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REVIEW

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Effects of environmental factors and storage periods on sesame seed quality and longevity

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Abstract

Sesame is one of the world's oldest oil seed crops grown mainly for its seeds. Lengthened storage time, inappropriate staking, back warded threshing method and poor storage facilities are major causes for postharvest and quality losses of sesame seed. Therefore, the objective was to review the effect of storage time and storage conditions on sesame seed quality and longevity. Seed quality and longevity are mostly governed by moisture content, temperature, humidity, storage period, pre-storage conditions, and pest infestations. Moisture content is a pre-requisite for long-term seed storage, and is the most important factor affecting seed longevity. Sesame seeds remain consistent and viable up to 12 months under appropriate storage facilities and conditions, otherwise it get lessened its viability. The crop should be harvested at the appropriate time and seeds should be stored at 6% or lower moisture content. In the tropics where temperature is as high as 33 °C and relative humidity of about 80%, seeds deteriorate rapidly. Varietal mixtures and harvest conditions affect longevity of seeds in storage. Pests such as, Mites, Indian mealy moth, Weevils, Flour beetles, are serious problems in stored sesame seeds. Under low seed moisture content and temperature, insects may not be a problem. Oil seeds require high-quality constructions to prevent leakages and to allow easy access to the bin for sampling and monitoring. Therefore, sesame seeds should be stored in well-constructed room/ware house to maintain seed viability and longevity.

Keywords Moisture content, Seed longevity, Sesame seed quality, Storage condition, Storage duration

Introduction

Sesame (*Sesamum indicum* L.) is one of the world's oldest oil seed crops grown mainly for its seeds that contain approximately 50 to 60% oil and 25% protein (Caliskan et al. 2004). Sesame seed is excellent source of quality oil which is close in quality to olive oil (Tunde-Akintunde and Akintunde 2007). Because of this excellent quality of the edible oil it produces, sesame is often called queen of the oil seed crops (Tunde-Akintunde et al. 2012a). Sesame has been known and used in Far East and Africa for more than 5,000 years (Borchani et al. 2010; Bedigian and Sesame 2010). The reported life zone for sesame is 11-35°C temperature, soil pH of 4.3 to 8.7 (Bedigian and Sesame 2010), Optimum temperatures for growing sesame is between 24 and 27 °C (Norman et al. 2017). Although, it is adapted to dry sites, sesame can also be produced in humid, tropical and sub-tropical regions (Naturland 2000). Sesame varieties have a wide spectrum of maturing (4 weeks to 6 months) and it requires only 500–650 mm of evenly distributed rainfall per annum (Bedigian and Sesame 2010). Sesame is well adapted to a wide range of soils, but requires deep, well-drained and fertile sandy loams (Geremew et al. 2012).

In the tropics 25% to 40% of stored agricultural products is lost because of inadequate storage facilities at different levels in each year (Hayma 2003). In Ethiopia post-harvest losses was estimated at 5% to 26% (Befikadu 2014). Lengthened storage time, inappropriate

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staking, traditional threshing method and poor storage facilities are some of the obstacles of sesame seed quality and quantity that farmers do not aware of. Post-harvest losses study in north Ethiopia revealed that about 13% loss of sesame occurred during drying, threshing, bagging and re-bagging (Kelali et al. 2014). Seeds of oil crops are susceptible to deterioration and can deteriorate even at 70% relative humidity. Oil crops cannot be stored for a long time and are described as poorly storable (Delouche 1973). Seed deterioration begins directly after a crop reached the physiological maturity stage. Therefore, in order to avoid both qualitative and quantitative losses due to several abiotic and biotic factors during storage, several methods such as seed treatment with suitable chemicals or plant products, as well as seed storage in safe containers are being adopted (Abdul-Baki and Anderson 1973; Oyekale et al. 2012). For every 1% moisture decline and for each 5°c decrease in temperature the storage period of seeds doubled (Harrington and Kozlowski 1972).Since sesame is a small flat seed, it is difficult to move much air through it in a storage bin (Oyekale et al. 2014); In addition, Oyekale*,* et al. *(*Oyekale et al. 2014) also reported that the seeds need to be harvested as dry as possible and stored at 6–7% moisture content. If the seed is too moist, it can quickly heat up and become rancid. Storage period and storage condition of sesame seed has no attention in our area. Most of sesame growers and traders in western Tigray store the sesame seeds in corrugated iron, which is much hotter (> 35 °C) than the ideal storage room which is < 25 °C (https://www.eagri50/GBR112/LEC30) required by small seeded crops like sesame. Therefore, the objective was to review the major factors associated with stored sesame seed longevity and seed quality.

