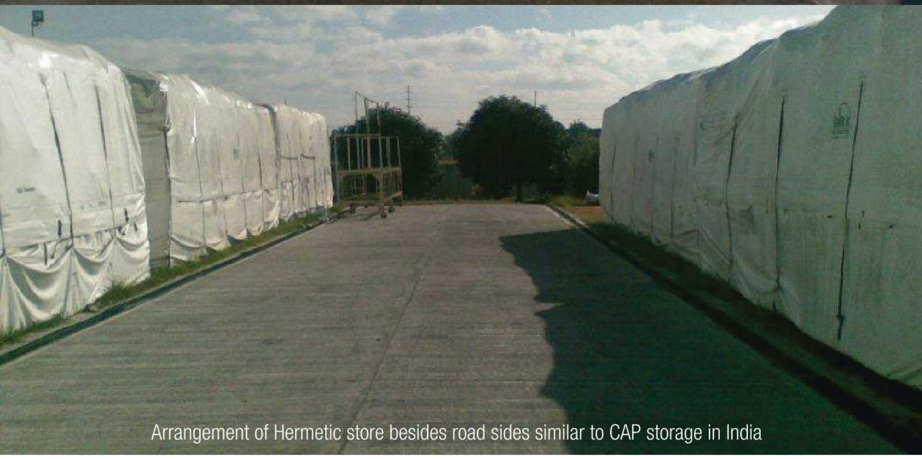
Safe Storage of grain under flooding condition in Hermetic store at Tamil Nadu



Arrangement of Hermetic store besides road sides similar to CAP storage in India

Hermetic System for Safe Storage of Agricultural Produce without Using Hazardous Chemicals

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1. Introduction

Food security is an economic access to food along with food production and food availability. India, with 2.4% of the world's surface area, accounts for 17.5% of its population, which means one out of every six people on this planet lives in India. With a population growth rate of 1.58%, India is predicted to have more than 1.53 billion people by the end of 2030. According to Alexandratos and Bruinsma (2012), food supplies would need to increase by 60% (estimated at 2005 food production levels) in order to meet food demand in 2050. The scientist and planner are focused only on increased food production and not on the protection of post-harvest food losses. Increasing the productivity of agricultural products is critical for ensuring food security, but this may not be sufficient to provide food for an increasing population. To sustainably achieve the goals of food security, food availability also needs to be increased through reductions in post-harvest losses at farm, retail, and consumer levels. Despite these recent

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accomplishments, agriculture in India has the potential for major productivity and total output gains, because crop yields in India are still just 30% to 60% of the best sustainable crop yields achievable on the farms of developed as well as other developing countries. Additionally, losses after harvest due to poor infrastructure and unorganized retail cause India to experience some of the highest food losses in the world. Producing more food also presents environmental challenges. Currently, agriculture contributes nearly a quarter of global greenhouse gas emissions, uses 37% of landmass, excluding Antarctica, and accounts for 70% of all freshwater withdrawn from rivers, lakes, and aquifers. To get to the bottom of this problem, we have only two alternatives: (i) increasing total cultivated land; (ii) increasing food production; and (ii) preventing post-harvest losses. The increasing human and animal population has reduced the availability of land over the decades. Moreover, total cultivated agricultural land is also shrinking due to its conversion into buildings, railways, roads, and other infrastructure. The second option, which makes sufficient food for the present and future populations, is to increase the productivity of food, both in quantity and quality, because not only do we need food to fill the stomach but also to compete with a balanced diet that may provide nutrients for humans. The Indian Council of Agricultural Research (ICAR), with 99 institutes, 65 agricultural universities, and 631 KVKs spread across the country, constitutes one of the largest national agricultural research systems in the world. But in Indian agriculture, there is still a technology deficit as far as world agriculture is concerned.

