

## Grain Storage Management in India

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### Abstract

India's grain production has steadily increased due to advances in technology, but post-harvest loss is constant at 10%. Losses during storage, accounts for around 6% of the total losses as proper storage facilities are not available. In India, food grains are stored using traditional structures by small farmers. The surplus grains are stored with government agencies like: Food Corporation of India (FCI), Central and State warehousing Corporations. The commonly used storage method is Cover and Plinth (CAP) storage, which is economical but loss of grains is inevitable. Very few scientific storage structures like silos are available with these agencies. The government is taking initiatives now in building silos for long-term safe storage of grains since we do not have enough storage capacity as of now. Drying of harvested grains to safe moisture levels will reduce losses to a greater extend. However, very less literature is available on behaviour of grains after harvest for Indian climatic conditions. Therefore, there is a need for research to develop management guidelines for safe storage and drying to ensure quality management of stored grains.

### Keywords

Post-harvest loss  
Storage  
Cereals  
Drying  
Guidelines

## INTRODUCTION

Agriculture is an important sector of the Indian economy, accounting for 14% of the nation's GDP, about 11% of its exports, about half of the population still relies on agriculture as its principal source of income and it is a source of raw material for a large number of industries. During 2011-12, India reached 259.32 million tonnes of food grain production. (State of Indian Agriculture, 2012-13). Population explosion, shrinkage of cultivable land along with grain losses is a major problem in a developing country like India.

Food grains undergo a series of operations such as harvesting, threshing, winnowing, bagging, transportation, storage, and processing before they reach the consumer, and there are appreciable losses in crop output at all these stages. The post-harvest

losses in India amount to 12 to 16 million metric tons of food grains each year, an amount that the World Bank stipulates could feed one-third of India's poor. The monetary value of these losses amounts to more than Rs. 50,000 crores per year (Singh, 2010).

Ramesh (1999) reported that high wastage and value loss are due to lack of storage infrastructure at the farm level. The losses during storage are quantity losses and quality losses. Quantity losses occur when insects, rodents, mites, birds and microorganisms, consume the grain. Infestation causes reduced seed germination, increase in moisture, free fatty acid levels, and decrease in pH and protein contents etc. resulting in total quality loss. Quality losses affect the economic value of the food grains fetching low prices to farmers (Ipsita et al., 2013).

The estimated postharvest losses at the farm level are 3.82 kg/ q for rice and 3.28 kg/q for wheat in 2003-2004 (Basavaraja et al., 2007). Post-harvest losses account for 9.5% of total pulses production. Among post-harvest operations, storage is responsible for the maximum loss (7.5%). Processing, threshing and transport cause 1%, 0.5% and 0.5% losses, respectively (Birewar, 1984). Among storage losses, pulses are most susceptible to damage due to insects (5%) compared to wheat (2.5%), paddy (2%) and maize (3.5%) (Deshpande and Singh, 2001).

Storage losses also vary geographically depending on the type of storage structures used. A study by Usha and Mohan (2007) indicated that in Coimbatore the storage loss estimated at the farm level indicated highest loss in black gram (40 %) followed by green gram (30 %), cowpea ( 30 %), bengal gram (20 %), mochai (20 %) and red gram (10 %). The predominant reason for this is the storage of pulses in gunny bags or baskets. The much-deserved attention falls on minimising the magnitude of post-harvest losses in order to cope with current and future demand and attain a state of food security.

### PURPOSE OF STORAGE

Grain storage is a component in the grain marketing supply chain that evens out fluctuations in the supply of grain from one season, usually the harvest season to other seasons, and from one year of abundant supply and releasing to lean years. Grain storage may be at farm, trader, and commercial or at government levels (Mushira, 2000)

- i. At the farm level, storage is normally inter-seasonal and helps household to ensure food supplies for the farmer and the family, cash or barter exchange and for seed.
- ii. At trader level, grain storage is for very limited time – over a period of

few days or weeks. The traders buy and sell quickly to make a profit.

- iii. Commercial storage, used by millers and co-operatives; the stock is hold for limited periods to meet demands for their needs or for their urban clients (Hall, 1980)

Government involvement in grain storage, through its own special departments, agencies or government grain marketing boards focuses on the intervention in the staple grain market to balance national supply and demand over a time. The purposes being to create a national food reserve especially for the urban population, national food security reserves, stimulation of productivity, price stabilisation and for political consideration such as placation of sectional interests (Proctor, 1994).