Sesame seed nutritional value

Light colored seeds are considered to yield better quality oil than dark seeds (Akinoso et al. 2006; Kanu 2011; Kim et al. 2014; Tashiro et al. 1990; Were et al. 2006). On the other hand, Kim et al. (2014) reported that black seeded sesame recorded higher oil content, protein content, carbohydrate, minerals and vitamins than the white seeded sesame (Table 1). However, Yermanos et al. (1972) reported no association between seed colors and oil contents. According to Geremew et al. (2012) and many other findings (Table 1) the oil content of the sesame seed varies between 40 and 60% depending on verities and growing environments and their interactions. Authors added that the oil is rich source of energy providing 582 kilo calories and 884 kilo calories, and fat 53.4 gm and 49.1 gm for whole and hulled seeds, respectively. Anilakumar et al. (2010) identified also sesame seeds are rich in phosphorous, iron, magnesium, manganese, zinc and vitamin B1. Kanu (2011) also reported that white sesame seeds are rich of Iron, Zinc, Manganese, Copper, Potassium, Sodium, Calcium and Phosphorus.

Table 1 Oil content, protein, carbohydrate and ash contents of different sesame from different countries

Authors	Country	Oil content (%)	Protein (%)	Ash (%)	Carbohydrate (%)	Remark
Adegunwa et al. (2012)	Nigeria	49.5–53.1	15–18.9	4.9–5.3	18.2–20.2	White Sesame
Asghar and Majeed (2013)	Pakistan	49.5–53.9	18.96–22.55	3.67–5.1	NA	White Sesame
Anilakumar et al. (2010)	India	43.3–44.3	18.3–25.4	5.2–6.2	14	White Sesame
Bahkali et al. (1998)	Saudi Arabaia	47.02	25.18	6.54	16.77	White Sesame
Bahkali et al. (1998)	Saudi Arabaia	49.07	23.13	7.71	NA	Black Sesame
Borchani et al. (2010)	Tunisia	44–58	18–25	5	13.5	White Sesame
Khier et al. (2008)	Sudan	52.2	25.9	4.6	19.3	White Sesame
Geremew et al. (2012)	Ethiopia	40–56	22–25	3.5	11.1–23	White Sesame
Abou-Gharbia et al. (1997)	Egypt	55	20	16	NA	White Sesame
Kim et al. (2014)	Korea	45	29.8	7	17–20	White Sesame
Kim et al. (2014)	Korea	43.6	27.8	7.2	17–20	Black Sesame
Ünal and Yalçın (2008)	Turkey	54.2	21	4.4	NA	White Sesame
Hassan (2012)	Egypt	57.8–59.3	21.4–23.2	4.3–7	3.1–4	White Sesame
Nzikou et al. (2009)	Congo	48.5	20	4.2	7.78	White Sesame
Kanu (2011)	China	52.61	22.2	4.32	15	White Sesame
Kanu (2011)	China	48.4	20.82	6.1	17.1	Black Sesame
Tunde-Akintunde et al. (2012b)	Nigeria	42–54	22–25	4–7	20–25	White Sesame
Tunde-Akintunde and Akintunde (2004)	Nigeria	50–52	17–19	4–7	16–18	White Sesame
Uzun et al. (2008)	Turkey	41.3–62.7	20	NA	NA	White Sesame
Yusuf et al. (2008)	Nigeria	40.3	18.1	11.2	16.6	White Sesame

The most abundant fatty acids is oleic (~43%), linoleic (~35%), palmitic (~11%) and stearic (~7%) acids, which together comprised about 96% of the total fatty acids (Elleuch et al. 2007). Sesame seeds are especially rich in unsaturated fatty acid, oleic and linoleic acids, which comprises more than 80% fatty acids, while the saturated ones are (palmitic and stearic acids) comprises less than 20% (Gharby et al. 2017). The main mono-unsaturated fatty acid of sesame seed (oleic acid), comprises up to 50% fatty acids in the seed (Anilakumar et al. 2010). Oleic acid helps lower bad cholesterol and increases good cholesterol in the blood and valuable sources of dietary protein with fine quality amino acids (18%). In addition, sesame seeds contain many important compounds such as sesamol (3, 4-methylene-dioxyphenol), sesaminol, furyl-methanthiol, guajacol (2-methoxyphenol), phenylethanethiol and furaneol, vinylguacol, and decadienal. All these compounds help board off harmful free radicals from the human body (Bedigian 1985). Sesame is rich in natural antioxidants, which are both oil and water-soluble (Hwang 2005). These antioxidative compounds preserve the stability of sesame seed and oil. Murata et al. (2017) reported that (+)-Sesamin, (+)-sesamolin and (+)-sesaminol glucosides are the major lignans in sesame seed. Due to the high pharmacological interest of sesamin and sesamolin, several isolation and purification methods of lignans of sesame seeds, sesame meal, and sesame oil of *Sesamum indicum* have developed (Michailidis et al. 2019; Reshma et al. 2010; Jeon et al. 2016; Wang et al. 2009). Furthermore, Chen et al. (2005) also reported that the major compounds of sesame, called sesamin and sesamolin, have shown many pharmacological activities, such as antiproliferative, antihypertensive, anti-inflammatory, and anticarcinogenic effects.