1.1 Post-harvest Losses

The post-harvest life and quality of food grains depend mainly upon the quality at harvest, storage practices, and factors influencing the storage environment. Improper storage of food grains results in high quantitative and qualitative losses. Jha et al. (2015) estimated a monitoring loss of ₹ 92,651 crore in agricultural and livestock produce in India every year during harvest, post-harvest operations, and storage. Post-harvest management of agricultural products is a significant challenge in developing countries. Post-harvest management, including handling and storage, plays a vital role in keeping agricultural commodities safe from deterioration. A grain saved is equivalent to a grain produced, which emphasizes the need for proper storage management. Farmers store food grains for their own consumption or for seed purposes, whereas traders and marketing agencies store food grains for financial gain. Storage of food grains by government organizations plays a vital role in domestic food security, price stabilization, and earning valuable foreign exchange through export. The Food Corporation of India (FCI) is the nodal agency in India for the procurement, handling, and storage of food grains. FCI, along with other procuring agencies, undertakes the procurement of wheat, rice, and coarse grains from the farmers at a minimum support price fixed by the Government of India. These agencies procure about 69 million metric tons of wheat and rice every year for creating buffer stock to maintain the supply chain for the whole year and ensure food security for the whole nation. Food grains procured by government agencies are generally filled in jute sacks of 50 kg in the market yards and then transported for storage. FCI and other organizations such as the Central Warehousing Corporation (CWC), State Warehousing Corporations (SWC), and private warehousing agencies, store the food grains filled in sacks in Cover and Plinth (CAP) structures, warehouses, and sometimes in concrete or metal bins. The duration of storage is usually one year for CAP storage and more than one year in warehouses. Aeration, fumigation, and sprays are applied at certain intervals to control insects and pests for safe storage. The gain or loss of moisture during storage is a common phenomenon. The extent of moisture migration depends on equilibrium moisture content (EMC). The EMC of food grains is influenced by the weather conditions, which vary in different agro-climatic regions.

Storage losses of food grains during storage in warehouses become an issue of concern in the absence of any scientific norms for losses as presented in *Figure 1*. It is assumed that storage losses are location- and season-specific to the extent that the concept of average levels of losses sometimes becomes insignificant. The quantitative loss is a reduction in weight due to the incidence of insects, rodents, birds, mites, fungi, bacteria, and the respiration of grains. Changes in temperature, relative humidity (RH), moisture content, and chemical changes affect the rate, at which weight gain or loss may take place during storage. The major economic loss caused by grain-infesting insects is not always the actual material they consume but also the amount contaminated by them and their excreta, which makes food unfit for human consumption.

Sources of infestation

There are several sources of infestation:

- Fields
- Carried-over commodities waste and rejects
- Agricultural machineries
- Processing plants Farm grain stores and re-used sacks
- Means of transportation
- Alternative hibernation sites and hosts

1.2 Chemical Methods of Control

During storage of grains in godowns and open (CAP) by various agencies like FCI and warehousing corporations, stored produce is repeatedly exposed to various chemicals as explained in *Table 1* and presented in *Figure 2*.

Figure 1: Storage losses in food grains

Table 1. Chemical Methods used in Grain Storage Structures

Fumigants (Gaseous Poisons)	Contact Poisons
1. **Aluminium phosphide:** Releases Phosphine Gas-. real insect killer	Used as surface protect ants and sprayed on the walls, bags filled with grains in stacks, alleys etc
2. **Methyl bromide** Releases Bromine Gas, Used on a small scale fumigation e g quarantines etc.	**Malathion 50 EC** Sprayed every fortnightly. Has little fumigant action also but it is contact poison **Delta Methrin 2.5% wp** Sprayed once in every 3 months on bags filled with grains

They are very toxic to man and animals and should be applied only by trained, experienced operators working in pairs. The hazards of using chemical methods are presented in *Table 2.*

Table 2. Hazards of using Chemical Methods

CAP Storage	Godowns
1. Repeated exposure of humans to these chemicals is dangerous.	1. Inappropriate chemical use, not following label directions is illegal.
2. Impart foul smell/odors to grains.	2. Can result in MRL violations. This includes using higher rates or not following timing of application directions as directed on the label. Withholding periods must be followed.
3. Chronic exposures may cause damage to lungs, kidneys and liver in humans.	
4. Repeated exposures to gaseous poison may cause neurological disorders.	

1.3 Hermetic Storage Technology

Hermetic technology as an alternative to traditional and chemical control methods has gained significant interest among farmers, the private sector, governments, and development agencies. Hermetic technologies owe their effectiveness to the airtight conditions created during storage. Biological processes such as respiration and metabolic activities are driven mostly by the presence of insects and other biological activities that lead to the depletion of oxygen and release carbon dioxide inside hermetic containers. Hence, the hypoxic environments these technologies create, become unfavorable to the development and reproduction of insect pests and thus minimize or stop grain damage as shown in *Figure 3.* Commonly used hermetic technologies include silos (metal and plastic), drums, cocoons, plastic bags, and other containers. These hermetic containers come in different forms and sizes.