### STORAGE STRUCTURES IN INDIA

Grains in India, is stored at farmers, traders and industrial levels. Appropriate technology for handling and storage of pulses are been developed in all parts of the globe. Grain storage structure are a collection of devices for grains used after harvesting to store grains safely until their consumption or transport elsewhere (Tiwari et al., 2012). Traditional storage practices do not guarantee protection against major storage pests of staple food crops, leading to higher percentage of grain losses, particularly due to post-harvest insect pests and grain pathogens (Tefera et al., 2011). Grain storage structure are classified as follows:

#### *Conventional Structures*

In India, around 60-70% of food grains produced is stored at home level in indigenous storage structures (Kanwar and Sharma, 2003). The percentage of overall food crop production retained at the farm-level and the period of storage is largely a function of farm-size and yield per acre,

family-size, consumption pattern, marketing pattern, form of labour payment, credit availability and future crop expectations (Greeley, 1978). Farmers use locally available raw materials to develop traditional structures differing in design, shape, size and functions. The materials used include paddy straw, wheat straw, wood, bamboo, reeds, mud, bricks, cow dung etc. Grains can be stored indoors, outdoor or at underground level (Channal et al., 2004). These structures made of bamboo, straw and other plant materials, allow free flow of air but causes insect infestation and damage by rodents (Karthikeyen et al., 2008). The different conventional storage structures in use are:

- Straw storage structures
- Bamboo/Reed storage structures
- Masonary storage structures
- Earthen storage structures
- Underground storage structures

Earthen pots and bamboo baskets are the most commonly used storage device, which is available with almost every household mainly for short-term storage, known by different vernacular names like Paanai and Urai in Tamil, Kulhi and Chabri/Peru in Himachal Pradesh. In the southern parts of India, grains are stored in tall mud pots or bins popularly called Kuthir, made up of clay soil and plant fibres. The height of the bin ranges from 1-3 m (Sundaramari et al., 2011). Kodambae and Mara thombarai are wooden structures constructed in the backyard of farm/home with a holding capacity of 1000 kg. (Karthikeyen et al., 2009).

In Himachal Pradesh, rectangular mud storage structures called Kothi and Kuthla are used to store grains like wheat, maize, paddy. These structures are kept about 30 cm high from the floor so that moisture does not affect it. Tunn is a type of wooden

structure fixed in the wall and partitioned into two for storage of different grains. The life of Tunn is about 40-50 years; grains remain safe in these structures for about 4-5 months (Kanwar and Neetu, 2006).

The Adi tribes of Arunachal Pradesh with their years of wisdom have been using an indigenous method of rat proof granary called Nahu. Use of stone pad at the bottom, wooden plate at the middle and airtight compartment at the top makes it a unique and innovative storage structure. Capacity of a Nahu varies from 5.0–8.0 tonnes depending upon the size of land holding of the farmer (Sarangi et al., 2009).

The tribal people of Koraput district of Orissa have their own indigenous way of storing crop seeds and grains called Dhoosi and Khaniki. Dhoosi is made of long straw rope twined spirally (Arunachalam et al., 2006). Garo tribes of Meghalaya, use grain storage structures made of thatch grass, bamboo, and wooden poles (De and Sarangi, 2006).

In Punjab, square shaped structures are constructed with mud or with bricks and cement with an outlet at the ground level called Bukhari. The upper portion is plastered with mud and straw. The structure covered with polythene sheet prevents moisture loss. Bharola is an egg shaped earthen storage bin. It had opening at top and was a portable structure. Its storage capacity was up to 40-80 kg (Dhaliwal and Singh, 2010).

#### *Improved grain storage structures*

Pusa bin is one of the important improved methods of storage developed by IGSMRI (Indian Grain Storage Management and Research Institute). One design consists of the floor and lower part of the walls burnt with a layer of plastic sheeting inserted between two bricklayers. This protects the grain from moisture and prevents air from entering. A separate tached rook around on

top provides protection from sun and rain (Proctor, 1994). The other design of Pusa bin is made of double walls of masonry each 4.5 inch thick with polythene sheeting in between. The outer layers have steel reinforcement and the sides are plastered with cement (Jelle, 2003).

PAU bin is a galvanized metal iron structure designed by Punjab Agricultural University. Its capacity ranges from 1.5 to 15 quintals (Acharya and Agarwal, 2004). Another improved structure known is Hapur Tekka. It is a cylindrical rubberised cloth structure supported by bamboo poles on a metal tube base. A small hole in the bottom facilitates grain removal (Jelle, 2003).

#### *Commercial grain storage structures*

In India, surplus food grains are accumulated in the warehouses owned by the Food Corporation of India (FCI), the Central warehousing corporation (CWC) or the State warehousing corporation SWCs. They have a network of storage depots strategically located all over India (Singh, 2010). These depots include silos and an indigenous method developed by FCI, called Cover and Plinth (CAP).