Major factors associated with the seed quality and longevity

Factors associated with stored seed

Seed moisture content

Moisture content is a pre-requisite for long-term seed storage, and is the most important factor affecting longevity (Ellis et al. 1989). High seed moisture causes various problems. The relationship between seed moisture and longevity is depicted in Fig. 1. Under higher seed moisture content, the longevity of the seed is too short (3 months, under room condition) (Fig. 1). Seeds stored in polypropylene (PP) bag, polyethylene bag and gunny bags have showed fluctuations in moisture content when stored for more than six months, while hermetic storage structure kept the seed moisture constant for about a year with little fluctuations (Fig. 2). Moisture content levels of sesame seeds stored in jute bags and PP bags was increased linearly, whereas hermetic bags (Purdue

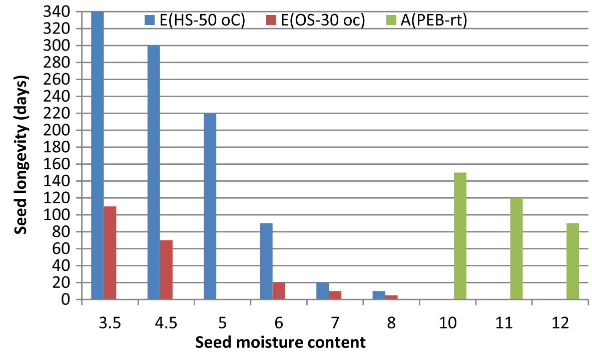
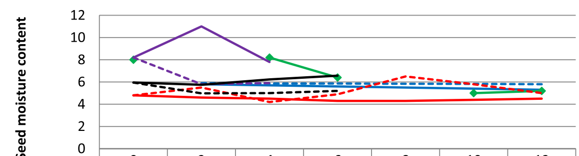


Fig. 1 Seed longevity under different levels of seed moisture content with higher and room temperature; E and A are authors, A = (Adebisi et al. 2008), E = (Ellis and Hong 2007) where, HS-50 oc = Hermetic storage under 50 °C temperature, OS-30 °C = open storage with 30 °C and PEB-rt = Polythene bags under room temperature



	0	2	4	6	8	10	12
K(PPB)		5.8	5.7	5.6	5.5	5.4	5.3
K(HS)		5.9	5.86	5.86	5.84	5.83	5.8
L(PEB)	8		8.2	6.4		5	5.2
C(HS)	4.8	4.6	4.5	4.3	4.3	4.4	4.5
C(PPB)	4.8	5.5	4.2	4.9	6.5	5.8	5
M(PPB)	8.2	11	7.8				
M(HS)	8.2	5.8	5.9				
T(PEB)	5.95	4.98	5	5.2			
T(GB)	5.95	5.75	6.23	6.57			

Storage Period (Month)

Fig. 2 Effect of storage period on moisture content(%) of sesame seed stored at room temperature; where K, L, C, M and T are Authors, K = (Neme et al. 2020), L = (Lima et al. 2014), C = (Cunha et al. 2015), M = (Muez 2017), T = (Awasthi and Thakur 2010) and the letters in parenthesis are storage structures, PPB = poly propylene bag, PEB = Polyethylene bag, HS = hermetic storage, GB = gunny bag

Improved Crop Storage, PICS and Super Grain Pro, SGP bags) were keeping constant the seed moisture contents throughout the 6 months of storage period (Alemayehu et al. 2023). Similarly, the conventional bags (jute and PP) exhibited highest increase in seed moisture content, while hermetically sealed PICS and SGP bags maintained a constant moisture content of sesame seeds (less than 7%) in the six storage months (Berhe et al. 2023). High moisture content increases the respiration rate of seeds, which in turn raises seed temperature and then seed longevity decline at a faster rate (Pammenter and Berjak 1999). According to McCormack (2004) in large-scale commercial seed storage, respiring seeds may generate enough heat to kill the seeds quickly, or to even start a fire if not dried sufficiently. The author added that small-scale growers are not likely to have such an extreme condition, but seed longevity will be affected.

Maintenance of seed moisture content during storage is mostly a function of relative humidity and, to some extent, of temperature (FAO 2018). Harrington (1972) stated that for each one percent increase in seed moisture, longevity decreases by half (between moisture ranges 5–13%). When moisture content is over 13%, fungi and increased heating due to respiration causes longevity declination at a faster rate (McCormack 2004). At moisture content of 18 to 20%, the respiration, and microorganisms cause rapid deterioration of the seeds (McCormack 2004). When moisture content is about 30% most seeds can germinate. Respiration and heating of seed is controlled by moisture content and respiration depletes reserved food, release and accumulates gasses that may affect viability of seeds in storage (Bakke and Noecker 1933). High levels of humidity can cause sesame to take on moisture again and go moldy; and hence, it should only be stored for a short period of time, or in airtight containers. Hence, if the critical 6% moisture content cannot be reached naturally by using sun drying; therefore, any appropriate artificial methods must be employed. This is for the reason that if moisture contents of sesame seeds is above 7% it can cause quality discounts (Hansen 2011). Therefore, for good storage longevity, sesame seed should be clean, low moisture content (6%) and a relative humidity of no more than 20 (Bennet 2011). Sesame seed tested after one year of storage in ambient temperature (18°c) has 92% and 66% of germination rates at 4.1% and 6% seed moisture contents, respectively. But, seeds tested after 4 years, germination percentage was 76% and < 10%, for 2.5% and 6% moisture contents, respectively (Chai JianFang et al. 1998). Generally, reducing sesame seed moisture content from 5 to 2% can increase longevity by about 40-fold (Ellis et al. 1986), however moisture content < 4% can result in extreme desiccation, causing damage to seeds (FAO 2018). This reiterates that low moisture content of the seed during the storage is the key factor for longer shelf life.

