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Comparative evaluation of quality changes in stored wheat (*Triticum aestivum*) in hermetic bags and conventional storage methods

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ABSTRACT

The efficacy of hermetic bags for storing wheat was compared with conventional grain storage structures such as steel bins and gunny bags. A qualitative analysis of moisture content, thousand kernel weight, germination percentage, sedimentation value, protein content, gluten content, gluten index, mold count, insect infestation and pasting characteristics were conducted on the wheat stored in all structures in respect to the time stored. Moisture content of the hermetic bags became constant after three months but in case of steel bins and gunny bags, the moisture content responded to changes in ambient conditions. It is suggested, hermetic bags can be a solution for preventing storage losses in India and an additional benefit is that no chemical fumigants are required which makes them environmentally acceptable.

Key words: Hermetic bags, Quality analysis, Wheat

The use of grain bags (Silo bags) to store grain for human consumption has been adopted successfully in recent years in Asia, Africa and Latin American countries (Bartosik, 2011). Silo bags are widely used in Argentina for storing wheat, soybeans, corn, and sunflower. Silo bag usage in Argentina has increased from 5 million tonnes in 2000 to 40 million tonnes in 2008 (Darby and Caddick, 2007; Villers et al., 2008, Abalone et al., 2011). Earlies studies showed that treatments based on reduced oxygen and high carbon dioxide (CO_2) contents are technically suitable to control arthropod pests in durable commodities and protect a quality product without pesticide. In recent decades, the demand for pesticide free safe food has increased. Hermetic bags have a potential to meet consumer demand, up to 10-15%. It is also called ‘sealed storage’ or ‘airtight storage’ or ‘hermetic storage’ or ‘harvest bag’ or ‘grain sausage’ (Darby and Caddick, 2007; Villers et al., 2010).

Bag storage is largely practised in the trade godowns– (flat covered storage managed by private buyers) and food corporation of India (FCI)for 25 to 500 tonnes, mainly because of ease in handling and transport. Bagged grain should be stacked on racks, at least 30 cm from the walls of the warehouse and separated sufficiently enough to allow for inspection and cleaning. Infested bags can be segregated and treated. Bags made of paper or paper laminated to cloth or cartons of fiber board offer more resistance to insect penetration than cotton or jute bags. Although storing grains in bags is not ideal, it is one of the most common methods of storage. Often, the bags themselves serve as a source of infestation.

Silos are usually constructed of steel or reinforced concrete and comprise high cells of various cross-sections placed side-by-side. They have inlets and hoppers for loading and unloading respectively. Mechanical equipment is also provided for loading and unloading large capacity silos. These silos range in size from 20 to 2,000 tonnes capacity (sometimes 10,000 tonnes). Silos have the advantage that they can be more easily sealed for fumigation and less grain is spilt or wasted.

It was found by Anankware et al. (2012), that bags and steel silos failed to preserve the quality of stored materials in hot humid areas and needed additional chemical methods for the prevention of

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rodents and insect infestation. The adverse effects of pesticide residues in food and the environment resulted in the imposition of limitations on pesticide registration by regulatory agencies (Villers et al., 2008). Consumer demand for chemical free and insect free products increased attention to the use of non-residue technologies for the protection of stored grain (Darby and Caddick, 2007; Navarro, 2012). Among the new gaseous application technologies that have successfully replaced fumigants are the manipulation of modified atmospheres through the use of hermetic bags, for insect control and for quality preservation of stored materials. Experiments revealed that sound wheat stored in a non-punctured bag that meets an equilibrium moisture limit of 12% is expected to maintain all processing quality parameters for 9 to 12 months storage (Darby and Caddick, 2007).

Hermetic bag storage has been adopted in 40 countries to store a number of commodities (Villers et al., 2010).This study was established to observe the significance of new hermetic bag techniques to minimize post-harvest losses and maintain the quality of the stored product under typical Indian conditions and to provide safe and quality products to the consumer.