CAP storage is a term given to storage of food grains in the open with adequate precautions such as rat and damp proof plinths, use of Dunnage and covering of stacks with specially fabricated polythene covers etc. FCI has 30.52 million tonnes (owned & hired) of storage capacity in over 1820 godowns all over India (Debashis et al., 2006). CAP Storage (Cover and Plinth) involves the construction of brick pillars to a height of 14" from the ground, with grooves into which wooden crates are fixed for the stacking of bags of food grains. The stacks are covered with 250 micron LDPE sheets from the top and all four sides. Food grains such as wheat, maize, gram, paddy, and sorghum are generally stored in CAP (cover and plinth) storage for 6-12 month periods. It is the most economical storage

structure and is being widely used by the FCI for bagged grains. These structures can be fabricated in less than 3 weeks. It is an economical way of storage on a large scale (Mishra, 1985).

Sawant (1994) described the modern grain storage methods such as Godown storage and silo systems for reducing storage losses. He compared Godown storage and silo storage with respect to functional, structural and financial aspects, which revealed the superiority of silo system. He found galvanized iron corrugated silos advantageous.

There are four silos in India i.e. Calcutta, Madras, Bombay and Hapur-Ghaziabad. These silos are made of either corrugated or flat galvanized steel sheets and corrugations are kept horizontal while in flat ones, the thickness of the sheet depends on the capacity of silos. The Hapur silo in Uttar Pradesh is about 6.7 m in diameter and 23 m in height having a capacity of 500 tonnes. There is a head house having a diameter of 8.5 m and height of 47.3 m. Head houses contain grain elevators, auxiliary tanks, grain cleaning and disinfecting equipment, grain drier and weighing machines. A drying arrangement for reduction of moisture content is also provided. There are provisions for recording temperature fluctuations in the silos aeration and fumigation. It is the only modern storage structure with the government (<http://hapur.nic.in/fcisilo.htm>)

The Government of Punjab, India's leading agricultural state, turned to IFC to structure a pilot public-private partnership to manage storage. LT Foods, a leading exporter of basmati rice with a strong distribution network, have built a modern, temperature-controlled steel grain silos with a capacity of 50,000 metric tons. The Government of Punjab may expand the program, adding as much as 2.5 million metric tons of capacity to its grain storage system.

(<http://documents.worldbank.org/curated/en/2011/10/16254577/india-punjab-silos>).

## FACTORS INFLUENCING SAFE STORAGE

**Table 1.** List of abiotic and biotic factors

Abiotic factors	Biotic factors
<ul style="list-style-type: none"> <li>• moisture content and temperature</li> <li>• storage period</li> <li>• intergranular atmospheric composition</li> <li>• types of storage structure</li> </ul>	<ul style="list-style-type: none"> <li>• physical seed characteristics</li> <li>• microorganisms</li> <li>• insects and mites</li> <li>• birds and rodents</li> </ul>

(Source: Mills, 1996)

Strong correlation exists between the biotic variables and their abiotic environment. The abiotic variables influence the presence and development of biotic variables (Sinha 1973; Wallace et al., 1983) and the improper interaction among biotic and abiotic variables causes grain deterioration.

Bacteria, insects, moulds and mites are responsible for losses in stored grain affects temperature and moisture of grains. The occurrence and numbers of stored grain insect pests are directly related to geographical and climatic conditions (Srivastava, 1985). Most of the insect species have remarkably high rates of multiplication and, within a season, they destroy 10-15% of the grain and contaminate the rest with undesirable odors and flavors. Insect pests also play a pivotal role in transportation of storage fungi (Sinha and Sinha, 1990). The survival and reproduction of biological agents in grain is dependent largely on the temperature and moisture levels (White, 1995; Wilson, 2013).

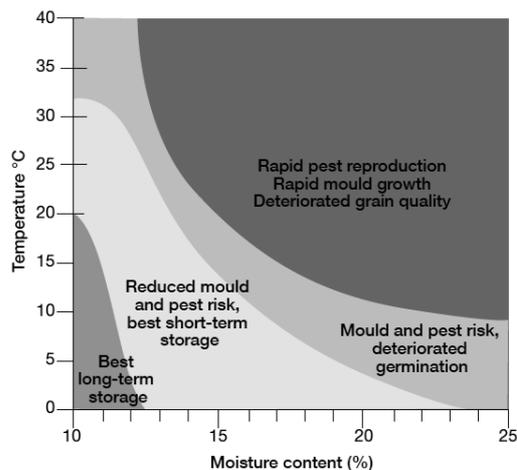
The focus of safe grain storage is to minimise losses during storage. Grain must be stored safely to meet the quality and quantity requirements meant for the various end uses. The factors affecting safe storage are broadly classified as abiotic factors and biotic factors (Table 1).

