Chapter

Postharvest Preservation Technology of Cereals and Legumes

Theophilus M. Ikegwu, Clement C. Ezegbe, Chioke A. Okolo and Chigozie E. Ofoedu

Abstract

Cereals and legumes are prone to perishability and have very short shelf-life if not given proper treatment. During different handling and marketing operations, there is a huge postharvest loss of agricultural produce. The qualitative and quantitative losses incurred in cereals and legumes commodities between harvest and consumption are huge. Qualitative losses such as loss inedibility, nutritional quality, calorific value, and consumer acceptability of fresh produce are much more difficult to assess than are quantitative losses. The major cause of postharvest loss (PHL) is the availability of poor infrastructure for postharvest technology (PHT) and processing of commodities. These losses can only be minimized by proper handling, marketing, and processing of the agricultural commodities; as well as the use of modern preservation technologies such as irradiation, radio frequency heating, etc. The sufficient knowledge of pre-and post-harvest preservation technologies and the provision of adequate and sufficient storage facilities for cereals and legumes handling and distribution would help to mitigate the incidence of postharvest deterioration and therefore improve the availability of cereals and legumes in the market and subsequent reduction in malnutrition for increased food security. Postharvest preservation technology of cereals and legumes is very fundamental in reducing postharvest losses and increasing food security.

Keywords: postharvest, physiology, deterioration, losses, postharvest technology

1. Introduction

The cereals are monocotyledons while the legumes are dicots. The cereal belongs to the grass family with more than 300,000 species. Furthermore, more than 190,000 species are angiosperms that are economically viable horticultural plants; and there are approximately 50 different types cultivated throughout the world in which about 51 species are grown. However, cereal's contribution to human nutrition cannot be overemphasized as it had been estimated that nearly 18 species of cereals cultivated provide more than 91% of the food supply to the world population. The cereals cover about 74% of the total tilled land surface. It had been estimated that more than 50% of the protein needs of the world population are provided by cereals [1, 2]. Currently, France ranks first in the Export of cereals such as wheat, rice, maize, and barley in Europe but 5th in the production of wheat in the world [1, 2]. Other cereals include millet, sorghum, rye, oats, etc. The major grains such as wheat, rice, and corn add up to make three-quarters of the worldwide production of grain [1, 2]. Therefore, cereal grains remain the main source of dietary carbohydrates for the supply of vital food energy to the diet [1, 2]. Although cereal grains, such as maize, rice, millet, and wheat are mostly in higher demand for energy provision, other cereals also provide very important food uses while there are more researches to explore the underutilized ones [3]. When cereal crops are grown for the edibility of their fruits, they are referred to as *grains* (botanically called *caryopsis*).

Structurally, the cereal seed is composed mainly of two components; the *endosperm* and the *embryo* (*germ*). The endosperm (more than 90% 0f the bulk seed) provides the energy. The pericarp (outer wall) develops from the ovary wall and encloses the endosperm. Beneath the pericarp is the testa (a selectively permeable layer) that borders the embryo which is a product of the inner reproductive gland (ovary wall). The permeability of testa to water is high and aids in seed germination but in the presence of salt, the testa may lose its vigor which would consequently lead to nongermination of seeds planted in soils with dissolved salts. The aleurone layer (with thick-walled cells) is free of starch and is the third important layer of cereal grain. Both testa and pericarp are called the bran. Conversely, legumes are flowering plants (dicotyledons) in the Leguminosae family and were derived from the latin word *legere* (to gather) and *legumen* (seeds harvested in pods) during the mid-17th Century. It includes chickpea, black gram, mung bean, and pigeon pea which have an estimated 16,000–19,000 species in 750 genera. Asia ranks first both in area harvested and in production capacity. India, on the other hand, accounts for 75 and 96% of the total global production of chickpea and pigeon pea, respectively [4]. The expression *food legumes* usually mean the immature pods and seeds as well as mature dry seeds used as food by humans. Based on Food and Agricultural Organization (FAO) practice, the term *legume* is used for all leguminous plants. Legumes such as French bean, lima bean, alfafa, or others that contain a small amount of fat are termed *pulses*, and legumes that contain a higher amount of fat, such as soybean and peanuts, are termed *leguminous oilseeds*. Legumes represent an important source of food in developing countries. Soybean, groundnut, dry bean, pea, broad bean, chickpea, and lentil are the common legumes in most countries. In some countries, depending on the climatic condition and food habits, other legumes are grown. Legumes are next to cereals in terms of their economic and nutritional importance as human food sources [3]. They are cultivated not only for their protein and carbohydrate content but also because of the oil content of oilseed legumes such as soybeans.

Legumes are sources of protein and are relatively costlier economically compared to cereals with great food value; and are reasonable nutrients for the maintenance of the body, e.g., vitamins and minerals. The legume has almost the same energy value per unit weight compared to the cereal grains (4.2 kcal), albeit, they provide more calcium, iron, thiamine, riboflavin, pantothenic acid, among others than cereals. The utilization of legumes is highest in India and Latin America owing to religious restrictions and food attitudes. Legumes also contain some anti-nutritional factors, such as trypsin and chymotrypsin, phytate, lectins, polyphenols, flatulence-provoking and cyanogenic compounds, lathyrogens, estrogens, goitrogens, saponins, anti-vitamins, and allergens. However, heat treatment is known to destroy the anti-nutrients, such as protease inhibitors and lectins, although it also destroys vitamins and amino acids. Legumes are a good source of dietary fiber; the crude fiber, protein, and lipid components have a hypocholesterolemic effect.