MATERIALS AND METHODS

The wheat (*Triticum aestivum* L.), variety 'WH 711' (8 MT) was used in this study, which was procured from the university farm. Three different storage techniques: Hermetic Storage, Metallic bin and Gunny Bags (grain bags made of woven jute) were used. To obtain the desired moisture content in wheat, it was spread uniformly on the floor and then sprinkled with the required amount of water and mixed thoroughly thereafter.Four hermetic bags of one tonne capacity each (Grain safe II™, GrainPro Inc.) were placed on a metallic frame table 75 cm × 75 cm × 150 cm (L×W×H) specially designed with a rat proof guards on each leg (Figs 3 and 4). The board of the table has a hole in the center for the drain tube of the bag. Forty gunny bags of 50 kg capacity 84 cm × 50 cm × 20 cm each were used. These bags were stacked in two piles of 20 bags each, 15 cm above the ground surface on wooden crates. Two steel bins were purchased 2 m in height and 1 m dia of 1 tonne capacity. These had three sampling holes on its outer surface, top, bottom and middle and were made airtight by application of wheat dough. They have one hole in the top for the Sensor USB cables and were sealed with silicone sealant. A mounting rod was used for the sensor placement inside the structures. It was designed using PVC pipes and fittings and provision was made to make it airtight by using silicone sealant (Fig. 2), to prevent the vertical movement of air inside the mounting rod. Each mounting rod had three sensors, top (T/RH), middle (T/RH/CO_2) and bottom (T/RH). The sensors at top and bottom section of the rod were the same, reading relative humidity (RH) and temperature (T) (Track-It™ Temperature and Humidity Data Loggers, MicroDaq.com, Ltd., Contoocook, NH). The middle sensor can read carbon dioxide (CO_2) (K-33 BLG 30%, CO_2. Meter.com, Ormond Beach, FL) and relative humidity (RH) and temperature (T). Studies showed that CO_2 distribution was almost uniform in the small-scale hermetic bags (where length of cross section is less than three meters) (Gaston et al., 2009). Therefore only one CO_2 sensor was installed in a sensor rod The