### *Moisture and Temperature*

The primary factors influencing spoilage of stored grain are moisture and temperature (Figure 1). Early harvesting as the potential to increase yield due to, higher moisture levels. Nevertheless, higher moisture content increases the risk of degrading postharvest quality and the grain needs to be stored carefully. When the moisture and storage temperature exceeds a particular level, microflora, mites will multiply, and the grain will spoil quickly (Wallace and Sinha, 1962).

In moist and warm grain, insects, mites and fungi can increase rapidly and produce moisture, heat and carbon dioxide by respiration, which further leads to deterioration of the grain bulk (White and Sinha, 1980). The stored grains maintained at a sufficiently low moisture level can be stored for many years without any significant loss in quality. Storage conditions had a significant effect on important nutritional values of stored rice, wheat and maize; and the change was

severe at elevated storage temperatures (Zia-Ur-Rehman, 2006).



**Fig1.** Effects of Temperature and moisture on stored grain (Adapted from CSIRO Ecosystems Sciences)

For most stored-product pests, the lower developmental threshold is approximately 18°C and the optimum development range is approximately 25-35°C. (Illelyi et al., 2007). Field peas and lupins stored at temperature of 35°C deteriorate at faster rate compared to high moisture content grains stored at 27°C. Grains stored at 20°C at 13% and 14% moisture content for lupins and field peas are ideal for storage with no loss in grain viability and mould growths during 10 months storage period (Cassells and Armstrong, 1998). Brown beans can be stored safely as long as 370 weeks at low moisture content (11 %) and low storage temperature (5°C), whereas grains stored at high moisture (23 %) and storage temperature (25°C) may last less than a week

(<http://www.grainscanada.gc.ca/storage-entrepose/aafc-aac/pfsg-pgef-8-eng.htm>).

Grain at typical harvest temperatures of 25–30°C and moisture content greater than 13–14 per cent provides ideal conditions for mould and insect growth. Therefore, cool and dry grains can be stored longer by preventing deterioration (Talbot, 1999).

### Stored product Insects

The major insect pests of stored grain are *Rhyzopertha dominica* (lesser grain borer), *Oryzaephilus surinamensis* (saw toothed grain beetle), *Sitophilus oryzae* (rice weevil), *Trogoderma granaria* (khapra beetle), *Tribolium castaneum* (red flour beetle), *Callosobruchus maculatus* (pulse beetle) and *Plodia interpunctella* (Indian meal moth). Insects infest the grains in the field, during handling or storage (NRI, 1996). Insect also causes secondary infestation during pulse storage, and may cause total loss within three months (Singh and Jackai, 1985; Metcalf and Metcalf, 1993).

Temperature management is one of the most promising insect management tools. Stored-product insects can live at temperatures from 8 to 41°C and inter-granular relative humidities from 1% to 99% (Mullen and Arbogast, 1979). Studies on control of stored product insects by low and high temperature has resulted in promising results (Fields, 1992; Loganathan et al., 2011).

### FUTURE RESEARCH AREAS

Today, there is increasing pressure on the grain-handling industry to manage a broader range of parameters involved in grain quality maintenance. Management protocols for quality management based on safe storage time and drying are the thrust areas, which needs focus right now.

#### Drying

Generally after harvesting, seeds must be dried to a safe moisture level before it enters the storage structure. According to Bala (1997), drying the grain has the following advantages:

- It extends the available harvest period;

- It reduces the field loss by promoting earlier harvest;
- It reduces the risk of spoilage in storage;
- It improves the marketability and acceptability of the grain;
- It eliminates necessary swathing by obtaining dry grain.

Harvesting of grains at high moisture increases the harvest period allowing a longer time for harvesting even when manual labour is scarce. Wet grain reduces shattering losses in the field. Many times, frequent rains force farmers to harvest “wet” grains. Therefore, artificial removal of moisture from grains is a necessity on all farms (Pabis et al., 1998).

Until now, various drying methods have been used to dry seeds. The most popular method of drying used by farmers is sun drying; solar energy is considered more applicable to low-temperature in-storage drying systems, which has gained more importance in the last decade for drying grain. Apart from solar drying, grains can be dried using air at near-ambient or high temperatures resulting in “near-ambient air” or “hot air” drying (Jayas and White, 2003). Near ambient or heated air is used for drying grains in mechanical drying systems. The choice of near ambient or heated air drying, and rate of drying depend on the available time to dry the grain before spoilage occurs. The available drying time varies from grain to grain depending on the grain condition and weather patterns. In tropical developing countries like India, a large proportion of the crop is harvested under humid and warm climatic conditions and most small farmers lack equipment for drying grains.