Varietal difference and seed handling before storage

Different varieties of a particular crop species may have different longevity when stored under the same conditions (Singh et al. 2016; Ellis et al. 1982). This might explain in enzyme activity differences, or differences in the chemical constituents of unique varieties. The storability of seed in a specific environment is largely determined by its inheritance and pre storage conditions (Delouche et al. 2016). Therefore, the differences should take into account in planning for storage. Timely harvesting, timely threshing, adequate drying, and careful handling minimize quality losses of the seed (FAO 2018; Delouche et al. 2016). Vigorous, high quality seed of most species stores surprisingly well even under relatively adverse conditions, while badly deteriorated seed stores poorly even though conditions are quite favorable (Delouche 1973; Delouche and Potts 1971). The most modern conditioned storage facility cannot really compensate for delayed or incautious harvesting, inadequate or improper drying, rough handling, and poor bulk storage (Delouche et al. 2016). The same author added that shelf life of sesame seeds varies 3 to 11 months according to varietal difference and storage conditions. Furthermore, Adebisi et al. (2008) and Stanwood (1987) reported a difference in seed vigor among sesame varieties under the same conditions. Harvest conditions may also affect longevity of seeds in storage. According to, Bewley and Black (1985) differences in harvest conditions are insignificant if storage conditions are good, but under adverse conditions, harvest differences can cause significant quality deterioration. Borgemeister et al. (1998) reported that the timing of harvest affects losses due to the possible development of fungi and the production of mycotoxins in most crops and in sesame too. Chemical seed treatment has been reported to be very effective in keeping seed quality of different crops, since it hampers the occurrence of fungi and storage pests. In addition to chemical seed treatment, organic materials of plant origin which are safer, cheaper and eco-friendly have gave due attention (Godlewska et al. 2021). Sesame seeds treated with neem leaf and pepper powder, under room temperature, maintained higher germination (89% and 82%), respectively after 18 weeks of storage time and the control recorded lower seed germination percentage (80.%) (Oyekale et al. 2012). Narayanan et al. (2019) reported that sesame seeds treated with Prosopis (*Prosopis juliflora*) leaf extract at 2%, Arappu (*Albizia amara*) leaf extract at 2%, Tamarind (*Tamarindus indica*) leaf extract at 2% and Pungam (*Pongamia pinnata*) leaf extract at 2%, gave good germination percentages compared to untreated one.

Seed mixtures problem

A given storage or a seed lot consists of a population of seeds, which might be physically and genetically similar, but might vary in level of longevity and deterioration from relatively non-deteriorated to entirely dead (Delouche and Baskin 2021). Therefore, Delouche et al. (2016) reported that deterioration within a given storage or lot is on an individual seed basis. Mechanical mixtures of different varieties seeds is specifically a problem on sesame production and storage (Ashri 1993). Sesame purity is disturbed from various sides such as adulteration or mixing of sesame with different sources of varying qualities and lack of transparency among chain actors (personal observation). Because there is lack of capacity to analyze quality characteristics such as oil content, percentage of admixture, fatty acid profile. And also, some traders and/or trailers mixing up low quality of sesame seeds with good quality for higher price purpose. Besides, diseases (blight) and insect pests (*P. interpunctella*) disturb seed purity. For instance Indian meal moth causes seed impurity through the contamination of dead larvae, frass and silk webbing and causing heating and molding of the seeds (Campos-Figueroa 2009; Gomes et al. 2015). Berhe et al. (2023) identified that *Corcyra cephalonica*, *Tribolium* spp. (*T. castaneum and T. confusum*), and *Rhyzopertha dominica* were most abundant stored sesame insect species and also their occurrence were more frequent in the tradition storage structures (PP and jute bugs) compared to the hermetic ones (PICS and SGP bags).

