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Review

Factors Affecting Postharvest Losses of Sesame (*Sesamum indicum* L.) and Their Mitigation Strategies

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Abstract: Current postharvest activities in the sesame value chain are prompting colossal losses, which reduce overall global productivity. This review portrays losses in sesame during various processing stages, from grain harvesting to marketing and transformation of crop seed into oil. Such losses in sesame not only reduce yield but also have an impact on the economy of its production territories. The loss in productivity is because the majority of farmers don't use adequate harvesting, packaging, or handling technologies to manage on-farm produce. Also, there is a lack of knack for minimizing postharvest losses. Therefore, the study penlights the inevitability of increasing production by raising productivity and quality while giving mitigation strategies to reduce postharvest losses. Elevating standardized productivity with accurate postharvest management is the only substitute for the gap between the global productivity average and the overall production potential of sesame.

Keywords: sesame; postharvest losses; value chain; oilseed; Pedaliaceae

1. Introduction

Sesame (*Sesamum indicum* L.), aka the "queen of oil seeds", is one of the prehistoric oil seed crops belonging to the family Pedaliaceae [1,2] and is eminent because of its proficiency in high-quality polyunsaturated fatty acids. Some of its components, such as "sesamol" and "sesamolinol", are highly noteworthy as they prevent oxidative rancidity. These antioxidants not only reduce oxidation but also make it highly valuable in its medicinal characteristics [3]. The utilization of sesame is diversified as it's a part of the confectionery industry and is also used in local foods as a weaning item. Its seeds contain fats (50%) and proteins (25%) [2] and are a rich source of vitamin E and amino acids (pantothenic acid). Despite its vast peculiar nutritional characteristics, sesame has a great potential to swap with [4] other biodiesels [5]. There is also a hovering demand for its oil utilization in the

soap, carbon paper, and perfume industries. Its straw is a source of animal feed and mulch in its production terrains [6,7]. Sesame oil is a substitute for edible oils, in addition to its high demand in animal feeds (especially in areas deficient in other sources of animal feed), where its oilcake is used to enhance dairy production [3]. Despite its culinary uses, the seed meal of sesame can expurgate the demand for other feeds in the poultry Industry [8,9].

In most developing countries, sesame is a chief oil seed crop that is adapted to hot climates, mostly in Africa and slightly in some belts of south East to central Asia. The major production territories include China, India, Myanmar, Sudan, Ethiopia, Uganda, Nigeria, and the United Republic of Tanzania. However, its productivity is relatively higher in China, Myanmar, and India (1312, 543, and 341 kg/ha) than in other parts of the 3rd world [3]. Almost 82% of the world's export was from these countries in 2014 [10,11]. Sesame has gained the attention of growers from the 3rd world, especially in Sub-Saharan Africa, where it is a bigger export commodity after coffee. The share of African regimes in its export is almost 14% [3,12]. In 2017, sesame's share in global trade was more than USD 1300 million [13–15]. Statistics for 2018 depict a raising trend in tariffs and duties on import and export, which is also a gesture of its elevated demand [16].

Sub-Saharan African states are the home to sesame; however, these states continuously face challenges associated with sesame production, such as abrupt climate changes, conventional production technologies, fluctuations in domestic and international markets, research gaps, and poor postharvest activities, which are subsequently hitting developing economies. Among these, poor postharvest activities are a major threat to overall productivity and a significant cause of elevated postharvest losses (PHL) during the whole value chain [1]. There is less emphasis on alleviating postharvest losses in sesame, particularly in these regimes, where the bud of PH losses are meshed with some primitive postharvest levels, such as the inefficiency of extension services to build Knacks in handling, packaging, and storage; inadequate postharvest storage facilities or on-farm storage technologies; on-farm value addition; limited processing facilities, and inadequate market access that leads the produce toward spillage losses [3]. Therefore, the conservation of produce during postharvest activities and other necessary value chain processes will not only cut such losses but can also boost productivity and the global economy [17,18]. Therefore, the main objective of the study is to understand the factors that influence postharvest losses in sesame by analyzing the data from developing countries such as Africa and South East Asia and also to propose some mitigation strategies to overcome such losses at various value chain levels [19].