Healthy cereal grains and legumes are the demanding enterprises of the recent era for the production of high yield in the next season. The cereal grains and legumes must be properly stored for the maintenance of a high-yielding crop. Losses of high magnitude are encountered during storage that is due to biological and non-biological agents. The incidence of high losses of cereals and legumes after harvest in many countries of the world could account for the food security issues such as malnutrition, diabetes, and hunger which are counterproductive to mitigating efforts towards the improvement of food security. The effect of low yield, poor quality of produce, and the prevalence of chemical toxicants and mycotoxin contamination are significant problems that militate against the genuine and concerted efforts to improve postharvest losses (PHLs), provide appropriate handling and processing technologies for improved postharvest opportunities. In an attempt to maintain high-quality crops during postharvest operations (PHOs), care must be taken during harvesting to minimize damage and ensure appropriate postharvest handling techniques. Reliable methods for the assessment of postharvest losses should be developed while the use of the appropriate techniques to minimize loss and ensure the quality and safety of crops that meet quality standards are desired. In developing countries, Nigeria inclusive, cereals and legumes produced mainly by small-scale farmers are produced and stored on farms [4]. Biological and non-biological agents have been implicated in the postharvest losses of cereals and legumes (**Figure 1**) [5, 6].

There is a direct correlation between plentiful harvest and postharvest spoilage. In countries with huge harvests, postharvest losses are higher than in countries with less bumper harvests which may be a consequence of a lack of care arising from a short supply of laborers to preserve the excess grains. Consequently, farmers may be forced to sell their grains at a less reasonable price during the harvesting season to prevent possible postharvest losses. The glut in the price of cereals and legumes could lead to short supply leading to increased losses arising from insect pest attacks (*Prostephanus truncates).* However, the effect of bumper harvests on losses had not been measured, and overall; the effect would be minimal compared with the losses resulting from an unfavorable climate at harvest. Certainly, farmers are often supplied with sufficient storage capacity in developed countries so that at least

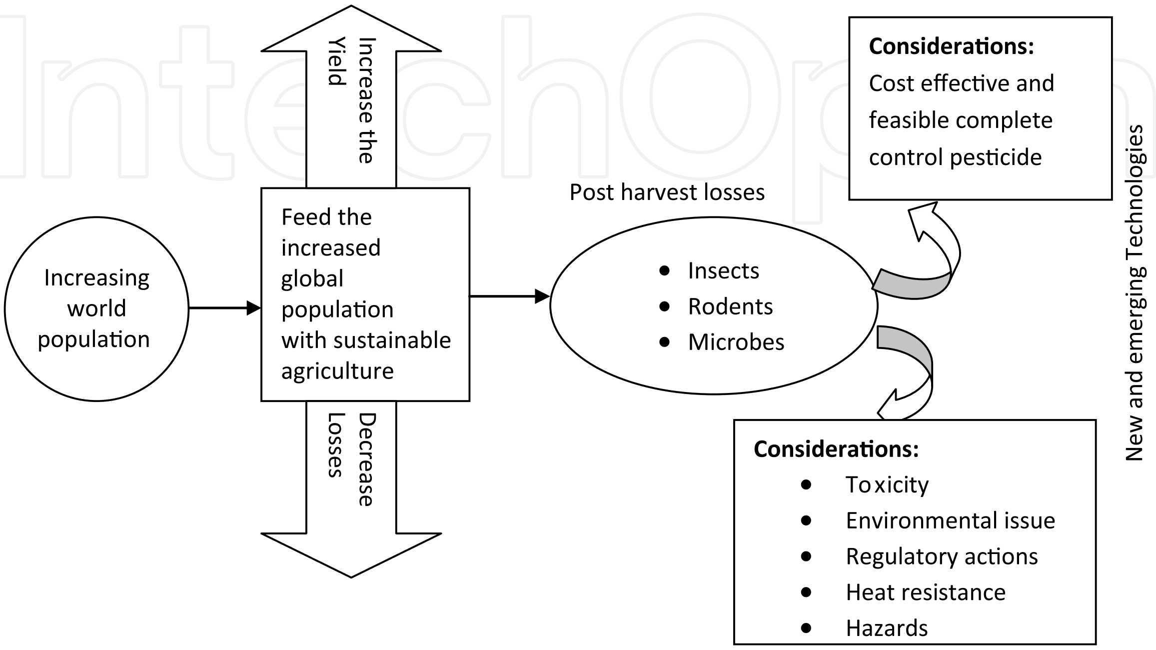

Figure 1.
Considerations for postharvest preservation technologies.

good harvests can be accommodated in fixed stores; unlike in developing countries where less attention is paid to farming and facilities for storage are lacking. In such instances, farmers are content to store surplus cereals and legumes in sacks in their houses. In most cases, especially, in locations where subsistence farming is common, the use of bag storage rather than traditional structures is practiced.

It was strongly believed by the 1970s that postharvest losses (PHLs) at the farm level were high due to traditional practices. However, traditional practices are unlikely culprits as farmers have survived more difficult conditions over long periods by adapting their practices to the situational challenges [7]. Nonetheless, compelling losses do sometimes occur that could be due to agricultural developments for which the farmer is not versed due to nonavailability of extension agents. Among these agricultural developments is the introduction of high yielding varieties that are more susceptible to pest damage, additional cropping seasons that result in the need for harvesting and drying when weather is damp or cloudy or farmers producing significant surplus grains, and because it is to be marketed rather than consumed by the household, the farmer failed to provide the necessary storage facilities for the preservation of the surplus grains.