Figure 2: Prevalent Storage structures and Chemical Control Measures

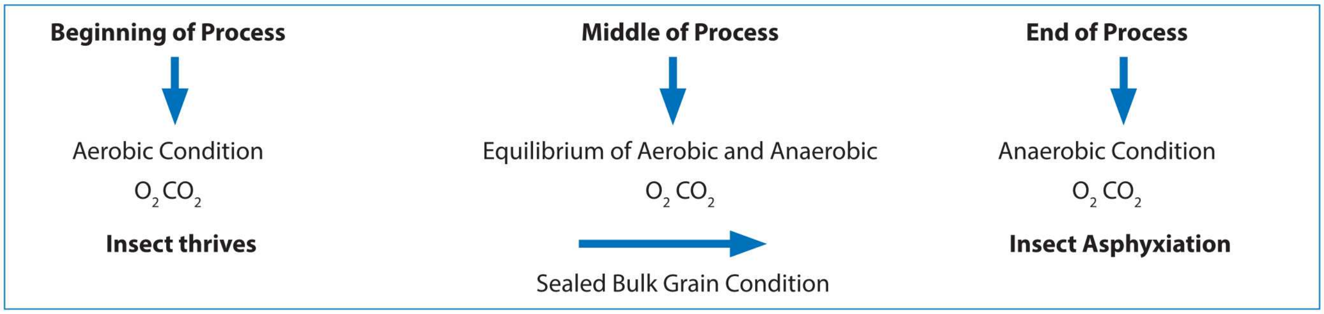


Figure 3: Process of oxygen depletion and carbon dioxide enrichment in hermetic micro environment

Hermetic storage is a technique that involves storing cereals in airtight containers such as polyvinyl chloride (PVC) bags. The process of respiration by grain, fungi, insects, and other microorganisms inside the bag causes depletion of oxygen and a buildup of carbon dioxide, which inhibits further growth of insects and fungi inside the bag (Navarro, 2006; Subramanyam et al., 2012). A gradual decrease in oxygen concentration and subsequent increase in carbon dioxide concentration result in insect mortality inside the container without any application of chemical fumigants. Insect respiration rates and metabolic activities are usually increased at an elevated temperature, causing more rapid depletion of oxygen in hermetic bags, and insect mortality is increased correspondingly (Jayas and Jeyamkondan, 2002). Although different insect species have varying levels of tolerance to a modified atmosphere (Navarro and Donahaye, 2005), a 35% carbon dioxide concentration for a shorter duration is lethal to test insects, even when the oxygen concentration is as high as 15%.

Hermetic storage takes three distinct forms:

Organic-Hermetic Storage relies on the metabolic activity and respiration of insects, microflora, and the commodity itself to generate a modified, non-life-sustaining low-oxygen atmosphere;

Vacuum-Hermetic Fumigation (V-HF): uses a vacuum pump to rapidly create a very low-pressure atmosphere for accelerated disinfestations of non-crushable commodities through asphyxiation; and

Gas-Hermetic Fumigation (G-HF) uses an external gas source (usually carbon dioxide) for crushable commodities, such as dried fruit, prior to shipment.

When the sealed storage is enriched with carbon dioxide or nitrogen and oxygen is depleted, it will lead to the asphyxiation of the entire living organisms in the bulk, who are normally agents of deterioration, and the crops will store well and their quality preserved. The oxygen-depleted atmosphere thus, generated prevents the development of cancer-causing mycotoxins and maintains the moisture level of the commodity regardless of the ambient humidity. The low permeability of the hermetic structure also maintains safe, constant moisture levels in previously dried commodities, regardless of ambient exterior humidity. Hermetic storage for grain reserves frequently uses large flexible plastic enclosures called Cocoons™ (also formerly called Cubes and Volcani Cubes) with a capacity of up to 300 tons for either indoor or outdoor storage.

1.4 Working of Hermetic Storage System

The process of disinfestation starts immediately after the stocking of the grains inside the storage structure as well as the sealing. The air concealed inside the bulk, which is composed of natural air, mainly 78% nitrogen, 21% oxygen, and 0.04% carbon dioxide, will begin to undergo a process. At the beginning of the process, a modified atmosphere is automatically created with a huge percentage of oxygen and less carbon dioxide. As the modified atmospheric condition progresses, it will get to the middle of the process where equilibrium conditions exist, and at the end, where there will be complete oxygen depletion and carbon dioxide enrichment, which will lead to insect asphyxiation, as shown in *Figure 1*. This application has been successfully used for the storage of granular and milled grains, paddy crops, pulses, oil seeds, and varieties of food materials worldwide.