2. Factors Responsible for Postharvest Losses (PHL)

2.1. Farm Mechanization

The primary factor responsible for PHL in the whole value chain is the farmers themselves. They are involved in harvesting operations such as threshing and winnowing. Harvested sesame stalks are whipped on drums to isolate the capsules and then squashed in the mortar, which separates the chaff and the grain. Later on, the sesame grains are collected manually. Farmers hire labor occasionally to accomplish these tasks; however, a lack of proper mechanization during harvesting operations ultimately leads to PHL [20]. Figure 1 identifies the factors bringing chaos to the sesame value chain.

2.2. Transporters

The produce is further transported to processors without any other on-farm value addition. Hence, inadequate crop handling by transporters while loading or unloading the produce in cargo containers is also a major cause of preliminary quality and nutritional losses.

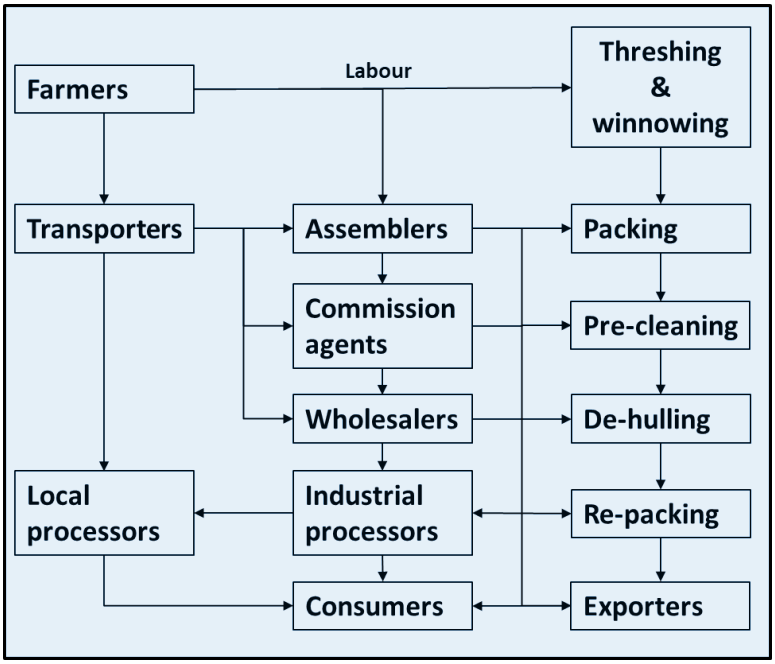


Figure 1. A flowchart showing factors responsible for the postharvest losses during the value chain process of sesame.

2.3. Assemblers

Assemblers contact farmers either at their residences or at local marketing stations to extend their business activities. Galadima and Isa [20] reported that assemblers purchase from a farmer during harvesting season and sell 98% of the produce to the retailers while the remaining 2% is for the ordinary domestic consumer (the weighing dimension "Mudu" is used, which is equal to 2 kg). Assemblers may sometimes perform minor packaging operations to sell the raw commodity [20].

2.4. Commission Agents

The third group along the sesame value chain is commission agents, who purchase an average of 29.3 tonnes of sesame per season either directly from farmers (14%) or assemblers (86%) [21,22].

2.5. Wholesalers

The fourth entity along the sesame value chain is bulk buyers who purchase an average of 162 tones per season from retailers and commission agents and sell further their produce to industrial processors and exporters after some value addition of re-bagging and de-hulling. Most wholesalers use polythene bags as packaging material. De-hulling is accomplished by hiring labor, which involves soaking sesame in lukewarm water for 5–6 h, proceeding with sun drying, winnowing, and milling with the help of mortar and pestle manually, as there is a complete lack of mechanization in most of the developing localities [20].

2.6. Processors

Usually, oil extraction is done by local processors, which involves the transformation of de-hulled sesame into oil and its by-product, sesame cake, which is utilized as animal feed. A considerable amount is wasted at milling sites while spreading sesame on mats, sometimes in poor storage facilities. At the same time, processing also threatens the quality of processing, which ultimately invites bacteria and hence reduces the export quality of the oil [23].

2.7. Labor

In most of the global terrains, approximately 67% of the sesame farmers hire labor, out of which only 12% use family labor and 22% use a combination of both families and hired labor [20]. Kailashkumar [24] reported the complete division of labor among the whole value chain, the maximum utilization of untrained labor is during harvesting (23%) and threshing (20%) operation, respectively. Unavailability of labor, lack of awareness, and poor management during harvesting operations trigger postharvest losses during the value chain process [24].