2. Preservation

Theoretically, any method of food preservation should prevent all the above three (microbial, enzymatic, and proteolytic) types of spoilage. However, current industrial innovation methods have failed to meet these expectations as a whole. Most importantly, microbial spoilage must be prevented at all costs in whichever preservation method was employed, but the effectiveness of thermo-bacteriological treatment for microbial destruction varies to different degrees in the prevention of enzyme activities, proteolytic reactions, and the destruction of different microorganisms. Recent innovative preservation technologies such as ohmic heating, irradiation, infrared, pulse electric field, edible coating, radio frequency, and encapsulation lack the ability to forestall all the concerns posed by spoilage effects completely. These industrial methods employ distinct preservation principles aimed at arresting and or preventing food spoilage. In a nutshell, the industrial method of food preservation makes use of the following principles;

i. The ability to remove moisture through the use of drying/dehydration, evaporation/concentration, etc.

ii. The ability to remove heat from food products by lyophilization/freeze concentration, refrigeration/cold storage, freezing, etc.

iii. Heat addition - heat could be added to food products to destroy microorganisms or inactivate their activities by canning, sterilization, pasteurization, thermization, etc.

iv. Addition of chemicals/preservatives – some chemicals called preservatives may be added to processed food to prevent contamination by the microorganism or forestall enzymatic/browning reactions. Examples of such chemical additives are sorbates, benzoates, etc.

v. Fermentation - during fermentation, secondary metabolites are produced by microorganism which preserves the food product.

vi. Controlled atmosphere storage – in controlled atmosphere storage, the food products' environment is modified to prevent spoilage.

Other methods are the application of high-frequency currents, irradiation, etc. Additionally, other technologies such as pyrolysis, gasification, combustion, and chemical and biochemical processing are used for the conversion of cereals and legumes by-products to chemicals, energy, and other value-added products in the food value chain.

3. Postharvest pest management

Pests pose a very big challenge during the postharvest storage of grain legumes, transportation as well as during distribution. The quality and quantity of grains are reduced by pests if not properly controlled. Pest infestation is a big source of worry for both farmers and food processors because of the losses in investment and profit depletion that come with it. Some of the grain pest control techniques conventionally adopted are fumigation and controlled atmosphere of CO_2 and N_2. Novel techniques have also been developed to take care of some of the shortcomings of conventional pest management practices like fumigation that make use of chemicals. Examples of some of the emerging technologies which have found use in pest management include irradiation, radio frequency, infrared, and microwaves [7]. Methyl bromide application and treatment with hot air on grain legumes storage facilities or systems is also a common practice for disinfection in the grain storage industry [4].

3.1 Irradiation (IR)

Food irradiation is a food preservation technique during which ionizing radiation (0.1–50 KGy) is used to destroy target microorganisms in order to extend the shelf life of foods. During irradiation, microbial inactivation is achieved through free radical development which disrupts DNA and cell membrane integrity [7]. It has shown to be effective in sprout inhibition, elimination of parasites and insects, destruction of spoilage, and pathogenic microorganisms [8].

Radiation treatment at low and moderate doses has been recommended for the disinfestation of legumes [8]. The treatment has also been found to be effective for the reduction of flatulence-causing oligosaccharides as well as trypsin and chymotrypsin inhibitors. With these effects of irradiation on anti-nutritional factors in legumes, the nutritive quality of irradiated beans is thereby improved. Stored produces, especially grains have been successfully decontaminated with ionizing radiation as it affects the internal structure [8, 9]. Irradiation technology has been very effective in controlling the *Aspergillus*, *Penicillium*, *Rhizopus,* and *Fusarium* fungi infection in many grains and prolonging the shelf life over 6 months [10]. The source of radiation that is usually utilized is Co-60 and selenium.

3.2 Radio frequency (RF) heating

Radio frequencies (RF) are electromagnetic waves that are able to penetrate dielectric materials. They usually are characterized by a wavelength of about 11 m and with a frequency range of 1 to 300 MHz [11]. With this ability to penetrate dielectric materials like food grains, they are able to produce heat volumetrically. They are able to do this through ionic polarization or dipole rotation. With the higher moisture content in food grains, their ability to act as dielectric materials is increased, allowing them to act as electric capacitors and resistors and useful in the storage and conversion and electrical to thermal energy. This can be possible within an electromagnetic field [11].

In comparison, the higher moisture content in insects and the consequent higher electrical conductivity would make them require higher lethal temperatures and higher lethal time. At a lethal temperature and time of 50°C for 29 minutes or 54°C for 5 minutes, it would be possible to completely destroy a wide range of insects. This process of higher heating rates and its application finds use in the disinfection of grains on an industrial scale [9, 11].

When insects feed directly on grains, they produce webs and feces on stored pulses thereby reducing grain quality and this represents a huge challenge during the storage, transportation, and distribution of grains. To mitigate this huge challenge, RF heating has been used in the disinfection of dried cereals and legumes. This was demonstrated using a 27 MHz and 6 kW RF unit where the RF proved superior to forced hot air with respect to heating time required (5–7 minutes as against 275 minutes) to heat 3 kg of legumes to 60°C. Good quality product and uniformity in temperature distribution across the surface and interior of the legumes was achieved in the legume samples by a combination of RF heating followed by a movement of forced hot air as grains move through conveyors at 0.56metres per minute. The final interior temperatures of the containments used were above 55.8°C while 57.3°C was recorded for the surfaces of all legumes tested with resultant low index values for uniformity of 0.014–0.016 (ratio of standard deviation to the average temperature rise) for the distribution of interior temperature and 0.061–0.078 for the distribution of surface temperatures. Legumes treatment with RF in combination with forced hot air (60°C) to retain the needed treatment temperature for 10 min followed by the rapid cooling of the air through a 1 cm product layer yielded products with high quality. There were no significant differences in weight, moisture, color, and germination when samples used for control were compared to treated ones [12].