Scientists in India have come up with a few notable drier models, which were used, by small and big group of farmers. A Small-Capacity Dryer was developed at G.B. Pant University of Agricultural and Technology,

Pantnagar (Singh et al. 1982). The Cup and Cone Dryer for Paddy Drying is somewhat different design of dryer has been tested at the old Paddy Processing Research Centre (PPRC) at Thirvarur in India (Pillaiyar et al. 1982). A Recirculating batch dryer has been developed at IIT, Kharagpur (Kachru et al. 1986).

Usually no proper guidelines for optimum drying of grains are available for most of the crops produced in India. They are usually over dried resulting in loss of quality and quantity. In addition to this, storage facilities receive tonnes of grains, which need to be dried before storage. In order to develop bulk dryers, mathematical models need to be developed (Jayas and White, 2003). Mathematical models, if based on the principles of physical and biological sciences and properly validated, can be used to study the effect of various parameters such as weather, grain condition, and size, shape, and material of the storage structure on the distribution of temperature, moisture, and gases (Jayas et al., 1994). If economic and social considerations are suitable this transferability can make the models globally rather than locally applicable as is expected of experimental studies (Jayas, 1995). This opens up newer areas of research for developing dryers and guidelines for proper drying.

#### *Safe storage guidelines*

Safe storage of grain is the time during which the grain can be stored safely without any significant loss in its quality and quantity. The farmer can keep the fresh grain only for a specific period to do post-harvest conditioning operations (Sathya et al., 2009). Storage period varies with respect to grain moisture content and the temperature. Guidelines must be developed for all the common grains at all possible moisture contents and temperatures to provide farmers information on the number of days available for completion of post-

harvest operations before grain deterioration occurs (Karunakaran et al., 2001).

According to Jayas (1995), seed maturity and condition; moisture content, storage temperature, storage time, molds, insects, mites, dockage, climate; and the storage and handling methods are the factors that affect the quality of the stored grain. Muir (2001) reported that rate of germination, fat acidity value (FAV), mould growth, physical appearance and nutritive values are the factors, all or some of which need to be monitored continuously to assess the condition of the stored grain.

Many countries like Canada and Australia have developed storage guidelines for grains like Durum Wheat (Nithya et al., 2011), Chickpeas (Cassells and Caddick, 2002), Canola and Rye (Sathya et al., 2009). Very limited data on deterioration of Indian crops is available. Hence, there is a need to develop safe storage guidelines to reduce storage losses.

#### *Good storage practices*

When grains are stored in large bulks without aeration they will be indirectly affected by the weather. The grain bulk will retain the heat it had at harvest in the centre of the bulk (Jayas et al., 1994) and reflect external ambient temperatures near the periphery. Grain can remain warm (15–25°C) throughout the winter (outside temperatures can be as low as 20 to 30°C) and air convection currents carry moisture to the top-centre of the bulk which can result in localized grain spoilage (Jayas, 1995; Sinha et al., 1973).

Hot spots in grain bulks often have moisture sufficient to support the mould growth even though the average moisture content of the bulk is very low or dry, once the mould spores germinate, they will produce moisture for their further development and mycotoxin production (Abramson, 1999). Hence, guidelines for good storage practices

are in need as outlined by White (2000) which includes the following procedures:

- Prepare the bin, before storing the new crop: sweep or vacuum the floor and walls; burn or bury sweepings that contain spoiled or infested grain; seal cracks to keep out flying insects from outside, rain, and snow; and spray the walls and floors with a recommended insecticide.
- Install an aeration system to reduce temperature gradients and moisture condensation.
- Dry tough or damp crops soon after harvest as they are more likely to heat and become infested with insects and mites than dry (straight-grade) crops, then cool after drying.
- Examine stored crops every 2 weeks for signs of heating or infestation; either check temperatures, carbon dioxide levels, and insect activity by traps, or probe and screen samples.
- Move heated or infested crops into another bin if outdoor temperatures are sufficiently cold to break up hot-spots and control infestation.
- Check the top of binned crops and remove snow, if present, before a crust of mold develops.
- If an insect infestation occurs and aeration is not available, seal the bin and fumigate the grain with phosphine gas.

#### **CONCLUSION**

Grain storage capacity in India cannot meet the storage requirement for buffer and operational stocks, public distribution system and farm level storage. Storage is an important link in the entire procurement and distribution system of food grains, produced seasonally but consumed all the year round. Therefore, storage facilities in India need to be strengthened by supplying them with the

much-needed scientific storage and drying equipment's. Setting up a community drying-cum-storage complex as suggested by Ojha (1984) has great potential, as it will help to reduce losses and to provide a better return for the grower. They will aid in enhancing India's ability to meet its food security objectives by increasing storage capacity, reducing losses, and increasing the efficiency of purchasing and distributing grain.