3. PHL in Sesame at Different Value Chain Stages

PHL is a term that identifies crop loss at its various value chain stages from harvest to the table [21,22]. There is an explicit estimation indicating that the global population will exceed 9 billion by 2050, with 2 billion uprises of more mouths to feed. If PHL has not culminated, farm productivity will need to increase by approximated 70%, which entails an investment of $83 billion each year to meet rising demand [21]. In developing regimes, a significant issue in food deficit is PHL at various value chain stages of the crop, a progressively alarming situation. It is predominantly severe in the 3rd world, where PHL cuts income by at least 15% for 470 million small farmers and downstream value chain processors. Also, there is anticipation that 1.2 billion people are food insecure globally; in such a case of food shortage panic, postharvest losses, and poor handling of farm produce count as major contributors. PHL consumes almost 1/4th of the global freshwater resources and 5th of farmland on unutilized farm produce [17]. Regardless of other valuable crops, sesame has particular significance among oil seeds. However, its postharvest losses range between 15–26% during harvesting, drying, threshing, cleaning, and storage, persistently a fireball on the global economy [21].

4. On-Farm Losses

4.1. Pre-Harvest Capsule Shattering

Dehiscence is a biological character in sesame's flowering array, which is responsible for most of the pre-harvest capsule shattering in the field, usually triggered by winds, birds, and rains, thus, reducing yield, ultimately. Besides this character, sesame has a determinant growth pattern, which is also a cause of most of the pre-harvest shattering. However, indehiscent cultivars less prone to shattering are also available [10]. In dehiscent cultivars, the harvesting operation is executed in two separate ways, which cause a grain loss of 13 and 2%, respectively, though partial dehiscent varieties showed a shattering loss of up to 3.8–31.7%. Yet, in the present perspective, these losses have been reduced up to 3.25–3.5%. In most 3rd world countries, there is no specific attention to cultivating non-dehiscent varieties [25].

4.2. During Harvesting

Losses occur at harvesting when all standing crop is cut and gathered in the form of piles, also called "hilla", in localities of Africa. As the crop matures, pod color patterns shift from brownish to yellow, and thus, the pod or capsule is shattered either due to over-maturity or pest attack. Sometimes, inadequate handling by farmers and laborers also becomes a factor of loss when some part of un-harvested sesame remains in the field. On account of these losses, [22] reported 55.38 kg per hectare loss of sesame, and these losses were relatively high in fields of small farmers (16.4%). On the other hand, harvested sesame stalks are left in the field and are not utilized by 53% of the farmers in most developing regions. Instead of utilizing straws as animal feed, there is a common practice of burning them to eliminate some major pests like sesame seed bug and its relative species; hence, nutritional losses occur as straw is also a good source of crude proteins (9.40%) [7].

4.3. PHL during Pile Stacking and Drying

At this stage, the harvested sesame is kept for drying, where most insect pests like termites, ants, and webworms attack and deteriorate the quality of the produce. It is estimated that the drying of harvested sesame is accomplished in 16 days, and during this period, almost 24 kg/ha of the produce is lost [21,26,27].

4.4. PHL during Transportation of Piles/Hilla

Related to the losses that occurred during the transportation of piles/hills from the place of cultivation to the place of threshing, the average distance reported is 15.2 m, while losses per hectare were 33.5 kg (approximately 9.92%) [26,27].

4.5. PHL during the Threshing

At this stage, grain is separated from sesame capsules or pods either with the help of manual beating on drums or with the aid of mechanical threshers; however, the use of mechanical threshers is low in the 3rd world, which increments the probability of grain loss. Another study revealed that approximately 0.834–1.01% of grain is lost at this stage, as shown in Table 1 [21,23].

Table 1. Crop loss at different value chain stages of sesame.

Losses at Different Value Chain Stages	Loss Per Hectare (kg)	Percentage Loss (%)	Responsible Factors
Pre-harvest losses	13.62	3.25	Shattering due to determinant/dehiscence nature of crop, wind, and pest
Losses due to un-harvested stalks/harvesting losses	55.38	16.4	Negligence of value chain actors
Losses during drying of hillas or piles	24.98	5.54	Over-drying, excessive grain maturity, and pest attack
Losses during threshing	4.0	1.01	Manual threshing, lack of extension services
Losses due to unthreshed capsules	0.68	0.15	Improper drying
Losses during cleaning	1.91	0.46	An inadequate or limited supply of packaging material, improper handling
Losses during transportation from farm to market	0.46	0.1	Improper packaging
Losses during storage	0.13	0.03	Improper storage facilities
Packaging losses at market centers	4.71	1.12	Negligence of value chain actors
Storage losses during export	0.105	0.02	Improper storage conditions
Other losses	——	——	Biotic and abiotic factors
Storage losses during milling/processing	——	——	Lack of knacks in handling the produce during milling, conventional milling practices
Total loss	calculated = 106.15 Reported = 55.56	calculated = 28.08 Reported = 12.67	

Source: [28].

