharvest losses estimated through farmers' interviews indicated about 23.50, 22.55 and 35.5% losses sorghum, millets and sesame respectively. These losses translate into 29,109.22 tonnes, 2,638.57 tonnes, and 1,424.26 tonnes in sorghum, millets and sesame crops. The economic impact of postharvest losses, based on import price for the year 2020 is about 5,901,602 million 985,825 and 2023,731 million USD for sorghum, millets, and sesame respectively.

The success of the rainfed cereals sector in KSA to emerge as a global player requires transformation from traditional cultivation to modern agricultural technologies to enhance the quality of seeds and minimize the losses during postharvest handling and processing. It requires adopting proper harvesting, postharvest handling, and processing technologies to meet the global standard of quality. Reducing postharvest losses by 75% can add about 21827, 1979 and 1068 tonnes of sorghum, millet and sesame worth 4,425,260, 739,368, 1,517,798 USD in sorghum, millet and sesame accordingly to the cereal crops sector of KSA.

Another issue in the rainfed cereals' sector is the limited value addition and processed products. Sorghum and millet are used in some traditional dishes. However, the sesame is processed into oil, using traditional technology i.e. water extraction technique, which decreases the quality and shelf life of the oil produced.

Proper harvesting and processing are essential to reduce quantitative and quality losses of rainfed cereals. The current assignment was carried out to evaluate the current scenario of harvesting, postharvest handling, and processing of rainfed cereals in KSA; and propose measures at each level to reduce the losses and retain the quality throughout the postharvest chain. The critical stages where the highest losses in sorghum and millet occur are harvesting and storage (6.5% each in sorghum and 5.5 and 6.0% in millet). While drying and storage result in 12.0% and 8.5% loses respectively

in sesame crop... Harvesting at the proper maturity stage can contribute significantly to loss reduction in rainfed cereals. Interventions in the drying process such as using tarpaulin sheets and ensuring proper seed moisture content can significantly decrease the losses at the drying stage. Similarly, seed cleaning and proper sorting of rainfed cereals enhance the market value and decrease losses due to diseases and pests. The traditional storage techniques with no temperature control and the least protection from moisture, light and pests are another major cause of postharvest losses. Adopting proper storage technologies i.e. packaging in hermetic bags and storage in siloes can be useful in decreasing the losses during the storage of rainfed cereals.

Since rainfed cereals are grown mainly by smallholders, who lack the resources and skills of modern but readily adoptable postharvest techniques in postharvest handling of RFCs. Hence, low input and easy-to-adopt technologies such as harvesting at physiological maturity, drying and threshing on tarpaulin sheet, specialized threshing floor, slightly modified storage structure and replacing gunny bags with hermetic bags are proposed to reduce the postharvest losses of rainfed cereals. Products diversification by producing value added products with low input technologies are suggested to enhance the market value and grower’s profit. The training of MoEWA staff and smallholders of rainfed cereals is of crucial in adopting better postharvest management of and decreasing losses in rainfed cereals.

SECTION 1: BACKGROUND OF THE REPORT

1.1 Background

The Kingdom of Saudi Arabia, with a total area of about 2.15 million km^2, is by far the largest country in the Gulf Cooperation Council. It is bordered in the north by Jordan, Iraq and Kuwait, in the east by the Persian Gulf with a coastline of 480 km, in the southeast and south by Qatar, the United Arab Emirates, Oman and Yemen, and in the west by the Red Sea with a coastline of 1,750 km.

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. The majority of the farmers in the Kingdom are smallholders 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 the rural sector thus is dependent on holistic consideration from the efficient management of production resources, processes and systems, technologies, value chain and supporting institutions.

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

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

In the green sector of SRAD, rainfed cereals, besides other crops, were selected due to their potential in the livelihood improvement of smallholders as well as their important contribution towards food security. There are significant gaps in the harvest, postharvest handling, and processing levels of the rainfed cereals value chain. Optimizing postharvest management and processing practices and technologies will reduce postharvest losses and ensure the quality of produce. Thus, can contribute significantly to the rainfed cereals sector in KSA.

Many inefficiencies are present at the harvest, postharvest and processing levels of all the commodity value chains with quite a large room for improvement. The farm produce must be properly and efficiently handled in the commodity supply chain to assure quality on arrival in markets. The SRAD target commodities are of different characteristics in terms of their consumption, their integration in the supply chain as primary or processed products and their perishability. These factors determine the methods and technologies to be applied to agricultural commodities. Additionally, inherent inefficiencies in the food production chain lead to poor quality, a high levels of food losses that adversely affect 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. Postharvest loss takes place from harvest up to the wholesale market. These losses can be appreciably reduced by improving functioning at harvest, postharvest and processing levels which will not only lead to avoiding food loss but will also result in adding margins for the smallholders as well as creating employment opportunities.

1.2 Cultivation of Rainfed Cereals in KSA

The agricultural land of KSA is estimated at about 770,000 ha (MoEWA, 2020). Most of the arable land is irrigated. Date palm is the prominent fruit grown over 152,704 ha as compared to other fruit (24,705 ha). Among the cereals crops, wheat, barley and sorghum occupy 86,963 ha, 81,520 ha, and sorghum 67,466 ha.

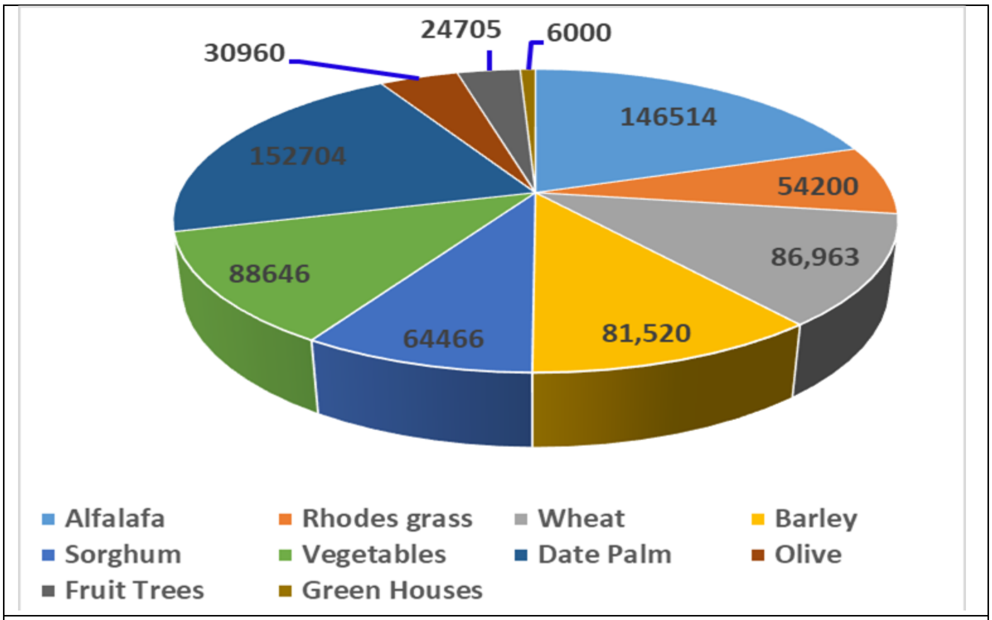


Figure 1. 1 Area (ha) of major crops in Saudi Arabia

The north and central regions of the country with sufficient irrigation provisions were the major focused areas to increase cereals and crop production (Kim *et al*., 2018). However, the declining water resource and recent government policy aiming at water conservation call for optimizing water use in irrigation as well as maintaining the production of critically important crops. There is renewed interest in rainfed cereals as a source of food and feed, which is grown in the southwestern regions of Saudi Arabia. The rainfed cereals have been traditionally grown in the Al Baha, Aseer, Jazzan and Makkah regions of southwestern Saudi Arabia. The moist air currents from the Red Sea cause precipitation on the slopes and valleys of the Aseer Mountains creating suitable conditions for crop production (Morgounov *et al*. 2022).

1.3 Postharvest Losses in Rainfed Cereals

Postharvest losses (PHLs) refer to the qualitative and quantitative losses in a commodity from harvesting to consumption (Hodges *et al*., 2011; Aulakh *et al*., 2013). Globally, about one-third of the food produced (about 1.3 billion tonnes), worth about US $1 trillion is lost during postharvest operations (Gustavsson, 2011). Hence, increased production is of little benefit without reducing the losses during harvesting and postharvest handling. Reducing losses through proper management during production, harvesting, postharvest handling and processing is essential for the sustainable development of the rainfed cereals sector (Minten *et al*., 2014). Food losses are also a major cause of pollution because unutilized food causes CO_2 emissions that degrade the environment. Therefore, reducing food losses is a major approach to meet the increasing global food demand and improving food security (Hertel, 2015; Reynolds *et al*. 2015). Postharvest management is considered as one of the primary strategies to increase food and nutrition security amid the increasing world population (Opara, 2010). It is envisaged as one of the ways to the sustainable development goals (SDGs) especially 2, 3, 12, and 13, aimed at Zero Hunger, Good Health and Well-being, Cutting down global food waste by 2030, and Climate Action accordingly (Castelein *et al*., 2021).

1.4 Objectives of the Study

a. Provide an insight into the rainfed cereals sector of KSA.
b. Evaluate the postharvest management and processing of rainfed cereals in KSA.
c. Identify the gaps in the harvesting, postharvest handling and processing of rainfed cereals.
d. Propose postharvest handling and processing technologies to minimize the postharvest losses in rained cereals for smallholders.
e. Propose measures/technologies to promote the rainfed cereals sector of KSA.
f. Suggest value addition measures to enhance the income of smallholders of rainfed cereals.

1.5 Methodology

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

i. **Review of Project Documents**: The project documents concerning the rainfed cereals were studied to get basic data/information on rainfed cereals especially, the harvesting, postharvest management and processing.
ii. **Meetings with the expert group**: Meetings with the expert groups of FAOSA on rainfed were held to appraise the overall status of the rainfed cereals, their postharvest management and processing.
iii. **Interviews with growers**: Interview questions were developed and the farmers/processors were interviewed in Jazzan region; a region where rainfed cereals are the predominant cereal crops. The interview covered a range of questions concerning production practices, time and methods of harvesting, postharvest handling techniques i.e. drying methods, packing, transport, processing methods and storage techniques adopted by the smallholders of rainfed cereals (Annexure 2).
iv. **Field Visits**: Visits to the production regions of rainfed cereals (Jazzan and surrounding towns) were conducted. The harvesting and postharvest operations were observed and evaluated. Questions about postharvest losses and remedial measures by the growers were recorded.
v. **Visits to Postharvest/ Marketing Facilities**: Several markets and related facilities such as Jazzan farmers' market, market vendors, transporters and storage of rainfed cereals were visited. Information regarding the handling of rainfed cereals during marketing, transport and storage was collected and evaluated.
vi. **Focus Group Discussions (FGDs):** FGDs with the extension staff and research staff of the Ministry and growers (members of cooperatives) of rainfed cereals were held to update on the problems and prospects of rainfed cereals.
vii. **Review of literature**: Desk review of literature/ reports concerning the harvesting, postharvest handling and processing of rainfed cereals especially in KSA. However, scientific literature from other countries was consulted to elaborate on certain aspects or draw a comparison.
viii. **Validation Workshop**: The findings of the study were presented to the growers of rainfed cereals, processors and experts from MoEWA in the validation workshop. The findings of the study were thoroughly discussed and the recommendations were deliberated upon in the socio-economic background of smallholders of KSA.

1.6 Limitations of the Study

The methodology adopted is limited by the fact that a detailed socio-economic survey could not be conducted due to the short time of the assignment. Hence, the survey questions were addressed through interviews with stakeholders. The data presented represent the mean values. However, this limitation was rectified by drawing information from other sources stated in the methodology.

SECTION 2: THE RAINFED CEREALS SECTOR IN KSA

2.1 The Global Scenario

Global agriculture is facing the challenge of increasing food production to meet the food demand of the increasing population and ensuring sustainability to preserve the environment. The increasing production requires increased inputs in the form of land, water, and chemicals, which are a serious threat to the environment. For instance, whereas ample water is required for higher food production, the increased consumption of water for irrigation threatens the water resources in many countries around the world. It has been estimated that the irrigation of crops consumes about 72 percent of global and 90 percent of water withdrawals in developing countries. Hence, it is desired that water use for irrigation should be reduced to sustain non-agricultural water uses i.e. humane, animal and industrial consumption. Hence, it is a challenge for agriculture to meet the two reciprocals of increasing food and decreasing water consumption.

Rainfed cereals i.e. sorghum, millets, and sesame, are grown throughout the world as a source of food and feed. Rainfed cereals are comparable in food value to other cereal crops (Table 2.1) and can be grown in harsh environments i.e. high temperature and low water availability. Hence, rainfed cereals are important food sources, especially in arid regions of the world. Therefore, the improvement of rainfed agriculture has emerged as a major strategy to cope with the increasing food demand and address environmental concerns of depleting water resources (Hofwegen and Svendsen, 2000).

Table 2. 1. Comparative nutritional value of rainfed cereals and maize

Nutrients	**Quantity (g/100g)**			
	Sorghum	**Millets**	**Sesame**	**Maize**
Carbohydrates	72.6	69-73	5.0–5.6	73.0
Protein	10.4	11.53	21.5–29.5	9.20
Fat	1.9	4-5	52–62	4.6
Sorghum: The sorghum seeds are also rich in different minerals such as Calcium 25 ad Iron 4.1 mg/100g. It also rich in β Carotene, Thiamine and Riboflavin.				
Millet: The millets contain several minerals such as Magnesium, Mg 228.00 mg, Manganese, 3.264 mg, Phosphorus, 570.00 mg, Potassium, 390.00 mg, Sodium,10.00 mg, and Zinc, 3.36 mg.				
Sesame: The sesame seed contains several important minerals such as Calcium 21mg, Iron 0.66 mg, and Potassium 69 mg.				
Maize: Ca 2.26 and Iron 2.7 mg/100g + Vitamin Niacin, Thiamine Riboflavin				
Sources: USDA Nutritional Database; Couch *et al.*, 2017, FAO, 1995				

The world over, sorghum, millets, and sesame were grown over 40.25, 32.12, and 13.97 million hectares, with a total production of 58.71, 30.46, and 6.804 million tonnes in the year 2020. The worldwide cultivation of sorghum and millets decreased during the years 2011-2020, but the production increased due to an increase in yield. By contrast, the area and production of sesame increased during the same period (Table 2.2). The sorghum and millet are relatively difficult to process and there is very little value addition in these crops. However, being an important source of food and feed in semi-arid climates. Climate change especially higher temperature and water deficit necessitate research and development in RFCs and adopting proper postharvest handling and processing techniques for rainfed cereals. It is needed to promote rainfed cereals and explore the postharvest handling and processing opportunities of rainfed cereals to ensure sustainability in rainfed cereals production.

Table 2. 2 Global cultivation (million ha) and production (million tonnes) of rainfed cereals

Year	Sorghum		Millets		Sesame Seed	
Year	**Area (M. ha)**	**Production (M. tonnes)**	**Area (M. ha)**	**Production (M. tonnes)**	**Area (M. ha)**	**Production (M. tonnes)**
2011	42.204	56.808	33.97	27.05	8.40	4.713
2012	39.258	57.321	31.26	26.63	8.54	5.384
2013	43.901	61.895	31.23	26.42	10.07	5.378
2014	44.644	68.301	32.24	28.44	11.21	5.971
2015	41.692	66.116	29.56	28.20	10.08	5.517
2016	44.314	63.491	31.09	27.53	10.89	5.577
2017	40.940	57.754	31.28	28.81	11.11	5.708
2018	41.937	60.128	32.68	31.63	11.80	5.889
2019	39.205	57.363	30.79	28.33	12.99	6.549
2020	40.252	58.706	32.12	30.46	13.97	6.804
Change	**-1.95**	**+1.89**	**-1.85**	**+3.41**	**+5.57**	**+2.09**

Source: FAOSTAT, 2020

2.2 Top Global Producers of Rainfed Cereals

Among the producers of rainfed cereals, the USA was the world's top sorghum producer (with 8,673.48 thousand tonnes) followed by Nigeria and Ethiopia with 6665 and 5265.58 thousand tonnes. Saudi Arabia produced 123, 869 tonnes and ranked 27th in sorghum production. India with 11,500 thousand tonnes, was the largest millet producer, followed by Niger and China with 30,800 and 2,700 thousand tonnes, respectively. The contribution of Saudi Arabia to global millet production is negligible. The global sesame production was about 487.000 thousand tonnes. Myanmar was the world's largest sesame-producing country (785,038 tonnes) followed by India and Tanzania with 755,346 and 755,346 tonnes, accordingly. Saudi Arabia ranked 46th, by contributing 4,119 tonnes to global sesame production (FAOSTAT, 2020) (Table 2.3).

Table 2. 3. The largest global producer of rainfed cereals

Rank	Sorghum		Millets		Sesame	
	Country	**Production(000 Tonnes)**	**Country**	**Production (000 Tonnes)**	**Country**	**Production (000 Tonnes)**
1	USA	8673.480	India	11,500	Myanmar	785.038
2	Nigeria	6665.000	Niger	3,800	India	755.346
3	Ethiopia	5265.580	China	2,700	Tanzania	663.935
4	Mexico	4352.947	Nigeria	2,000	Nigeria	588.334
5	Sudan	3714.000	Mali	1,800	China	392.414
6	China	3600.000	Sudan	1,500	Ethiopia	296.001
7	India	3475.410	Ethiopia	1,100	Burkina Faso	244.086

Rank	Sorghum		Millets		Sesame	
	Country	Production(000 Tonnes)	Country	Production (000 Tonnes)	Country	Production (000 Tonnes)
8	Brazil	2672.245	Burkina Faso	1,000	South Sudan	206.163
9	Niger	1896.638	Senegal	900	Chad	177.870
10	Burkina Faso	1871.791	Chad	689	Uganda	143.234
27th	S. Arabia	123.869	S. Arabia	NS	46th S. Arabia	4.119

Source: USDA, 2021, FAOSTAT, 2020

2.3 International Trade of Rainfed Cereals

The global export volume of sorghum was 1.72 million tonnes during the year 2020. The USA with 1.39 million tonnes was the largest exporter of sorghum, followed by Argentina and Australia with 84.653 and 49.561 thousand tonnes. Saudi Arabia exported a negligible quantity of sorghum but it imported 291 tonnes and ranked 75th among the sorghum importing countries (Annexure 1. a).

The global export of millets was 516,592 tonnes in 2020. The largest exporter of millet was Ukraine (116,395 tonnes) followed by the USA (100,158 tonnes). The millet export of Saudi Arabia was 278 tonnes and it ranked 69th exporter of millet. By contrast, Saudi Arabia was 32nd millet importing (3,897 tonnes) country (Annexure 1. b).