3.3 Infrared

Infrared is a segment in the electromagnetic spectrum found in between the microwave region and the visible spectrum area characterized by a wavelength of about 0.5 to 100 μm [9]. The absorption of infrared rays produces vibrations in the molecules of water, with consequent heat generation. Infrared-based technologies have been found to be energy-efficient and eco-friendly when compared with other conventional methods. Infrared technology also has many other merits like short process duration, uniform effect on food material, low energy requirement, high rate of heat transfer, and enhanced quality of products [9]. As a result of some of the above-listed characteristics, infrared-based technologies have been used in very many food operations like boiling, heating, drying, peeling, recovery of polyphenols and antioxidants, freeze-drying, roasting, microbiological inactivation, grains sterilization, juice and bread production, and cooking. The idea of the usage of infrared rays to disinfect/sanitize grains was established in the early 1960s and 1970s. Based on its exceptionally effective microbial inactivation characteristics, grain industries usually adopt it as a preferred operation for grain disinfection against various chemical methods. Infrared operations involve three different mechanisms in destroying micro-organisms namely thermal inactivation, induction heating, and the distortion of DNA integrity. As documented by [9], the Infrared treatment of mung bean for 5 minutes at an intensity and temperature of 0.29 kWm and 70°C respectively resulted in the total inactivation of fungal growth. Since the penetration rate of infrared is low, its effectiveness gets reduced with an increase in the depth of food. It is therefore recommended more for food surfaces sterilization than other processes. Catalytic-infrared emitters have also been developed and used for the control of weevils in rice, merchant grain beetle, and saw-toothed grain beetle. Generally, a little exposure of about 60 seconds is adequate to destroy insects that strive externally or internally in the grains kept in storage facilities [9].

3.4 Microwaves

Microwaves are electromagnetic radiations with short-wavelength; which has an excellent microbial destruction potential when compared to other conventional chemical methods. Microwave technology is now a highly adopted process by most grain industries for disinfection [8, 13]. They provide protection on grains from insects [10], storage fungi, and field fungi [12]. However, treatment with the use of microwave can induce several adverse effects on seed germination and can affect grain quality. These adverse effects of microwaves are due to variations in heating caused by the difference in cold and hot spot temperature [9].

3.5 Fumigation

Fumigation is a very active pest control technique. Phosphine gas for example is used to kill grain pests at every growth level of their life cycle; this is inclusive of pests with high resistance ability. Nonetheless, the phosphine gas application level needs to be up to 300 parts per million (ppm) and sustained at this level for a minimum of one week at 25°C or more. Alternatively, at a temperature of 25°C or less, a 200 ppm concentration of phosphine gas should be maintained for 10 days for effective and efficient destruction of pests that destroy legumes. Phosphine application exists in two forms; they include bag chains and tablets. There are also a number of ways with which each choice can be adopted effectively in a gas-proof secured silo. Bag chains are also considered a very safe system that assures one of not having any fumigant residue on the grain nor having the operator harmed in whatever way. The next form that phosphine exists in tablet form and is the most widely used and accepted. There exists a third approach in phosphine application which involves the use of a phosphine blanket and is mostly used for very large storages of above 600 tones. The application of phosphine and the concentrations to be used depend on the silo (which should be gas-tight and sealable) volume used for the fumigation. The phosphine concentration to be used is strictly determined based on the volume of the silo rather than the quantity of grain in the silo [13].

An airtight-covered silo especially one that passes the half-life pressure test must have to remain sealed through the entire fumigation period in other to attain a perfect fumigation result with the use of phosphine tablets and/or bag chains. In an airtight-sealed silo, fumigation is expected to last for 7 days with a temperature of above 25°C, and 10 days if the temperature falls between 15 and 25°C. Nonetheless, if the temperature in the silo is less than 15°C, pests particularly insects will be inactive and phosphine is not usually effective at such low temperatures. Based on the ineffectiveness of phosphine at temperatures lower than 15°C, phosphine application is not advisable at temperatures lower than 15°C. The silo must remain closed when fumigation is on and should only be accessed by personnel with suitable personal protective equipment (PPE) as it is dangerous for the operator. Constant opening of the silo is also detrimental to the effectiveness of the fumigation process considering the fact that the phosphine gas concentration and absorption rate would have been reduced below the lethal level recommended for pests' destruction. Recommendations for the phosphine label came to be as a result of detailed testing by the industry, in other words, making use of phosphine as indicated on the label will ensure perfect results [13]. Phosphine is rated high as a very reliable fumigant for the control of pests in grain storage facilities and other production enterprises [13]. Nevertheless, there has been a continuous misuse of fumigants with a resultant effect of poor pest control and the development of resistance in certain species of pests. More so, just as the continuous use of herbicides that has the same principle of action advances weeds being resistant, continuous use of phosphine could lead to grain pest resistance. Nonetheless, in the case of herbicides, the development of resistance by pests can yearly be circumvented by alternating the chemicals used. The same cannot be said for stored grain fumigation as options are limited and where available, they are not cost-effective [13]. In other words, it is best to avoid the resistance of phosphine by using it as instructed.

Other fumigants and a controlled atmosphere may be used for stored grain pests but they are often high in price. However, to prevent resistance of stored grain pests, phosphine sealed in a silo that is impermeable to gas should be used.