4.6. PHL Due to Un-Threshed Capsules

If sesame capsules are not dried completely, it affects the grain extraction process during threshing, and an approximate amount of 2.74 kg/ha (11.56%) is lost at the threshing

sites. Improper threshing practices by the value chain actors, either farmers or laborers, contribute to such losses [21,29].

4.7. PHL during Cleaning Operations

During this phase, winnowing, packaging, and re-bagging operations are performed, and losses occur mainly due to underprivileged cleaning activities either by the actor or un-calibrated machines. Sometimes, the grain is lost because of the higher pressure of wind, and a limited supply of packaging material at this stage contributes to a 3.184% average grain loss [21]. However, some other sources reported 0.46% losses, as shown in Table 1 [30,31].

4.8. PHL during Storage

Desale et al. [22] reported an average of 6.73% losses taking place at various storage and warehouses in between the marketing and processing of sesame. Value chain actors use rented stores or their own. Meanwhile, lack of extension services, technical knowledge, and improper storage facilities are major causes of loss during storage at various value chain stages.

4.9. PHL during Milling

Currently, the sesame seed oil is extracted through conventional approaches involving pressing the grains in a mortar and the subsequent addition of hot water into the mortar, which causes the oil to float on the water's surface, where it is skimmed off. Conventional extraction approaches include cleaning, de-hulling, boiling/roasting, pounding, and oil extraction. Such a traditional extraction process harvests a meager yield of sesame oil and resultantly increases oil contents in by-products (sesame cake); thus, nutritional losses take place [32].

Table 2 describes the estimated postharvest losses in sesame during various operations, including harvesting, drying, transportation, threshing methods, and storage methods using different materials [23].

Table 2. Estimated loss through factors that adversely affect postharvest losses in sesame during various operations, including harvesting, drying, transportation, threshing methods, and storage methods using different materials.

Postharvest Operations		Estimated Losses (%)
Harvesting		
Harvesting Methodology	Machine	0
	Manually	100
Harvesting exceeding the limit of potential harvest	<One fifth	67.4
	One fourth	12.6
	One Third	9.3
	(1/2) of harvested seed	8.5
Time of Harvesting	September–October	7.0
	October–November	64.1
	November–December	28.9
Major Causes of Postharvest losses during harvesting	Birds	0.7
	Insects	7.4
	Other	1.9
	Possible Shattering due to late harvest	90
Field Drying		
Principal reasons for postharvest losses during drying	Contact with animals and rodents	13.4
	Insect pests	1.5
	Wind and Rainfall	34.8
	Drying for a long duration	50.4

Table 2. *Cont.*

Postharvest Operations		Estimated Losses (%)
Post-Harvest Losses at Field drying	(1/5th) of the grain	51.1
	(1/4th) of the grain	20.7
	(1/3rd) of the grain	15.6
	Half of the Grain	12.6
Drying Period	>20 days	6.3
	20 days	33.3
	15 days	51.9
	10 days	8.5
Location for Drying	Drying on cement or plastic sheets	4.4
	Drying of sesame bundles in the field	95.5
Transportation		
Factors of Postharvest losses during winnowing and threshing	Chaff during winnowing/cleaning seed left in the straw	52.4
	Incomplete Threshing	29.6
	Quality defects (soil, immature)	18.1
Postharvest losses at the threshing	(1/5th) of the grain	68.9
	(1/4th) of the grain	13.7
	(1/3rd) of the grain	9.6
	Half of the grain	7.8
Method of threshing	Manual	100
Transportation	Walking on plastic/canvas/woven sheets and carrying the bundle without wrapping	96.1
	Walking on plastic sheets/canvas while transporting/bundle wrapping with plastic sheets	3.9
Storage and storage materials		
Duration of storage	>7 month	3
	<1 month	51.5
	4–6 month	5.9
	1–3 month	39.6
Location of Storage	Specific storage for sesame	48.5
	Storage with other crops	51.5
Types of Storage	PICS bag/Grain Pro	4.1
	Gombisa/Gotera	3.3
	Polypropylene bags	92.6
Role of gender in preparation of storage place	Men	92.2
	Women	5.2
	Both	2.6
Transportation means to storage places	Vehicle	10.4
	Human Labor	21.5
	Donkey	68.1
Cleaning Practice	No cleaning	24.4
	Cleaning of storage places before storage	75.6