The global export of sesame was 3.53 million tonnes, with Sudan (492,351 tonnes) and India (276,265 tonnes) as the major exporters. Saudi Arabia exported 68 tonnes of sesame seeds. By contrast, it imported 49,612 tonnes and was the 7th largest importer of sesame (Annexure 1. c).

The oil of sesame is another valuable product that is traded on a global scale. The total export of sesame seed oil was 80,691 tonnes. China exported 11,650 tonnes of sesame seed oil in 2020, followed by India (10,770 tonnes). During the same year, Saudi Arabia ranked 89th in the export of sesame seed oil by exporting 200 tonnes. However, Saudi Arabia also imported 1,563 tonnes of sesame seed oil and was the 14th major importer (Annexure 1. d).

2.4 Import and Export of Rainfed Cereals by KSA

Annual consumption of sorghum, sesame and millet was estimated at 203,000, 36,000 and 15,000 tons respectively. The current local production of sorghum, millet and sesame is short of 79131, 24299 and 10988 tonnes respectively. As a result, the KSA has to rely on the import of rainfed cereals to meet the local demand. The average sorghum import of Saudi Arabia during the years 2015-2020 was 306.71 tonnes, costing 168,570 USD, at USD 549.60 per tonne. The average import of millet during the years 2011-2020 was 9289.4 at 317,570 USD and a price of USD 341.86 per tonne (Table 2.4).

Table 2. 4. Mean import prices of sorghum (2015-2020) and millets for the years 2011-2020.

Commodity	Import			Export		
	Tonnes	Value (1000 USD	Price (USD/tonne	Tonnes	Value (1000 USD	Price (USD/tonne
Sorghum	306.71	168.57	549.60	Negligible		
Millets	9289.40	3175.7	341.86	Negligible		

Source: FAOSTAT

Saudi Arabia has been a regular importer and exporter of sesame seeds. During the years 2011-2020, the mean annual import of sesame seed was 47,447.9 tonne, worth USD 68465.9 at an import price of USD 1442.97 per tonne. By contrast, Saudi Arabia exported an average of 2015.5 tonnes, worth 187300 USD at a sale price of USD 469 per tonne (Table 2.5). The export of sesame is also of no significant benefit to the national economy as the export price of sesame seed is less than half the import price (Table 2.5). In addition, Saudi Arabia also exported 278 tonnes of sesame oil at the rate of 1687.05 USD/tonne but imported 1563 tonnes of sesame oil at the price of 1442.97 USD/tonne during the year 2020 (Table 2.5).

Table 2. 5. Export and import of sesame seeds by Saudi Arabia.

Years	Export			Import		
	Quantity (Tonnes)	Value (000 USD)	Price (USD/tonne)	Quantity (Tonnes)	Value (000 USD)	Price (USD/tonne)
2011	248	380	1532.26	34571	43162	1248.50
2012	246	469	1906.50	42171	56307	1335.21
2013	426	722	1694.84	40369	71646	1774.78
2014	18	38	2111.11	44318	92010	2076.13
2015	175	263	1502.86	47430	70401	1484.31
2016	19	49	2578.95	46869	50945	1086.97
2017	325	273	840.00	44977	50496	1122.71
2018	113	296	2619.47	50961	70629	1385.94
2019	25	57	2280.00	73201	108569	1483.16
2020	278	469	1687.05	49612	70494	1420.91
Mean	187.3	469	1875.30	47447.9	68465.9	1442.97

Source: FAOSTAT

2.5 Current Situation of Rainfed Cereals in Saudi Arabia

According to the KSA general authority of statistics (2015), there are about 243,999 growers in the crop sector and over 57.1% farms of the national total in southwestern Saudi Arabia. However, the area under cultivation on these farms was only 10–12% of the total land registered as being under farms in KSA (Morgounov *et al*. 2022). It indicates the smallholding in southwestern Saudi Arabia. Despite small holdings, a variety of fruits, vegetables, and several cereal crops are grown in southwestern Saudi Arabia. The main cereal crops grown in these regions are sorghum, wheat and millet. Sorghum and millets are the most cultivated crop, mainly in the Jazzan region. Sesame is another popular crop and is in high demand by local consumers. Landraces or older varieties of rainfed cereals are commonly grown using conventional technologies with the minimum, if any, inputs, which result in low yield. The land-race variety of millet (Dukhn) and sesame (Semsem) are common in the region. There are three common sorghum varieties in the region.

a. Alhamra: These grains are red-colored, locally called as Zoar. The variety is predominant in Besh governorate of Jazzan. The grains are highly preferred by consumers and can be sold at SR 15-20/kg.
b. Al-Baidha: The grain of this variety is white in color. The Albaiba variety can compete with Alhamra variety and is grown at about comparable area in Jazzan the region.

c. Shahila: The Shahila variety is grown over a relatively small area of about 5-7%. The grains are between gold – yellow (Red-White) in color.

The sorghum and millet are C4 plants and well adapted to high temperatures and drought conditions. The sesame is cultivated in the coastal plain and rocky habitats. (Al-Turkia, 2019). In KSA, sorghum, millets, and sesame are grown over 52,243, 5,551 and 1,629 hectares, respectively sharing 87.94, 9.33, and 2.74 %, respectively (FAO, 2020) (Table 2.6).

Table 2. 6. Cultivation of rainfed cereals in KSA

Year	Sorghum		Millets		Sesame Seed	
Year	Area (ha)	Production (Tones)	Area (ha)	Production (Tones)	Area (ha)	Production (Tones)
2011	43,899	114,022	3,086	5,208	2,621	4,538
2012	44,399	117,091	2,844	4,924	2,514	4,431
2013	45,438	118,393	2,632	4,486	2,507	4,786
2014	42,101	110,299	3,802	8,022	2,060	3,485
2015	63,101	166,033	4,222	7,309	1,943	3,839
2016	60,740	157,764	4,467	7,539	1,833	2,639
2017	58,467	152,341	4,726	8,055	1,729	3,258
2018	56,279	147,353	4,492	8,634	1,658	3,132
2019	50,165	123,837	4867	11,405	1,629	4,119
2020	52,343	123,869	5,551	11,701	3,056	4,012
Trends	**+8,444**	**+9,847**	**+2,465**	**+6,493**	**+435**	**-526**

FAOSTAT, 2020

2.5.1 The Soil and Climatic Condition of Rainfed Cereals Growing Region in KSA

Soil: Sesame grows best on medium to light, well-drained soil. Heavy clay soils require good drainage or raised beds and light irrigation. Sesame performs best in slightly acid to alkaline soils (pH 5-8) with moderate fertility. The main agricultural area of Jazzan lies in the coastal plain where alluvial silts and fine sands from the highlands are deposited in the valleys, thus enhancing the fertility of the soil.

Temperature: The Jazzan region is located in the southwestern corner of Saudi Arabia and has a relatively wide coastal plain, a transitional rocky habitat and a chain of mountains up to 2621 meters above sea level (Masrahi, 2012). The climate varies from hot and humid near the sea in the coastal plain. The hottest months are from May to September, when the mean monthly temperature can reach 39°C. (Annexure 2).

Precipitation: Jazzan receives relatively low annual rainfall (146 mm) as compared to Asser (444 mm) and Al-Baha (631mm). The monthly mean precipitation in Jazzan, Aseer, and Al-Baha is 12.17, 36.96, and 52.58 mm, respectively (Annexure 2). The wet season in Jazzan lasts for 2.0 months, end of June 28 to the end of August. However, much of the precipitation in Jizan is in the month of July. The annual rainfall is low in the coastal plain, but higher up in the Aseer Mountains which through rainfed streams in "wadis" is the main source of irrigation for seasonal agriculture (Annexure 2).

2.5.2 Input sourcing

Input Suppliers: Farmers generally purchase inputs such as seeds, fertilizers, pesticides, and equipment from private shops in the nearby town/city areas. Certified seeds are available to farmers from agriculture cooperative societies at subsidized rates. Agriculture universities also provide selected seed varieties to farmers on cost basis.

b. Land Holding: As per agriculture census 2014 data, there are 285,166 landholders in the country of which about 92% are engaged in crop production. About 80% of the farmers are smallholders who have less than 50 Donums (5 hectares). The smallholders own about 6% of the agricultural land.

2.5.3 Production Practices and Management

a. Multiple Cropping: The smallholders are, generally, engaged in the production of multiple crops including cereals, fruits and vegetables. Livestock (sheep and goats) rearing is common with most of the smallholders. The rainfed cereals are grown primarily in Makkah, Aseer and Jazzan, and to a small extent in Madinah and Al-Baha regions.

b. Planting and Plant Care: Proper land preparation is essential for a good stand. Since the sesame seed is small, conventional or no-till methods, having a proper seedbed enhances stand and yield. Almost all the farmers generally broadcast seeds, use little or no fertilizer and untreated seeds. There is no regular weeding and the soil are not fertile. Sesame is a broadleaf plant and most of the herbicides cannot be used. Hence, manual weeding especially during the early stages of growth is critical for moisture conservation and economic yield.

c. Irrigation Water: For cereals (sorghum, millet, sesame), farmers depend mainly on rain water for irrigation. However, some farmers in Jazzan have bore-well facilities that provide water both for irrigation and drinking. The growers of rainfed cereals in Jazzan have no provisions for rainwater harvesting.

d. Field Workers: The rainfed cereals growers generally employ non-Saudi citizens to conduct the fieldwork. The laborers are hired for SR 1200 to 2000 as well as boarding and lodging at the farm. The farm owners also bear the cost of Iqama (SR 600 per staff per year) and visa fees (SR 2000 per person). Due to high cost, some growers have the tendency of need-based hiring of laborers, whose farming skills, cannot be ascertained. Thus, the casual laborers system can adversely affect productivity and increase the losses during harvesting and postharvest handling of rainfed cereals.

e. Weak Extension Service: The extension services of MoEWA lack the human resource and skills to regularly visit the farms and update the growers about modern agricultural practices in production and postharvest handling of rainfed cereals. One extension worker who accompanied the mission in Jazzan was not technical staff, a basic requirement for onsite technical advice. As a result, most of the smallholders are least aware of modern technologies and follow traditional practices.

f. The Missing Link: The interview with extension staff at Jazzan, however, revealed that Saudi farm owners are, usually not available at the farm due to their engagements in other economic activities. As a result, the extension staff communicates with non-Saudi managers or workers. Hence, there is a poor linkage between extension staff and the farm owners.

2.5.4 Enabling Environment

Due to the importance of rainfed cereals in Saudi Arabia, the government of Saudi Arabia promotes rainfed cereals to enhance the livelihood of the smallholders and slow down the depletion of water resources. For this purpose, the government of KSA has taken several initiatives and supports the growers of rainfed cereals.

2.5.4.1 Access to finance

Most of the smallholders (80-85%) use personal investments for different activities. However, some growers get financing through Agriculture Development Fund and Commercial banks or other informal sources. The Directorate of Agriculture provides crop-specific financial support to small farmers through the Agriculture Development Fund. These crop-specific loans are interest-free with no limits on the loan amount and funds up to 70 percent of the project cost, based on the feasibility report.

2.5.4.2 Access to Business Development Services (BDS)

The extension department supports awareness creation and provides training to the growers. However, some growers have not received any formal training. As a result, the smallholders rely on personal experience and traditions transferred from generation to generation, which has little room for business development.

2.5.4.3 Organizational Support

In addition to MoEWA services such as research, extension, and plant protection departments, other government organization such as Munsha'at (Saudi Small and Medium Enterprises General Authority), Saudi Food and Drug Authority (SFDA), Agricultural Development Fund, ministry of labor and social development, Saudi Arabia Grain Organization (SAGO), Saudi Agriculture and Livestock Investment Company (SALIC), etc. are there to provide the policy guidelines and enabling environment. These organizations provide policy guidelines and support the growers of rainfed cereals in the implementation of policies adopted at various forums.

2.5.4.4. Risk Management

There is no crop insurance facility in KSA. However, the farmers are compensated by the government for serious calamities on large scale i.e. fires, floods, disease epidemics, etc.

2.5.4.5 Farmers' Cooperatives

The government of KSA established the Cooperative Societies Council (CSC) on 17th March 2008 and got it formally affiliated with International Cooperative Alliance (ICA) on 28th January 2016. At present, there are over 200 agriculture cooperatives societies in the country, which can be commodity specific to general ones engaged in multiple crops. These societies provide some inputs such as seeds for some crops (sorghum and alfalfa) at a 10% discount. The members devote time to the day-to-day operations and management. However, they work voluntarily, which hinders their efficiency. However, most smallholders are not members of cooperative societies. Even the members of cooperative societies are inclined for working in a society without any financial benefits. It might be the reason that the smallholders are not enthusiastic about becoming a member of cooperative societies and these societies have not been as effective as expected.

2.5.4.6 Subsidies Extended

The government offers subsidies to promote the cultivation of sorghum, millets, and sesame. A farmer growing these crops on one-hectare land, with accepted ownership documents, can receive SR 4/kg for their sorghum and millet, and SR 6/ kg for sesame production. Most farmers, the mission met, claim the benefits of subsidies extended by the government. However, farmers who receive subsidies make little use of it in agriculture but consider it as an additional source of earnings. However, some smallholders are unable to go through the procedures involved in claiming such subsidies.

2.5.4.7 Promotion of Organic Farming

Department of Organic Production and Saudi Organic Farming Association promotes organic production and certification in the country. Farmers are encouraged to follow organic practices and are supported to sell organic produce directly to consumers. Several supermarket retail chains have exclusive organic segments in their stores and they are interested to procure directly from farmers. Because of such incentives, rainfed cereals production is predominantly an organic farming system. Most of the farmers in the Jazzan region indicated that no pesticides are used in producing the rainfed cereals. According to the farmers, organic produce fetches higher prices (Growers Interviews 2021).

2.6 Gender roles

Cultural traditions limit women's access and participation in farm-based activities as the agriculture fields are located away from residential areas. Generally, the agricultural farms are managed by foreigners, who stay at the farms. During the mission visit, the presence of women was not observed in any agricultural activity. Some women, however, attended the training sessions at MoEWA office, Jazzan. It seems that the involvement of women in agriculture, if any, is limited to either small scale processing or household activities.

2.7 Harvesting and Postharvest Management and Processing of Rainfed Cereals

Despite, the prospects and incentives extended to increase the production of rainfed cereals in Saudi Arabia, the share of KSA to the global rainfed cereals production and trade is negligible. Harvesting, postharvest handling and processing of rainfed cereals are based on traditional practices. The crop is harvested based on visual maturity indices i.e. color changes of the ears (sorghum and millets) and leaves (sesame). The harvested crop is dried, threshed and winnowed, and transported to markets for selling or shifted to storage (Figure 2.1). Inefficient production practices, improper harvesting and postharvest handling, and lack of processing and value addition have been hindering the rainfed cereals sector to perform to its potential and contribute significantly to the livelihood of smallholders in KSA.

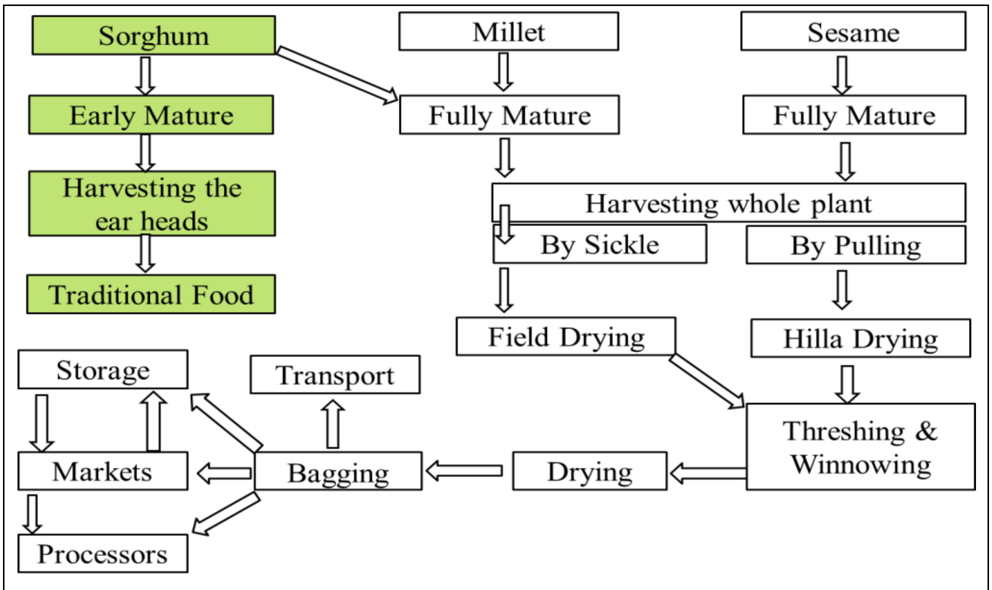


Figure 2. 1. Harvesting and postharvest handling of rainfed cereals. The green boxes indicate the traditional food use of sorghum.

2.7.1 Postharvest Losses in Rainfed cereals

The postharvest losses in rainfed cereals vary greatly among different countries. In a study in Ethiopia, the postharvest losses of sorghum and millets were estimated to be about 12.5 and 11.0% (Befikadu, 2018). However, according to another study the losses could be as high as 30% to 50% (Kumar and Kalita, 2017). In sesame, the postharvest losses are reported to be 17% (Neme *et al*., 2020). However, growers, interviewed by this mission report losses as high as 30% (Growers interviews, 2022).

In Saudi Arabia, rainfed cereals are mostly grown by smallholders with limited resources. The growers have little access to modern technologies and mechanical farming. Hence, the growers with smallholding mostly use traditional technologies in harvesting, postharvest handling, and processing of rainfed cereals, which increases postharvest losses. There are no published estimates of postharvest losses in rainfed cereals in KSA. However, the postharvest losses estimated through farmers' interviews revealed a large variation. The average losses in sorghum, millets and sesame were 23.50, 22.55 and 35.5% respectively. Hence, it is needed that proper harvesting, postharvest, and processing technologies suitable for smallholders are adopted to minimize postharvest losses and quality.