3.6 Controlled atmosphere

In spite of the fact that phosphine is the common most used gas fumigant, there exist other gas fumigants for controlling pests in stored grain. These alternatives are however more expensive than phosphine and still require a gas-tight, sealable silo but they offer other options for resistant pest species. Nitrogen (N_2) and carbon dioxide (CO_2) have the advantage of being nonchemical control alternatives. Because nitrogen and CO_2 methods of control change the balance of natural atmospheric gases to produce a toxic atmosphere, they are hence referred to as controlled atmosphere (CA) [13].

3.6.1 Carbon dioxide (CO_2)

Treatment with CO_2 involves displacing the air inside a gas-tight silo with CO_2 at concentrations high enough to be toxic to grain pests. This requires a seal impermeable to gases, measured by a half-life pressure test of no less than five minutes. In order to eliminate all life stages of the main grain pests, CO_2 must be retained at a minimum concentration of 35% for 15 days [14]. To achieve a 35% concentration level of CO_2 for 15 days, 30 kg (size G) cylinder per 15 tones of storage capacity is required. CO_2 is an odorless, colorless, non-flammable gas that is approximately one and a half times heavier than air. Food grade CO_2 comes in form of a liquid in pressurized cylinders and when released from the cylinder, changes to a gas. Carbon dioxide is less effective at temperatures below 20°C. This is because insects are less active at this temperature, so the CO_2 concentration must be maintained for an extended period.

3.6.2 Nitrogen

Grains stored in a nitrogen saturated environment ensure the control of insects and preserve product quality without the use of chemicals [13]. Nitrogen-based storage systems maintain the quality of canola and pulses through the inhibition of the respiration process that causes oxidation, which may result in the increase in free fatty acids, loss of color, and seed deterioration [13]. Grain treatment with nitrogen (for the purpose of pest control) is safe, environmentally friendly, and involves the usage of electricity for its major operations. Nitrogen produces no residues when used, so grains can be sold instantaneously whenever decided as against what is practiced for chemical fumigants which have recommendation period for withholding after fumigation [13]. The use of nitrogen as an insect control technique involves the use of Pressure Swinging Adsorption (PSA) technology in adjusting the atmospheric composition of the grain storage system to expel other gases other than nitrogen, thus depriving the pests of the needed oxygen. The method of application entails purging the silo to its base with gas majorly composed of nitrogen. This is done in order to force out from the silo the oxygen-rich air through the top of the silo. Several hours of operation are required for PSA to build up about 99.5% pure nitrogen and before the air composition reduces to 2% oxygen. It is difficult for adult insects to thrive in 2% concentration of oxygen, provided this concentration is maintained for 21 days at 25°C or above for the temperature of the grain [14]. The inhibition of the different stages of the life cycle of insects (eggs, larvae, and pupae) will be difficult below these recommended temperatures and the number of days for grain storage. For grain temperatures below 25°C, this treatment duration should further be extended to a 28-day period. Additional purging of the silo may be needed to get rid of oxygen that has diffused from the grains and it must be re-evaluated 24 hours after fumigation in order to achieve effective and efficient pest control.

4. Drying technologies

Scientists from all over the world continuously search for new and effective means and use of renewable sources of energy as a result of the continuous increase in the price of fossil fuels and increased levels of greenhouse gas emissions. The world's energy intake is doubled every 20 years and this increase in energy consumption, has resulted in fossil fuels causing many environmental problems and pollution [15]. Drying is a processing technique used for food product preservation and reducing food spoilage. About 3.62% of the world's energy is used for the drying of agricultural products [16].

Presently, the requirement for new drying technology that promotes the higher quality product and efficient drying in shorter periods is the current need. And as a result, hybrid drying systems have emerged as an excellent technique for their versatile drying outcomes, with lower energy requirements and minimum environmental impact. Lately, various hybrid solar dryers which are more efficient in conjunction with other sources for heating the air, hence reducing drying cost and energy consumption have been developed [17, 18].

Grain legumes are usually dried after harvesting before storage in storage facilities [17]. Drying grain legumes to a recommended safe moisture level is fundamental in achieving safe storage of grain legumes. However, too rapid drying of nuts can lead to hardening of the grain core with poor interior while very slow drying may result in microbial growth which will lead to quality deterioration. Recirculation of the solar drying air is thus employed to make efficient use of the heated air by giving a drying rate that provides acceptable product quality.

Drying of pulses is essential because they contain high moisture content of about 18–25% at the time of harvest and, for safe storage, the optimum moisture content need to be in the range of 9–12% to avoid mycotoxin production. It is essential that the grain is dried to a safe moisture level as quickly as possible to avoid deterioration regardless of the drying system employed. There are several techniques of non-natural open-sun drying of grains with hot air. Some of these forms of drying include spouted-bed drying, fixed bed drying, moving bed drying, fluidized-bed drying, and thin-layer drying [19]. Apart from some of these specialized dryers used for grain drying, all-purpose grain drying systems can as well be used in the drying of grain legumes. Generally, as documented by [20], dryers or drying systems are categorized depending on the following:

a. The flow of grain wherein the dryers are denoted as - batch, recirculating and continuous dryers,

b. The relative motion of the grains and the circulating air used for drying. Concurrent, counter-current, cross/mixed flow dryers are found in this category.

c. The source of heat: solar, propane, and electrical dryers are examples of dryers in this category.