Its major advantage is the prevention of hazards, enormous number of resources spent on labor, and fumigation of stored products using phosphine, methyl bromide (MB), or pesticides or insecticides that may harm potential consumers. Laboratory data has confirmed that organic hermetic storage creates less than 1% oxygen environment after 15 days if stored properly and prevents the production of FFA, which produces rancidity. Its potential in the storage of crops with FFA will be a major breakthrough.

Microflora and Critical Moisture Content

Molds, yeasts, and bacteria make up what we call the microflora population. At elevated humidity, they contribute significantly to the respiration processes within the stored commodities. Most mold populations are aerobic, meaning they need oxygen for their development. Humidity requirements for rapid mold growth of aerobic microflora are within the range of 65% to 85% RH as shown in *Figure 4*. Another term of importance is critical moisture content, which is the level that a commodity's moisture content will reach at a given temperature in equilibrium with 65% RH. At higher levels of moisture content, significant mold growth will take place, except, importantly, when stored in a controlled atmosphere with low O_2 and high CO_2 levels.

Figure 4: Mold affected grains due to high moisture content

1.5 Types of Hermetic Storage Systems

The existence of three different types and several different forms of hermetic storage has to do with meeting different post-harvest storage and transportation needs. The most widely used form of hermetic storage is organic-hermetic storage. These systems are used for medium to long-term storage of conventional grain bags and are commercially available in 5- to 300-ton capacities. They are used for farm, village, district level, or commercial storage of bagged grains or seeds of many different types for periods ranging from a month to, in some cases, several years. The commodities range widely in value, from such high-volume grains as sorghum, wheat, pulses, corn, and rice to expensive commodities such as spices, cocoa, coffee, and various hybrid seeds. A further distinction in hermetic storage types has to do with transportability. Most hermetic storage systems made from flexible food-grade PVC are lightweight and portable when empty, but not portable when full. With the introduction of Super Grain bags in 2001, hermetic storage became possible during transport and subsequent distribution. Major applications at present are for a variety of seeds, coffee, and cocoa beans.

With fumigants, full penetration of the commodity is often a problem; repeated applications are frequently necessary, and fumigants do not prevent losses from rodents or the growth of molds. In addition, insects have developed tolerance to widely used fumigants, and the most popular fumigant, methyl bromide, is being phased out. Refrigeration and freezing, in the case of seeds, remain widely used but consume significant energy and require special facilities. Hermetic storage as compared to older storage processes is still relatively new and not as well known, but its use in some 20 countries and its increasing acceptance in particular niche markets where the need for better storage techniques is urgent are causing rapid growth.

This grain storage study using the hermetic cocoon has been carried out in the Department of Processing and Food Engineering of Punjab Agricultural University, Ludhiana. A 5-ton capacity cocoon store along with a carbon dioxide and oxygen analyzer were procured from Grain Pro Philippines. The wheat and moong beans, 40 quintals and 10 quintals each, were procured from PAU farms at Ludhiana and KVK Moga, respectively. Grains of wheat, paddy, and canola, as well as dry fruits like almond, cashew, and raisins were also procured in lesser quantities (15 kg) for lab-scale study in plastic and jute bags or containers for studying its respiration under ambient storage at different moisture contents.

1.6 Installation and Loading of Cocoon

Gas-Hermetic Fumigation is a flood protected gas-tight storage designed for insecticide-free fumigation specifically carbon dioxide fumigation to immediately control any infestation and safe storage of durable agricultural commodities. G-HF are either standard size or custom-made to enclose stacks of boxed, crated or bagged agricultural commodities. It is made of flexible UV-resistant Polyvinyl Chloride that is resistant to rodents and has low permeability to oxygen (O_2), and moisture as shown in *Figure 5*.

G-HF is able to withstand floods below zipper line and can maintain the gas resulting from the respiration of insects and commodity; low oxygen and high carbon dioxide levels will control infestation and mold growth.