5. Factors Affecting PHL in the Value Chain

As the last lot has been sealed into storage, it is often practiced to forget about the maintenance of grain quality. Therefore, inadequate storage maintenance leads to grain deterioration and ultimately creates a mess of useless grain mass. PHL occurs mainly due to escalating malpractices during handling and storage. Accordingly, by boosting the efficiency of the overall management program, the chances of grain deterioration can be curtailed. The review portrays some factors which instigate PHL and are responsible for quality alterations during storage and other value chain processes (Figure 2).

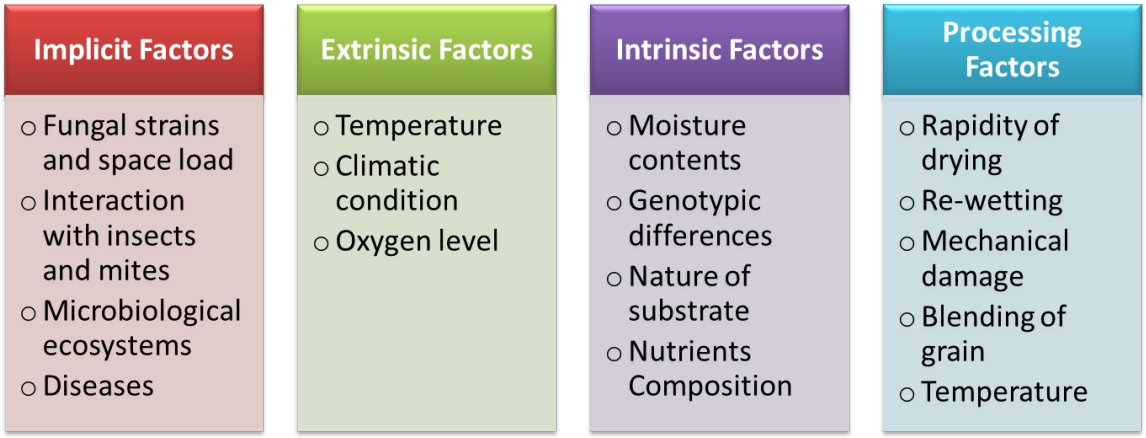


Figure 2. Integration of biotic and abiotic factors impacting postharvest losses of sesame.

5.1. PHL Due to Abiotic and Biotic Factors

5.1.1. Abiotic Factors

Moisture Content

The most critical factor responsible for maximum grain deterioration in sesame is moisture content [33]. It assists molds and other pest species to multiply at intermediate temperatures of 20–40 °C with a combination of below 70% humidity during the storage [34]. Contrarily, low moisture subsides the growth of mold and other storage pests. The hygroscopic tendency of the grain makes its maintenance more challenging to cope with the store humidity, which also becomes the cause of higher moisture content. Furthermore, the provision of all the aeration facilities and optimum management cannot save the grain in case of higher grain moisture [21]. Kumar and Kalita [35] reported that decreased moisture levels keep relative humidity below 70% and restrict mold growth. In normal conditions of moisture and temperature, a 1% reduction in seed moisture content or each 5 °C drop in temperature can double the storage life of sesame. The specific moisture level below which mold and microbial growth are restricted is termed safe moisture content. Safe moisture content for sesame seed is 6% or less; therefore, harvesting should be done at the utmost dry stage of the crop. However, the safe moisture content depends on storage time; if storage time is short, moisture above safe limits can be tolerated.

Store ventilation is another crucial factor that enhances the moisture level and is also responsible for the condensation of moisture during the night when the temperature is very low, as the walls of the store or warehouse are cooled below the dew point. The store's walls can acquire more condensation and increase the moisture under the layers of stored grains. Generally, moisture condensation occurs rapidly when grain temperatures are higher due to excessive drying (10–100 °C or above) [21], especially during cold weather conditions. After drying, as the grain begins to cool in the storage, condensation is quickened. Condensation on sidewalls and roofs is more common and can be minimized through proper ventilation. This fluctuating moisture condensation not only invites storage pests but also deteriorates the oil quality of stored grain. Here, it is also necessary to understand that stored grains are living entities continuously respiring while emitting huge quantities of moisture and temperature. Grain waste occurs at higher rates due to these fluctuating humid conditions as the multiplication of *aspergillus* species is high, which deteriorates the grains while producing aflatoxins. Simultaneously, oxidative stress due to the production of ROS stimulates rancidity and produces a stinky odor deteriorating the export quality of grain [21].