Environmental factors

Temperature

So as to minimize losses at storage it is crucial to know the optimum environmental conditions for storage of the product, as well as the conditions under which its attackers flourish (Hayma 2003). Pantry temperature has to be between 10 °C and 21 °C to prevent the seeds from going rancid [https://www.savorysuitcase.com/how-to-store-sesame-seeds/]. The stored products, as well as the organisms attacking stored products are living things and they use oxygen and give out carbon dioxide, water and heat. The rate of respiration, and thus the amount of carbon dioxide, water and heat that are produced is strongly dependent on the temperature and the moisture content of the seeds. Storage temperature had a profound effect on seed longevity as expected (Ramtekey et al. 2022). Sesame seeds having 9% moisture content stored at 4 °Ctemperature showed about 50% germination after five years, while the seeds stored at ambient temperature lost their ability to germinate within one year (Singh et al. 2016). Temperature and relative humidity have direct relationship with seed moisture content. Under higher seed moisture content, the longevity of the seed is too short (3 months, under room condition) (Fig. 3A) but, 9–18 months under lower temperature. The duration of seed longevity increases by one-fold when temperature reduced from 30 °C to 20 °C or from 20 °C to 10 °C (Fig. 3B). Furthermore, elaborated that reducing storage temperature from + 20 to − 20 °C can increase sesame seed longevity by roughly 40 fold (Ellis et al. 1986). According to Hayma (Hayma 2003) the rate of respiration is reduced approximately by 50% for each 10 °Creduction in temperature. Seed longevity increases as temperature decreases. When temperatures is between 0^{o-}50 °C, for each 5.6 °C decrease in temperature seed longevity doubled (Harrington 1972). The longevity of seeds is generally not affected by subfreezing temperatures/low if seed moisture content is less than 14%, because ice crystals do not form. A common rule of thumb is; the sum of the RH % and temperature in the storage environment could be less or equal to 100 (^{O}F + RH ≤ 100) for satisfactory seed storage (FAO 2018). Generally, the cooler and drier the surrounding environment is best for storage. It is very crucial to maintain temperature consistency along the stored seeds/sack rather than keeping a low temperature level.

Relative humidity

Commercial seed is usually packaged under conditions of ambient humidity. Because relative humidity has a significant effect on seed moisture content and it is important to understand the relationship between humidity and seed moisture. Higher relative humidity affects negatively the seed moisture content and longevity of the seeds as

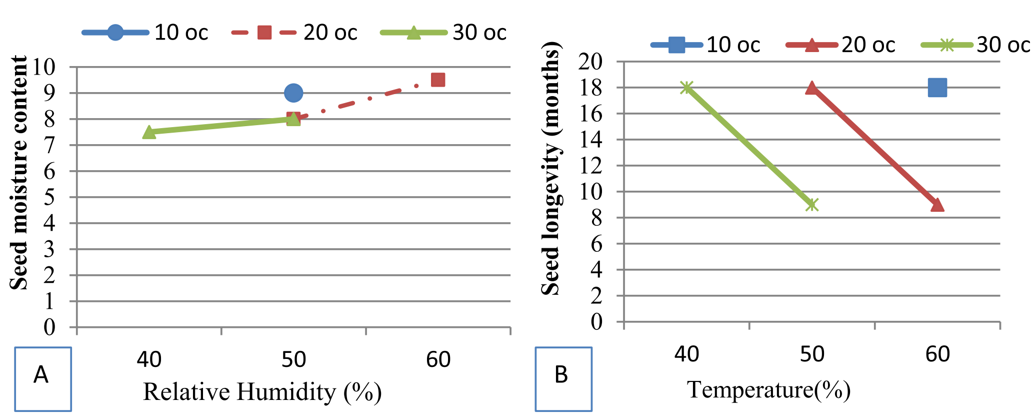


Fig. 3 Seed moisture content under different levels of relative humidity (A) and temperature (B) and seed longevity under different levels of relative humidity and temperature (Delouche et al. 2016, 1973)

well. The duration of seed longevity increases by one-fold when relative humidity reduced from 60 to 50% or from 50 to 40% (Fig. 3B). Regardless of the type of storage conditions, the moisture content of seed eventually comes into equilibrium with the moisture in the surrounding air. If relative humidity is above 70%, the moisture content of oilseeds may rise to about 13% dramatically (McCormack 2004), while relative humidity below 45% can keep optimum moisture content of the seed (<7%). Keeping the humidity level of storage below 50% is obligatory to avoid moisture absorption by the seeds, which can lead to spoilage [https://www.savorysuitcase.com/how-to-store-sesame-seeds/]. The majority of orthodox seeds lose viability quickly when the humidity approaches 80% at temperatures of 25°c to 30°c, but when stored at a relative humidity of 50% or less and temperature below 5°c, seeds will remain viable for at least 10 years (Copeland 1976). Deterioration of oil crop seeds was progressive with time. Reduced germination percentage observed for seeds stored at less than 8% moisture content and above 40% relative humidity after 6 months storage period (Vertucci and Roos 1990).

Insect and disease infestation

The process of seed harvest and cleaning removes most debris and insects, but certain fungi, bacteria, and insects make their way into stored seed. Bacteria do not have a significant role in seed deterioration because free water is required for bacterial growth, and if the moisture content of the seed is high enough to support bacteria, the seed is more likely to succumb to deterioration due to other causes such as fungi, respiration, heating.

