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Postharvesting Techniques and Maintenance of Seed Quality

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Abstract

Healthy seeds and grains are the demanding enterprise of the recent era for the production of high yield in the next season. The seeds must be stored for the maintenance of high-yielding crop. During storage, major losses of seeds are caused by various biological and nonbiological factors. There is a need to examine reasonable factors of these crop losses, which ultimately affect the market value and quality of the seed. The quality of seeds can be maintained by using careful postharvest handling techniques. There is need to establish the well-suited methods to assess the losses during the process and to use the best technique to minimize the loss and to ensure the quality and safety of the crop. The target is to achieve the high-quality seeds of the national and international standards that could meet the demand of the supplier. This chapter emphasizes on the aspects and postharvest techniques that are used to maintain seed quality. A comprehensive review of the better, economical, convenient, and productive methods is provided, focused on the needs of developing countries but also with relevance in more industrialized countries.

Keywords: crop maintenance, handling techniques, storage losses, postharvest

1. Introduction

Seed industry survives for the sake of better quality of seeds and postharvest storage techniques. It is a seed quality program that seeks the high achievement and gives the quality assurance. Seed quality is one of the most demanding enterprises of present days. The majority of the seeds especially cereals and legumes by small-scale farmers are produced and stored on the farms.

The major problem is the damage due to biological factors such as molds, and insects can be alleviated by implicating effective storage techniques [1–4]. It is the foremost priority of the farmers to prevent the crop losses and storage of seeds/grains. Farmers often purchase the new seeds/grains from the market to produce the next crop for higher yield due to the risk of crop loss. There is a need to develop the effective strategies for seed storage that can give the confirmation of better crop yield and reduce the risks of storage losses [5].

1.1. Valuable seeds: achieving seed quality

The value of the seeds allows the farmers to produce high-yielding crops from good quality healthy seeds. Seed quality is the measure of the potential to produce desired quality, healthy, and high-yielding crops at low planting rates [5]. Seed quality can neither be obtained automatically nor by a permanent process. There is nature's pressure against the quality of the seeds. Efforts are being made to produce best quality seeds for the farmers. Any handling or production stage can reduce the quality of the seed. To alleviate these losses, careful technical management is required for all seed operations [6].

1.2. Principles of seed storage

Seeds when stored in natural environment or ambient temperature respond readily to temperature, available oxygen, and relative humidity. Metabolic activities, age, and longevity of seeds can be manipulating by controlling the humidity temperature and oxygen [7]. Reduction of seed moisture content up to an appropriate limit is prerequisite for storage as seed could be damaged because of desiccation. Seeds can be stored for a longer period due to lower level of humidity. According to the thumb rule, the life of the seed doubles by decreasing the moisture content to 1% in case if seed moisture content is between 5 and 14%. Higher moisture content is more affected by higher temperature so seeds need to be stored in cool location. The life of the seed doubles by decreasing the temperature to 5°C and is applicable between 0 and 50°C [8].

Oxygen level can be controlled by hermetic storage in a sealed container which reduces the physiological aging of the grains as well as reduces the physical damage due to insects and fungal growth [8].

2. Postharvest techniques of seed storage

2.1. Drying

Physiological maturity attained by the cereal and legumes at moisture content between 35 and 45% is crop dependent. Temperature affects the storage of seeds at moisture content between 10 and 14%. For high-quality yield of crops, timely harvesting and drying are necessary. Biologically active seeds deteriorate readily under most of the circumstances due to fungal contamination and attack of insects and other pests. The main purpose of drying is to reduce the respiration in seeds [6, 9]. The process also impedes qualitative damage due to fungi and

other insect pests. Drying can itself affect the quality of the seeds. Extensive drying under very high temperature can damage the seed. In summer season, simple drying methods are used through exposure to sun and adequate wind. The alternative drying methods have been devised for high-yielding varieties and improved farming practices and irrigation to deal with increased production or harvesting in wet season in multi-cropping [10, 11].

2.2. Sun drying

Sun drying of seeds is the drying method in the tropical developing countries. The method is employed when crop is ready for the harvest. Some seeds like maize can be sun dried although during drying, crops get sensitive to insect infestation, rodent or birds' attack, and mold damage. A threshed seed drying by spreading on sheets or tray is a common phenomenon but has a risk of soil or stone contamination. For example, paddy at rice mills is at large quantity [6]. Rice is dried on especially build drying floor that allow easy run off of rain water. The seeds are dispersed in thin layer and turned at regular intervals to facilitate drying and covered at night with the help of sheets. There are some disadvantages of the process that temperature is an uncontrollable factor. In paddy rice, high temperature can cause stress or cracks in the seeds which lead to high level of damage during milling. Yield can be contaminated by dust, atmospheric contamination or insect infestation, or human or animal disturbance [6, 9].