Temperature

High temperature affects the quality of sesame as it speeds up the oxidation processes [36], which ultimately leads to lipid peroxidation, thus reducing not only seed viability but also storability [21,37]. Solar heat is among the major cause of alleviating tem-

perature in the store. Sometimes, heat is generated by the grains due to oxidation processes or due to the presence of any insect. Therefore, it is necessary to control the temperature even in small stores and warehouses, which is not a convenient task, although it can be achievable through moisture content reduction. Grain temperature can also be reduced by passing forced air through the grains [21], otherwise moist grains and molds can respire at the same rate and may increase storage temperature simultaneously. Aeration can enhance the longevity of sesame grains 4 times as compared to non-aerated grains. Fluctuations in grain temperature can produce convection currents which assist the moisture content to move to the center of the storage or warehouse. In the spring season, moisture migration becomes a major threat to the spoilage of grain as kernels or grains depict a damp surface and sometimes form a crust. Moisture migration is elevated in heaps of storage as moisture movements are higher due to the vapor diffusion process [21]. Problems associated with moisture migration can be reduced by storing grains at −9 to −12 °C temperatures [21,38].

Other Factors

Some other factors have not been reported before; however, their role is evident as some of these factors are also the cause of PHL. These factors include storage, storage type, and time. Other factors that induce PHL include initial grain condition during different value chain stages, type or mode of storage or warehouse, weather conditions responsible for pre-harvest shattering, mode of transport, managerial handling knacks, and unavailability of extension services to the farmers [35,39].

(a) Storage Type and Storability

In most developing regions such as Africa and South Asia, grains are stored in locally constructed stores that use mud, straw, bamboo, and bricks material in their construction, and sometimes farmers store grains in bags and granaries [40,41]. Generally, grains are stored in bulk in these countries. Usually, mud bins, pots, straw structures, and plastic containers are used for storage purposes. Gunny or polythene bags are also used for short-term storage periods. Contrarily, steel and plastic silos are used for long-term storage periods. In western parts of Africa, conical structures containing jute bags, baskets, or raised platforms are used to store the grains. Sometimes farmers use cow dung ash in small bags, wood cribs, iron drums, or in metal silos for storing the grains. Nkokwe is a kind of traditional conical structure used in Kenya and Malawi. Almost all these structures are not scientifically designed and ruin the grain quality. They expose the grain to biological and environmental deterioration [35].

(b) Pre-Storage Grain Conditions

Further improvement in grain quality is not possible during storage; therefore, it is necessary to maintain the initial grain quality at the time of storage. It is recommended that only high-quality grains be allowed inside the storage or warehouse [42]. The following parameters are recommended to maintain the initial grain quality:

- Store old and new grain lots in seclusion and clean the entire storage site, including the walls and the roofs [43];
- Remove all the old grain lots and storage, harvesting, and handling equipment [43,44];
- After drying, it is necessary to cool the grain properly before entering the storage [45,46];
- Properly regulate the combine harvesters or threshers to shrink grain damage [47,48].

(c) Climate Change

Climate change is a neglected factor that has a severe impact on crop productivity [49], PHL [50], and value chains [51]. It affects the production and postharvest activities directly by ushering in variations in agro-climatic conditions (such as drought, extreme weather, and precipitation rates) and indirectly by up-surging new diseases and pests [52]. Additionally, the high albedo of the earth, with the combination of elevated levels of temperature and atmospheric carbon dioxide, is causing a loss in productive land and decreasing crop productivity [53]. Mycotoxins are hazardous chemicals produced by molds during elevated

relative humidity and temperature levels and affect sesame during storage and other value chain stages [54]. These mycotoxins are produced by mold species, in which aflatoxins are more notorious for deteriorating the product quality, as 30% of liver cancer occurs due to food containing aflatoxins/mycotoxins. Aflatoxins affect 4.5 billion people directly, as per reports by the Food and Agriculture Organization (FAO). Poor nutrition carrying vast amounts of aflatoxins leads to stunted growth and weak immunization in children. Meanwhile, aflatoxins are the major cause of the rejection of export consignments, resulting in billion-dollar losses [53]. All these losses are happening due to increased precipitation and humidity in formerly dry climates, and this broadening spread of toxins has a huge impact on changing climatic patterns.