2.7.2 Economic Impact of Postharvest Losses

The production of sorghum, millets, and sesame in KSA is about 123,869, 11,701 and 4,012 tonnes, respectively. The quantity of rainfed cereals lost during harvesting and postharvest handling account for about 29,109.22 tonnes, 2,638.57 tonnes, and 1,424.26 tonnes in sorghum, millets and sesame accordingly. The economic impact of postharvest losses, based on import price for the year 2020 is about 5,901,602 million 985,825 and 2023,731 million USD for sorghum, millets, and sesame respectively (Table 2.7). In addition to the direct loss of the commodities and profit, the cost of inputs i.e. land, water and labor resource are also wasted. For instance, with the current yield of sorghum (2.37 tonnes/hectare), millets (2.11 tonnes/hectare) and sesame (1.31 tonnes/hectare), the postharvest losses equate to 12279, 1250.51 and 1087.22 hectares land and all other inputs wasted due to postharvest loss.

Table 2. 7. The economic impact of postharvest losses in rainfed cereals in KSA

Crops	**Area (ha)**	**Production (Tones)**	**PH Losses (%)**	**Lost Quantity (Tonnes)**	**Import Price (USD/ Tonnes)**	**Impact (USD)**
Sorghum	52,343	123,869	23.5	29,109.22	202.74	5.901,602
Millets	5,551	11,701	22.55	2,638.57	373.62	985,825
Sesame	3,056	4,012	35.5	1,424.26	1420.9	2,023,731

Note: Postharvest losses are approximated from reported losses. The financial impact is estimated based on the import price paid by KSA in the year 2020.

2.7.3 Harvesting Practices of the Rainfed Cereals in KSA

a. Harvesting Stage

The sorghum and millets are harvested when the ears begin to turn color from greenish to yellow-brown. The sorghum crop is, sometimes, harvested at an early mature stage, to make a traditional dish called the “Khabir”. For this purpose, the sorghum is harvested when the seeds are not fully mature and release the white milky fluid (endosperm) when pressed between the two fingers. For grain purposes, sorghum is harvested when the grains are ripened. The growers harvest the sesame crop when the lower leaves in the plants turn yellow

b. Harvesting Methods in KSA

For dried grain, the whole plant is cut with sickles and allowed to dry for one week. The heads are cut and threshed accordingly. The dried stocks are cut and stored for feeding animals. For harvesting before the fully mature stage, only the ear heads are removed. The sesame is harvested by pulling the plants from the soil along with the roots and left in the field for 24 hours to allow defoliation of the stalks. After the defoliation, the stalks along with the capsule are shifted for hilla drying to another field (Figure 2.2).

Figure 2. 2. Harvesting of millets, sorghum and sesame crops

2.7.4 Postharvest Handling of Rainfed Cereals in KSA

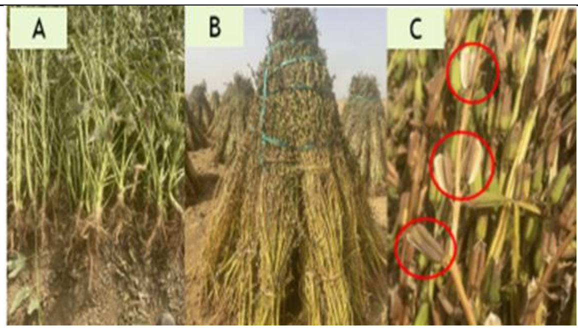
2.7.4.1 Pre-Drying of Rainfed Cereals

The harvested sorghum and millet plants are tied into bundles of convenient sizes and stacked in the field for drying. After 2-3 days, the ear heads are removed from the plants and collected on the threshing floor. In some cases, the ear heads are removed from the standing crop and collected at the threshing floor for drying and threshing. The ear heads are allowed to dry for 5-6 days before threshing.

The sesame crop is field-dried in two stages. In the first stages, the harvested 3-5 plants are bunched and spread on the ground for about 24 hours in the field to allow rapid defoliation of the stalks. The leaves are left in the field and goats and sheep are allowed to feed on these leaves.

In the second stage, the defoliated stalk along with the capsules are taken to another field, where it can be protected from animals, and 6-8 bunches are placed upside up for hillas (locally called tent) drying. The bundles of stalks are tied with a strip at 2-3 points at an appropriate distance and left to dry for 5-7 days (Figure 2.3). Once the drying is complete, the hilla-dried stalks are shifted to the threshing floor.

Figure 2. 3. Hilla drying of Sesame for defoliation (A), in Hilla (B), and splitting of capsule during Hilla drying (C)



2.7.4.2 Threshing, Winnowing and Cleaning of Rainfed Cereals

Threshing releases the seed from the husk to expose the grain. The threshed grains are winnowed in the wind or by using a sieve to remove the small pieces of stalk, chaff and other impurities. The threshing and winnowing of rainfed cereals are, generally, conducted manually which increases the cost of threshing due to more labor engagement and increases losses of grain.

The sorghum and millets are threshed by placing them in bags and hitting gently with a stick to separate the grain from the husk. The growers do not prepare specialized threshing floors but use an up-land place usually near the farm building. One grower has a mechanical thresher for sorghum and desired to have one for sesame as well. The sesame crop is threshed by gentle beating with a stick to release the grain from the capsules (Figure 2.4).

Figure 2. 4. Manual and mechanical threshing of sesame

The sorghum and millet grains are winnowed or washed in water to remove the chaff and dust. When water is used for winnowed the grain, the grains are dried on clean plastic sheets for 2-3 days. The sesame is manually cleaned or sieved to remove the impurities.

2.7.4.3 Packing/ Bagging of Rainfed Cereals

The rainfed cereals are, generally, held in gunny bags labeled as 50kg. The gunny bags cost about SR 11.00 (about 3.5-4.0 USD) in local markets. The gunny bags allow air and moisture to get into the bags and are a major cause of insect damage to the grains stored in the bags. Since the smallholders of rainfed cereals do not use any pest control measures while storing the produce, infestation by insects is a likely outcome during storage.

2.7.4.4 Storage of Rainfed Cereals by Smallholders in KSA

The rainfed cereals in KSA are generally stored in the open yard near the houses of the growers. The sorghum and millets are stored for 9 months, while the sesame is stored for about 6 months. The rainfed cereals are stored by making temporary/ semi-permanent structures near the house. While there are different types of storage, all have a raised platform to protect the uptake of moisture from the ground. Technically, there are three variants of storage structures used for storing rainfed cereals in Jazzan (Figure 2.5).

a. Open Yard Storage

Sand blocks (about 10-12 cm in height) are spaced about 3-4 feet apart and kept on the ground. A wooden plank (about 3 cm thick) is placed on top of the blocks to make a platform for the stacking and the 6-10 bags are stacked one on top of the other. The bags are then covered with a tarpaulin sheet to protect them from rain and birds.

b. Steel Platform

Some growers use steel platforms for the storage of rainfed cereals. While it is a good approach to protect the bags from moisture uptake from the ground, it is prone to moisture uptake from the air.

c. Iron Cage Covered Storage

Iron cage-covered storage is made by erecting an iron grill around the platform of the storage to protect the produce from birds. One such storage was observed in Jazzan region.

Steel Built Platform	Opened Yard Storage	Steel Caged Storage

Figure 2. 5. Storage technologies adopted by growers of rainfed cereals

2.7.4.5 Postharvest Losses in Rainfed Cereals at different stages

The postharvest handling of cereal crops involves a series of operations such as harvesting, field drying, threshing, winnowing, bagging, transportation, storage, processing, and marketing. Postharvest losses may occur at any stage of the supply chain from the farm through postharvest handling and marketing (Hengsdijk and de-Boer, 2017). According to a World Bank report, the greatest losses occur at the farm gate. For example, in Ethiopia, of the total PHL, the highest losses occur during harvesting (33%) followed by drying and threshing with 26% and 18% but increase further to about 30% due to the multiple loading and unloading activities in transporting to markets or storage (Tagnan *et al*., 2017). There have been significant efforts in developing countries to reduce postharvest food losses, however with limited success (Sheahan and Barrett 2017). Some of the common causes of losses at different stages of production and post-production handling are summarized in table 2.8.

Table 2. 8. Postharvest losses of rainfed cereals at different stages of the supply chain

S.No	Stage	Cause of pre and Postharvest Losses
1	Before Harvest	Insects, pests and diseases, and Birds feeding on immature cereals grains
2	At harvest	Under or over mature grains
3	Drying	Careless drying with no provision for shattered grains, improper drying
4	Shifting for threshing	Release of grains from ear head or capsules
5	Threshing	Poor threshing adjustment, contamination with dust.
6	Post-threshing drying	Contamination with dust, improper drying
6	Bagging	Poor quality bags that allow moisture to reach grains, storage pests, and physical loss of material during bagging.
7	Storage	Improper storage structure with no control over rodents & birds and soil moisture resulting in physical losses and contamination
8	Improper Handling	Storage, transport, and marketing cause the loss of cereals grains

2.7.4.6 Marketing of Rainfed Cereals

There is a well-established network of rainfed cereals supply chain in the country. The local produce is marketed by different channels. Some growers sell their produce directly to retailers or consumers. This system is more prevalent in farm gate selling or marketing in farmers' markets. Still, other growers sell their produce to traders who amass the produce for marketing in wholesale markets in distant cities, processors, or exporters (Figure 2.6).

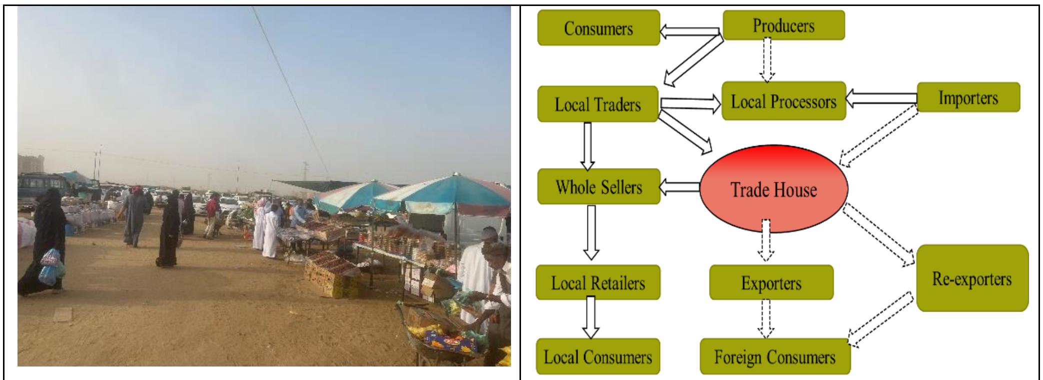


Figure 2. 6. Farmers market Jazzan and marketing channels of rainfed cereals in KSA

The farmers' markets are the primary sites of marketing for smallholders. These markets are organized once a week in various towns around Jazzan. In the farmers' markets, the produce is amassed by large-scale market vendors who are responsible for the onward handling and marketing of the produce. Some of the problems in marketing rainfed cereals include:

a. **Price instability**: The price of rainfed cereals can be as low as 50% during the harvesting season. It is the major reason that every grower tends to store the produce, which subsequently leads to postharvest losses in rainfed cereals.
b. **Competition from other countries**: Rainfed cereals especially sorghum and millet compete with produce imported from other countries, which sometimes has larger grain size and superior quality but a disadvantage to local producers.
c. **Quality Inspection**: The market vendors check the quality of the produce by inserting an iron rod into the bags to allow some of the grains to spill out of the hole. If the deal is not completed, another large-scale dealer repeats the same practice. It result is a significant increase in grains losses during subsequent handling.

2.7.4.7 Consumption of Rainfed Cereals

Rainfed cereals are consumed in different ways in Saudi Arabia. The sorghum stalks are used predominantly for feeding domestic animals. Sorghum grain is also used in some of the traditional dishes. The millet and sesame are rarely used as feed. Sesame is mostly consumed as seeds, adding value to other products i.e. date and bakery items and sesame seed oil. A negligible quantity of rainfed cereals are exported but the import of rainfed cereals and sesame seed oil has always been higher than the export quantity.

2.7.4.8 Processing of Rainfed Cereals in KSA

a. Sorghum and millets

The processing of rainfed cereals especially sorghum and millets convert the coarse cereals grains into a product fit for consumption (Rai *et al*., 2012). For instance, the major components, protective pericarp, endosperm containing starch, and germ; of millets, grain partially separated or modified in processing. The processing of rainfed cereals in KSA is limited to primary processing.

The sorghum and millets can be processed by dry milling, wet milling, and fermentation. However, in KSA, sorghum and millets are processed by dry milling. The cleaned grain is conditioned, by the addition of water, to soften the endosperm, and milled by the conventional roller mills to separate the endosperm, germ, and bran from each other.

b. Sesame

Sesame oil (locally called Sulait) is the major processed product of the sesame crop. Almost all the sesame growers (99.99%) used the traditional method of extracting oil called the Ghani method.

However, one farmer has installed a hydraulic press in Damad village. The by-product of sesame processing into oil is sesame cake, a protein-rich feed for animals.

i. **Traditional Method:** The sesame seeds are added into a wooden collection pot and pressed by mechanical method with another wooden rod (Pistil). This method requires low initial cost, but the oil quality is poor as the addition of water enhances rancidity and results in poor taste and decreased storage life (Figures 5 A & B).

ii. **Hydraulic press methods:** The hydraulic press method uses modern technology to extract sesame oil (Figure 2.7). The sesame seeds are pressed in an electrical press machine to extract the oil. It has the benefits of:

a. It is about 6 -8 times more efficient in time. Whereas, the traditional technique extracts 4-5 liters per hour, the hydraulic press 30-40 liters per hour.

b. The Hydraulic press is believed to extract more oil per unit weight of sesame seed. However, due to the addition of water used in the traditional method, it cannot be verified.

c. The oil produced by the hydraulic press is less prone to rancidity and has a longer storage life.

Figure 2. 7. Sesame oil extraction by traditional (A), semi-mechanical (B) and hydraulic press methods (C)

2.7.4.9 Value addition and Product Diversification of Rainfed cereals

Value addition helps the growers in diversifying their marketing options and increases profit. It creates business opportunities and jobs for youth in rural areas. There exist value addition opportunities in the form of organic cereals production, sesame oil unit, cereals flour units and food-based enterprises. However, most small producers find it challenging to embark on value addition. To the smallholders, the production of value added food products on a commercial scale is far more complex than just cereals production and selling. As a result, there is very little value addition in rainfed cereals in the Kingdom of Saudi Arabia, except for their use in traditional dishes. However, sesame seed is used in adding value to other products such as date and confectionery, and extraction of sesame oil. As a result, the smallholders do not realize the potential economic benefits of rainfed cereals. Capacity building and training of smallholders on value addition activities and technologies can enhance the income of smallholders through value addition.

2.8 Prospects and Challenges of the Rainfed Cereals Sector in KSA

Rainfed cereals with relatively lower water and nutrient requirements as compared to other cereals such a wheat and rice, and almost comparable food value necessitates that the cultivation of rainfed cereals is optimized in arid regions like Saudi Arabia. Hence, the government of KSA is committed to increasing the cultivation of rainfed cereals. However, while there are good prospects for rainfed cereals in the Kingdom of Saudi Arabia, there are several challenges to cope with as well. Cereals.

A. Prospects of Rainfed Cereals in KSA

a. **Source of Food**: Rainfed cereals are an important source of food in the arid and semi-arid regions of the world (Duodu *et al*., 2003). Being drought and heat tolerant, the cultivation of rainfed cereals reduces the risks of food insecurity in arid and semi-arid regions (Doss *et al*., 2008).

b. **Water Conservation**: Since rainfed cereals are drought tolerant, they can contribute to the water conservation efforts of the government of Saudi Arabia.
c. **Jobs and Business Opportunities**: Rainfed creates jobs and business opportunities in rural areas of KSA.
d. **Integration into Cropping Pattern**: The sesame due to its characteristics i.e. nematode resistance, drought tolerance, nitrogen recovery and rotational suitability can integrate well in the cropping patterns in southwestern Saudi Arabia.
e. **Source of Feeds**: There are about 3.3 million domestic animals in KSA, which serve the food demand (milk and meat) of the nation (MoEWA, 2020). Rainfed cereals can serve as a source of feed for domestic animals.
f. **Promotion of Bio-diversity**: Rainfed cereals attract a wide variety of pollinators and birds, which can add to the mitigation of the environment and sustainability (Couch *et al*., 2017).
g. **Substitute of other Cereals**: Rainfed cereals are as nutritious as the other cereals crops i.e. wheat, rice, or maize. The sorghum, millets, and maize are comparable in carbohydrates and protein content. The sorghum has lower fat than maize, but the millets are comparable and sesame is superior to maize in fats and protein content.
h. **Health Benefits**: Sesame has been long known for its nutritious and health benefits (Birania *et al*., 2020). The sesame contains about 52–55 percent oil, which is high in unsaturated fatty acids and is also rich in minerals such as K, P, Mg, Ca, and sodium (Couch *et al*., 2017). Several phytochemicals with high anti-oxidant activities i.e. vitamin E, Sesamolin, Sesamin and tocopherols are found in sesame seeds (Birania *et al*., 2020).
i. **Value Addition**: The value-added processed products of rainfed cereal can integrate or substitute the food products of other cereals.

B. The Challenges/ Problems of the Rainfed Cereals Sector in KSA

a. No Research Base: The rainfed cereals are traditionally grown in southwestern Saudi Arabia. There has been no research work conducted on maximizing production despite limited resources i.e. water and other inputs.

b. Lack of Modern Technologies: The smallholders of rainfed cereals cannot afford the modern technology in planting, harvesting, postharvest handling and processing of rainfed cereals. The smallholders, therefore, use traditional technologies in the cultivation, harvesting and postharvest handling of rainfed cereals, which decrease the yield and increase postharvest losses. Improper land preparation, broadcasting methods of sowing and reliance on little rainwater for irrigation decrease the yield of rainfed cereals.

c. Narrow Germplasm Base: A limited number of varieties of rainfed cereals are grown year after year. While some seed is provided to the farmers, there is no formal seed production program in the Jazzan research institute or Jazzan University.

d. Water and High Temperature: The target rainfed cereals can tolerate high temperatures and water deficits. Yet the increasing temperature and erratic rainfall can threaten the productivity of rainfed cereals.

e. Poor Postharvest Handling: The harvesting and postharvest handling of rainfed cereals are conducted manually by unskilled laborers, which decreases the quality and storage life and increases the postharvest losses in rainfed cereals.

f. Improper storage: The growers generally store cereals grain in ordinary structures near their houses. The cereals grain are exposed to light, moisture, insects and pests, which increases the storage losses of rainfed cereals.

g. Weak Extension Service: The extension services seem weak and delinked from smallholders. Hence, the flow of knowledge and skills of modern agricultural practices and technologies are not transferred to the smallholders efficiently. The smallholders, therefore, follow the traditional practices for generations. The extension workers, on the other hand, are constrained by the non-availability of Saudi farm owners. Thus, they can suggest improvements only to the non-Saudi managers and workers.