2.3. Solar drying

It is the modification of sun drying in which sun rays are collected in an especially designed unit for air removal in adequate ventilation system. The unit has 20–30° higher temperature than open drying, and less time is consumed in the process [12]. In solar dryers, solar collector is used to heat air which then allowed to pass to the seed beds. It comprises two basic designs: natural convection dryers use thermal gradients and forced convection dryers force the air through solar collectors and seed layers. These dryers are suitable for farm use. The former design of the Asian Institute of Technology in Bangkok has been used as blueprint for several convection dryers and comprises a drying bin, a solar chimney, and a solar collector [13]. The solar collector consists of black polythene sheet or layer of burnt paddy husk; it is covered with clear polythene sheet. Perforated platform presents in drying bin. The disadvantages of the process are as follows: high structural profile, stability problem in windy condition, and the need of replacement of polythene sheets at regular intervals [6].

2.3.1. Mechanical dryers

The same principle of drying is used by mechanical dryers as forced convection solar dryer; the dryer forced the air through the seed bed and the air is heated with the help of a flat plate instead of conventional means. In modern automated storage system, drying takes place at one of the two points either in prestorage dryers (prior to loading seeds in freestanding loading) or in store dryer (after loading in final storage compartment) [9]. In prestorage dryers, ambient air is used in continuous flow dryers, and heat is generated by thermostatically controlled furnace which is powered by electricity, diesel, or gas. Heat may be supplied by

direct or indirect way. Indirect way is preferred due to the separate outlet for the combustion product not through seeds. In the batch dryers, seeds are fed into properly defined batches, whereas in continuous flow dryers, the grains are flowed into the system and recovered at desired moisture content [6].

2.3.2. Tray dryers

Tray dryers are batch dryers of flat beds. The seeds are dispersed on the mesh tray at the depth of 600–700 mm, and warm dried air is passed through seeds to sufficiently dry them [6, 14].

2.4. Radial drying bin

Radial drying bin comprises two vertical metal mesh cylinders, one inside the other. Seeds are loaded between these two cylinders, and air is blown to the inner cylinder and passed from the inner to the outer mesh cylinder. By reversing air through seeds, air can be sucked from the central cylinder. However, there is the risk of overdrying of seeds in the inner cylinder which are in direct contact with the hot air. Air is wetter and cooler at the leaving side toward outside [6].

2.5. Continuous flow dryers

Moisture content of the seeds can be removed by sucking or blowing hot air by top-to-bottom passage through the system. Bin is present at the top of the drying section with cooling system at the base. Seed beds can be horizontal, vertical, or inclined. Seeds are moved by conveyors, scrapers, vibration, or gravity. The degree of drying depends upon the speed, size, and rate of flow of outlet conveyor of the dryer. Continuous flow dryer is varied by relative direction of air stream and seed flow [15]. Several continuous flow dry techniques are described below.

2.5.1. Cross flow

The seed passes through the two perforated sheets downward to the column by allowing horizontal passage of air through the seeds. The advantage of the dryer is that the moisture gradient can be defined at any stage of drying seeds [6].

2.5.2. Counterflow

A round bin is used to unload seeds with the upward flow of air. Little evaporative cooling takes place when hottest air passes through the driest seeds.

2.5.3. Concurrent flow

In concurrent flow, wettest seeds are exposed to the hottest air during passage of air through seed bed. High temperature improves the efficiency of the dryer and cools the seeds by moisture evaporation [6, 16–18].

2.5.4. *Cross flow*

Cross-flow dryers have been used widely in recent years, but mixed-flow dryers have advantages over cross-flow dryers. Mixed flow dryers, combination of concurrent, counter and cross flow dryers has great advantage of efficient fuel consumption. But reduction in output because of uneven flow of seeds leading to uneven drying is one biggest hindrance in adaption of mixed flow drying [6].

2.5.5. *Tower (mixed flow)*

They consist of tall rectangular bins for storage, and triangular ducts are present along the width of the dryer at horizontal position. Half of the ducts are used for induction of warm air and removal of damped and cooled air is done by remaining ducts. It has multiple directions of seed flow and air flow [16–18].

2.5.6. *Louvered bed dryer*

The seeds are passed through different types of batches; the hot air is blown to the seeds to dry them. The dryers work on the principle of cross-flow dryer. The speech and depth of the drying beds depends upon the degree of drying. The two basic designs of the dryers are conveyor dryer and cascade dryer. The cascade dryers are gravity fed cross-flow dryers. The seed depth is controlled by roller dams and speed is controlled by output elevators. There can be incorporated changes to vary the length of the dryer. In conveyor dryer, air is blown to seeds through inclined louvered bed and the seed flow is controlled by variable speed, roller chain conveyor and heavy duty. These dryer can be one directional, two directional, or multidirectional; the variation in direction assists in removal of waste material and reduction in size of the dryer [6].

3. In store drying

This is an alternative method of drying in which seeds are load into bulks floor storage or in bin and then they are dried in stores [19].

3.1. Bulk on floor storage

They consist of especially strengthened wall which can bear the weight of seeds. The seeds are loaded in uniform depth. At one side of the building, fan is present for the aeration purpose and the plenum chamber runs along the center of the store or walls with perforated lateral ducts, below or above the floor level under the bulk of seeds [6].