For safe and scientific storage, a lot of research is required to develop management protocols on grain storage, drying and quality management in silos for our climatic conditions. It will be useful to store grains for FCI, CWC and SWCs in their storage facilities. Importance should be given to carefully selection the storage site, storage structure, implementation of Integrated Pest Management (IPM), ensure proper aeration of grains followed by regular inspection of grain stock.

### Reference

- Abramson, D., Hulasare, R., White, N. D. G., Jayas, D. S., and Marquardt, R. R. 1999. Mycotoxin formation in hulless barley during granary storage at 15 and 19% moisture content. *Journal Stored Products Research*, 35: 297-305.
- Acharya, S.S. and Agarwal, N.L. 2004. *Agricultural Marketing in India*, New Delhi. 114p.
- Arunachalam, V., Chaudhury, S.S., Sarangi, S.K., Ray, T., Mohanty, B.P., Nambi, V.A., and Mishra, S. 2006. *Rising on Rice: The Story of Jeypore*, M S Swaminathan Research Foundation, 3rd Cross Street, Institutional Area, Taramani, Chennai -600 113, INDIA.
- Bala, B.K. 1997. *Drying and storage of cereal grains*. Enfield, NH: Science publishers Inc. 64p.
- Basavaraja, H., Mahajanashetti, S.B., and Udagatti, N.C. 2007. Economic Analysis of Post-harvest Losses in Food Grains in India: A Case Study of Karnataka, *Agricultural Economics Research Review*, 20: 117-126.
- Birewar, B.R. 1984. *Post-Harvest Technology of Pulses, Pulse Production - Constraints and Opportunities*. Oxford and IBH Publishing Co., New Delhi, India, 425-438.
- Cassells, J., and Caddick. 2002. *Stored Grain Research Laboratory, CSIRO Entomology*, 206-214.
- Cassells, J., and Armstrong, E. 1998. *CSIRO Stored Grain Research Laboratory*.
- Channal, G., Nagnur, S. and Nanjayyanamath, C. 2004. *Indigenous grain storage structures*. *Leisa India*, 6(3):10.
- De, L.C., and Sarangi, S.K. 2006. In: *Trends in Organic farming by SS Purohit and D Gehlot*. Agrobios Publishing, Jodhpur, 435 p.
- Debashis, B. Francis Kulirani, B. Datta-Ray, B. 2006. *Agriculture, Food Security, Nutrition and Health in North-East India*. Mittal Publications, New Delhi. 269p.
- Deshpande, S.D. and Singh, G. 2001. *Long Term Storage Structures in Pulses, National Symposium on Pulses for Sustainable Agriculture and Nutritional Security*, Indian Institute of Pulses Research, New Delhi, 17-19.

- Dhaliwal, R.K. and Singh, G. 2010. Traditional food grain storage practices of Punjab. *Indian Journal of Traditional Knowledge*, 9 (3), 526-530.
- Fields, P.G., 1992. The control of stored-product insects and mites with extreme temperatures. *Journal of Stored Products Research*, 28: 89-118.
- Greeley, M. 1978. Recent Indian experience with farm-level food grain storage research. *Food Policy*, 39-49.
- Hall, D.W. 1980. Handling and storage of food grains in tropical and subtropical areas. FAO, Rome, Italy, 350 p.
- Ileleji, K. E., Maier, D. E., and Woloshuk, C. P. 2007. *Journal of Stored Products Research*, 43: 480-488.
- Ipsita, D., Girish, K., and Narendra, G.S. 2013. Microwave Heating as an Alternative Quarantine Method for Disinfestation of Stored Food Grains. *International Journal of Food Science*, 13.
- Jayas, D. S., Alagusundaram, K., Shunmugam, G., Muir, W. E., and White, N. D. G. 1994. Simulated temperatures of stored grain bulks. *Canadian Agricultural Engineering*, 36(4): 239-245.
- Jayas, D. S., Alagusundaram, K., Shunmugam, G., Muir, W. E., and White, N. D. G. 1994. Simulated temperatures of stored grain bulks. *Canadian Agricultural Engineering*, 36(4), 239-245.
- Jayas, D. S., White, N. D. G., and Muir, W. E. 1995. *Stored grain ecosystems*. New York, NY: Marcel Dekker, 757p.
- Jayas, D.S. 1995. Mathematical modeling of heat, moisture, and gas transfer in stored grain eco-systems. In *Stored-Grain Ecosystems*, ed. D.S. Jayas, N.D.G. White and W.E. Muir, New York, NY: Marcel Decker Inc. 123-167.
- Jayas, D.S. and N.D.G. White. 2003. Storage and drying of grain in Canada: Low cost approaches. *Food Control*, 14: 255-261.
- Jelle, H. 2003. The storage of tropical agricultural products. Agromisa Foundation, Wageningen, 60p.
- Kachtu, R.P., Srivastava, P.K., Bisht, B.S., and Ojha, T.P. 1986. Hundred bankable post harvest equipment developed in India. Central Institute of Agricultural Engineering (CIAE), Bhopal, 278 p.
- Kanwar, P., and Sharma, N. 2003. An insight of indigenous crop storage practices for food security in Himachal Pradesh, In: *Food and nutritional security, agrotechnology and socioeconomic aspects*, edited by Kanwar, S.S., Parveen, K., Sardana, and Satyavir. (SAARM, India), 175-179.
- Kanwar, P., and Neetu, S. 2006. Traditional storage structures prevalent in Himachali homes. *Indian Journal of Traditional Knowledge*, 5(1): 98-103.
- Kartikeyan, C., Veeraraghavantham, D., Karpagam, D., and Firdouse, S.A. 2009. Traditional storage practices, *Indian Journal of Traditional Knowledge*, 8(4): 564-568.
- Karunakaran, C., Muir, W.E., Jayas, D.S., White, N.D.G., and Abramson, D. 2001. Safe storage time of high