SECTION 3: GAPS ANALYSIS AND BENCHMARKING HARVESTING, POSTHARVEST HANDLING AND PROCESSING OF RAINFED CEREALS

3.1 Gaps Analysis

A gap analysis of the current situation in contrast to the standard systems helped identify the main impediments in harvesting, postharvest handling, and processing of rainfed cereals. There are several gaps in the harvesting, postharvest handling, and processing of rainfed cereals in the kingdom of Saudi Arabia. The major gaps in the existing system of rainfed cereals production, postharvest handling, and processing are presented below, so that effective intervention can be suggested/ adopted to promote the rainfed cereals sector of KSA.

3.1.1 Increasing Yield and Enhancing Quality

The production of rainfed cereals in KSA can be economically viable crop husbandry. With greater reliance on precipitation and minimum inputs used in cultivation, the cost of production is limited to the soil preparation and labor engaged. Some farm owners engage permanent farm labor on a monthly salary of 1500-2000 per month. Still, other growers engage daily paid laborers on a need basis and job-specific activities. Engaging casual laborers may add to uncertainty in the availability of farm laborers, cost incurred on laborers is decreased. The cost of production of sorghum, millet and sesame is 7136, 9810, and 6135 SR/hectare, while the net income with subsidies is 23815, 25400, 27535 and 21065 SR/hectare (annexure x). The BCR for sorghum, millet and sesame is 3.24, 1.53 and 3.52, respectively. However, the net income of the rainfed cereals is below the subsistence earning of SR 36000 per annum. Hence, efforts are needed to increase the yield, reduce losses and promote quality to increase the income of the growers of rainfed cereals.

3.1.2 Gaps in Maturity at Harvest

No Scientific Methods in Maturity Determination: No scientific methods or standards ("complete dry down" or grain texture for example) are followed to determine the proper maturity stage for harvesting the rainfed cereals. The growers simply follow their sense of visual observation and touch perception to decide on the harvesting time. The yellowing of the leaves in the lower parts of the plant is considered an indicator of the maturity of the grains. At this stage, the grain may not be physiologically mature and harvesting at this stage may result in low dry matter, small seed size and poor quality. Similarly, the growers who grow both sesame and sorghum harvest sorghum at a late mature stage after completing the sesame harvest due to labor shortage. The sorghum, harvesting is, therefore, delayed and birds may cause losses of sorghum grains.

3.2 Postharvest Handling

3.2.1 Gaps in Drying of Rainfed Cereals

The growers conduct field drying of rainfed cereals with no protection from birds, insects and pests, especially ants, and dust contamination. In sesame, the hilla drying is done without placing a tarpaulin sheet below the hilla. Hence, the grains released from the capsules are lost to the ground. The dehiscence of the sesame capsule along the suture before shifting to the threshing area may result in the complete loss of sesame seeds.

Some of the growers are well aware of the losses during the drying of the sesame crop. According to the growers, the mission met, the losses during the drying of sorghum (5-8%) and millets (5-6%) are relatively low as compared to sesame (9-15%). However, one grower in Damand town reported 20- 25% losses of sesame seeds during drying. Interestingly, no efforts are made to decrease the losses due to socio-economic reasons including labor costs and extra spending on the tarpaulin sheets. One grower considers birds as friends that feed on insects "so it is better they feed cereals grains as well". Still, others believe that feeding birds add "Baraka" to the produce.

3.2.2 Lack of Mechanical threshing and Winnowing

The manual threshing of rainfed cereals is time-consuming, requires more labor and exposes the grains to pests, increases chaff and dust contamination (Kumar *et al*., 2013), which decreases the quality (Abagisa *et al*., 2015). Winnowing and washing of sorghum and millets necessitate further drying which increases the exposure time of grains to pests and dust. One grower who has a mechanical thresher for sorghum, reported higher efficiency as well as decreased labor cost with mechanical thresher (Figure 3.1).

Figure 3. 1. Manual and mechanical threshing of sesame

3.2.3 Improper Packaging and Bagging of Produce for Storage

The grains of rainfed cereals are, generally, kept in gunny bags for storage. These bags allow air and moisture to get into the bags, which on contact with the grains inside initiate the deterioration of grain quality and promote mold development.

3.2.4 Lack of Proper Storage Structure for rainfed cereals

The smallholders of rainfed cereals in storage structures built in the open yards near their houses. The sorghum and millets are stored for 9 months, while the sesame is stored for about 6 months. These storage structures are built on raised platforms to avoid moisture from the ground. While there are a variety of structural variations, these are not built on a scientific basis to protect against moisture and pests.

a. Insects: Storage insects especially *Sitophilus oryzae* sorghum grain losses of 61.3 % over 5 months of storage (Pramod, 2002, Adetunji *et al*., 2014). The rainfed cereal growers remove the Tarpaulin sheet from time to time to expose the bags to the sunlight. It is believed to kill most of the insects in the bags. The high temperature of the area may kill the insects, especially in the upper layer of the storage. However, it cannot completely eradicate the insects' problem.

b. Birds: Birds are another serious threat in open yard storage. The birds not only feed on grains but also damage the sacs, thereby increasing the losses during transportation and shifting. The presence of birds dropping in cereals is also a food safety concern in international trade.

c. Rodents: Rodents are a serious threat to stored grains in the storage of rainfed cereals. The rodents cause multiple damages to the stored cereals. They not only chew the grains but also damage the bags and cause contamination i.e. rodent hair, droppings, and urine, which could transmit diseases to humans (Fekadu, 2007).

4. Aflatoxin contamination: Grains could be stored in large quantities in silos for long-term purposes mostly for industrial use. However, smallholders store grains of rainfed cereals in jute bags. Storing grains in such bags, especially in unpredictable weather conditions that fluctuate between hot dry warm humid conditions could contribute to mycotoxin contamination especially if the drying process is faulty. These bags allow free passage of air, which could carry toxigenic fungal spores into the grains. Hence, if stored for long periods (>3 months), there is a possibility of mycotoxin contamination (Adetunji *et al*., 2014).

The gaps in harvesting and postharvest handling result in significant postharvest losses at different stages. The losses may vary at each stage in different crops. However, losses due to improper harvesting stage, poor drying techniques and pests attack during storage are the major stages of losses in rainfed cereals. The cereals growers are well aware of the postharvest losses, especially during harvest and postharvest handling but consider it natural and no postharvest treatments/techniques are adopted to decrease the losses during processing and storage. The losses in rainfed cereals estimated, based on farmers' interviews, during harvesting and postharvest handling are presented in (Table 31).

Table 3. 1. Postharvest losses of rainfed cereals at different stages of handling in KSA

Handling Stage	Sorghum		Millets		Sesame	
	Average Losses (%)	Quantity Lost (tonnes)	Average Losses (%)	Quantity Lost (tonnes)	Average Losses (%)	Quantity Lost (tonnes)
Harvesting	3.5±0.83	4329	2.5±1.27	293	3.5±1.32	140
Drying	6.5±1.83	8051	5.5±1.10	221	12±4.07	481
Threshing	2.5±0.75	3097	4±1.35	468	4.5±1.81	181
Cleaning	1.3±0.53	1548	1.5±0.59	176	2.5±0.71	100
Packaging	0.8±0.36	929	1.25±0.63	146	1.25±0.82	50
Transport	1.0±0.49	1239	0.75±0.44	88	1.5±0.65	60
Storage	6.5±1.84	8051	6±2.31	702	8.5±4.17	341
Marketing	1.5±0.79	1858	1.05±0.50	123	1.75±0.51	70
Total	23.50±2.45	29103	22.55±2.21	2639	35.5±4.18	1424

3.2.5 Gaps in Marketing of Rainfed Cereals

The farmers' markets in Jazzan are the major marketing channel for rainfed cereals. While the retail selling price is fixed by the growers, the bulk price is fixed by negotiation between producers and market vendors. The locally produced rainfed cereals are in competition with imported produce. Domestic sesame is preferred but imported sorghum and millet have a marketing advantage due to larger grain size and price competitiveness.

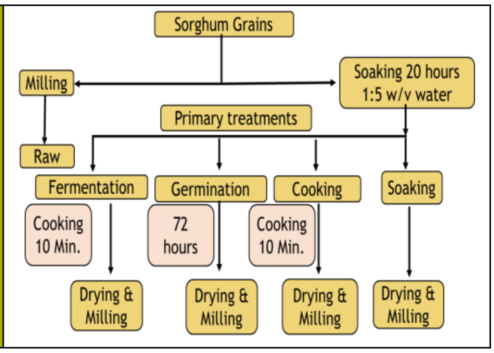
The quality of produce is checked by inserting an iron rod into the bags to allow some of the grains to spill out of the hole for checking. Repeated damage to the bags increases the physical loss of grains from the bags.

3.2.6 Gaps in the Processing of Rainfed Cereals

In KSA, sorghum is, generally, produced for feed purposes in addition to grains. However, millet and sesame are cultivated for their seeds. At present, sorghum and millet have not been accepted as popular food items and have no utilization in industrial-scale commercial processing. The sesame is processed into different products. The sesame seeds are also used to add value to different confectionery products. Sesame oil production and sesame cake (a byproduct of oil extraction used as feed) are common in KSA. Some of the constraints in the processing of rainfed cereals include:

a. The millets have a small size grain and large germ, which limits its utilization in the industry.
b. Poor digestibility of proteins and carbohydrates, and low palatability of sorghum and millers limit their utilization as food crops or processed forms on a commercial scale.
c. The lack of gluten, limits millet flour to make an elastic and cohesive dough.
d. There is a single method (dry milling) of processing sorghum and millets and the potential of wet milling and fermentation has not been explored.
e. Sesame oil is extracted by semi-mechanical traditional technology by adding water, which increases the risk of rancidity and decreases the storage life.

Figure 3. 2. Primary processing of sorghum and millets by dry, fermentation germination, cooking, and soaking treatments



3.2.7 Gaps in Contamination Control

Besides, the physiological deterioration, toxigenic fungi contaminate food crops in the field, after harvest or during transportation (Bennett and Klich, 2003). Hence, proper drying and care during storage are crucial to prevent the proliferation of fungi (IARC, 2015).

3.2.8 Lack of Research & Development

There is no Research and Development effort for developing or introducing new varieties with superior yield potentials and reducing losses in rainfed cereals. For instance, non-dehiscent sesame cultivars can significantly reduce losses during drying and increase growers' income. Similarly, certified seed production and provision to smallholders on cost basis is of limited scale. As a result, most farmers interviewed by the mission, in Jazzan region reported keeping their own seed

There is also a lack of research and commercialization efforts. Rainfed cereals can be used in fortified and mixed floor products (Saleh *et al*., 2013). While the sesame seeds are processed into sesame oil and sesame cake (a byproduct in oil extraction used as feed), exploring, the utilization of sesame and millets plants as feed can be an enormous incentive to increase their cultivation. . Research and commercialization efforts are needed to enhance the production of rainfed cereals.

3.2.9 Gaps in Quality Control and Consumers' Safety Compliance

There are no provisions for quality control and consumers' safety for local produce; although such regulations are in place for imported products and enforced by SFDA. The Saudi GAPs certification system requires compliance of Saudi GAPs to receive a certificate for their produce (MEWA, 2019). However, the phytosanitary certification has yet to get momentum in rainfed cereal.

Table 3. 2 A summary of Gaps analysis of rainfed cereals in KSA

Practices	KSA	Advanced Countries	References
Harvesting Method	Manual and Mechanical	Manual+ Mechanical	Chapke *et al*., 2020
Drying Optimization	Based on visual observation	Observation + Lab Testing (moisture %)	Chapke *et al*., 2020
Threshing	Manual	Mechanical	Kumar, 2021
Packaging/ Bagging	Gunny Bags	Hermetic Bags	Mlambo *et al*., 2017
Storage	Home storage + Large Scale Storage	Home + Large Scale Storage	Anonymous, 2018
Processing	Low-Tech.	High tech, Machinery	Al Kurki, 2008
Marketing	Poorly Organized for domestic	Well organized by Value Chain	Desire *et al*., 2017
Value Addition	Limited Value Added products	Several Value-added Products	Yared *et al*., 2020; Ganapathy, 2010.
Quality Standards	Not Defined	Well defined	Scheuring *et al*., 1981

Phyto-sanitary Standards	Observed properly for the export market	Observed Properly for export	Government of India
Fortified and mixed floor products.	No commercial products	Several commercial scales products	Saleh *et al*., 2013

3.3 Benchmarking Harvesting, Postharvest Handling, and Processing of Rainfed cereals in KSA

Benchmarking refers to the performance including processes, products, or operations of a business/ farming sector against certain reference points i.e. the same sector in another country. It allows insights into a system, usually more efficient and profitable, and allows comparison with a reference system to identify the weaknesses and propose measures to strengthen the existing system for improved performance.

The primary purpose of benchmarking is to identify gaps in performance and uncover opportunities to improve an existing process. Benchmarking allows a better understanding of existing processes, comparing performance against internal and external benchmarks, and finding ways to optimize and improve the existing processes by interventions and practices adopted by the comparators to increase the efficiency of the existing system.

The success of benchmarking depends on the selection of a comparator that is more efficient despite comparable challenges/ conditions. The quality of the output is a major factor for a meaningful comparison of the competitiveness and proposing interventions in an existing farming system. It is also essential to consider specific challenges due to the socio-economic status of stakeholders that influence the inputs, labor employed and the logistic support required for activities connected with postharvest handling and processing.

3.3.1 Selection of Comparators for Benchmarking

Minimizing the postharvest losses in rainfed cereals necessitate the evaluation of existing harvesting, postharvest handling, and processing, identifying gaps at each stage, and benchmarking against standards practices in other countries. For this purpose, the status of rainfed cereals was evaluated based on:

a. How a country is performing better despite comparable economic or climatic challenges.
b. How much they are successful in harvesting, field drying, stacking, and storage, and pest control during storage is evident from their export markets, as an indicator of quality.
c. Harvesting, postharvest handling, and processing technologies adopted in rainfed cereals in countries selected for benchmarking.

Based on the criterion set forth, Sudan, India and USA are selected for benchmarking. The production of sesame is negligible in the USA, therefore, India being a major producer and exporter is considered for benchmarking of sesame.

a. India

In India, the sorghum crop is grown on over 5503.062 hectares, produces 4770 thousand tonnes, and is the second largest sorghum producer in the world. The millets crop is grown over 9714.019, which produces 12490 thousand tonnes, India with 1520 thousand hectares produces 658 thousand tonnes of sesame seeds (Table 3.3). India has been traditionally growing rainfed cereals and has made considerable progress in postharvest handling, processing, and value addition of the target crops. India with a food grain storage capacity of about 877370 tonnes.

India is among the major exporter of sorghum (36,617 tonnes worth 164,670 thousand USD). India exported 76,481 tonnes of millets worth 24956 thousand USD), and sesame (276265 tonnes worth 447,843 Thousand USD) (Table 3.4). In export markets, Indian sorghum and Sesame has the highest price of 449.71 and 1621.06 USD/tonne respectively, which is due to proper harvesting, postharvest handling, storage and processing technologies in India.

India has well developed postharvest handling system of rainfed cereals. Postharvest research, support of the government and farmers' cooperatives are instrumental in increasing the production and export of rainfed cereals. India also has diversified its products of rainfed cereals. For instance, there are 10 different value added products of sesame in India. The leaves, roots and whole plant are also used for medicinal purposes in different traditional medicines.

b. Sudan

Sudan ranks 1st in the area grown with sorghum (5793.609 thousand hectares) and 5th in production (2537.957 thousand tonnes) among the top sorghum-producing countries. The millet crop is grown over 2424.630 and the total production is about 484.96 thousand tonnes. Sudan is the world's largest sesame-growing country (5173 thousand hectares), producing 1525.104 thousand tonnes (Table 3.3). In addition, Sudan offers a comparable situation to KSA in terms of climate and water scarcity. Hence, it being one of the top producers of target commodities, is ideal for benchmarking.

Sudan has been through several problems in enhancing its export such as farmers' lack of knowledge of GAP, pest control, harvesting and post-harvesting practices, and contamination issues during harvesting, drying, and transporting processes. Yet it has the highest export price of millet (USD 666.67 /t). Sudan is also the largest sesame exporter with 492351 tonnes worth 615966 at an export price of USD 1251.07/tonne (Table 3.4).

Sudan has established several regulations to produce high quality rainfed cereals. For example, some of the regulations concerning sesame crop include maximum levels of mycotoxins in sesame seed (SDS2928:2005), sesame Oil (SDS0047:2009), package or label of the food commodities (SDS28890:2007) and pesticide residue in food.

The Sudanese export requirements are in line with the requirements of the International Plant Protection Convention (IPPC) all export markets require the National Plant Protection Organization (NPPO) to issue a certificate of plant health, that certifies that the consignment is free from infectious diseases and pests. The fumigation of sacks of threshed sesame seed is a standard practice in some regions, and in others, it is undertaken only where there is evidence of insect pests, or as a condition of trade (with the issue of a fumigation certificate by the NPPO. Typically, aluminum phosphide is used (sold under various brand names such as QuickPhos and Celphos) which releases phosphine gas (PH3), which is a universally permitted treatment.

c. USA

The sorghum crop is grown on 2061.900 thousand hectares, about less than half of the area of India and Sudan. However, the USA ranks first in sorghum production (9473.62 thousand tonnes). The USA is a relatively small producer of millets with 208.88 thousand tonnes from an area of 195.870 thousand hectares (Table 3.3). The USA is the major exporter of sorghum (6586.58 thousand tonnes worth 1,392,917 thousand USD) and millet (100,158 tonnes worth 46,143 thousand USD). The USA export of sesame seed is 15,035 tonnes worth USD 21,447 at a sale price of USD 1,426.47/tonne (Table 3.4). While the sesame crop is grown over a negligible area in the USA. The USA is not only the top producer of sorghum and, but also a technologically advanced country with a fully mechanized production, harvesting, and postharvest system. Hence, it is also included for benchmarking the rainfed cereals grown in KSA.