3.2. In bin drying

This type of drying comprises one or more bins for drying purpose and other bins for storage. The dryers reduce the chance of physical damage due to the lesser handling. The shallow layer

of seed along the bins for drying reduces time consumption and makes the process safer. The semi-dried batches free the space for incoming seeds and consist of lateral ventilated system or ventilated floors about 0.5 m above the base [6, 20].

3.3. Bag dryers

The drying in bags is difficult because there is not proper insurance of passage of air through the seeds. In sack platform dryers air is blown through the floor of air duct whereas in fan blowers heated air is blown from the floor apertures and sacks are placed on them. Larger bags are stacked in the center of tunnel in moisture extraction unit. Through the air ducts, hot air is blown with the help of a fan. One must be careful of correct dimension to avoid uneven drying. However this system is not appropriate for even drying of seeds because of short circuit over certain areas. [6].

4. Storage losses

It is reported that a total of 30% crop losses take place due to harvest. However, this is the “worst case” figure to cite for the crops in priority area of development. Storage losses cannot be predicted before harvest. There can be many biological, climate, handling, harvesting, storage, and distribution and social and cultural factors which can cause crop losses. By careful handling, 50% postharvest and storage losses can be disseminated. There is no such method to predict the exact figures of such losses. Efforts have been made to determine the reliable baseline methods to figure out crop loss activities. A methodology has been made to estimate the standardized postharvest losses by crop activities [21]. Loss assessment and loss reduction programs have been prompted by the Food and Agricultural Organization (FAO) of the United Nations. The focus of these programs was to obviate the reduction of crop losses of staple foods. The methodology for assessment of seed loss during harvest was summarized [22], although there was no universal method to assess storage losses. Sampling procedures, varied handling and storage produce, and irregular movement of batches make the loss assessment phenomena non-generalized especially for perishable commodities. Care should be taken in designing a methodology with positive aims to make it acceptable, economical, and meaningful. The methods are varied for perishable commodities due to their different nature whereas relatively uniform for cereal seeds. To find out standard moisture content and dry matter, the weight loss of undamaged and damaged seeds can be compared. The purpose of storage is to avoid both biological and financial losses of yield. To obviate these losses, we must have known the root causes of these deprivations [9].

4.1. Loss and damage

The term damage and loss can be confusing sometimes when used synonymously. Loss is defined as the measurable qualitative or quantitative decline in foodstuff. Superficial deprivation of commodities is defined as the damage, in which physical spoilage results in loss of commodity. Damaged commodity can either be used but loss is a permanent decline. [6, 7].

4.2. Categories of storage loss

Categories of qualitative or quantitative storage loss have economic impacts. Physical weight or volume loss which is considered as quantitative loss can be figured out readily. Quality losses can be measured by the simple judgment of commodity and comparing with standard quality items. Commodities can be rejected by changes in taste, texture, appearance, loss of nutritional value, and the presence of contaminants. The following categories can be listed to demonstrate the storage losses of crops [23].

The primary cause of losses directly affects the stored crops. They may be biological, chemical, or biochemical in nature.

4.3. Biological losses

Biological factors responsible for crop deprivation are rodents, insects, birds and microbes (fungi and bacteria). Microbes grow on the crops and cause the weight loss, crop spoilage, and other defects which reduce the market demand of the yield. Development of infestation can make trouble if produce is stored for longer period. The damage or loss caused during storage in the cereal seeds by birds, rodents, and the condition can be harsher by microbial (fungi and bacteria) attack in the field. There will be quality loss, if the disease is superficial; it can be quantitative loss if infections penetrate into deeper layers of seeds. In case of superficial disease, it is possible to remove damaged area and use the rest of the portion [14, 24, 25]. *Chemical losses* involve loss of flavor, color, texture, and nutritional value due to pesticides and chemical reactions [26]. *Biochemical losses* can be softening, discoloration, and bad flavor due to enzyme-activated reactions. *Mechanical losses* are due to bruising, breakage, processing, and injury during handling or harvesting. *Physical losses* are related to climate condition such as low or high temperature, improper storage atmosphere, and high humidity. Physical factors can also mediate chemical and biochemical losses [7]. *Physiological losses* involve weight losses due to respiratory heat loss. Susceptibility of infection and damage by pathogen increases during wilting, senescence, ripening, and wilting. Microbiological and biological factors are important in seed, whereas mechanical, physiological, and microbial factors cause losses in perishable crops. The factors that encourage primary crop losses are secondary losses by inappropriate handling of equipment, technology, and control. The factors are lack of harvesting equipment, skills, packaging, handling, adequate containers, appropriate transport, drying and storage conditions, proper processing technique, and adequate management [6, 9].