- moisture wheat. *Journal of Stored Product Research*, 37:303-312.
- Loganathan, M. Jayas, D.S. Fields, P.G. White, N.D.G. 2011. Low and high temperatures for the control of cowpea beetle, *callosobruchus maculatus* (F.) (coleoptera: Bruchidae) in chickpeas. *Journal of Stored Product Research*, 47: 244-248.
- Metcalf, R.L., and Metcalf, R.A., 1993. *Destructive and Useful Insects: Their Habits and Control*. R.R. Dinnelley and Sons Company, Chicago, Illinois. 43p.
- Mills, J.T. 1996. Quality of stored cereals. In *Cereal Grain Quality*, ed. R.J. Hendry and P.S. Kettlewell, London, UK: Chapman and Hall, 441-478.
- Mishra, B. 1985. *Economics of Public Distribution System in Food-grains*. Ashish publishing house. New Delhi. 104p.
- Muir, W.E. 2001. Changes in grain moisture content during storage. In *Grain Preservation biosystems*, edited by W.E. Muir, Winnipeg, MB: Department of Biosystems Engineering, University of Manitoba, 143-159.
- Mullen, M.A., Arbogast, R.T., 1979. Time temperature relationships for various stored product insect eggs and chilling times for selected commodities. *Journal of Economic Entomology* 72: 476-478.
- Mushira, M.A. 2000. *Manual on grain management and equipment maintenance in silos*. FAO, Nigeria. 42 p.
- Nithya, U., Chelladurai, V., Jayas, D.S., White, N.D.G. 2011. Safe storage guidelines for durum wheat. *Journal of Stored Products Research*, 47(4): 328-333.
- NRI (National Resource Institute), 1996. *Insect Pests of Nigerian Crops: Identification, Biology and Control*. Chatham, NRI, U.K., 153 p.
- Ojha, T.P. 1985. Problems and prospects of community type drying-cum-storage complexes in rural areas. In: *Storage of agricultural durables and semi-perishables*. CIAE, Bhopal, 1-6.
- Pabis, S., Jayas, D. S., and Cenkowski, S. 1998. *Grain drying: Theory and practice*. New York, NY: John Wiley, 303 p
- Pillaiyar, P., Yusuff, K.M., Narayanswamy, R.V., Venkatesan, V., and Ramachandran, K. 1981. Drying parboiled paddy with cup and cone dryer. *Journal of Agricultural Engineering*, 18, 122-126.
- Proctor D L, 1994. Grain storage techniques—Evolution and trends in developing countries, FAO Agricultural Services Bull, 109. FAO, Rome. Italy. 154p.
- Ramesh, A.1999. Priorities and Constraints of Post harvest Technology in India, In: Y. Nawa, *Post harvest Technology in Asia*. Japan International Research Centre for Agricultural Sciences, Tokyo, 37p.
- Sarangi, S.K., Singh, R., and Singh, K.A. 2009. Indigenous method of rat proof grain storage by Adi tribes of Arunachal Pradesh, 8(2): 230-233.
- Sathya, G., Jayas, D.S., White, N.D.G. 2010. Safe storage guidelines for canola as the seeds slowly dry, *Canadian Biosystems Engineering*, 51: 329-338.