Most of storage fungi are outgoing when the relative humidity is above 65%. Fungi may affect seeds through production of toxins and heat. Heat production (important in large seed lots) can cause seed discoloration, mustiness, and caking (Hayma 2003). When relative humidity reaches 70%, the moisture content of the seed has reached about 13%, the point at which increased respiration and fungi infestation become a problem. Mold growth is encouraged through moisture, damaging the seeds depending on the moisture content of the seeds (Hong and Ellis 1996). Mycotoxin levels in sesame stored in polypropylene (PP bags) and Jute bags were increased, whereas much lower in hermetic bags after six months storage period (Alemayehu et al. 2023). Except seed moisture is at least eight percent or below, fungi and insects such as weevils can breed causing rapid destruction of seeds in a short period of time. After six months of storage, conventional storage bags (jute and pp bags) had the highest larval counts (more than 60 insects per kilogram of sesame seed), while the hermetically sealed PICS and SGP bags had the lowest live insect count per kilogram of sesame seed (Berhe et al. 2023). In hot and humid condition, mites, weevils, flour beetles, and borers can be a serious problem in stored seed, but if the seed is dried to 6–8% moisture content and if temperature reduced to below 20 °c insects may not be a problem. Indian meal moth (*Plodia interpunctella*) and sesame seedbug (*Elasmolomus sordidus*) are the only reported major storage insect pest of sesame (particularly in Ethiopia) that causes higher seed loss (Muez et al. 2008; Zenawi 2017). As already indicated in Fig. 4 the Indian mealmoth start damages from three to six months storage period. In addition, the percentage of loss due to the insect ranges 5–14% (Fig. 5). At a moisture content of 15% and a temperature of 30–35 °C, insects become very destructive (Bewley and Black 1985). In the warm dry areas, *P. interpunctella* is major storage pest, which can cause about 12% seed loss under non-standard sesame storages in a year (Zenawi 2017), as storage time increased (to 18 months) seed damage by the insect increased also up to 25%. A study conducted in western zone of Tigray, on sesame seedbug (*E. sordidus*) found very huge weight loss (94%) of sesame seed (Muez et al. 2008), this happened under severe infestation of the insect.

Storage conditions and storage duration

Storage conditions and facilities

The requirements for oil seeds storage facilities differ little from those for cereals. Oil seeds are very sensitive to heating in storage and, therefore require better construction to exclude moisture. Ambient temperature and relative humidity in tropical countries exceed the levels even for short-term storages (Delouche et al. 2016). Sesame seeds are sensitive to storage conditions and should be stored in a cool and dry environment (temperature between 10 °C and 21 °C) to prevent the seeds from rancidity (https://www.savorysuitcase.com/

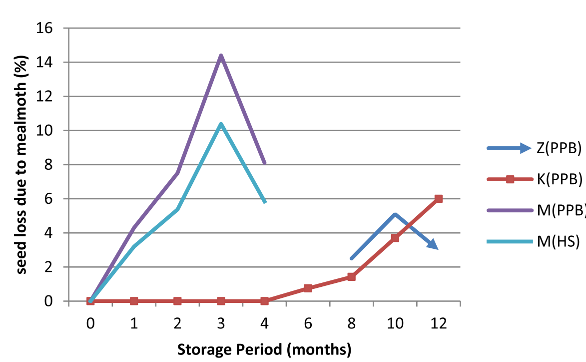
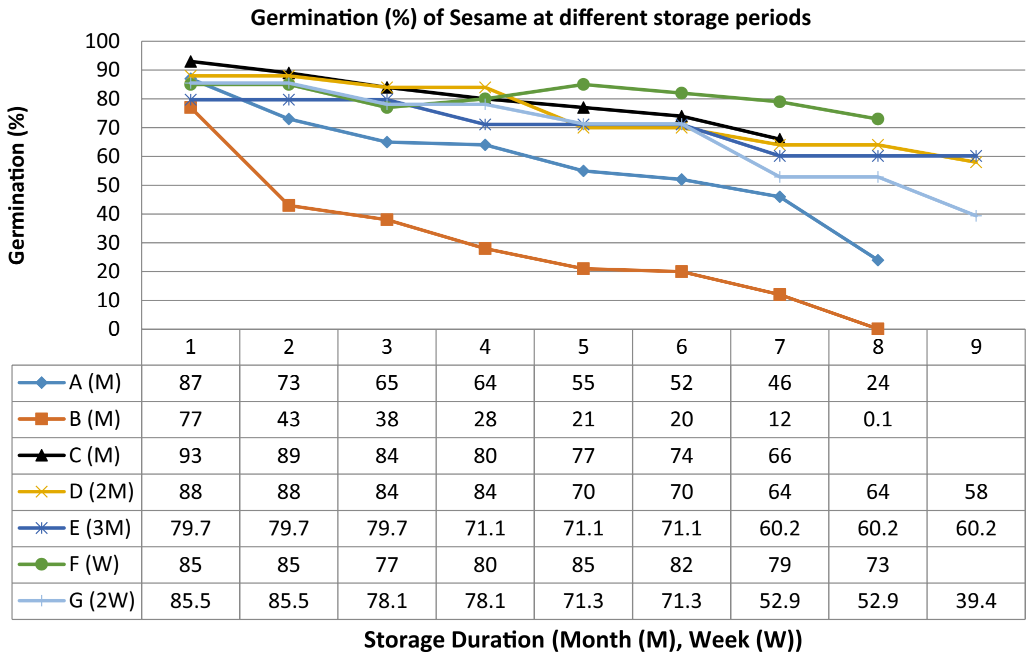