1.7 Variation in Gaseous Concentration during Storage in Cocoon

The cocoon after loading of grains was flushed with carbon dioxide from the external source. The gas was flushed twice in two days at 7.5 kg per charge. During the first charge, the concentration of carbon dioxide was measured by the carbon dioxide analyzer provided, which indicated a level of 43%. This 43% concentration of carbon dioxide corresponds to an oxygen level of approximately 11.5% (as per the manual provided). At such a level of oxygen concentration, the lesser grain borer comes under stress and usually stops feeding on food grain. During continued exposure to such a gaseous environment for two weeks, all the insects present get killed. Since we have kept four jars containing a heavy infestation of insects (100 insects per 500 gins of wheat grain), the second charge of the same amount was given after 24 hours to ensure a higher concentration of carbon dioxide and ensure that gas penetrates within the porous intergranular spaces. The carbon dioxide analyzer indicated a value of 88% concentration for carbon dioxide. This concentration of carbon dioxide gas corresponds to an oxygen concentration of 2.5% as shown in *Figure 6*. In such a gaseous environment of ultra-low oxygen, all the microflora, including aflatoxins, get inactivated. The plot in Figure 6 indicates that carbon dioxide concentration is reduced slightly over 150 days to reach a value of 59%, which

Figure 5: Setting up of cocoon bag on site and sampling from cocoon for evaluation

is well above the threshold of 35%. This fall could be due to the frequent measurement of gases from inside the cocoon and also to the drawl of grain samples. During the month of January 2023, a squirrel cut the cocoon near its bottom, which was sealed, and carbon dioxide gas was again flushed inside the hermetic cocoon store.

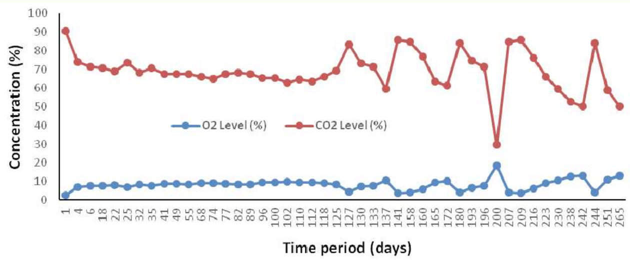


Figure 6: Gaseous composition variations inside the cocoon with time after flushing carbon dioxide gas

1.8 Effect of Gaseous Composition on Grain Deterioration during Storage

Grain deterioration is related to the respiration of the grain itself and of the accompanying microorganisms. Breathing is a carbohydrate oxidation (burning) process that produces carbon dioxide, water vapor, and thermal energy. Typical carbohydrates (such as starch) and burning (aerobic respiration) are expressed by the general equation

$$C_6H_{12}O_6 + {}_6O_2 = {}_6CO_2 + {}_6H_2O + \text{heat}$$

Spoiled grain, in comparison with good grain, releases larger quantities of heat and carbon dioxide. This depends on various factors, such as the grain moisture content (MC), temperature (T), and the and the presence of molds or insects. Temperature monitoring of grain in storage is a common method to detect the spoilage of grain because organisms release a large amount of heat in the spoilage locations. In grain storage, all living organisms release carbon dioxide, and the quantity of released carbon dioxide is closely correlated with their metabolic rate. Fungi and insect activity, together with the condition of the grain, may be effectively monitored by following the carbon dioxide concentration changes in stored grains.

The hermetic store, which had 50 quintals of food grain (wheat and moong), was opened after 12 months to physically monitor the changes in the grains. *Figure 7* and *Figure 8* depict the condition of stored grains. The grains have been in sound condition without any insect activity. There were no visible traces of any powder when grains were allowed to fall freely, indicating no insect activity during the storage period. The

Table 3: Effect of Moisture Content and Temperature on respiration of wheat and moong

Moong Moisture Content (%)	Temp. (° C)	CO_2 Concentration (%) after 24 h	O_2 Concentration (%) after 24 h	CO_2 Concentration (%) after 48 h	O_2 Concentration (%) after 48 h
15	8	10.9	12.4	4.1	19.80
20	8	17.3	5.83	8.3	11.70
25	8	15.3	2.81	5.6	8.83
15	32	21.8	1.60	20.9	2.00
20	32	30.5	1.00	24.5	2.52
25	32	28.8	0.18	25.4	1.38
15	42	19.4	2.80	19.6	3.13
20	42	34.3	0.12	35.3	0.00
25	42	32.5	0.19	29.1	0.41

Wheat Moisture Content (%)	Temp. (° C)	CO_2 Concentration (%) after 24 h	O_2 Concentration (%) after 24 h	CO_2 Concentration (%) after 48 h	O_2 Concentration (%) after 48 h
15	8	1.60	20.6	1.32	20.6
20	8	15.8	8.07	12.8	7.09
25	8	18.0	5.61	16.4	5.23
15	32	3.8	17.4	5.8	15.60
20	32	19.7	0.01	21.6	0.50
25	32	23.4	0.01	25.7	0.05
15	42	3.0	17.4	4.0	16.5
20	42	19.9	2.65	24.8	2.20
25	42	33.7	0.01	38.9	0.03