4.4. Weight loss

Weight loss is not necessarily the sign of loss of crops. Reduction in moisture content can be a reason of weight loss. Shrinkage factor is a tool to recognize for commercial transactions. Moisture loss can lead to economic loss if it is not taken into account by grading for price control. Weight loss can be due to feeding of birds, insects, rodents, and microorganisms. Weight loss can be measured by comparing the weight before and after storage in the sack. There can be also an increase in moisture content due to water production in seed by insect infestation and can lead to an increase in weight. If insect infestation increase the moisture

content of seed or insect may consume seed, leaving behind dust, weight loss cannot be detected easily [27]. To detect these losses, a useful mass of infested and noninfested seeds is ground into flour, and their weight is compared. A decrease in flour yield of infested mass than sound mass will be observed. Be aware of malpractices to compensate weight loss by adulteration of stones, earth, or sand and water. So there is a need to assess not only moisture changes but also the quantity of foreign matter present in the yield [23, 28].

4.5. Quality loss

Quality is an important trait considered by the consumers, and local traders have different criteria for assessment according to circumstances. Biochemical factors (acidity, sugars, flavor, and smell) involve size, shape, and appearance. Quality loss can also be due to contamination and foreign matter (insect fragments, rodent hair, excreta, weed seeds, earth, glass, stones, and parts of plants) content. Contaminants that are difficult to remove comprise soluble excretion of insects, pesticides, oils, toxins produced from fungal infections, and pathogenic organisms spread by rodents. Loss potential will be increased by raising the standard rules by consumers [24, 29].

4.6. Nutritional loss

The loss depends upon the qualitative and quantitative loss of nutritional value to the human population which affects the nutritional status of that population. This is mainly caused by feeding of pest on selective part of seed. *Plodia* and *Ephestia* feed selectively on the seed embryo and remove the vitamin and protein content. Many pests feed on bran of cereal seeds as a result reduced vitamin content. *Liposcelis* spp. selectively feeds on bran of rice and embryo (Pike, 1994). Weevil is an endosperm feeder and declines the carbohydrate content [6, 30].

4.7. Loss of seed viability

The loss of seed viability is linked with. The reasons of the losses may be temperature, excessive respiration, moisture content, infestation, light, and infestation-controlling methods. Insects that are selective to attack the embryo cause great losses in germination as compared to others. Seed loss can be detected by standard germination tests [31].

4.8. Commercial losses

Commercial losses are either due to direct consequences (foregoing factors) or indirect consequences (cost of preventive action or equipment). There may be a loss of goodwill, monetary loss, and loss caused by legal action. Intercountry trade might be affected by commercial loss. Losses can be rapidly reduced by experience and knowledge. Postharvest losses not necessarily take place due to inappropriate storage. There may be biological, physical, or mechanical factors in deterioration of cereal seeds. There is a need to broaden the intervention techniques to deliver high-quality product from the field to the market. For

example, after the Tanzania outbreak of pest in the maize crop, Somalia and Malawi refused to take the maize due to insect spreading [32].

4.9. Temperature-dependent injury

High-temperature solar radiation on exposure deteriorates the fresh commodities rapidly. By increase of temperature, respiration also increases; there should be proper ventilation and cooling of the crops to obviate the problem. In similar way, there can be crop injury due to low temperature between 0 and -2°C . However some crops of tropical and subtropical origin showed tolerance for chilling injuries at $12\text{--}14^{\circ}\text{C}$. Chilling injuries (skin pitting, discoloration, uneven or abnormal ripening, and sensitivity to rapid deterioration) are apparent when commodity is removed from the environment [7, 29].

5. Assessment of losses

5.1. Assessment of seed losses in storage

The agents causing seed loss during storage are insects, rodents, and molds. In past this issue gained attention of many scientist but still there is a need to find some more effective technique to avoid seed loss due to insects. Insects can cause both qualitative and quantitative loss by boring or feeding on seeds; weight loss has got more attention [6].

5.2. Weight losses caused by insects

The assessment is made through collection of samples of seed and various intervals after storage and comparing the samples to observe the changes in subsequent samples. Assessing quantity loss with subsequent samples at different intervals will be used to estimate storage losses at different occasions. Sample collection from each batch of seed and their quantity loss are estimated accordingly. Sample should be collected without disturbing the pattern of infestation in the bulk stores. Three samples must be collected when subsequent regular sampling is not possible: first, at time of storage; next, in the midway of storage period; and last, at the final few weeks of seed storage.

The pattern of used seed and quantity loss is noted [22, 27].

5.3. Methods of estimation of weight loss

There are two methods used for estimation of weight loss by the insects, when subsequent sampling is possible: volumetric method and thousand grain mass (TGM) method.

In this case, when subsequent sampling is impossible, count and weight and converted percentage methods are used [6].