Fig. 4 Effect of storage time on webbing loss of sesame seeds due to Indian Meal moth under room temperature; Z, K, M are Authors, K=(Neme et al. 2020), Z=(Zenawi 2017), M=(Muez 2017), where PPB=poly propylene bag and HS=hermetic storage



	1	2	3	4	5	6	7	8	9
A (M)	87	73	65	64	55	52	46	24	
B (M)	77	43	38	28	21	20	12	0.1	
C (M)	93	89	84	80	77	74	66		
D (2M)	88	88	84	84	70	70	64	64	58
E (3M)	79.7	79.7	79.7	71.1	71.1	71.1	60.2	60.2	60.2
F (W)	85	85	77	80	85	82	79	73	
G (2W)	85.5	85.5	78.1	78.1	71.3	71.3	52.9	52.9	39.4

Fig. 5 Sesame seed germination (%) in different storage durations A,B,C,D,E,F and G are authors where: A (Adebisi et al. 2008) (Variety: 93A–97), B (Adebisi et al. 2008) (Variety: C-K-2), C (Narayanan et al. 2015), D (Cunha et al. 2015), E (Adam et al. 2018), F (Oyekale et al. 2012), G (Oyekale et al. 2014). (M) and (W) are storage durations in Months and Weeks respectively: M, 2 M, 3 M, W and 2W: stands for germination after every month, 2 months, 3 months, every week and every two weeks respectively

how-to-store-sesame-seeds/). For the small size and free flowing characteristics of oil seeds requires high-quality construction to prevent leakage (Mayko 2016). As mentioned in this reference roof and door openings, joints between structural components (roof to wall, wall to floor), and even bolt holes must be sealed carefully to avoid losses.

Earthen pots and gourds, jute sacks, plastic bags, metal silos and metal drums are among the different storage materials for oil crops (Hayma 2003; Groote et al. 2013). Metal silos are relatively expensive to farmers regardless of its effectiveness and farmers are reluctant to use it (Kimenju and Groote 2010). Furthermore, (Groote et al. 2013; Abass et al. 2018; Chigoverah et al. 2016) reported that polypropylene bags are commonly used by farmers to store their grain in sub-Saharan Africa. Although these authors reported that these bags generally fail to protect grain from postharvest losses. This bag is a common packaging material for sesame staying stored for about a year in Ethiopia and Sudan. On the other hand, (Odjo et al. 2020; Ndegwa et al. 2016; Quellhorst et al. 2018; Tefera et al. 2011) reported that hermetic technologies like Perdue Improved Crop Storage (PICS) bags are crucial in reducing postharvest losses in many crops. The PICS bag is relatively better than polypropylene (pp) bags, sisal sacks and polyethylene lined polypropylene bags for sesame storage with germination rate of 93% after stored for 12 months (HuARC 2019). Hermetic storage technologies (PICS and SGP bags) effectively control moisture and temperature of sesame seeds, thereby maintain the quality of seeds during a six month storage (Berhe et al. 2023). Temperature levels of sesame seeds stored in jute bags and PP bags was higher, whereas in the hermetic bags (PICS and SGP bags) was lower throughout the 6 months of storage period (Alemayehu et al. 2023). Regardless of the construction material used, storage structures must be as weather proof as possible, yet still allow easy access to the bin for sampling and monitoring. The weather proofing process must include the floors of bins set on grade. Concrete floors may resist the movement of water through the slab, but moisture can still enter the bin in the form of vapor. For this reason, a vapor barrier such as polyethylene should place between the concrete and the gravel base.

Duration of storage

Seeds of oil crops are vulnerable to deterioration and they cannot be stored for a long time and are described as poor storable commodity (Delouche 1973). Seed deterioration causes reduced seed quality, viability, vigor and finally seed death. Ranganathan et al. (2023) explains that seed deterioration can cause cellular damages, and result in delayed seedling emergence, reduced ability to withstand stresses, and ultimately loss of viability.