Table 3. 3 Area (000 ha) and production (000 tonnes) of rainfed cereals in countries selected for benchmarking

Crops	**Sorghum**			**Millets**			**Sesame**	
Countries	**India**	**Sudan**	**USA**	**India**	**Sudan**	**USA**	**India**	**Sudan**
Area (000 ha)	5503.062	5793.609	2061.900	9714.019	2424.630	195.870	1520	5173.521

Production (000 tonnes)	4770	2537.957	9473.62	12490	484.96	208.88	658	1525.104

Source: FAOSTAT, 2020

Table 3. 4 Export of rainfed cereals by the countries selected countries for benchmarking

Export	**Sorghum**			**Millets**			**Sesame**		
	Quantity (tonnes)	**Value (000 USD)**	**Price (USD/t)**	**Quantity (tonnes)**	**Value (000 USD)**	**Price (USD/t)**	**Quantity (tonnes)**	**Value (000 USD)**	**Price (USD/t)**
India	36,617	16467	449.71	76,481	24,956	326.30	276,265	447843	1621.06
Sudan	1193	386	323.55	24	16	666.67	492,351	615,966	1251.07
USA	6,586,580	1392917	211.48	100,158	46143	460.70	15,035	21447	1426.47

Source: FAOSTAT, 2020

3.2 Benchmarking Summary

The benchmarking focused on harvesting, postharvest management, and processing of rainfed cereals i.e. sorghum, millet and sesame, in Jazzan, southwestern KSA. The objectives of the analysis were to evaluate the existing harvesting, postharvest management, and processing of rainfed cereals, and to identify the potential for improvement through benchmarking. For this purpose, the FAO's 4S (screening of relevant data, surveying, sampling, and synthesis) method was used to collect information through a survey questionnaire/ direct observation and interviews of growers in Jazzan region and evaluation against relevant literature. The salient features of harvesting, postharvest handling and processing of rainfed cereals against the countries selected for benchmarking are summarized in table 3.5. It was observed that:

a. No scientific methods are observed in deciding the maturity stage and harvesting of rainfed cereals. In contrast to the properly defined maturity stages in technologically developed countries, the rainfed cereals are harvested when lower leaves in the plants begin to turn color, a stage before the optimal maturity stage. It can increase weight loss and disease incidence during storage.

b. Sun drying in the open field is common in rainfed cereals with no provisions for protection against rain, soil, dust birds and pests. The sesame is dried by (Hilla) drying but without placing a polythene sheet or tarpaulin under the hilla stacking.

c. The ear head of sorghum and millets, and capsule of sesame lose the seeds during drying and threshing, which is lost to the soil. Proper threshing floor and placing using tarpaulin sheets during drying and threshing will decrease the losses of seeds in rainfed cereals. Mechanical threshing is adopted in other countries which decreases the losses during threshing.

d. The grains/ seeds are, generally, bagged in 50 kg bags for storage or marketing. Gunny bags are being replaced with hermetic bags in technologically advanced countries. The hermetic bags can significantly decrease the losses due to moisture exposure and insect infestation.

e. The growers store the sorghum and millets for 9 months but sesame is stored for 6 months only. The grains are stored near the houses in open yards and covered with a tarpaulin sheet. Some growers store these grains in their houses on the floors without using any wooden planks under the bags. Still, others have steel grills around the storage to protect against the birds. However, none of these storage structures are effective against moisture exposure and pest infestation.

f. The marketing of rained cereals is usually conducted in wholesale and farmers' markets. The smallholding producer shifts the produce to such markets in different vehicles i.e. cars, pickups and small trucks. Some growers sell their produce directly to retailers. However, most growers sell the grains/seeds to wholesale dealers, who amass the produce and transport it to the trade house, from where it is transported to distant markets and processing.

g. Sorghum and millets are mainly used for human consumption in some traditional dishes. The sesame, however, is processed into sesame oil which increases the market value. The extraction of sesame oil also produces sesame cake as a by-product, which is a rich source of proteins and can be used in animal feed. The dried stalk of sesame plants is used for burning only.

h. There is very little value addition of rainfed cereals. The only important value-added product is sesame oil. The sesame seeds are also used as a topping agent in various bakery items and dates. However, commercial-scale processing such as sorghum flacks, puffed sorghum, millet biscuits, cakes, vermicelli, noodles, and rusk is needed to promote rainfed cereals on a sustainable basis.

i. Since the growers of rainfed cereals of KSA hardly use any chemical fertilizers and pesticides, the produce has the special commercial advantage of being organic in nature. The government of KSA has developed several testing laboratories to ensure phytosanitary measures. Phyto-sanitary certification is free of charge. However, the majority of the smallholders of rainfed cereals do not seek organic certification. According to the growers interviewed by the mission, organic certification is a complex process. Hence, the growers need to be encouraged and facilitated in organic certification.

j. Developing extension bulletins and conducting training on production, modern and affordable postharvest technologies, commercialization, and diversification of products are of central importance for the development of rainfed cereals in KSA. Hence, the growers should be regularly trained in adopting new technologies in production, harvesting, postharvest management, and value addition to decrease postharvest losses and ensure a higher return to the growers.

Table 3. 5 Summary table of benchmarking harvesting, postharvest, and processing of rainfed cereals.

Practices	**Countries**				**References**
	KSA	**India**	**Sudan**	**USA**	
Harvesting and Drying					
Harvesting at proper maturity	×	√	√	√	Scheuring *et al.*, 1981, Lee, 1981
Postharvest Handling					
Field (Hilla) drying on tarpaulin	×	√	√	√	Anonymous, 2014
Single-step hilla drying	×	√	√	√	Anonymous, 2014
Harvesting adds	×	×	×	√	Fromme *et al.*, 2017
Bird and Insects Protection	×	√	√	√	Farmers Interview, 2022
Proper moisture content ensured	×	√	×	√	Langham, 2008
Transport and threshing while protecting the seeds					
Provision to collect dropped-out seeds	×	√	√	√	Farmers Interview, 2022
Mechanical Threshing	×	×	√	√	Kumar *et al.*, 2013; Abagisa *et al.*, 2015.
Drying after threshing for 1-2 days	√	√	√	√	Farmers Interview, 2022
Storage of sorghum, millets and sesame seeds					

Hermetic storage technology/ bags	×	√	√	√	Okolo, *et al*., 2017; Paterno et a., 2015,
Jute Bags	√	√	√	×	Niyogi, 2021, Sinha and Sharma, 2004
Modified Atmosphere packing	×	√	√	√	Banks and Annis, 1990, Paterno *et al*., 2015
Ensure seed MC of about 6% for long-term storage by farmers	×	√	√	√	Langham. 2008
Chemical pests Control measures	×	√	√	√	Stejskal *et al*., 2014.
Physical control (exposure to low or high temperature)	√	√	√	√	Donahaye *et al*., 1994
Biological control (Plant parts, powder or extract)	×	√	×	√	USAID, 2012
Processing of rainfed cereals	√	√	√	√	Sharma and Kapoor 1997, Werle *et al*. 2016;
Dry, wet and fermentation processing	×	×	√	√	Taylor, 1983
Pearling of millets	√	√	√	√	Malik *et al*., 2021
Sesame oil production	√	√	√	√	Patel and Verma, 2015
Microbial testing	×	√	√	√	Gebremeskel et al., 2021
Value Addition	×	√	√	√	Anderson and Hanselka 2009; Rao *et al*., 2014; Rao, 2016
Commercial Scale Value Added Products	×	×	√	√	Yared *et al*., 2020; Ganapathy, 2010, Saleh *et al*., 2013
Well Organized value chain	×	×	√	√	Desire *et al*., 2017
Quality Control Measures of Sesame Seeds					
Required at all stages of production, harvesting, postharvest handling and processing	×	√	√	√	USGC, 2016-17, USDA, 2020, Doko, 2014. MOA (India). 2007
Ensure product integrity, purity	×	√	√	√	USDA, 2013, Doko, 2014.
Major Quality control tests can be performed	√	√	×	√	USGC, 2016-17, USDA, 2020
Visual assessment to eliminate foreign matters, moldy seeds	√	√	√	√	USDA, 2008, USDA, 2020, MOA. 2007
Enabling Environments					
Government Support	√	√	√	√	
Certification of services/products	√	√	×	√	USGC, 2016-17
Road and transport infrastructure	√	×	×	√	Safgrad, 2016
Proper transportation facilities	√	×	×	√	Safgrad, 2016

Marketing Infrastructure	√	√	√	√	Markets Visits, 2021

3.4 Best Harvesting Practices, Postharvest Handling and Processing of Rainfed Cereals

Best harvesting practices, postharvest handling and processing techniques ensure proper maturity at harvest, optimum moisture content for threshing and storage, storage in appropriate condition, and minimizing contaminations both physical (hairs, facets) and chemical (pathogenic products, Aflatoxin-A). Some of the best practices before harvest and in postharvest handling and processing with the possible outcome are presented in figure 3.3.

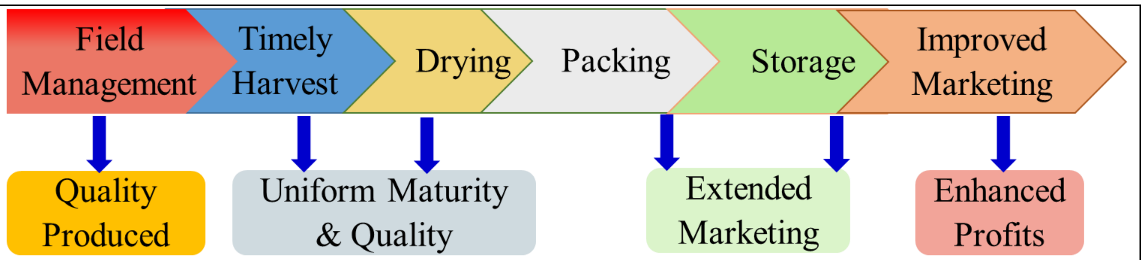


Figure 3. 3. Best practices in harvesting and postharvest handling of rainfed cereals

3.4.1 Ensuring Harvesting at the Optimum Stage of maturity

The harvesting operation has a significant effect on the quality of grains (Tirkey and Shyam, 2016). Whereas early harvesting decreases yield, the seed's dry matter content and increases sensitivity to pathogens, delayed harvesting leads to early sprouting.

The harvesting maturity of sesame is complicated by the indeterminate growth habit, where flowering, capsule formation, and seed development continue simultaneously. The seeds in the first capsule are more mature than the capsule at the top of the plant. Hence, attaining uniform maturity is more challenging.

The rainfed cereals (sorghum and millets) and sesame should be harvested at 75% physiological maturity, in light maturity indices are summarized in table 3.6 and figure 3.4 and 3.5.

Table 3. 6 Maturity indices of rainfed cereals

Crop	Maturity Indices
Sorghum and Millets	i. The leaves change from green to brownish ii. The entire plant starts to dry (dry down) iii. The grains cease to increase in size and have maximum dry matter. iv. The grains of sorghum and millets become hard and contain less than 25 and 30% moisture. v. Development of black layer at the seed attachment point in sorghum. vi. Development of a dark spot at the bottom of the grain in sesame.
Sesame	i. The sesame crop matures after 90-120 days after planting. ii. The leaves begin falling off and the stem changes from green to yellow and then red color. iii. Two-thirds of the pods turn from green to yellow or brown. iv. The milky white immature seeds turn to a darker shade of color. v. The seeds have a brown tip at the placenta attachment point. vi. The capsules also may develop a dark seed line on one side.

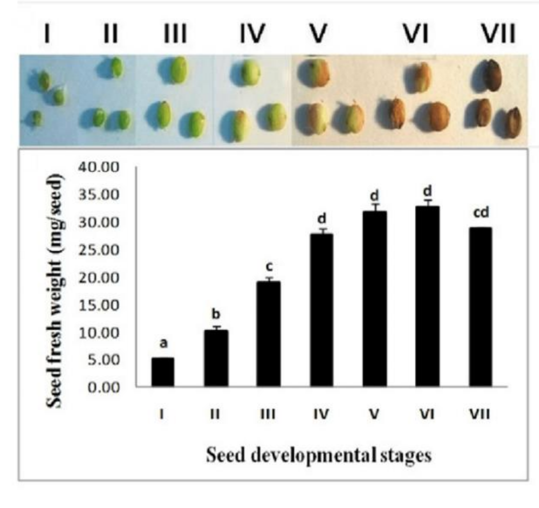


Figure 3. 4. Changes in sorghum seed weight with maturation (source: Mred et al., 2018).

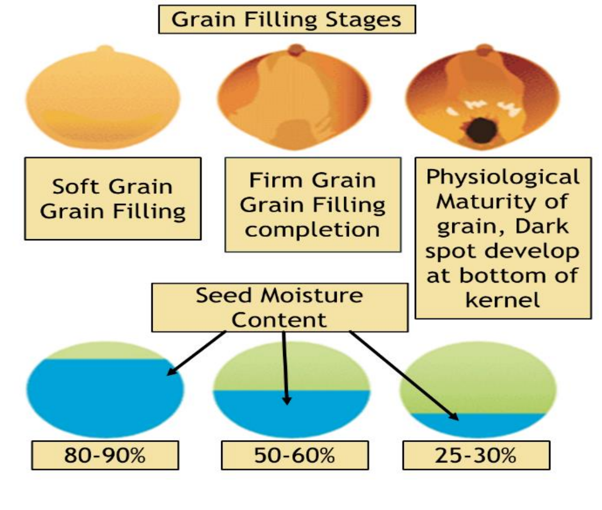


Figure 3. 5. Maturity and moisture content of millets.

3.4.2 Method of Harvesting Rainfed Cereals

It is desirable to cut the head slightly below the inflorescence at a slanting angle using a knife or harvester. Bunch the heads together and carry them to a spread polythene sheet over a threshing floor for drying. The sesame should be harvested with a sickle and the 3-5 plants bunched together. For drying, the bunches are stacked and placed upright on a tarpaulin sheet. During sesame harvesting, care should be exercised to avoid damaging the seed, which may adversely affect the viability of the seed, storage performance, and oil quality.

3.4.3 Field Drying

The seed’s moisture decreases content before harvest. High moisture content can adversely affect grain quality and decreased storage life (Table 3.7). Rainfed cereals are, generally, field dried in almost all countries around the world. However, the sorghum and millets seeds are dried on clean-lined surfaces, protected from rain, dust, insects and animals, and dried to at least 13% moisture content.

Table 3. 7 The seed moisture content in relation to harvesting, drying needs and storage.

Stage	**Moisture Content (%)**	**Grains Firmness/ hardness**
Near Maturity	About 30	Seeds are too soft
Mature Grain	About 25	Seeds are too soft to withstand threshing
Harvesting	Less than 25%	Poor standability
Drying Required	Less than 20%	Seeds ready for harvesting
Ready for storage	10-15%	Seeds are dry and hard in and crunchy

Drying and Threshing over Tarpaulin: The splitting of the capsule of sesame during the hilla drying may result in 9-15% loss of sesame seeds (Farmers interviews). The fallen grains in the field (below the hilla) invite a large number of ants, which add further to the losses of sesame seeds. The introduction and breeding of non-dehiscent sesame cultivars is required to decrease losses in sesame during drying and threshing. However, hilla drying over tarpaulin or plastic can recover the seeds released from the capsule (Figure 3.6). A tarpaulin sheet costs about 45 USD/25m^2. It requires 3 sheets (135 USD) for drying sorghum and millet, and 4 sheets (180 USD) for drying sesame per hectare of crop. The cost can be easily recovered due to decreased losses during drying.

Figure 3. 6. Sesame Hilla drying without Tarpaulin (A) and proper tarpaulin sheet placed below the hilla (B) to collect the sesame seeds dropping out of the capsules.

Effects of high moisture on cereal grains

It is essential to ensure the moisture content of the dried seeds before bagging for storage or processing (Langham, 2008). High moisture content results in:

i. Moist seed leads to low yields and clogs during oil processing. The moist seed loses moisture, which results in low dry weight after complete drying.
ii. Moist seeds are prone to fungal infestation. The moisture content of 13.5% minimizes mycotoxin contamination (Paterson and Lima, 2011).
iii. Moist seeds generate more heat during storage, which enhances the rate of deterioration and rancidity in oil-rich seeds (sesame).

3.4.4 Drying Methods

The rainfed cereals are exclusively dried by sun drying in KSA. The sun-drying is less effective in cloudy and rainy seasons. The grain drying efficiency depends on the weather, the thickness of the grain layer, and the efficacy of turning the grains. The poor air circulation, contamination with dust and stones, and moisture absorption from the ground, the grains are exposed to pests and pathogens. Some low cost interventions to improve the drying efficiency of cereals grains could be:

a. Raised platform with the top covered by polythene.
b. Solar tunnel drying requires no fuel and can be effective for drying cereals (Chua and Chou, 2003). However, high temperature (65-80°C) can build up under the plastic or glass sheet, which may damage the grains.
c. Convection air drying of cereal grains can be another alternative for smallholders of rainfed cereals
d. Forced air/ Hot Air Drying: For large quantities of grain, forced air or hot air drying is used.

3.4.5 AflaSTOP Drying

A USAID project, The AflaSTOP, in Partnership for Aflatoxin Control in Africa (PACA) has recently developed an innovative, mobile maize drying device that can dry maize in batches of 500 kg and lower the M.C. to about 13.5% in 3 h. Although this technology has only been piloted in Kenya, Tanzania, and Rwanda (AflaSTOP, 2019), it is yet to be commercialized. Considering the working mechanism, the same can be used for rainfed cereals in KSA.

3.4.6 Mechanical Threshing and Winnowing

The traditional methods of threshing are time-consuming and labor-intensive and becoming increasingly uneconomical (Kumar *et al.*, 2013). Mechanical threshers have been developed for rainfed cereals, which are more efficient, save time and labor as well as retain the quality of the products during threshing (Abagisa *et al.*, 2015).

3.4.7 Packing/Bagging

The wholesale packing of rainfed cereals is in 50 kg gunny bags, which are prone to losses of grains during storage and marketing. It is estimated that jute bags increase postharvest losses by 6.6% during storage (Sinha and Sharma, 2004). Using Hermetic bags for grain destined for storage retains the quality by minimizing the losses due to insects' infestation (Figure 3.7). For retail marketing, the growers sell the rainfed cereals in loose packing. However, the trader packs the seeds in small size packing, which increases the price significantly. For instance, the sesame seed price at the farmers' markets is about 12-15 SR/kg. However, with proper cleaning and packing, the sesame is offered at SR 23-25 per kg at Lulu Hyper Market, KSA.

Qualities of good packaging material

a. The packaging material should be suitable for the intended use.
b. The packaging material must preserve the quality of sesame seeds.
c. It must be affordable and should not increase the marketing cost.
d. It must be convenient in handling during transport, storage and marketing.
e. It must prevent spoilage during transit and storage.
f. It must be clean and attractive.
g. It must be free from chemical residue.
h. Packing material must protect against moisture, pests and light.
i. For storage purposes, the rainfed cereals are stored in 50 kg jute bags, which should be replaced with hermetic bags.