Regardless of the type of dryer used in drying grains, the concurrent heat energy transfer and moisture loss principle/process is the same for the drying of grain legumes and equally for other grains [19]. The process of drying grains involves the loss of free moisture which involves the drying of the grain until its equilibrium moisture content is attained. The equilibrium moisture content of the grain implies the final moisture content attained by the grain at a pre-determined relative humidity and temperature. The cardinal factors that influence the drying rate of grain legumes are temperature, grain moisture content, relative humidity, and air velocity [19].

The use of solar dryers is also another medium for drying legumes. A lot of solar drying systems exist for grain drying such as direct, non-direct, and solar. Solar dryers have the problem of the dehydration process being stopped as a result of an absence of solar radiation and absence of radiation at night or low insulation, which decreases the quality of the grains. So far, there have been efforts to proffer solutions to the problems of solar systems, some of which include – the addition of thermal storage materials, phase change materials, and adding a variety of heating modes either direct or indirect [21]. This has led to the evolution of several types of solar dryers. Thermal storage materials have the ability to store thermal energy when there is solar radiation and then make use of this thermal energy when the sun is not available. Three main forms of solar dryers exist with varying sizes, designs, and magnitude [22].

4.1 Classification of solar dryer

The three major types of solar dryers with various sizes, capacities, and designs are:

i. Direct solar dryers

ii. Indirect solar dryers

iii. Mixed-mode solar dryers

4.1.1 Direct type solar dryer

This is a form of the solar dryer where the radiation from the sun is used directly incident on the grains to be drained. The dryers are quite simple in structure, less expensive, little or no maintenance needed, and also simple to use. It can be fabricated with a wooden box with a glass cover and some holes for air entrance and exit also. After the usage of the direct type of solar dryers, the food products are usually not very nice in appearance, color, texture, and with a reduced nutritional quality. In direct-type solar drying, produces to be dried are spread on the ground or mats exposed directly to the sun to absorb solar radiation. As noted by [23], sun-dried grains are prone to high crop losses due to:

i. Non-uniform moisture loss

ii. Attack by insects and rodents

iii. Inability to attain moisture levels that are safe for the safe storage of grains

iv. Proliferation of micro-organisms and possible toxin production.

These challenges have led to the development of other drying techniques like solar drying to overcome the aforementioned challenges. Solar dryers have faster rates, better efficiency, more hygienic with less crop losses when compared to sun drying [23].

4.1.1.1 Open sun drying

Here, food products are placed right under the sun, below solar radiation to get rid of their moisture properties. The difference in density in the air from the atmosphere allows for air movement. In other words, to get a product dried, they are usually spread in a large area under solar radiation. It is usually time-consuming till it is dry to a required level. All that is needed is a large surface ground done with concrete or a suitable soil area with products laid on them between ten to thirty days depending on a favorable weather situation. This form of drying technique consumes a lengthy time of sun subjection which can sometimes bring down the nutrition level of the products, like sapping off their vitamins.

Open solar drying is a good choice for food drying but comes with a lot of problems such as reduced product quality, adverse effects of rain, moist, wind, animal consumption, and dust [24]. The use of industrial drying comes in as another option which is very expensive. It would need a lot of fossil fuel which will result in air pollution. Nonetheless, the spread and adoption of solar energy is likely to take prominence in the coming years and is without negative environmental effective factors [24].

4.1.1.2 Cabinet type solar dryer

The cabinet form of the dryer is advantageous for preserving smaller food products such as vegetables, pepper, and fruits. It has a roof that is transparent with covers that could be either single or two, made using a black-colored plate cover that serves as an absorbing entity for the storage of energy from the sun. Suitable perforated holes allow for the free flow of air and the removal of moisture.

4.1.2 Indirect mode solar dryer

When it comes to moisture removal and heat transfer, indirect sun dryers differ from direct solar dryers. This style of drier is utilized for quick drying. The atmospheric air is heated in a solar air collector in this dryer, and then this hot air moves towards the drying cabin, where products are kept to dry, and the hot air absorbs some moisture from the drying products before exiting through the chimney.

4.1.3 Mixed mode solar dryer

The term "mixed mode solar dryer" refers to a solar dryer that uses both direct and indirect heating methods. The inlet air is heated at the solar air collector before entering the drying chamber in a mixed mode solar dryer. Some of the drying chamber's sides are composed of glass, which adds to the drying chamber's overall warmth. The product is dried using a combination of hot air and direct sunlight in this procedure. In comparison to direct and indirect solar dryers, mixed mode solar dryers require less drying time. Biomass has been used in hybrid sun dryers as an auxiliary heat source to keep drying going all night. Cashews, for example, have been dried in these dryers [23].

4.1.3.1 Greenhouse solar dryer

Tent dryers are similar to greenhouse sun dryers. They have vent sizes that control airflow. Board glazing is used on all sides of this type of drying system. The greenhouse drying system provides a higher degree of control when used in conjunction with the appropriate settings. The main benefit of a greenhouse solar dryer is that it can provide alternate heating with charcoal or briquette burners during inclement weather and can also be used at night.

Greenhouse solar dryers are a type of solar dryer that was developed to address some of the issues that open solar dryers face. The greenhouse solar dryer might be created out of polycarbonate sheets in parabolic shapes, with direct current blowers to help with airflow in the dryer, which has a floor area made out of concrete [24]. Solar radiation intensity was observed between 390 to 820 W/m^2.