(d) Managerial Factors

Lack of information due to poor extension services is another major influence accelerating PHL. Most of the developing countries in South Asia and Africa face challenges regarding the lack of information and technical skills. These managerial factors keep on growing when small farmers do not store and sell grains collectively. Another risky prospect is the unavailability of labor, needed equipment such as harvesting and threshing combines, packaging containers, cleaning, and cooling machinery. Lack of spare parts and maintenance by technical staff is at a negligible rate in the 3rd world, which is also an indirect cause of PHL. On the other hand role of governmental policies is evident, as some regions have a powerful impact on international as well as local markets [55].

5.1.2. Biotic Factors

Grain losses due to biotic agents such as microbes, insects, rodents, and birds are often higher when there is a lack of maintenance [26,56]. Several fungal pathogens attack sesame, and many are seed born, for example, *Alternaria dianthicola*, *Aspergillus flavus*, *A. ustus*, *Macrophomina phaseolina*, *Alternaria sesami*, *A. sesamicola*, *A. tenuis*, and *A. longissima.* Among these pathogens, *Alternaria sesami*, *A. sesamicola*, *A. tenuis*, and *A. longissima* were reported during storage in Korea [55]. Even so, *Penicillium citrinum* and *Fusarium* species were associated with sesame grains [55,57].In addition, bacteria also prevail the deterioration, though; as such, no bacterial specie is reported remarkably in the case of sesame.

Insects are another major threat to PHL; many species of Indian meal moth are found in sesame storage, contributing to 5–26% storage loss [58,59]. Other postharvest insect pests of sesame include *Sitophilus* spp., *Tribolium* spp., and *P. interpunctella (Hübner) (Lepidoptera: Pyralidae)*. Among these, *P. interpunctella* is economically very important as its larvae is an external feeder, and it uses a wide range of host diets, contrastingly 18% of weight loss is reported because of this specie. Studies conducted by Zenawi and Gebremichael [60] in Tigray and North Ethiopia depict a substantial grain loss of 25.2% during storage.

Insect/Pest

Another prominent reason for yield losses in sesame is pests/insects (Table 3). The Sesamum crop is badly influenced by the attack of capsule borer, leaf webber, and jassid. Therefore, the extremity of these insects becomes slight to severe, and estimated yield losses of about 2.56 and 3.90% were observed. Approximately 36% of farmers reported moderate attacks by capsule borer and sesame leaf webber, while 12% reported severe attacks [61].

Weeds

Another dilemma in sesamum production was weed intensity (Table 3). Madhana, Itsit, Bhakhra, Motha, and Grass were the weeds found in sesamum crops. Motha and Itsit are weeds responsible for yield losses of about 0.96% and 2.58% [61].

Diseases

Principal Diseases considered by farmers have been mentioned in Table 3. The major diseases that infected the sesamum crop were phyllody and blight. Therefore, the yield losses induced by these diseases were 2.84 and 0.90%. However, the severity of phyllody

was more than that of blight. Over 38% of farmers reported moderate, 16% severe, and 6% very severe phyllody [61].

Table 3. Estimated yield losses due to biotic factors.

Biotic Factors	Yield Loss %
Pest/Insects	
Sesame leaf webber and capsule borer (*Antigastra catalaunalis*)	2.56
Jassid (leafhopper)	3.90
Weeds	
Grass	0.12
Motha (*Cyperus rotundus*)	0.96
Bhakra (*Tribulus terrestris*)	0.14
Madhana (*Dactyloctenium aegyptium*)	0.46
Itsit (*Trianthema monogyna*)	2.58
Diseases	
Blight	2.84
Phyllody	0.90

Microorganisms

Mycotoxins, produced by many fungi, are likely to contaminate stored sesame seeds. Aflatoxin is one of the most important mycotoxins, produced primarily by *Aspergillus* species such as *A. parasiticus* and *A. flavus*, which contaminate plants and their products [62,63]. Four aflatoxins have been identified as being more prevalent in food, namely AFB1, B2, G1, and G2. AFB1 is the most vital metabolite of *Aspergillus* species because it is highly carcinogenic and has been classified as a group A1 carcinogen by the International Agency for Research on Cancer [64]. Over half of the world's population (four billion people), primarily in developing countries, is at risk of chronic exposure to unknown levels of aflatoxins, which has been linked to decreased growth rate and feeding efficiency, decreased liver and kidney function, and immune system suppression [65].