5.4. Volumetric method

Volumetric method is commonly known as the standard volume weight (SVW) or bulk density method. This is used to measure the bulk density of clean sample by the use of equipment. SVW is figured out from the sample of the seeds at the beginning of the storage period, and losses are determined. This method strictly calculates the weight loss by grain boring of insects and moisture difference over a subsequent time period in standard volume container. In standard volumetric method to determine accurate ratio for moisture content and dry weight of seed, moisture can be taken as constant term and the crop as dry matter. However, volume and frictional characters can also be affected by changes in moisture content. There is direct relation between moisture content and volume of the sample therefore seed should be packed loosely. To make the moisture constant, it is necessary to calculate the standard volume of dry matter at different moisture contents. The process is time-consuming and needs care and equipped laboratory [33]. Another factor affect the volume of sample is weight of insecticidal dust, adheres to the seed surface increase the volume of seed and frictional character. Sieving can be a useful phenomenon to remove dust. However, volumetric phenomena are less helpful due to overassessment of losses [6, 34].

5.5. Thousand grain mass method

This method differs from volumetric method in comparison with fixed number of seeds instead of fixed volume. This means that weight of seeds is multiplied by thousand and corrected by a dry matter. It is calculated by weighing and counting the seeds in a given sample. Standard reading is made by taking measurement at the beginning of storage of seeds, and then subsequent readings are compared with baseline reading [35].

5.6. Count and weight method

The method, sometimes called gravimetric method, is applied where the baseline readings of seed storage are not obtained in the start of the season. A sample of 1000 seeds and minimal medium are used in this estimation. Weight and number of seeds in each sample fraction is determined after isolation of damaged seeds. The results are then calculated by putting the values in the following equation:

$$\frac{(U \times N_d) - (D \times N_a)}{U (N_d + N_a)} \times 100 = \% \text{ weight loss} \quad (1)$$

where U = weight of undamaged seeds, D = weight of damaged seeds, N_a = number of undamaged seeds, and N_d = number of damaged seeds.

In this method, moisture content of the separate fraction is unnecessary for a single sample, and differences of assumption are likely small. The method does consider hidden infestation in damaged category, and it considers seed infestation that is random by the insect which is not necessarily to be true [36]. The method can cause misleading results for low level of

infestation and multiple infestations in large seeds. The method is useful in field level for quick estimation at extremes. To overcome the biased estimation, several refinements have been made. For example, different-sized seeds have different moisture contents and can have hidden infestation. These seeds are graded according to size and categories before counting and weighing [22]; severely attacked grains are separated, and reading of hidden grains is taken after emergence of infestation [37, 38]. There is another way to know the hidden infestation by dissecting seeds, but the method is tedious and has a chance of change in moisture content of seeds, for the sake of calculations that are needed to be made on dry matter.

5.7. A count and weight method modification

In this modification of count and weight method, highly infected grains have also been taken into account. To avoid the underestimation of losses, the number of infected seeds is counted for sum of the seeds in whole sample [39]. To assess the weight loss, the following equation is used:

$$\frac{[TND(D + U)] + FW(N_d U - N_a D)}{[TND(D + U)U] + [FW(N_d + N_a)U]} \times 100 \quad (2)$$

where U is the weight of undamaged seeds, D is the weight of damaged seeds, N_a is the number of undamaged seeds, and N_d is the number of damaged seeds.

The weight loss is calculated by averaging weight loss of two subsamples.

The percentage weight loss is calculated by deviation in Eq. (3):

$$\frac{\text{Undamaged weight (UW)} - \text{final weight (FW)}}{\text{Undamaged weight (UW)}} \times 100 \quad (3)$$

The undamaged weight of the sample (in the absence of missing seeds) is figured out by applying assumption in count and weight method. The average unit weight of undamaged grains in the original sample will be equal to the average unit weight in the remaining undamaged grain subsamples. The undamaged weight of the whole original grain sample is figured out as the product of the total number of seed estimated in the original sample and unit weight of undamaged seeds in the subsamples. The total number of seeds is the sum of the damaged and undamaged seeds. The final step will be the ratio of the final sample weight to the average unit weight of the seeds. The method focuses on missing seeds of the sample instead of underestimating lost samples as in conventional count and weight method [39].

5.8. The converted percentage damage method

The method is suitable for quick estimation of loss by boring insects without using equipment such as during a rapid field appraisal. Weight loss is assessed by taking percentage damage

seed as sample. A study has been made to find out the relationship of damage and weight loss [23]. A conversion factor can be used subsequently to estimate the weight loss of same type to seeds in different samples. The conversion factor is calculated by the following formula by using same count and weight method and so faces same type of errors:

$$\frac{\% \text{ damage seeds}}{\% \text{ weight loss}} = \text{Conversion factor} \quad (4)$$