Figure 3. 7. Packing sesame for retail sale (A) and packaging storage of RFCs in gunny bags (B) and Hermetic bags (C)

3.4.8 Storage Management for Rainfed Cereals

The storage losses of cereals are estimated to be about 1–2%, in developed countries, with grains stored in well-managed silos. However, it may be as high as 20–50% in developing countries, due to improper storage management (Jayas, 2012). In India, post-harvest losses caused by unscientific storage techniques are about 10% of total food grains (Sinha and Sharma, 2004). The storage losses in sorghum, millets and sesame are estimated to be about 6.5, 6.0 and 8.5% respectively (Farmers interview, 2022).

The postharvest losses of rainfed cereal during storage are influenced by seed physiological factors, storage atmosphere and biological factors such as pests and diseases. The most important factors that influence the storage of seeds include seed moisture content, storage temperature, relative humidity of storage, and storage pests of rainfed cereals. The outcome of storage management depends on the interaction of these factors (Lima *et al*., 2014). The rainfed cereals store best either at low (below 15°C) or at high temperatures (above 35°C). However, for long-term storage, low-temperature storage is preferred. The humidity of the storage should be less than 60%.

3.4.8.1 Seed moisture content

The seed moisture content (MC) is the most critical factor in the storage of cereals grains, which determines the rate of physiological deterioration (Magan and Aldred, 2007). The optimum MC for drying sorghum and sesame is 13-15 and 10%, respectively. High moisture in seeds reduces seed viability and causes mechanical damage during processing and decreases the milling quality affected. (Table 3.8). In addition, high moisture in seeds provides favorable conditions for mold incidence during storage.

Table 3. 8 Moisture content of millets in relation to harvesting and storage

Moisture Content (%)	Grains Firmness/ hardness
Less than 20%	Seeds ready for harvesting
14-15%	Grains are dry and ready for threshing
14%	Short-term storage of less than 06 months
13.5%	Long-term storage of more than 06 months

3.4.8.2 Storage Temperature

The storage temperature has a direct impact on the physiological deterioration and storage life of seeds. The higher the temperature, the higher is disease incidence, pest infestation and physiological deterioration, and the shorter is the storage life (Magan and Aldred, 2007).

3.4.8.3 Relative Humidity

The relative humidity of the storage atmosphere interacts with storage temperature and seed moisture content and influences the rate of seed deterioration and fungal growth (Magan and Aldred, 2007) (Figures 3.8 & 3.9). Thus, the relative humidity and temperature should be kept low to retain the seeds/ grain quality during storage. As a rule of thumb, the relative humidity and temperature must not exceed 100.

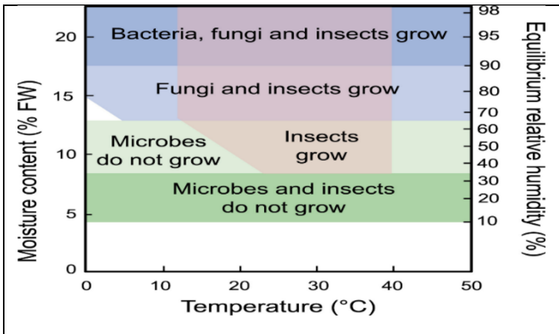


Figure 3. 8. The interaction of temperature and seed moisture content on the growth of microbes and insects in grain storage

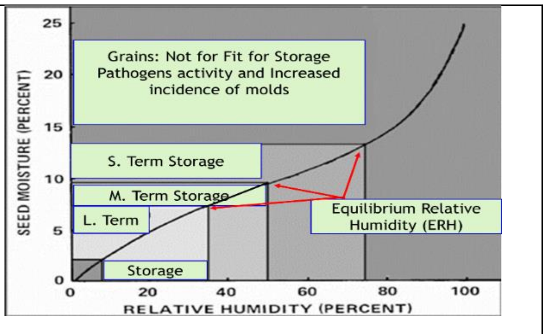


Figure 3. 9. The influence of relative humidity and seed moisture on desirable storage duration of grains.

3.4.8.4 Management of Insects/pests during Storage

The major causes of storage losses are pests i.e. grain insects, rodents, and birds.

i. **Insects**: Storage insects especially grain borers are a serious problem during the storage of rainfed cereals. The farmers remove the tarpaulin cover once a while to kill the insects in the bags by the high temperature. However, it cannot completely eradicate the insect problem in stored grains.
ii. **Birds**: Birds are also a serious threat to the grains but also damage the sacs, thereby increasing the losses during transportation and shifting.
iii. **Rodents**: The rodents feed directly on the seed, damaging the bags and their droppings (feces and hairs) are a serious cause of contamination of grains during storage. These storage pests can be controlled by different techniques such as:

i. **Chemical control measures**: Chemical control is the most common and most effective method of controlling pests during the storage of grains. Aluminum phosphide @ 9 g/tonne

(3 tablets of 3 grams each) are effective in closed storages. In the Storage Shed fumigation of 21 tablets is needed for 28 m^{-3}.

ii. **Physical control measures**: The insects infesting stored grain require proper temperature, moisture content of the grain, and oxygen for normal development and multiplication. The goal of physical measures is to the physical conditions unfavorable for insects' growth and development.

a. **Low and High Temperatures**: The optimal temperature for most of the storage insects is between 25 and 30°C. Thus, the insects can be controlled by either increasing or decreasing storage temperature. In the range of 13 and 25°C, the lower the temperature, the slower is the insects' development. Similarly, the higher the temperatures above 35°C, the slower is the development of insects.

b. **Hot air**: Some of the modern techniques for high-temperature disinfestations using heated air grain driers and solar radiations have been used for disinfesting grains. Refrigerated aeration of grains stored in bins is as effective as insecticide treatment in controlling storage pests (Donahaye *et al*, 1994).

c. **Irradiation**: Low-dose irradiation (Less Than 1kGy) completely kills or sterilizes the common grain pests, and even the eggs deposited inside the grains. However, irradiation treatments are applicable only in large-scale commercial operations.

d. **Controlled Atmosphere**: Insects can be controlled by decreasing O_2 or increasing CO_2 or N_2 concentration in the grain storage.

e. **Use of plant products**: The powders of leaves of Neem offer good protection against insects when mixed with grains. Neem leaf powder and turmeric powder at 10g /kg are effective against storage pests.

f. **Hermetic Bags and air-tight silos**: Proper storage management and protection from pests can decrease postharvest losses during storage (Jha *et al*., 2015). At the farm level, rainfed cereal especially sorghum and millets can be stored in hermetic bags, which give complete control of insects in the stored grains. For lose grains storage, airtight silos, that create a modified atmosphere is an eco-friendly solution to control insects during storage (Murdock *et. al*., 2014).

g. Rodents are not easy to control by physical measures. However, the angular construction of the storage platform can minimize the entry of rodents into the storage.

3.4.9 Transport of Rainfed Cereals

An inadequate and inefficient transportation system increases qualitative and quantitative losses resulting in an increase in the cost of marketing. The transport care involves:

a. It must protect the produce during transportation from adverse weather conditions.
b. It must deliver the product to the consignee in the stipulated time.
c. Preferably, it should not be used for transporting animals or chemicals. If it is unavoidable, the vehicle should be thoroughly cleaned before transporting the cereals grains/seeds.

3.4.10 Economic impact of reducing losses through postharvest management

a. Quantity recovered: If the harvesting and postharvest management are optimized in KSA to 75% efficiency, it can recover 29103, 2639 and 1424 tonnes of sorghum, millets and sesame seeds. With the import price of these commodities for the year 2020, it account to about 4.43 million, 0.739 million 1.52 million USD saving in import of sorghum, millets and sesame, respectively (Table 3.9).

Table 3. 9. Economic impact of postharvest management and processing at 75% efficiency

PHL Stages	Losses (tonnes)			Quantity Recovered			Import Values USD (2020)		
	Sorghum	Millets	Sesame	Sorghum	Millets	Sesame	Sorghum	Millets	Sesame
Harvesting	4329	293	140	3,247	220	105.32	658,280	81,970	149,642

Drying	8051	221	481	6,039	166	361.08	1,224,269	61,832	513,059
Threshing	3097	468	181	2,323	351	135.41	470,873	131,152	192,397
Cleaning	1548	176	100	1,161	132	75.23	235,436	49,182	106,887
Packaging	929	146	50	697	110	37.61	141,262	40,985	53,444
Transport	1239	88	60	929	66	45.14	188,349	24,591	64,132
Storage	8051	702	341	6,039	527	255.77	1,224,269	196,728	36,3416
Marketing	1858	123	70	1,394	92	52.66	282,524	34,427	7,4821
Total	29103	2639	1424	21,827	1,979	1,068	4,425,260	739,368	1,517,798

b. Saving inputs: With the current national yield of sorghum (2.37 tonnes/hectare), millets (2.11 tonnes/hectare) and sesame (1.31 tonnes/hectare), decreasing postharvest losses by 75% is equivalent to the recovery of 9209.82, 937.88 and 815.42 hectares of wasted land resource and other inputs used in producing the rainfed cereals.

c. Price escalation: Postharvest management is a value addition process and enhances the price. The farmers' price of sorghum (SR 3-4), millet (SR 4-5) and sesame (8-10). The market traders enhance the value by thorough cleaning and better packing with proper postharvest management. Thus, the price escalates and the consumers' price of sorghum, millet and sesame is 13-15, 12-14 and 25-30 SR/kg, respectively (Table 3.10).

Table 3. 10. Price escalation (SR/kg) with PHM along the supply chain.

Commodity	Farmer Price	Cleaning/ Sorting	Packing	Whole Sale	Consumers Price	Value added Products
Sorghum	3-4	5-6	8-9	10-12	13-15	Variable
Millets (Local)	4-5	6-8	8-10	11-12	13-15	Variable
Sesame (Local)	8-10	10-12	15-18	20-25	25-30	Variable

3.4.11 Processing Techniques of Rainfed Cereals

Processing of Sorghum

Sorghum grains can be processed by dry milling, wet milling, and fermentation. In dry milling, the grains are cleaned and conditioned by adding water to soften the endosperm and milled by the conventional roller mills to separate the endosperm, germ, and bran from each other.

Another milling process for sorghum is 'pearling' or decortications. In this case, cleaned grains are wetted by spraying water for 2-3 min. and immediately milled in rice huller, to remove a major part of the coarse fiber and pigment, with a minimum degree of cracking of the grain. A maximum of 12 percent polishing can be carried out. This type of milling can give products rich in protein (up to 27 percent) and fat but low in fiber. The products can be used in the preparation of food products with high protein content.

Millets Processing

The primary processing of millet is adopted after harvest to clean, destone, and store the produce. The millets are grains are partially or completely decorticate before further processing and consumption. The whole grains can be directly dry-milled to produce broken or cracked grains, grits, coarse meals and fine flour. In secondary processing, the cleaned grains are ground into flour for further use in the preparation of secondary processes i.e. flour, porridges, popped, salted ready-to-serve grains, sprouted cereals, roasted and malted foods or mixed with other flours to form composite flours for soft and stiff porridges (Bangu *et al.*, 2000). The milling of millet and sorghum grain is carried out either manually at the homestead level or in small mechanized mills at the village or governorate level. These small-scale milling equipment are also not efficient enough and should be replaced by modern grain mills that can be run on solar power. Similarly, husking and flaking machines to make porridges, etc. should be established.

Sesame Processing

Sesame seed processing is carried out in three main steps which are cleaning and sorting. Dehulling both wet or dry is not common in Saudi Arabia and the seeds are further processed for the extraction of oil. The traditional processing method of semi-mechanical oil extraction with water is common in KSA. However, one grower, the mission met, uses a hydraulic press for sesame oil extraction. It is suggested that improved mechanical oil extractors can increase oil extraction by 50% and should be adopted by smallholders to increase the oil extracted as well as enhance the quality of the oil.

3.4.12 Value Addition and Products Diversification

Value addition aims at increasing the market value of a product. Rainfed cereals can be processed into a variety of value-added products. The demand for value added products has been increasing with changing lifestyles. The farmers and processors can enhance their profits through product diversification in rainfed cereals. However, the smallholders are unable to maximize their profits through product diversification due to a lack of knowledge of relevant technologies. There are several value added products of sorghum and millets that can be adopted by smallholders to enhance their income from sorghum and millet production (Table 3.11).

Table 3. 11. Value added products of rainfed cereals

Sorghum		
Input	**Product**	**Description and use**
Seeds	Bran	Sorghum offal, sorghum milling waste, and sorghum mill feed is a mixture of grain pericarp (bran) and variable amounts of grain fragments (endosperm, germ).
Seed	Flour	Sorghum gluten feed is a by-product of the manufacture of sorghum starch or syrup by wet milling. It consists of a mixture of bran, steep liquor and other residues.
Flour	Starch	Sorghum gluten meal is another by-product of sorghum starch extraction. It consists of the gluten (protein) fraction of the grain that remains after the separation of fiber and starch.
Starch	Cake	Sorghum germ meal (sorghum oil germ cake) is a by-product of sorghum starch extraction. It contains the germ of sorghum grains from which part of the oil has been pressed.
Millets Products		
Input	**Product**	**Description and use**
Seeds	Flakes	Thick roasted flakes used in making Musli
Seeds	Pops	The whole seeds can be mechanically popped at 230°C
Seeds (Hulled)	Bakery	Incorporated into traditional snacks and sweets.
Seeds	Flour	Common bakery products such as biscuits, cakes, cookies

A. Sorghum and Millets Products: The millets can be processed into a variety of value-added products such as popping and puffing, extrusion cooking, vermicelli, and bakery products (Birania *et al*., 2020)

a. Popping and Puffing: Popping and Puffing is a traditional technique that involves exposure of Millet grains to high temperatures for a short duration to produce super-heated vapor inside the grains. It cooks the grain and expands the endosperm, breaking out the outer skin. Puffing differs from popping because it involves a controlled expansion of the kernel, while the vapor pressure escapes through the micropores of the grain. Popping and puffing impart acceptable taste and desirable aroma to the snacks (Figure 3.9).

There are different methods of popping/puffing. The conventional method of dry heat, sand and salt-treated, hot air popping, popping in hot oil, and microwave heating (Birania *et al*., 2020). The cleaned, puffed grains are ground into flour for further use.

.**b. Extrusion cooking:** Extrusion cooking is the process of preparing low-energy (low fat or low protein) foods. Extrusion technology can be used to produce ready-to-eat snacks.

c. Vermicelli: Millet or sorghum can be mixed with wheat for making vermicelli.

d. Baking: The use of millet flour alone in the formulation of bakery items causes grainy products due to the different starch properties. However, mixing 30-40% millet flour and fine wheat flour are effective to prepare bakery products (Figure 3.10).

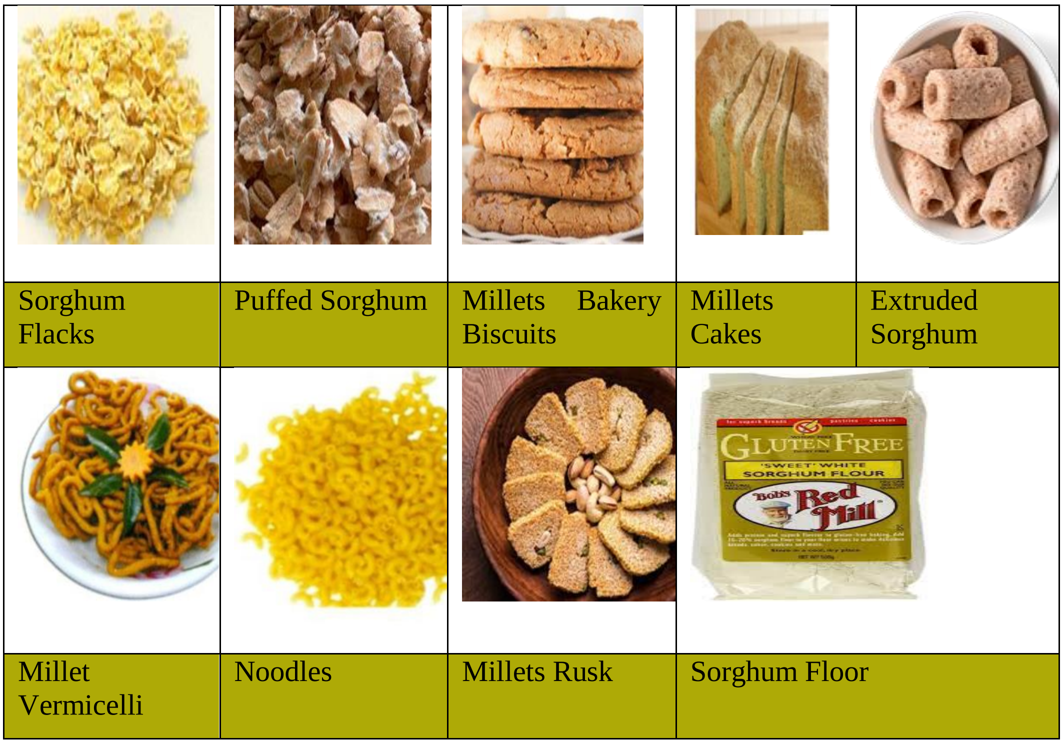


Figure 3. 10. Value added products of rainfed cereals

B. Sesame Products

The sesame seeds can be processed into a variety of value added products such as seeds, hulled seeds, sesame oil and sesame cake feed. Some of the potential value added products of sesame are presented in table 3.12.

Table 3. 12 Potential value added products of sesame

Input	Product	Description and use
Seeds	Confectionery	Fried seeds may be bound together with sugar syrup to give sweetmeats.
Seeds	Biscuits	The whole seeds can be baked into biscuits
Seeds (Hulled)	Bakery	Incorporated into bread or as decorative toppings.
Seeds (roasted)	Oil	Particularly used in oriental cuisine. The flavor is quite strong.
Oil	Medicinal treatment	Treating ulcers and burns
Oil	Margarine	For use as a butter replacement
Oil	Aerosol	A synergist for pyrethrum sprays
Low grade oil	Multiple	Soaps, paints, lubricants, illuminants

Hulled seeds	Tahini	Paste of sesame seeds used as part of middle eastern food
Tahini	Dips and spreads	Various ingredients such as chickpeas or eggplants or added to tahini to make dips and spreads such as hummus
Tahini	Halva	A sweet made from tahini and sugar with other added flavorings
Cake	Animal feed	Protein-rich useful supplement
Cake from hulled seeds	Ingredient	Use in some Indian cooking.

a. Sesame Seeds: The seed of sesame are used directly for its health benefits. The seeds can be mixed with sugar and eaten. The sesame seed is also ground and used as flour for making traditional bread. Sesame seeds are also used as a source of oil and flavor in several traditional dishes. The sesame seed is used in value addition of other products such as confectionary items and dates to enhance its market value.