(a) (b) (c) (d)

Figure 7 (a, b, c, d): Condition of grain after one year of hermetic storage

one-liter capacity jar filled with sound grains and inoculated with a heavy infestation of lesser grain borer also did not have any living insects in the grain. There was some powder at the bottom of the jar along with dead insects, indicating that a proper concentration of carbon dioxide and oxygen killed the insects and stopped other degradative activities. The grains were also free from any uncharacteristic smell or odor. Thus, it is concluded that gas hermetic fumigation (GHF) is a safe and organic way to safely store food grains without exposure to hazardous chemical poisons for a long period of time, in excess of one year.

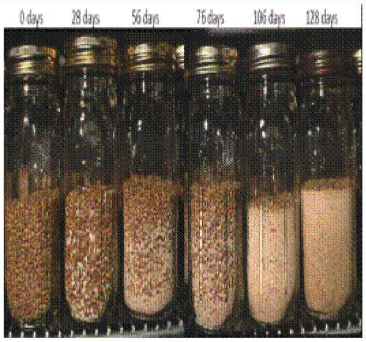
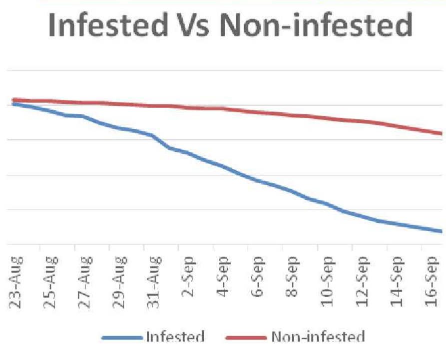


Figure 8: Condition of wheat grains stored at ambient condition in four months

The oxygen concentration depletes at a faster rate as presented in *Table 4.* It indicates the presence of insect activity and control of insect activity begins when the its concentration goes down to 10% from 21% While slow consumption of oxygen in the stored grains represent the absence of any insect or microbial activity.

Table 4: Variation in gaseous concentration in infested and non-infested grains

DAY	O2 CONCENTRATION	
	Infested	Non-infested
1	20.20	
2	19.80	20.80
3	19.20	20.70
4	18.60	20.60
5	18.40	20.50
6	17.50	20.40
7	16.80	20.30
8	16.40	20.20
9	15.70	20.10
10	15.40	20.00
11	13.90	19.90
12	13.20	19.70
13	12.10	19.60
14	11.20	19.50
15	10.10	19.30
16	9.20	19.00
17	8.50	18.80
18	7.70	18.60
19	6.50	18.40
20	5.90	18.20
21	4.80	17.90
22	4.10	17.70
23	3.40	17.40
24	3.00	17.00
25	2.50	16.70
26	2.10	16.20
27	1.70	15.80



1.9 Conclusion

Agricultural products, including grains, are living, biologically active entities with physiological functions. Current methods of safe storage of agricultural produce focus more on modifying storage environmental conditions like temperature and relative humidity with little consideration of respiration requirements. The degradation of grain quality, insect infestation, and microbial activities during storage can be checked by careful control over the surrounding gaseous composition, especially carbon dioxide and oxygen concentrations. Maintaining oxygen levels below 13% for 15 days (maintain >35% CO_2 concentration within 15 days) or maintaining oxygen levels below 9% within 10 days (maintain >55% CO_2 concentration within 10 days) completely eliminates all life stages of insects. The oil-bearing material, especially rice bran, groundnuts, etc., can be safely stored without any increase or production of free fatty acids during storage. Further germination of the stored grains remains unaffected. Wheat (Variety Pb 550, 40 quintals) and green gram called moong (Variety SML 832, 10 quintals) have been stored in different storage bags, and their quality was assessed throughout the 18-month storage period. Variation in important grain storage parameters such as moisture content, bulk density, thousand-grain weight, grain damaged percentage, and germination rate is limited, which is responsible for safe grain storage for long periods. A cocoon bag is a viable grain storage system that maintains the quality and freshness of stored products without the use of any hazardous chemicals. The system can be installed on farm fields as well. These works can be used to develop effective storage strategies for maintaining the quality of wheat during storage, which is essential for food security and economic sustainability.

Conflict of Interest/Acknowledgement

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