To overcome the error of count and weight method, 10% or more damaged sample seeds are used. The sample size should not be smaller than 500 seeds taken as the percentage of the total seeds present. Rapid loss technique is a rapid weight loss assessment in the field based on the damage and weight loss relationship. Standard graphs are used in this technique to relate percentage damage and weight loss of samples under study [6, 21]. For preparing reference graph, ten samples of 500 seeds are required in the laboratory. Weight loss is estimated by count and weight method, and percentage damage is calculated. The graph is plotted between percentage weight loss and percentage damage. In the field, clean sample of 200 seeds is gathered, percentage damage seed is determined, and loss figure of reference to graph is read off. For a sample of 200 seeds of Bambara or cowpeas, the technique depicts accuracy on $\pm 7\%$. The method is better than percentage damage method and allows good assessment of weight loss by taking many individual samples in short time period at the field. Visual scales are rapid loss assessment methods. The abovementioned techniques are time-consuming and need appropriate equipment and well-trained technicians. Visual scale has benefit in assessing damage in fields, is ideal for field use and rapidity, and is required only for reference scales and operator unbiased. This technique enables wider coverage in small time and small sample error. On-site loss assessment avoids extra spoilage and anomalous results by double checking on the site before leaving. The visual scale should be calibrated according to the objective of the study, weight loss, and farmer perception of value [6, 21].

5.9. Losses by vertebrate pests

Vertebrate pests such as rodents and birds remove the whole seed from the sample so it is impossible to estimate loss by vertebrate pests. The loss can be assessed by comparing the reference percentage of seed loss and average seed weight [40]. Population studies and feeding trials are used to calculate the losses by pests and rodents, but these are often with small accuracy in comparison to efforts expanded [41]. Pests used stored grains only as their part of diet; feeding trial can overestimate the loss of stored seeds. The quantity of seed loss by rodents is questionable. Loss of crops due to rodents goes behind when compared with loss of storage container, personal property, buildings, and potential health risks.

5.10. Weight loss by molds

Seeds infected by molds will cause weight loss; the weight loss can be assessed by the same method that is used to calculate weight loss by insect. The moldy seed weight loss increased

due to the absorption of moisture so the loss by mold can be compensated. The method is not that good to assess the real loss of seeds, and the seeds may be misled as undamaged seeds due to no apparent indication of infestation on surface. To estimate the weight loss due to mold, damaged seeds are separated from undamaged seeds, and then moldy seeds are discriminated from damaged seeds. The weight loss due to mold will be equal to the weight of mold [21, 27].

5.11. Total loss in a season

The above losses are the seed losses at a given point in a time. The picture can be misleading; there must be a relation in the pattern of seed used in a season. In an undisturbed stored crop, if the sample loss is 10% throughout the storage seasons, the total loss will be due to insects. The seeds will loss at different quantities at different intervals of time due to insect exposure at different time lengths throughout the season [27]. The percentage loss of seeds increases gradually with time due to increase in insect infestation. After permitting changes in moisture content, the loss in seeds can be calculated by measuring the weight of seeds at the time when the seeds are still in the store and when taken out from the store. The loss other than insect damage can be obtained by subtracting the loss caused by other insects. The overall losses of the seed after store are considerably lower than the suggested value. Many loss assessment protocols at commercial and farm level have been reported [22]. The key to get the best assessment result is to draw an acceptable methodology for each commodity.

There were small figures for losses in commercial operations and none for cooperative level storage. The condition reflects the buying and selling of seeds in the developing world in short time period. This gives the picture of private sector (market liberation and parastatal marketing) involvement, but there is few information about storage loss. Entrepreneurs could store large quantity of seed for longer time period. However private sector has increased this level for farm storage. Many efforts, time and money was invested to measure the storage losses in farm storage, but the effort was not fruitful like the earlier projects. Moreover, the study should be undertaken with the postharvest sector as a whole, and precise measurements should be avoided. Social survey can be helpful to discover the farmers' problem for loss assessment and appropriate measurement techniques [42].

6. Harvesting and maturity indices

Harvesting and improper handling of commodities can cause bruises and injuries which directly affect their market value and make them unattractive. Injuries give the open space for microbial attack, that cause rotting, respiration increase, and shortage of storage life. Improper harvesting can cause crop loss and severe damage in seeds [9, 43].

6.1. Harvesting and handling

Harvesting is the first step of postharvest and is the last step of crop production. The method and condition of the harvest affect the further handling, processing, and storage of crops. Premature harvest causes loss of quality of seeds, and due to high water content, they will deteriorate in the store. Overmature crop harvest causes biological and physical losses of crops by consistent wetting and drying of crops [9]. Damp seeds need to be threshed quickly and dried after harvest. Different parts of plant are harvested by different harvesting methods; in case of forage, the whole plant is trimmed off; in case of cereal seeds, partial or part of the plant is threshed and cleaned; and straw or chaff is removed for further processing. Small scale produces performed threshing and harvesting by threshing combines harvesters (equipped through community groups) while in developing countries threshing and harvesting carried out by hand unlikely cause damage or deterioration of crops in store. Large-scale commercial producers use mechanical harvester equipment; their use is limited due to the production of cash crops. Post-harvest risk of crop damage in storage is reduces by manual harvesting Small scale produces performed threshing and harvesting by threshing combines [9, 21]. Conventionally, seeds are beaten with stick or against hard surface (wooden bar, log of wood, stone, and wooden metal or tub) for the sake of threshing. The methods can cause damage or cracks on the seeds, while seeds that are trodden under foot will be a less damaging method for the seeds. Grain heads or ears of sorghum, millet, or wheat are commonly beaten with sticks. However, manual harvesting is laborious, and economical process has the risk of physical damage. Maize cobs are beaten with sticks or shelled by hand, which result in high-level damage. Mechanized threshers are made to reduce the damage of seeds; the models are highly sophisticated.