Sesame Oil: Sesame oil is the most important processed product. The sesame oil is marketed in local and distant markets. The local markets prefer the taste of sesame oil extracted by traditional techniques. However, in distant markets, consumers prefer the oil extracted by hydraulic press. It indicates the prospects of high-end marketing of sesame oil. At present, the oil quality is not evaluated but it should be tested against international standards to promote its export.

Sesame Cake: The sesame oil extraction process produce sesame cake, a protein-rich as a by-product that is used as a feed (Figure 3.11).

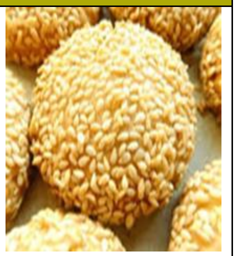
Sesame oil

Sesame cake (Animals 'Feed)

Sesame Bar

Sesame seeds

Dates Topping



Cookies with Sesame Toppings

Figure 3. 11. Value-added products of sesame seeds

3.4.12 Quality Control and Consumers Safety

Quality control and consumer safety are essential considerations in modern-day agriculture. There have been increasing incidences of mycotoxin contamination in sorghum, millet, and sesame in Northern Nigeria (Apeh *et al*., 2016). Contamination by humans, animals, birds, rodents, insects and pests can occur during postharvest handling or storage. The high-end and modern markets are especially sensitive to aflatoxins. The European Union has established maximum levels of 4 µg/kg for total aflatoxins and 2 µg/kg for aflatoxin B1 in seeds, nuts and other dried products for direct human consumption.

The Kingdom of Saudi Arabia has established testing labs for pesticides and aflatoxin determination. Using any practice or input that is detrimental to human health or the environment is prohibited by law. However, farmers' participation and testing of products is limited. It is needed to realize the full potential of rainfed cereals, grown with minimum (almost no) pesticides. At present, the testing labs can be assigned the task of certifying the major quality traits required in high-end marketing such as:

a. Measurement of % moisture content
b. Measurement of % oil content in sesame seeds
c. Visual assessment of seeds including:
   i. The presence of foreign matters
   Ii. Uniformity of maturity and soundness of grains
d. Microbial tests to ensure
   i. Freedom fungal infestation (for Aflatoxin contents)
   ii. The incidence of the bacterial disease
e. Ensure compliance with Saudi GAPs aimed at ensuring food safety
   i. Provide the appropriate environment for agricultural workers and use safe water for handling the produce or processing.
   ii. Ensure a Saudi GAP certification.

3.12.1 Ochratoxin-A Contamination and Control

Ochratoxin-A is produced by a fungal infection of cereal grains during storage. The grain temperature and moisture content are critical storage factors that affect Ochratoxin-A production. Thus, best storage practices and potential hazard analysis and critical control points (HACCP) are essential and effective measures for identifying and controlling the risk of contamination during the storage and processing of rainfed cereals.

Control of Ochratoxin-A: Several actions can be taken to minimize Ochratoxin-A contamination of stored cereals. The control measures depend on good field hygiene, harvest at the proper time, proper drying and cooling, monitoring temperature, relative humidity, and insect infestation during storage.

Table 3. 13. Control of Ochratoxin-A in stored produce

Action and Impact	Action Needed
High-Impact Actions and Activities	
Good Storage Design and Conditions	Ensure that stores are well designed and maintained with good ventilation and airflow.
Good Harvest and Store Hygiene	Clean harvest and store machinery to prevent any fungal spores from being carried over between seasons
Timely Harvest	Service and maintain machinery to avoid harvest delays (Tirkey and Shyam. 2016.)
Adequate Drying Capacity	Ensure adequate drying capacity is available for the amount of cereal harvested to avoid a backlog of high moisture content grain (Lee, 1981).
Rapidly Dry Grain	Rapidly dry grain with hot-air or bulk drying to MC below 18% to minimize the risk of ochratoxin A occurrence in storage.
Rapidly Cool Grain	Rapidly cool grain to below 15°C (Donahaye *et al*, 1994).
Medium Impact Actions and Activities	
Continued Drying	Dry to below 15% moisture content for long-term storage, thereby producing conditions, which are not conducive to fungal activity (Sinha and Sharma, 2004).
Continued Cooling	Cool grain in winter months to below 5°C
Low-Impact Actions and Activities	
Monitor Temperature and Moisture Content	Perform continued monitoring of temperature and moisture content and act on any problems encountered immediately

Monitor Insect and Mite Activity	Use traps and sieving to monitor insects and mites and control them where necessary (Pramod, 2002)

3.13 Summary: Reducing Field Losses of Rainfed Cereals

a. Reducing losses in the field

i. Avoiding fungal and bacterial infestation before harvest.
ii. Avoiding irrigation with contaminated water
iii. Ensure harvesting at the proper stage.
iv. Consider the average season of the crop as a clue to the harvesting stage.
v. Observe the crop for “dry down” stage; the leaves turn yellow and give a dried appearance.
vi. Observe reddish color development in sesame as an index of maturity.
vii. Assess the textural changes (Sorghum and Millets) in seeds and the seeds' color change from milky white to darker shades (sesame).
viii. Field drying near the threshing facility.
ix. Place plastic or tarpaulin sheets to collect seeds shattered during hilla drying (Lee, 1981).

b. Reducing losses during threshing and bagging the produce

i. Prepare a good solid threshing floor.
ii. Thresh properly dried cereal grains
iii. Use a mechanical thresher (Abagisa *et al*., 2015) or by drawing a stone roller over the ear heads but avoid damage to the grains during threshing.
iv. Allow proper drying of sorghum and millets after threshing. Clean and dry the grains in sun for 6-7 days to reach 13-15% moisture content.
v. Adding Actellic Super (sorghum and millets) for prolonged storage.
vi. Use of Purdue Improved Crop Storage (PICS) hermetic bags for storing the seeds.

c. Reducing Storage Losses

i. Clean and disinfect the storage before storage of grains.
ii. Store the rainfed cereals at the optimum seed moisture content (13% for sorghum and millets) and (less than 9% for sesame) and maintain relative humidity at below 60%.
iii. The storage bags should preferably be new, clean, and undamaged to prevent airflow and contamination.
iv. Store the dried grains in moisture-free conditions. Avoid contact with a concrete floor to minimize dampness that may cause mold to develop.
v. For short-term storage of fewer than six months, the grains can be stored in a clean and properly roofed store to protect against rainfall. For long-term storage, the moisture content of the sesame grains must be 6-7%. A high moisture content increases the incidence of spoilage during storage.
vi. The storage should be constructed such that rodents may not enter the storage.
vii. No chemicals should be kept in storage facilities to avoid the risk of possible contamination.

The PICS Hermetic Bags, which is a triple-layer sealed plastic bags that cut off the oxygen supply to create hermetic conditions and eliminate insects should be used for the storage of dry grain (Chigoverah and Mvumi, 2016).

3.14 SWOT Analysis

Based on a preliminary review, the following strengths, weaknesses, opportunities and threats of the sector in respect of KSA rainfed cereals sector are identified, which will be helping in formulating a roadmap for its strategic development. There is a general balance between these four pillars suggesting that sector development is realistic but needs to take into account several important factors. The SWOT analysis of rainfed cereals indicates the potential for improvement in postharvest handling and suggests innovation in the overall background of the rainfed cereals sector in KSA (Table 3.14).

Table 3. 14. SWOT analysis of the rainfed cereal sector of KSA.

Strengths	Weaknesses
a. The RFCs contribute to food security and nutritional requirement. b. Presence of experience growers, skills and knowledge base for RFCs. The interest of growers to increase the production of RFCs. c. Availability of land resources for cultivation of RFCs. d. Government support for RFCs, organic production and certification. Growers' interest as is evident from the increased area and production of RFCs. e. Higher price of local produce (Sesame). f. Presence of "Farmers'" markets provide business opportunities in rural areas. f. Low water consumption making RFCs a strategic alternative under limited irrigation production system g. Awareness of the benefits of sorghum, millet and sesame products for human health. h. The sorghum acts as a major source of feed for domestic animals.	a. Limited and variable rainfall deplete water resource and increase the cost of irrigation. b. Inadequate applied research support. c. Lack of adopted improved varieties and technologies. d. Absence of full-scale certified seed production for rainfed crops. e. Lack of technical skills and knowledge of extension and support services to cereals' producers. f. Poor post-production handling. g. Inadequate storage and marketing infrastructure. h. Lack of mechanized on-farm operations i. Lack of farmers' interest in agricultural cooperatives for rainfed cereals. j. Higher production cost compared to imported grain and products.
Opportunities	**Threats**
a. Under Saudi Vision 2030, MoEWA's mandate to support small farmers of RFCs. b. Interest and willingness of big retail chains to procure directly from small producers through their cooperatives. c. Certified cereals and products from KSA can target the growing demand for organic produce, especially in export markets. d. High-end markets i.e. Danube, Lulu, Carrefour, Tamimi that sell processed cereal-based products and have dedicated organic sections. e. An increasing number of hajj and Umrah pilgrims and visitors enhance the demand for cereal-based products.	a. The increasing cost of agricultural laborers leads to an increased cost of production. b. The cultivation of cereals in small patches of land makes it uneconomical. c. Reliance on rain and limited water resource threaten crop productivity. d. Price competition from cheaper imported produce and processed products. e. Lack of skills in postharvest handling of rainfed cereals increases PHLs. f. Lack of value addition and cereals-based products and low popularity as food crops. g. The youth migrate to larger cities for jobs and business and ignoring the generation threatens sustainability.

3.15 Action plan

In light of the growers' interviews, meetings with the experts (FAO), FGDs, literature review and observation during visits to the fields and markets, and validation with experts from research and extension departments, and progressive growers, the action plan is suggested to promote the postharvest handling of rainfed cereals (Table 3.15). The action plan is aimed at:

a. **Postharvest losses recognition**: The MoEWA and the government of KSA need to realize the economic impact of postharvest losses in rainfed cereals and commit themselves to reducing postharvest losses.
b. **Capacity Building**: Saudi Arabia needs to invest in developing the postharvest skills of the growers and MoEWA staff to adopt the innovations required to decrease postharvest losses in rainfed cereals.
c. **Adopting postharvest handling technologies**: New postharvest handling and processing technologies such as produce hygiene, mechanical drying, hermetic bags, and pest and disease control measure. It can be achieved by mobile drying, threshing services operating as private businesses, and AflaSTOP technology for cereals grain.
d. **Promote value addition**: Enhanced the quality of rainfed cereals and greater utilization as value added products.
e. **Environment-friendly and Sustainable technologies**: The smallholders need to adopt different practices and technologies which ensure sustainability, environment-friendly, and climate change mitigation.
f. **Human resource development**: Organize training for the growers and extension staff in the postharvest handling and processing of rainfed cereals.
g. **Enhanced collaboration in the relevant department**: The collaboration between extension staff and growers and with other relevant departments must be strengthened to adopt measures to minimize the losses during harvesting, postharvest handling, and processing.

Since MoEWA provides financial support for most of the tools/ equipment recommended in the action plan, postharvest handling and processing can be optimized with almost no cost to the growers at this stage. The recovery of lost produce in rainfed cereals, with a postharvest handling system, at 75% efficiency, can be about 21827, 1979 and 1068 tonnes. The financial benefits based on import price for the year 2020 will be about 4,425,260, 739,368, 1,517,798 USD in sorghum, millet and sesame accordingly.

Table 3. 15 Action Plan for rainfed cereals

Actions	**Responsibility/ Support**	**Outcome**	**Methodology**
Harvest at Physiological maturity	Growers/ MoEWA	a. Superior grains quality b. Properly dried grains and optimum moisture content. c. Decreased losses by 75% during harvesting	Training of MoEWA staff and growers
Cost: No cost to the growers			
Benefits: Decreasing losses due to physiological deterioration and physical losses by 75% during harvesting, 3246.9, 219.4 and 105.3 tonnes of sorghum, millet and sesame can be recovered, which is worth 658280, 81970 and 149642 USD based on import price, 2020.			
Drying of RFCs before threshing using Tarpaulin	Growers	Decreased grains/seed losses during drying of RFCs	Adopting drying using tarpaulin sheets
Cost of Tarpaulin sheets @ 45USD/25$m^{2,}$			
Benefits: A 75% reduction in grain/seed losses during drying will recover 6,038.6 and 165.5 tonnes of sorghum, millets and sesame. At the 2020 import price, the recovery will be worth 1,224,269, 61,832 and 513,059 USD.			

<table>
<tr><td>Mechanical threshers and threshing floor with rain and birds protection</td><td>Growers/ MoEWA</td><td>Enhanced threshing efficiency and decreased labor costs by half.
Decreased contamination and grain damage</td><td>Facilitate the provision of mechanical threshers and establishing rental service for threshing</td></tr>
<tr><td colspan="4">Cost: 1000-5000 USD (one time) depending on capacity</td></tr>
<tr><td colspan="4">Benefits: Sorghum and Millets: Decreased laborers required from 10-12 to 3-4 and cost from 720 SR to 400 SR/hectare (133-240 USD/year).
b. Decrease damage to grains and losses during threshing.</td></tr>
<tr><td>Storage structure with angular platform 0.5 m above the soil</td><td>Growers/ FAO & MoEWA</td><td>Minimize birds and rodents damage</td><td>Growers with MoEWA support</td></tr>
<tr><td colspan="4">Cost: Variable depending on size</td></tr>
<tr><td colspan="4">Benefits: Variable depending on size</td></tr>
<tr><td>Air-tight and moisture-resistant packaging. i.e. Hermetic Bags</td><td>Growers and MoEWA</td><td>a. Protection from light, and moisture.
b. 100 percent control insects damage</td><td>Adopting proper packaging technology for roasted beans.</td></tr>
<tr><td colspan="4">Cost: Hermetic bags at the rate of 3.5-4.0 USD/ bag
Sorghum and Millets: Requires 41 bags (164 USD) per hectare
Sesame: Requires 27 bags (108 USD) per hectare</td></tr>
<tr><td colspan="4">Benefit: The losses during storage due to insects decrease by 100%.</td></tr>
<tr><td>Dry cards and hygrometers</td><td>Growers and MoEWA</td><td>Ensure proper moisture content
Decrease pathogenic incidence
Decreased losses during storage</td><td>Use dry cards and hygrometers to ensure proper moisture content</td></tr>
<tr><td colspan="4">Cost: The hygrometer and dry card cost 8-100 USD and 5 USD, respectively.</td></tr>
<tr><td colspan="4">Benefits: Depends on other storage-related factors. Hence, it is calculated along with storage losses.</td></tr>
<tr><td>Value added products</td><td>Growers and MoEWA</td><td>Conversion of grain to different value added products</td><td>Promotion of small-scale processing units and business diversification</td></tr>
<tr><td colspan="4">Cost: Variable depending on which products are developed</td></tr>
<tr><td colspan="4">Benefits: Variable depending on the type of products developed</td></tr>
<tr><td>Organic Certification</td><td>Growers and MoEWA</td><td>Certified organic produce and higher returns</td><td>Simplifying the certification process</td></tr>
<tr><td colspan="4">Cost: No Charge to growers</td></tr>
<tr><td colspan="4">Benefits: Enhanced access to high-end and export markets.</td></tr>
<tr><td colspan="4">Fully Functional Postharvest System assuming 75% efficiency</td></tr>
<tr><td colspan="4">Cost: Variable and born by MoEWA</td></tr>
</table>

Benefits: Proper Postharvest system with 75% decrease in postharvest losses can result in annual financial benefit to Saudi Arabia of about 4.5 million USD, 0.74 million USD and 1.52 million from sorghum, millet and sesame.
Note: The estimates of quantity recovered as 75% of PH Losses and monetary value is calculated based on import price for the year 2020.

SECTION-4: CONCUSSIONS AND RECOMMENDATIONS

4.1 Conclusions

The rainfed cereals i.e. sorghum, millets, and sesame have traditionally been grown in the Kingdom of Saudi Arabia, especially in the Jazzan, Aseer and Al-Baha regions. Whereas the millet and sesame are grown for their seeds, sorghum is an important source of food and feed. The rainfed cereals are well adapted to high temperatures and drought conditions prevailing in these regions. Hence, there is enormous potential to increase the cultivation of rainfed cereals in Southwestern Saudi Arabia. However, the lack of proper harvesting, postharvest handling, storage and processing technologies limits the profitability of rainfed cereals in KSA.

While a smallholders are interested in increasing the cultivation of rainfed cereals, the traditional methods of cultivation and post-production handling of rainfed cereals hinder increased cultivation and profitability. The smallholders follow a traditional farming system of rainfed cereals, which has several flaws in harvesting. Postharvest harvest handling i.e. field drying, threshing, packaging, storage and processing. As a result, rainfed cereal grains are prone to losses during harvesting and postharvest handling. The processing of sorghum and millets is limited to dry milling and there is no value addition of these cereals in KSA. The only commercial-scale processing is of sesame, which is processed into sesame oil. The sesame oil is marketed in domestic both local and distant markets. The sesame oil is extracted with water by a traditional technique, which decreases the quality and storage life of the oil.

Improper harvesting, postharvest management and processing result in high postharvest losses, worth millions of US dollars. Saudi Arabia, despite its favorable climate and long experience of rainfed cereals cultivation, has to rely on import of rainfed cereals to satisfy its domestic requirements. To meet the increasing demand of rainfed cereals, Saudi Arabia needs to increase production and decrease the postharvest losses in rainfed cereals. Modern technologies of postharvest handling and processing are needed to minimize postharvest losses. The introduction of proper drying techniques, the use of hermetic technologies (bags and silos) for storage can decrease the losses of rainfed cereals.

Value addition is an essential component of crop production. The rainfed cereals can be converted to different value-added products such as the multigrain floor, puffing or popping, millet malting, noodles and vermicelli, and bakery products. However, there is minimal value addition in rainfed cereals. Value addition and product diversification enhance the market value, as well as create jobs in rural areas. It increases growers' income and so contributes to the social fabric of a region.

There is almost no Research & Development support available to the smallholders. A small number of cultivars are being grown year after year. There is no national-level certified seed program to provide quality seeds of new varieties that can ensure higher yields and reduced losses. Research on developing new products and their commercialization is needed for the sustainability of the rainfed cereals sector. The development of fortified and mixed floor products will enhance the food use of rainfed cereals. Utilization of sesame and millet stocks for making feed for domestic animals can be a significant effort to increase the cultivation of these cereals in KSA...

With proper postharvest management and processing technologies, rainfed cereals can emerge as profitable crop husbandry, open new opportunities, and add further variety to the food sector of KSA. Reduction in losses will not any add to the margins of profit but will also help in achieving food security. It will contribute to sustainability, biodiversity and climate change mitigation efforts. Training of growers and extension workers of MoEWA in postharvest management and processing is needed to reduce the postharvest losses in the rainfed cereals and provide a sound basis for a profitable and sustainable rainfed cereals sector in Saudi Arabia.