Greenhouse drying is one of the world's oldest methods of crop preservation. It entails the phenomena of heat and mass transmission. The product's thermal energy is used in two stages. The temperature of the product rises in the first step due to sensible heat, and the moisture in the product vaporizes in the second step due to the provision of latent heat of vaporization [25]. The greenhouse dryer provides a regulated environment in terms of relative humidity and temperature, which is better for crop drying and hence reduces drying time. The essential processes in the construction of a greenhouse system include vaporization. The greenhouse drier provides a regulated environment in terms of relative humidity and temperature, making crop drying more efficient [25].

a. Natural convection greenhouse dryer

b. Forced convection greenhouse dryer

4.1.3.1.1 Natural convection greenhouse dryer

Incident sun energy is passed through the canopy and used to heat the crops in a natural convection greenhouse dryer. The temperature of the crop rises as a result of solar radiation absorption. The thermosyphic effect is used to operate the natural convection greenhouse drier. Humid air is vented through the dryer's chimney or evacuated through an outlet on the top, while warm air is pumped through the crop by buoyancy forces. Natural convection mode refers to this type of airflow within the drying chamber, and a natural convection greenhouse drier is one that works in this manner [25].

4.1.3.1.2 Forced convection greenhouse dryer

The forced convection greenhouse dryer was born out of a desire for increased air circulation and drying rates. To adjust temperature and moisture evaporation according to the weather conditions, an optimal airflow should be given in the greenhouse drier during the drying process. An exhaust fan on the upper half of the west wall is used to evacuate humid air. Forced convection greenhouse dryers employ a fan or blower to control airflow [25].

The mixed mode solar dryer outperforms other types of solar dryers in terms of drying efficiency, drying time, and thermal efficiency. It has been discovered that a mixed mode solar dryer with a Phase-Change-Material is the best for drying grains with higher efficiency and shorter drying times, as well as being smaller, having fewer moving parts, and requiring less maintenance [19]. In a mixed mode solar dryers with 1.5 m/s air velocity, beans with up to 60% moisture content can be reduced down to 6% within six hours of drying [19]. The time required for drying depends on factors like solar radiation, ambient condition, and relative humidity while the solar collector efficiencies can be as high as 61.82% [21].

5. Storage of grain legumes

Cleaning of grains to remove extraneous materials and contaminants is very fundamental in achieving good and safe storage. It established that cleaning before storage of grains influences the quality of the grain [26]. Cleaning involves the removal of unwanted extraneous material (straws, sand, stone, etc.) from the grain. The storage of grain legumes is a very cardinal stage in the postharvest handling of legumes. Its importance is based on the fact that if the optimal conditions for their safe storage are not maintained a high level of postharvest losses could be incurred. Different microorganisms and pests have the ability to destroy grain legumes after their harvest, during storage, or transportation to various locations of interest. Depending on the prevailing intrinsic and external factors, postharvest losses of grain legumes are estimated to be about 9% for USA and 40–50% for many developing countries [27].

The rapid decline in color, oil quality and ability to germinate, and many other changes in the quality characteristics of grain legumes can be caused by increase in temperature and moisture. High moisture content and elevated temperature of grains can lead to the development of molds in the category of *Aspergillus species, Fusarium species, and Penicillium species,* and the production of some mycotoxins such as aflatoxins, ocharatoxin A, and patulin produced by molds. High moisture content and temperature above optimal levels also aid the infestation of different varieties of insects (granari weevil, grain borer, grain moth, grain beetle, etc.) which feed directly on the grains with a resultant effect of the decline in grain quality and quantity. Infestation of grains by fungi results in reduced nutritional quality, reduction in the quality of proteins that synthesize gluten, and the ability of grains to germinate. Other effects include free fatty acid elevation, lowered starch content, increase in total soluble solids, the decline of non-reducing disaccharides and oligosaccharides. The grains can also be charred due to hot spot development and the formation of mycotoxins may occur as a result of fungal contamination creating very big public health issues [7, 17]. Globally produced grains of about 25% are contaminated by toxins from molds – mycotoxins [28]. The aflatoxins with the greatest intoxicating effect, genotoxic and carcinogenic characteristics of greatest concern are B1, B2, G1, G2, and M1 aflatoxins (**Table 1**) [31].

During storage, grain legume pests are capable of destroying up to 33–50% of global produces [27]. This gives an insight on the seriousness of pest infestation and attack on grains if proper control measures are not put in place. The quality degradation which results in loss of the quantity of leguminous grains globally during storage can get up to 60% in some instances [27]. These losses are primarily

Chemical fumigants (phosphine tablets and methyl bromide)	**Compound/Mechanism**	**Effect**	**References**
Chemical Fumigant	Phosphine Tablets and methyl bromide	Toxic to living organisms and humans	[17]
Sensor-based vacuum hermetic fumigation and storage	Hermetic contaminant, very low oxygen concentration	No harmful effect to humans	[29]
Irradiation	Ionizing irradiation (0.1–50 kGy)	Effective in fungal destruction Grain disinfection	[8]
Radio frequency	1–300 MHz up to 11 M wavelength, penetrate dielectric material and produce heat volumetrically	Destroy insects and disinfect dry grains	[30]
Infrared	0.5–100 μm	Vibrations in molecules of water with heat generation	[30]

Table 1.
Postharvest preservation technologies.

as a result of insect infestation, rodents attack, micro-organisms like mold as well as the breakdown in the normal physiology of grains. It's a well-known fact that pathogenic micro-organisms, insects, rodents, and unwanted contaminants are capable of posing health hazards in grains when consumed. In storing grains from leguminous crops, the usage of suitable packaging and packaging materials is very crucial in achieving good results in postharvest management of leguminous grains. Packaging also serves a very key role during distribution and marketing (to maintain quality) [27].