Seed harvesting is carried out by a combination of various steps of threshing, cleaning, or combine harvester. Large-scale harvesting is carried out by mechanical equipment that is especially designed to harvest cereal seeds [6].

6.2. Storage structures for seeds

Seeds/grains are durable crops that usually require simple systems in their storage.

6.3. Farm-level storage

For protective outdoor or indoor storage, the seeds must be guarded for physical damage such as high temperature, adverse weather, snow and rain, and biological factors which include microorganisms, birds, rodent, mites, and insects. The process of farm storage is used by various countries to store major part of seeds [44, 45]. The storage structure varies in capacity and has range of 100 kg to few metric tons. Modifications in locally prepared storage structure could be done according to climatic conditions. There are some traditional storage structure. The bins are commonly made of ferro-cement, plywood, metal, and high-density and high-molecular-weight polyethylene. Plywood is the most suitable storage structure and underground structures of different shapes and sizes, which work on the principle of hermetic storage. This builds the higher level of carbon dioxide and low oxygen level which is lethal to

pest and microbial attack during seed storage [46]. Traditional methods are cheaper, but they are not effective against pest and microbial attack. Silos or metal bins are also used at farm level to store seeds.

6.4. Bagged storage

In developing countries, seeds are stored in gunny or woven polypropylene bags in traditional warehouses, whereas silos for bulk storage, seeds elevator, and flat storage structure are used in developed countries [45, 47]. Bag storage is a laborious and costly process and has greater chance of seed spillage and biological losses. There may be water seepage and humidity problem due to inappropriate flooring of warehouses. Bags do not need any fumigation facilities or aeration system. In developing countries, the system will be uneconomical due to small farm size and cheaper manual labor.

6.5. Bulk storage

There are two types of bulk storage of seeds; it may be vertical (silos or bins) or horizontal (on floor stores). Horizontal stores comprise especially constructed floors of warehouses containing proper ventilation on the floor and walls that are strengthened to withstand the weight of the seeds. Bins and silos are especially designed stores, either round or square, in grouped or freestanding form, and incorporating unloading and loading usually of aeration systems. The alternative forms of bulk storage are belowground or partially belowground storage or enameled, sealed silos, for the storage of high moisture content seeds. The process is appropriate to bulk handling or storage of seeds [48, 49].

6.6. Hermetic storage

The traditional methods of storage in the natural build of oxygen and lower level of oxygen protect the seeds from biological damage. This traditional storage method is not effective for the seeds that have lesser moisture content, and infestation is less than insects per kilograms of seeds. The controlled atmosphere treatment and fumigation have to be supplemented in hermetic storage [50].

6.7. Outdoor storage

This is the temporary measure of storage in case of lack of permanent storage. The godowns and silos are built on plinth, and the stacks of seeds are covered with polyethylene covers. The stacks must be properly aerated in a week by raising the cover to the seventh or eighth layer. The cover and plinth (CAP) technique is used commonly for wheat and paddy. However, there is a chance of damage of cover by wind or rain, and effective fumigation cannot be achieved [44].

6.8. Storage practices for quality seeds

Quality of seeds can be maintained by especially designing the small stores to silo or warehouses which play a protective role against adverse temperature conditions, ground water, rain water, pests, and thefts. The structure and contents of the store should be managed [9].

7. Moisture control

A water disposal system and well-designed roof are required (overhung or gutter) to hinder the water running to the store. Drains move the water away from the stores. In large warehouses, side by side joining of stores should be avoided to prevent the water run into the store. Raised floor and proper drainage system protect against the risk of the flood, and water-proof floors and walls guard against ground water. There must be proper ventilation system to control the humidity inside the storage structure [27].

7.1. Protection against temperature

It is difficult to control temperature in the storage structures; it needs special design elements to control temperature. Temperature can be ascertained by the use of controlled ventilation. In the cold night, temperature can be manipulated by insulated stores. Stores can be built in east-west direction, and using shiny material outside the stores can be an effective strategy to control heat. Thick wall and wide roofs (for shade) can further reduce the heat of the storage structure. Heater and refrigerators can be installed to modify temperature in stores; the equipment will perform well in case of insulated stores. However in these stores, degree of insulation depends upon atmospheric condition outside of it. [6, 51].

8. Modified atmosphere storage (MAS) and controlled atmosphere storage (CAS)

In modified atmospheric condition, the gases are added or removed from surrounding to make a controlled atmospheric composition around seeds, which differs from air (78.08% nitrogen, 20.95% oxygen, and 0.03% carbon dioxide). This includes the reduction of oxygen and elevation of carbon dioxide concentration. CAS and MAS are different in level of control although CAS is more exact. The process is used to facilitate whole-store fumigation [52, 53].