4.2 Recommendations

a. Harvesting: The rainfed cereals should be harvested at proper maturity. In addition to color changes in leaves, adopting harvesting at physiological maturity and seed moisture testing will decrease the losses during the harvesting operation.

b. Introduction of non-dehiscent sesame cultivars: For the sesame crop, the introduction of non-dehiscent varieties will greatly reduce the losses, especially during the drying and threshing of the sesame crop.

c. Drying of Rainfed Cereals: The drying process should by conducted by making hillas in one field with proper rain protection. The same field should be used for threshing. It is recommended to make hillas over plastic or tarpaulin sheets and protected them from birds and ants. Drying technologies i.e. hot air drying should be used to shorten the drying processes and minimize the damage by birds and ants, and loss of grain during drying.

d. Storage of rainfed cereals: The current small-scale storage structures provide little protection against birds, pests, moisture and light. Improved storage structures and management techniques will minimize storage losses in rainfed cereals. Hermetic storage technology and bags should be adopted in the storage to minimize insect damage to the rainfed cereals and decrease the losses to grains during storage.

e. Protection from rodents: The rodents can reach otherwise un-accessible areas and damage the grain by eating and causing contamination. Storage structure with an angular platform limits the access of rodents to the storage rooms and decreases the damage to the grains.

f. Value Added Products Development: The development of the value added products enhances the market value of the rainfed cereals and provides alternative marketing options to the growers. It will facilitate the large-scale production of rainfed cereals.

g. Feed Production: Rainfed cereals are dual-purpose crops. Despite high grain prices, it is grown over the least area because its stalks are not used as feed. The value of the sesame crop can be markedly enhanced if the sesame stalks are also made into useful feeds. One such easy-to-adopt technique is chopping the stalks and use as feed for animals.

h. Quality Control and Phyto-sanitary Certification: While, the Kingdom of Saudi Arabia has stringent quality control measures, it is needed to increase the growers' participation in Phyto-sanitary certification, especially for aflatoxin. It will ensure quality and food safety and allow a higher return to the growers.

i. Training on good harvesting and post-harvest practices

The growers are the primary drivers of change in promoting the quality of rainfed cereals and their products. It is needed to provide basic postharvest training to extension workers as well as the growers of rainfed cereals. Training, with a focus on reducing postharvest losses through proper harvesting, postharvest handling and value addition, using affordable and reliable technologies will minimize the postharvest losses and offer business opportunities in rainfed cereals.

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Annexure 1. Sample Questionnaire for Rainfed Cereals

The questionnaire is designed for growers/ traders of rainfed cereals. It contains questions related to production practices, harvesting, postharvest handling and processing as well as marketing of rainfed cereals, The interview/ discussion about this survey will start with a brief introduction by the interviewer to explain:

1. The survey is aimed at getting general information about the farming and postharvest handling of rainfed cereals and will not reveal the personnel information in any reports based on the response of the growers.

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

3. If a growers feel not to reveal any information requested in this questionnaire, he/she can inform the interviewer about such questions.

A. General (Demographic) Information

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

1. How much area do you cultivate with RFCs (Dunum/ Hectares)?
   ____
2. How much of your land (Percentage) is dedicated for the RFCs?

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

3. Do you grow any other crop in the field? Indicate the number of crops

No	1	2	3

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

Yes	No	If yes	Job/Business?	

5. How many youth / female workers are involved in RFCs production ____________%?
6. Are you part of any growers cooperatives in the region

B. Production Practices

7. How much is your experience of the cultivation of rainfed cereals (years)?

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

8. How much seeds do you use per hectare or Dunum? ______________________________
9. Which variety/varieties do you cultivate for different RFCs?

Sorghum				
Millets				
Sesame				

10. What is the basis of your selection of cultivating the rainfed cereals?

Crop	Food Value	Feed Value	Both Food and Feed	Others if any
Sorghum				
Millets				
Sesame				

11. Which agriculture practices do you use in the cultivation of rainfed cereals?

Practice	Land Preparation	Weeding	Irrigation	Fertilizers	Any Other
Sorghum					
Millets					
Sesame					

12. Do you engage full-time labor or part-time (need-based) laborer in RFC production?

Crop	Full-Time	Part-Time	Both	Details of labor engagement
Sorghum				
Millets				
Sesame				

13. How many laborers do you engage for the following operations?

Operation	Sorghum	Millets	Sesame
Land Preparation			
Sowing			
Weeding			
Irrigation			
Harvesting			
Drying			
Threshing			
Packaging			

14. When do you consider you crop mature for harvesting?

Crop	Follow Others	Changes in seed	Changes in leaves	Any Other
Sorghum				
Millets				
Sesame				

15. What is the range of minimum and maximum yield of different rainfed cereals?

Crops	Sorghum	Millets	Sesame	

16. How and for how long do you dry the rainfed cereals?

Crop	On the soil	On Tarpaulin sheets	Drying period (days)
Sorghum			
Millets			
Sesame			

17. How do you thresh your produce?

Crop	On the soil	On Tarpaulin sheets	Manual	Mechanical
Sorghum				
Millets				
Sesame				

18. How long do you dry the seeds after threshing?

Crop	Do not dry	1-2 days	3.4 days	5-6 days
Sorghum				
Millets				
Sesame				

19. What do you do for protecting the rainfed cereals during storage?

Crop	Open air	Rain Protection	Light Protection	Pests Protection
Sorghum				
Millets				
Sesame				

20. How do you market the rainfed cereals

Crop	Directly to consumers	Farmers market	Market Traders	Processors
Sorghum				
Millets				
Sesame				

21. How much (range of minimum and maximum) of seed is lost during the following operations?

Operation	Sorghum	Millets	Sesame
Before Harvest			
Harvesting			
Drying			
Threshing			
Post threshing drying			
Packaging			
Marketing			
Storage			

C. Facilities and Problems

22. Which factor adversely affects the production of rainfed cereals?

Lack of Fertilizers	Lack Irrigation	Pests and disease	Any Other

23. Do you get timely help for the following?

Advice/ Services	Yes	No	Advice/ Services	Yes	No
Fertilizers application			Harvesting time		
Pests/ disease control			Drying process		

24. In case of any problem, you get help from?

Personnel Experience	Extension Staff	Fellow Growers of Rainfed cereals	Literature

25. Do you certify your produce as organic produce? If No, give the reasons

Yes	No	Reason

26. Are you a member of farmers' cooperative? If not, give the reason

Yes	No	Reason

27. Do you intend to start mechanical farming? Yes ______________, No ______________
28. Do you feel the need for training to decrease postharvest losses?

Yes	No	If Yes, Specify which aspect of postharvest handling of training

29. Are you satisfied with the current farming system? ______________________________
30. Any Other questions that may emerge during the interview

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

Jazzan	Temperature			Precipitation	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	20	31	25	14	3
February	20	32	26	4	1
March	20	34	27	6	1
April	22	36	29	16	2
May	24	39	32	8	1
June	27	38	33	1	1
July	27	39	32	11	2
August	27	38	33	27	4
September	25	38	33	10	2
October	24	37	31	19	2
November	21	35	28	14	1
December	19	32	26	16	2
Average	23	35.75	29.58	12.62	1.83
Aseer	**Temperature**			**Precipitation**	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	10.7	21.1	15.6	10.67	2.45
February	12	23.1	17.4	13.94	3.27
March	13.6	24.5	18.9	29.12	6.64
April	15.6	26.1	20.7	69.54	13
May	18.5	28.9	23.6	76.34	14
June	19.9	31.4	25.7	15.69	5.27
July	19.4	30.5	25	44.83	8.73
August	18.8	29.1	24	105.38	18.73
September	18.1	29.2	23.6	26.43	7.36
October	15.5	26.6	20.8	18.67	5.45
November	12.9	23.5	18	24.2	7.82
December	11.2	21.7	16.2	8.75	2.45
Average	15.52	26.31	20.79	36.96	7.93
Al Baha	**Temperature**			**Precipitation**	
Month	Min (°C)	Max (°C)	Mean (°C)	Millimeters	Rainy Days
January	10.8	19.6	14.9	45	3
February	12.2	21.8	16.7	25	1
March	13.9	23.6	18.5	36	1
April	16.4	25.8	20.8	46	2
May	19	28.8	23.7	52	1
June	20.9	31.1	25.9	30	1
July	21.1	30.4	25.5	36	2
August	20.3	29.2	24.6	150	4
September	19.1	28.5	23.6	130	2
October	16	25.6	20.6	39	2
November	13.4	22.6	17.8	19	1
December	11.3	20.5	15.7	23	2
Average	16.20	25.63	20.69	52.58	1.83

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

Annexure 3. International trade of rainfed cereals during the year 2020

Annexure 3. a Global top exporters and importers of sorghum

Rank	Countries	Export Quantity	Rank	Countries	Import Quantity

		(tonnes)			(tonnes)
1	USA	1392917	1	China	4,849,052
2	Argentina	84653	2	China	4813474
3	Australia	49561	3	Japan	382269
4	France	39187	4	Mexico	327825
5	Kenya	27246	5	South Sudan	132551
6	Ukraine	20889	6	Spain	125316
7	India	16467	7	Ethiopia	110779
8	Uganda	12439	8	Italy	87110
9	Hungary	11601	9	Sudan	81407
10	China	9884	10	Eritrea	63602
142	S. Arabia	Negligible	75	S. Arabia	291
Total Global Export		1719308	Total Global Import		11679061

Annexure 3.b Global top exporters and importers of Millets

Rank	Countries	Export Quantity (tonnes)	Rank	Countries	Import Quantity (tonnes)
1	Ukraine	516,592	1	Indonesia	755,46
2	USA	100158	2	Belgium	28679
3	India	76481	3	Germany	28023
4	Russia	42962	4	UK	25536
5	France	25317	5	Türkiye	24759
6	Tanzania	17469	6	Netherlands	18587
7	Türkiye	14159	7	Iraq	18583
8	Pakistan	12377	8	Nepal	18350
9	Myanmar	12117	9	UAE	18082
10	Netherlands	9369	10	Canada	16322
69	S. Arabia	278	32	S. Arabia	3897
Total Global Export		516592	Total Global Import		503743

Annexure 3. c Global top exporters and importers of sesame seeds

Rank	Countries	Export Quantity (tonnes)	Rank	Countries	Import Quantity (tonnes)

1	Sudan	492351	1	China	1060381
2	India	276265	2	Türkiye	223162
3	Nigeria	261235	3	Japan	204864
4	Ethiopia	228089	4	India	149097
5	Tanzania	167091	5	Rep. of Korea	77662
6	Myanmar	138913	6	Israel	68747
7	Mozambique	100304	7	**Saudi Arabia**	**49612**
8	Brazil	72000	8	UAE	46397
9	Burkina Faso	60770	9	China, Taiwan	43230
10	Mali	58212	10	Iran	40277
68	Saudi Arabia	68			
Total Global Export		3520119	Total Global Import		2413114

Annexure 3. d Global top exporters and importers of sesame oil

Rank	Countries	Export Quantity (tonnes)	Rank	Countries	Import Quantity (tonnes)
1	China	11650	1	USA	22016
2	India	10770	2	China	6296
3	Japan	8550	3	UK	5005
4	China	6925	4	France	3025
5	Lebanon	6847	5	Canada	2957
6	Mexico	4757	6	Netherlands	2795
7	China, Taiwan Province of	4271	7	China, Taiwan Province of	2673
8	Singapore	3283	8	Japan	2643
9	Netherlands	2975	9	Singapore	2639
10	Germany	2410	10	Australia	2584
89	S. Arabia	200	14	S. Arabia	1563
Total Global Export		80691	Total Global Import		81560

Annexure 4. Cost of production and monitory return/ hectare of Rainfed Cereals

Annexure 4.a. Cost of production and monitory return/ hectare of Sorghum

Costs Involved	Min	Max	Mean
Soil Preparation (3-5 Hours x SR 80-100 /hour)	240	500	370
Seed per hectare (12-18 kg/hectare @ 10-15 per kg)	200	375	287.5
Tillage 5 laborers @ SR 80-100 per day (8 hours)	400	500	450
Harvesting 6-8 laborers @ SR 80-100 per day (8 hours)	480	800	640
Drying 2-3 Laborers @ SR 80-100 per day (8 hours)	160	300	230
Manual threshing 8-12 Laborers @ SR 80-100 per day (8 hours)	640	1200	720
Harvesting Bags Required 80 kg bags @ SR 4 Bag	208	168	188
Miscellaneous Spending (Laborers Food and Lodging etc.)	3500	5000	4250
Total annual Cost	5828	8843	7136
Seed yield (1750-2100Kg/ hectare) @ SR 6-8/kg	10500	16800	13650
Feed Yield 3500-4200 bundles @ SR 2-3/Bundle	7000	12600	9800
Total Income (Seed + Feed)	17500	29400	23450
Subsidy @ SR 4/kg Produced	7000	8400	7700
Gross Income	24500	37800	31150
Net Income	18672	28957	23815
BCR	3.20	3.27	3.24

Annexure 4. b Cost of production and monitory return/ hectare of millets

Costs Involved	Min	Max	Mean
Soil Preparation (3-5 Hours x SR 150-200 /hour)	450	1000	725
Seed per hectare (8-10 kg/hectare @ 15-20 per kg)	120	200	160
Tillage 5 laborers @ SR 80-100 per day (8 hours)	400	500	450
Harvesting 4-5 laborers @ SR 80-100 per day (8 hours)	320	500	410
Drying 2-3 Laborers @ SR 80-100 per day (8 hours)	160	300	230
Manual Threshing 10-12 Laborers @ SR 80-100 per day (8 hours)	800	1200	720
Harvesting Bags required 60 kg bags	20	26	23
Cost of 60 kg @ SR 4 Bag	80	104	92
Miscellaneous Spending (Laborers Food and Lodging etc.)	6000	8000	7000
Total annual Cost	8350	11830	9810
Seed Price 1800-2200 Kg/ hectare@ 8-10/kg	14400	22000	18200
Subsidy @ SR 4/kg Produced	7200	7200	7200
Total Income	21600	29200	25400
Total Income	34200	41800	38000
Net Income	25010	27970	26490

BCR	2.72	2.02	2.37

Annexure 4. c Cost of production and monitory return/ hectare of sesame

Soil Preparation (3-5 Hours x SR 80-100 /hour)	240	500	370
Seed per hectare (8-10 kg/hectare @ 15-20 per kg)	120	200	160
Tillage 5 laborers @ SR 80-100 per day (8 hours)	400	500	450
Harvesting 4-5 laborers @ SR 80-100 per day (8 hours)	320	500	410
Hilla making and drying 4-5 laborers @ SR 80-100 per day (8 hours)	320	500	410
Manual Threshing 8-12 Laborers @ SR 80-100 per day (8 hours)	640	1200	720
Harvesting Bags required 60 kg bags	20	26	23
Cost of 60 kg @ SR 4 Bag	80	104	92
Miscellaneous Spending (Laborers Food and Lodging etc.)	2000	5000	3500
Total annual Cost	4140	8530	6135
Seed yield 1000-1300 (Kg/ hectare@ 15-20/kg)	15000	26000	20500
Subsidy @ SR 6/kg Produced	6000	7800	6900
Total Income	21000	33800	27400
Net Income	16860	25270	21065
BCR	4.07	2.96	3.52

Annexure 5: Cleaning and Grading Machines and their suppliers

Cereals Cleaning and Grading Equipment

AflaSTOP Drying: A USAID project, The AflaSTOP, in Partnership for Aflatoxin Control in Africa (PACA) has recently developed an innovative, mobile maize drying device that can dry maize in batches of 500 kg and lower the M.C. to about 13.5% in 3 h. Although this technology is yet to be commercialized, it has only been piloted in Kenya, Tanzania and Rwanda (AflaSTOP, 2019). Considering the working mechanism, the same can be used for the target rainfed cereals.

Equipment: Seed Cleaners/Graders

Equipment	**Technical description**	**Output**
Manually Operated Grain Cleaner	This machine is used for cleaning and grading of grains. It is manually operated and separates impurities like stubble, chaff and dirt from the grain. There are 3 extra sieves to make it suitable for a variety of cereals and pulses.	150 kg/hr.
Grain Cleaner ML	Grain cleaning machine.	500kg/hr.
Grain Cleaning Machine M-L	An electric powered machine for cleaning milled rice	500kg/hr.
Precision Air Classifier S-M	This machine is used for 3 functions - to separate hulls mixed with un-hulled seeds; to recover oil-bearing kernels from the hulls; and to separate light materials from heavy materials.	150-2000 kg/hr.
Gravity Separator M-L	This machine grades the seeds on a gravity basis into heavies, mediums and lights so that the best quality seeds can be made available for export. Throughput 500kg/hour.	500 kg/hr.

B- Suppliers of cleaning and grading equipment

Acufil Machines	India
Central Institute of Agricultural Engineering	India
Forsberg Agritech India PVT Ltd	India
Goldin (India) Equipment (PVT) Limited	India
John Fowler India Limited	India
Premium Engineers PVT Ltd	India
Rajan Universal Exports Manufacturers PVT Limited	India
Kongsonglee Kanchang	Thailand
Sai Gon Industrial Corporation (SINCO)	Vietnam
Gauthier	France
Marot	France
Alvan Blanch	UK
Hydraulic Press for Oil Extraction for sesame	China, India
Grain Milling Machine	China, Holland, Germany,
Chopper for Rainfed Cereals	India, Pakistan,
Silage and Haylage Machine	India, Pakistan

C- Operation: Quality control

Supplies for testing and quality control

Equipment category	Scale	Name of Equipment	Technical Description	Image
Temperature control	S-M	Thermometer general purpose	Made of stainless steel (0- 150 C), this thermometer comprises a mercury- filled, toughened bulb, with an anti-roll cap. Seven versions are available, differing in temperature range and graduation. Length: 30.5cm.	

Weight control	S-M	Add and weight scale	This measures the weight of foods. The add-and-weigh facility allows the continuous weighing of ingredients to be carried out in the same bowl. Measurements are carried out in 25g increments. Capacity: 3kg.	
Weight control	M	Portable platform scale	These scales weigh bulky/large materials such as sacks of flour. The equipment includes a cast-iron box, steel knife edges, and a platform-on- wheels. Weight of scales: 250kg. Dimensions: 40.6 x 63.7cm.	
Seed Moisture Content	S-M		Used for estimating the moisture content of the seed grain during drying and storage	
Steel Bins	S		Rodent-proof steel bins	

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