Germination percentages was decreasing under longer seed storage periods, because longer periods of storage denatures the protein content, reduce enzyme activity and carbohydrate contents of seeds (Boakye Boadu and Siaw 2019). In sesame storage, consideration should be given to the initial quality of the variety in question; because better initial quality may likely guarantee longer storability and longevity of the seed. Ethiopian' sesame producers that put their seed in storage was ranged from 1 to 18 months; in which most farmers (about 73%) store their seed up to3 months, about 18% store their sesame seed up to six months and the remaining 9% store 10 to 18 months (Muez and Fettien 2014). Seed longevity is highly explained as a factor of storage length, moisture content, temperature, storage type, variety, environment and the interactions. As storage duration extends, seed quality declines due to exposure to challenging external factors and therefore deterioration of physio-chemical situation of the seed reduces its viability and might kill the seed. Sesame seed moisture content increased linearly and reached 9.2 per cent in 10 months storage period under natural condition (Kavitha et al. 2017). The increase in moisture content of the seeds might be directly related to the relative humidity of the storage environment. As storage period and temperature increased, the quality of sesame seed oil affect negatively due to acidity and peroxide increments (Rababah et al. 2017). The sesame seed longevity is highly affected by temperature and moisture content; the seed with 3.5–6% moisture content can stay viable 3–9 months in hermetic storage having 50 °C, 1–3 months in open storage under 30 °C and seeds having 10% moisture content can stay as long as 9 months under room temperature condition (Fig. 5). Combination of low seed moisture content and low storage temperature is actually the ideal condition for seed storage. Regardless of the storage type and organic chemical treatment the mean germination percentage decreased from 91 to 65% after stored for 10 months (Narayanan et al. 2019). Adam et al. (2018) also reported that the longevity of sesame is highly affected as the storage duration increased irrespective of the storage type, variety, environment and the interactions. Many authors also reported that the germination of sesame seeds decreases as the storage duration increased (Fig. 5). Good quality seed of the oil crops can be stored satisfactorily up to 9 months under 30 °Cand 50% relative humidity; up to 18 months under 20 °Cand 50% relative humidity (Delouche et al. 1973). The quality of stored sesame seed depends upon the environment, genotype and their interaction and at about 8 months after storage. There was a sharp decline in seed viability to less than 25%, irrespective of storage location and variety (Adebisi 2010). Sesame seeds stored in jute and PP bags scored low germination percentages (bellow 50%) in contrast, the germination percentages of sesame seeds stored in the hermetically sealed PICS and SGP bags remained constant (about 90%) after 6 months of storage (Berhe et al. 2023). Such sharp decline in seed viability after a given storage period might be due to adverse storage conditions of the humid tropics (Adebisi 1999; Adebisi and Ajala 2000). Sesame seed shelf life as told by Geremew et al. (2012) is about 12 month under standard storage condition. The seed longevity can determine by moisture content, humidity and temperature; as many researchers witnessed that one percent increase in moisture content, longevity diminished by half. In crop seeds like sesame, deterioration is even faster immediately after harvest, because of its high oil content and rapid cellular respiration occurring (Oyekale et al. 2014). In the tropics where the temperature can be as high as 33 °Cand relative humidity of about 80%, seeds deteriorate rapidly (McCormack 2004). Specifically, sub-orthodox seeds/oilseeds deteriorate even at 70% relative humidity since they require lower moisture content than other grains. Storage period greatly influenced deterioration of seeds during storage in the tropics and sub-tropics (Islam et al. 2017). Seed deterioration starts soon after a crop has attained the physiological maturity stage. Hence, so as to avoid the quantitative and qualitative losses because of several abiotic and biotic factors during storage, different methods are being developed such as seed treatment with suitable chemicals or plant products, and seed storage in safe containers (Abdul-Baki and Anderson 1973). Therefore, sesame seeds need to be stored in dry cool rooms to lengthen its shelf life.

Conclusion

Seed loss, including quantity and quality losses can occur at different steps from harvesting to final consumption or next cropping period. It may be caused because of physical damage due to insects, rodents or birds damage or physiological damage like development of fungus and others. It is very important that seeds stored in any storage material or packaging material should be capable of producing plants when sown in the field having high viability at the start of storage and maintain it during storage. Sesame seed quality and longevity is mostly governed by moisture content, temperature, humidity, storage period, pre-storage condition, pest infestation, purity and lack storage facilities. Moisture content is a pre-requisite for long-term seed storage, and is the most important factor affecting seed longevity. Seed longevity increases as temperature and humidity decreases. Sesame seeds remain consistent and viable for 6 months up to 12 months. In the tropics where temperature is as high as 33 °C and relative humidity of about 80%, seeds deteriorate rapidly. Varietal mixtures and harvest conditions can affect longevity of seeds in storage. Pests such as, mites, weevils, flour beetles, and moths can be a serious problem in stored seed. However, if the seed dried to 6–8% moisture content and temperature reduced to below 20 °c insects may not be a problem. The requirements for oil seeds storage differ little from cereals. Oil seeds require good quality construction to prevent leakage. Storage structures must be waterproof and should allow easy access to the bin for sampling and monitoring.

Abbreviations

HuARC	Humera Agricultural Research Center
TARI	Tigray Agricultural Institute
PP	Polypropylene bag
PICS	Purdue Improved Crop Storage
SGP	Super Grain Pro bag

Author contributions

ZG has intiated and write the draft, FB revised and arrange its structure and DF has mad second and third revisions made some improvements.

Availability of data and materials

We declare that whatever data have been used in the manuscript will be kept remain intact. These data can be made available to anyone who desires to see it from the corresponding author on request.

Declarations

Ethics approval and consent to participate

It is to declare that we have all the ethical approval and consent to take participate in research paper writing and submission to any relevant journal from our organization where we are working and mailed.

Consent for publication

It is declared that the information given in the manuscript now can be published by the Publication House and Journal of "Agriculture and Food Security".

Competing interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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