- Sawant, S.D. 1985. Modern grain storage for reducing storage losses. In: Storage of agricultural durables and semi-perishables. CIAE, Bhopal, 25-36.
- Singh, B.P.N., Narain, M., Saxena, R.P., and Saskas, B.C. 1982. A continuous grain dryer for small throughput. Technical Bulletin No. AE/5/82. Department of Agricultural Engineering, GBPUAT, Pantnagar.
- Singh, P. K. 2010. A decentralized and holistic approach for grain management in India Current science, 99 (9):1179-1180.
- Singh, S.R., Jackai, L.E.N., 1985. Insect pests of cowpea in Africa: their life cycle, economic importance and potential for control. In: Singh, S.R., Rachiek, O. (Eds.), Cowpea Research, Production and Utilisation. Wiley Interscience Publications/ John Wiley and Sons Ltd, Chichester, 217-231.
- Sinha, A.K. Sinha, K.K. 1990. Insect pests, *Aspergillus flavus* and aflatoxin contamination in stored wheat: a survey at north Bihar (INDIA). Journal of Stored Products Research, 26(4): 223-236.
- Sinha, R. N., Yaciuk, G., and Muir, W. E. 1973. Climate in relation to deterioration of stored grain- A multivariate study, *Oecologia*, 12: 69-88.
- Sinha, R.N. 1973. Interrelations of physical, chemical, and biological variables in the deterioration of stored grains. In Grain Storage: Part of a System, ed. R. N. Sinha and W.E. Muir, 15-41. Westport, CT: The AVI Publishing Company, Inc.
- Srivastava B.P., 1985: Insect pests of stored wheat in Madhya Pradesh India. Journal of Entomological Research, 141-148.
- State of Indian Agriculture, 2012-13, Government of India, Ministry of Agriculture, Department of Agriculture and Cooperation, Directorate of Economics and Statistics, New Delhi, 15 p.
- Sundaramari, M., Ganesh, S., Kannan, G.S., Seethalakshmi, M., and Gopalsamy, K. 2011. Indigenous grain storage structures of South Tamil Nadu. Indian Journal of Traditional Knowledge, 10(2): 380-383.
- Talbot, M.T. 1999. Management of stored grains with aeration, Circular 1104, Institute of Food and Agricultural Sciences, University of Florida, Agricultural and Biological Engineering Department, Florida Cooperative Extension Service.
- Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P. M., Shiferaw, B., and Banziger, M. 2011. Crop Protection, 30: 240-245.
- Tiwari, B.K., Gowen, A., and McKenna, B. 2012. Pulse Foods Processing, Quality and Nutraceutical Applications, 172-192.
- Usha Rani, B., and Mohan. S. 2007. A survey on available gadgets, methods in pulse storage and its losses in Coimbatore district. Indian Journal of Agricultural Research, 41 (3): 224 - 227.
- Wallace, H.A.H., and Sinha, R.N. 1962. Fungi associated with hot spots in farm stored grain. Canadian Journal of Plant Science, 42:130-141.

- Wallace, H.A.H., Sholberg, P.L., Sinha, R.N., and Muir, W.E., 1983. Biological, physical and chemical changes in stored wheat. *Mycopathologia*, 82:65-72.
- White, N. D. G. 2000. Protection of farm-stored grains, oilseeds, and pulses from insects, mites and molds. Cereal Research Centre, Agriculture and Agri-Food Canada, 6-8.
- White, N.D.G. 1995. Insects, mites, and insecticides in stored-grain ecosystems. In *Stored-Grain Ecosystems*, ed. D.S. Jayas, N.D.G. White and W.E. Muir, 123-167. New York, NY: Marcel Decker Inc.
- White, N.D.G. and Sinha, R.N. 1980. Changes in stored-wheat ecosystems infested with two combinations of insect species. *Canadian Journal of Zoology* 58:1524-1534.
- Wilson, C. L. 2013. Establishment of a world food preservation center: concept, need, and opportunity. *Journal of Post-Harvest Technology*, 1(1): 1-7.
- Zia-Ur-Rehman. 2006. Storage effects on nutritional quality of commonly consumed cereals. *Food Chemistry* 95:53-57.

### Web Reference

- <http://www.grainscanada.gc.ca/storage-entrepouse/aafc-aac/pfsg-pgef-8-eng.htm> Canadian Grain Commission: Protection of farm-stored grains, oilseeds and pulses from insects, mites and moulds (accessed June 11, 2013).
- <http://hapur.nic.in/feisilo.htm> The Food Corporation of India: Bulk food storage silo (accessed June 4, 2013).
- <http://documents.worldbank.org/curated/en/2011/10/16254577/india-punjab-silos> International financial Corporation, World Bank Group: Success Stories, India: Punjab Silos. (accessed June 10, 2013).