8.1. Protection against theft

Security guard or fence may be needed to guard the store. Lights are installed to illuminate the stores [6].

8.2. Protection from birds and rodents

Bird and rodent contact can be hindered by avoiding the free spaces for the access to the seeds. Rodent guards are commonly tight-fitting shelves, or conventional methods could be tying of thorn bushes to the stores as barrier. Walls of the stores should be smooth, and roof should be rodent proof to avoid their contact inside the storage structure [54].

8.3. Protection against insect

The small size insects can easily enters the storage buildings therefore it is difficult to make insect-proof walls and roofs because they can enter from even small cracks. For protection against insects, smooth walls, controlled ventilation, cleaned stores, floor without cracks, and curved floor wall can be effective. For protection against termites, termite-resistant material should be used (concrete, stones, fire bricks, and termite-resistant wood) [55].

9. Transport

The transport of commodities from field to storage houses can produce some injury, which can later cause deterioration of produce. This main focus is to keep the produce dry and moisture-free. The risk of insect infestation of seeds from the contaminated container has insect residual. Mechanical injury is produced from vibration during transport, poor condition of vehicle and roads, poor driving, insecure container stacking, the use of unsuitable container, and careless handling. Overheating is produced from the sun or vehicle engine that results in moisture loss of produce, and this leads to natural breakdown and decay [6].

10. Quality and safety

The quality of a product defines the class, degree, excellence, or superiority of the crop. The quality of the durable commodity is the combination of characteristics, properties, and attributes that give the commodity value as the food or a source of next crop yield. Foreign material or high moisture content can affect the marketing quality of the crop. High moisture may encourage the shrinkage or biological and biochemical damage in seeds. Low moisture in pulses and paddy rice can break or damage the seeds. The discolored and broken seeds lower the marketing quality and increase the chance to insects and microorganism attack [14, 27]. The main objective of a farmer is to produce apparently good product with few visual defects, and product must score high on yield, disease resistance, ease of harvest, and shipping quality and achieve the national and international quality standards. For the buyer or consumer, the appearance is more important; they are eagerly concerned in healthy seed and lifelong storage. The product should be assured safe for the distribution to suppliers and market [7].

11. Postharvest quality assessment techniques

There are two methods to assess the quality of crop after harvest such as analytical or objective and subjective or sensory method [56]. There are limitations for subjective method in quality evaluation of hazardous material [57]. Objective method is destructive or nondestructive in nature. Manual sorting of commodities is outdated, costly, unreliable, subjective, laborious, and slow. Food depicts complex and dynamic behavior with respect to varietal and time dependency. Nondestructive methods classified according to physical principles are visual inspection, x-ray imaging and computed tomography, near-infrared spectroscopy, ultrasonic testing, thermographic testing, electromagnetic testing, liquid penetrant testing, magnetic particle testing, acoustic emission testing, infrared and thermal testing, magnetic resonance imaging, electronic nose, etc. [58].

Quality assessment or grading has the following benefits:

- i. It helps to facilitate the purchase of an unseen product.
- ii. Quality and safety improvement incentives.
- iii. Grading makes the market information meaningful.
- iv. It helps in facilitating quality and price comparison.
- v. It reduces the deception and fraudulent marketing risk.
- vi. Diverse marketing mechanism can be enabled through the process such as commodity exchange, future trading, inventory credit, credit letters, and facilitating resolution of disputes regarding composition or quality [6].

12. Future challenges for postharvest technology

In increasing urban population and shifting lifestyle in developing countries, demand for food has increased many times. Seed is a unit which not only is used as food but also responsible for production of the next generation. The most attention-demanding perspectives in seed biology are postharvest management and quality maintenance of seed. Although in past years, great success has been achieved in development of novel packaging, storage and transport systems, pests, and seed-borne disease control for market access. However, to achieve future goals, further research and technology development should be dedicated to explore genetic aspects of quality traits like stress resistance, resistance to postharvest diseases, and pest management. Researchers should try to work on integrated approaches for postharvest management of seed. Nanotechnology is an emerging field which is leading to tremendous achievements in crop sciences. Seed biologist should also try to explore this field so that seed could be preserving for longer time without altering the genetics.

13. Conclusions

Seed quality should be maintained for the better quality crops. Maintenance of the seeds is the major problem in the developing countries these days. There is a need to establish better, economical, convenient, and productive methods for postharvest handling and seed storage. Researchers should focus on translating knowledge into agricultural outputs. The chapter deals with the value of healthy seeds, factors affecting the seed quality, postharvest techniques for the seed storage, and techniques and safety measures for their quality assessment for the maintenance of good quality seeds to meet the international standards emphasizing on the needs of developing countries. This could be achieved by opting more sensitive and advance technologies with special emphasis on seed response to environmental and maternal factors.

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