In village areas of developing and even developed nations, grains including pulses are still kept in traditional storage facilities which are fabricated with natural materials or woven threads. Typical examples of some of the traditional storage structures used include underground pits, thatched roof storage, plastic containers, and basket silos. Though these local structures have a low construction and maintenance cost, they are not very durable, easily invaded by insects and pests resulting in grain legume quality deterioration. Developing nations are currently adopting warehouse storage structures for storing their grains in very large quantities [17].

The materials used for the construction of storage facilities and structures have a direct influence on the moisture content and temperatures in the storage structures [17]. Wooden sticks, concrete blocks, cement, bamboo, and metals (aluminum or steel) are some of the very common materials used for the fabrication of storage structures for grains.

5.1 Silo

Silos are currently very common storage facilities for storing grain in many countries and constitute about 79% of all on-farm grain storage facilities in Australia. Silos are very ideal storage alternative for grain legumes (pulses) especially the cone-based variant which makes for very easy grain unloading/discharge with very low seed damage possibilities [15]. For long-term storage of above three months duration, there is a need for the incorporation of aeration cooling systems and the use of gas-tight sealable storage which are recommended for efficient and effective fumigation regimes in managing and achieving best quality control. Metal silos are fabricated by incorporating augers and ventilators for grain aeration in order to reduce the formation of hot spots. Metal silos with ventilators and augers are considered advanced grain storage systems as they have the ability to extend the shelf-life of grain legumes through controlled respiration and the development of unfavorable conditions for all sorts of grain legume pests [7, 17].

It is advisable to always fill and empty silos from apertures provided at the center of the silos. This is especially important with grains as most grains have a high bulk density and loading or unloading outside the central opening at the center will put an uneven load on the structure which may cause the silo to collapse [14].

Metal silos of different sorts, fabricated with galvanized iron or recycled oil drums have been developed as an economic, effective, and efficient containers-storage option. These silos are suitable for a long duration of storage of cereals and grain legumes in a water-resistant and hermetically controlled environment. Grains stored in metal silos provide protection from rodents, insects, and water, and are thus very good storage systems for pulses [32]. However, there is a need to protect or shield silos from direct sun rays and other heating sources capable of increasing the temperature of the grains contained therein to avoid condensation. As an alternative, silos can be situated in well-ventilated areas with shade to avoid elevating the temperature of the silos [32]. It is worthy of note that metal silos are very efficient and effective for grain storage but they are also expensive [33].

If there is direct exposure of silos to sunlight or the external air is lower than that in the silos which contain the grains, there may be a formation of currents of convectional flow. As a result of the convectional air currents generated, the moist air is being blown pass through the grains. As the moist air travels and meets cooler surfaces like the silo walls, condensation of the moisture will take place and the grain within that area will get dampened. This dampening occurrence is a cardinal problem associated with grains stored in silos made of steel and particularly utilized for storage in hot areas with daily clear sky [28]. High day temperatures and cool night temperatures are a result of a clear sky. The problem of elevated temperatures can be mitigated in small silos by providing a shield in form of a roof or a hat, to prevent direct contact of sun rays with the surface of the silos. Solutions for larger silos may involve grain silo ventilation or transferring of the grains from the silo with a high temperature to another one that has a cool condition. Grain movement during the transfer of grains to another cool silo has the tendency to provide grains with more homogenous moisture content. In a case where the moisture content is too high, then there will be a need to dry the grains again [28].

5.2 Hermetic bags/cocoon

It's still possible for foreign pests like *Callosobruchus maculatus* and *Callosobruchus chinensis* to be located in grain legumes storage systems during storage if appropriate pest management regimes are not strictly adhered to. Grain legumes storage in hermetic bags/Cocoons has to a large extent aided farmers in many countries in storing and extending the shelf life of their produces as they await periods with better produce value and pricing. This has resulted in better financial gains for farmers that make use of Hermetic bags/cocoons storage in extending the shelf life of their produces with the target of a better sales period [33]. The technique of using hermetically sealed polyethylene silo bags is an effective alternative for the protection of stored grain legumes in commercial storage systems and is presently gaining more prominence for both on-farm sites and off-farm sites [34].

6. Conclusion

Legumes are very important food crops that supply good amounts of plant source protein to our meals. Postharvest losses are incurred if grain legumes are not properly handled, prepared, and stored. Some of the notable postharvest handling practices adopted to preserve and extend the shelf life of legumes include drying, pest control, and storage.

Pest control in harvested grains can be achieved through emerging technologies like irradiation, radio frequency ionization, infra-red, and microwave technology. Pest management can also be done through the age-long chemical means of fumigation as well as controlled atmosphere technology as an alternative.

The drying of grain legumes through the traditional means openly spreading in the sun yields poor drying results. Drying of grain legumes is better done through artificial means with hot air dryers or solar dryers of different sorts. Solar dryers have evolved greatly as a result of the need to reduce the level of greenhouse gases emitted by non-solar dryers, high fuel prices to run non-solar dryers, and the need for a renewable type of energy, unlike the non-solar dryers.

Storage of grain legumes for bulk commercial purposes is done in silos while hermetic bag storages are utilized for small-scale storage in other to achieve a fairly optimal storage condition for grain legumes.

Author details

Theophilus M. Ikegwu[1*], Clement C. Ezegbe[1], Chioke A. Okolo[1] and Chigozie E. Ofoedu[2]

1 Faculty of Agriculture, Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

2 School of Engineering and Engineering Technology, Department of Food Science and Technology, Federal University of Technology, Owerri, Imo State, Nigeria

*Address all correspondence to: tm.ikegwu@unizik.edu.ng

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