6. Mitigation Strategies to Overcome Post-Harvest Losses

A cohesive management system with an integrated approach is fundamental to alleviating the PHL. Despite this, it is vital to research crop biology and agronomic practices, including harvesting techniques, fungal ecology, and storage conditions, even during the marketing and transportation of sesame grain and oil. Several mitigation strategies have been developed; however, adaptation levels should consider on time during various value chain stages [66,67].

6.1. Pre-Harvest Mitigation Strategies

The following are the pre-harvest mitigation strategies:

- Special attention to the research and development of breeding new varieties should be given to avoid pre-harvest shattering and determinacy in crop behavior. New varieties with modern breeding technologies, viz. transgenic breeding, should be cultivated to avoid mycotoxin infestation, determinant behavior of crop, and spoilage during storage due to rapid rancidity. Simultaneously, old varieties or cultivars must be improved genetically to enhance storability [26,68];
- To avoid quality losses in the final product, it is necessary to choose certified and approved seed cultivars for sesame production [69];
- Proper harvesting should be accomplished at a proper time interval so that maximum shattering can be avoided to reduce PHL. Also, calibration and maintenance of harvesting machinery should be done; in this regard, modern mechanization techniques must

be adopted by the farmers of developing regimes to avoid losses during harvesting and other shattering losses during the piling up of sesame stalks [70];

- Pre-harvest mitigation strategies should also include education tutorials and rural awareness campaigns to educate farmers via modern postharvest technologies concerning packaging material, storage methods, Intercultural operations, mode of transportation, and Cargo services [71];
- A proper strategic plan to develop new and accessible markets is necessary, as well as the farming community must follow the packaging and marketing standards to meet the demands of the international community [67,72];
- Socio-economic surveys or analyses of sesame's value chain are necessary to understand the extent of PHL [73,74].

6.2. Post-Harvest Mitigation Strategies

Below are the post-harvesting mitigation strategies:

- The grain can attain moisture rapidly after harvest; therefore, it is necessary to initiate the drying procedure immediately after harvest. It is recommended that the harvested crop should be dried up to 7–8% moisture content without any further delay. Poor and slow drying increases mycotoxin concentration, and it is better to expose the product to rapid drying. Contrastingly, sun drying can cause fungal growth; therefore, it is efficient to use solar dryers instead, which provide a controlled sanitary environment [67,75];
- Biological and biochemical agents should be used to manage mycotoxins within the storage. In the case of sesame seeds, protectants must be used to avoid insects or other pests, including fungal pathogens [76];
- Postharvest campaigns that facilitate best practices of drying, fumigation, cleaning, and insect control should be conducted in farmer meetings, as well provision of the best packaging material should be made compulsory by the government body [67,77];
- Stringent mitigation strategies are required when rural development rates are slow, and there is a lack of improvement in storage or marketing infrastructures [67,78];
- Neme and Mohammed [67] reported some rigorous mitigation strategies, which are also listed in the Codex Alimentarius Commission (CAC, 2012) [79], particularly in case of mycotoxin contamination, that include dry, well-vented storage structures which can aerate grains properly through air circulation, as well as serve to lower temperature fluctuations;
- Subsidy programs should be pre-organized by the legislative bodies to better facilitate farmers, and there should be the provision of standardized transportation or processing equipment; also, cold or controlled storage conditions must be managed to overcome cargo losses [69,80–82];
- Modern packaging technologies like modified atmosphere packaging or oxygen scavengers must be adopted by the farmer community to overcome the exacerbating loss ratios [83,84].

7. Conclusions

In the global scenario, PHL proliferates almost across all the food value chain stages. There is an intense need of the hour to reduce PHL while promoting efficient resource utilization to secure the livelihood of farming communities. Furthermore, there is a need for increased investment by the public and private sectors to provide opportunities for the integration of PHL interventions to demonstrate value propositions. Consumer education is as necessary as for farmers. It includes purchasing skills, the importance of losses, and better product purchase, which also promote competition among sesame producers. Incentives are needed to develop public-sector and private-sector partnerships to reduce exacerbating PHL. In the case of developing countries, there is a gap between research and the end consumer that can only be reduced through better extension services. There is an

extensive range of priority areas for further research efforts regarding minimizing losses and conducting loss analysis studies.

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