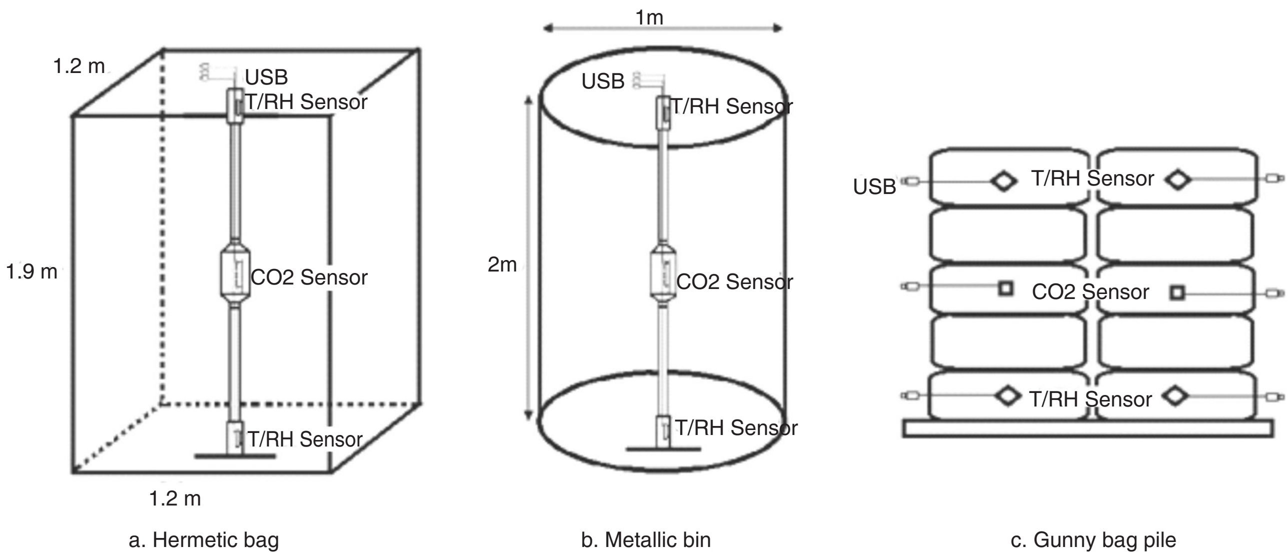

Fig. 1. Sensor installation inside the structures

Table 1 Overview of the experimental setup

Merthods & Experiment Name		Start date	Stored capacity	Moisture content (w.b.)
Hermetic Storage	H1	24 July 2013	1 tonne	11.53%
Hermetic Storage	H2*	24 July 2013	1 tonne	11.80%
Hermetic Storage	H3	29 July 2013	1 tonne	13.43%
Hermetic Storage	H4*	29 July 2013	1 tonne	13.42%
Metallic Silo	S1	22 July 2013	1 tonne	11.76%
Metallic Silo	S2	22 July 2013	1 tonne	11.70%
Gunny Bag Pile	B1	26 July 2013	1 tonne	12.23%
Gunny Bag Pile	B2	26 July 2013	1 tonne	12.26%

*Deliberate introduction of 80 adult specimens of *Rhyzopertha dominica* on 13 August 2013

sensors inthe top and bottom section have a built-in energy cell andthe middle sensor is powered by an external battery through a wire cable. The measured data were recorded by a built-in memory card on the sensors. Each sensor was connected with USB cables which were conducted outside the structure to transfer data to a laptop. The PVC fittings have a number of holes for facilitating flow of gases inside the rod for respective measurements. Each sensor rod was tested on computer before placement inside the structure (Fig.2).

Sensor placement in hermetic bag/ steel bins/ gunny bags: Hermetic bags were placed on the table shaped metallic frame of angle iron (1.5m×1.5m×0.75 m) and a drain tube (Fig. 4) from the bag was pulled through the center hole of the wooden sheet placed on the table. The tube was closed with wooden sticks and rubber bands and then it was rolled and tightened by plastic tapes. Sensor rods were placed inside the bags and then filled with wheat up to the brim (Fig. 4). The zip of the bag was fastened by a key. One side of the zip was used as an outlet for USB cables and sealed completely by using silicone sealant.

During filling, the bag expands, therefore, the bags were put in a propathene wrapper to maintain the original volume. To prevent rats attacking the bag, rat guards were tied to the each leg of the metallic frame. The sensor rod was placed at the center of the bag after testing. The steel bin was filled with wheat up to the brim (Fig. 5). The USB cables from the sensors were taken out through a top orifice and whole structure's infiltrations or leak points were sealed with wheat flour paste in order to obtain some airtightness. The sensors in strong plastic boxes were put in the middle of the gunny bags which were then filled with wheat. The gunny bags were tied around the neck of the bag and the USB cables were conducted outside the bag through the top. All filled gunny bags were stacked on the wooden crates in two piles (Fig. 6).

The experimental design and related information presented in Table 1.

Manual insect infestation

To test the effectiveness of hermetic storage, 160 adult specimens of Lesser Grain Borer (Rhyzopertha dominica) were inserted inside two hermetic bags by piercing a small hole in the top surface on 13 August 2013. Eighty insects were inserted into bags H 2,11.80% m.c. and H 4,13.42% m.c. (Fig.6). The hole was patched with PVC strip and silicone sealant.

Sampling procedure

A sample of wheat was taken from three layers of the individual structures at top, bottom and center, with a sampling probe (Fig.3) and then mixed together to make a representative sample. These samples were sealed in plastic zipper bags for further qualitative analysis. The closed sampling probe was inserted inside the structures and then opened to simultaneously sample from all layers. Wheat samples were collected at the beginning of the experiment and then at intervals of 30 days from all structures. Samples were collected vertically in the hermetic bag and horizontally in both steel bins and gunny bags piles. The sampling orifices of the hermetic bag were patched with a piece of PVC (same material as hermetic bag) and silicone sealant, due to failure of the glue provided with the hermetic bag. In the steel bins rubber plugs were used for the closure of the sampling orifices.

Method for quality analysis

Moisture content was estimated in samples using AOAC method (1995). A Standard Germination test was carried out by taking 100 seeds of each treatment combinations replicated × 3 and were tested in the laboratory. The final count of germination was recorded on the eighth day and the number of normal seedlings counted and expressed as percent

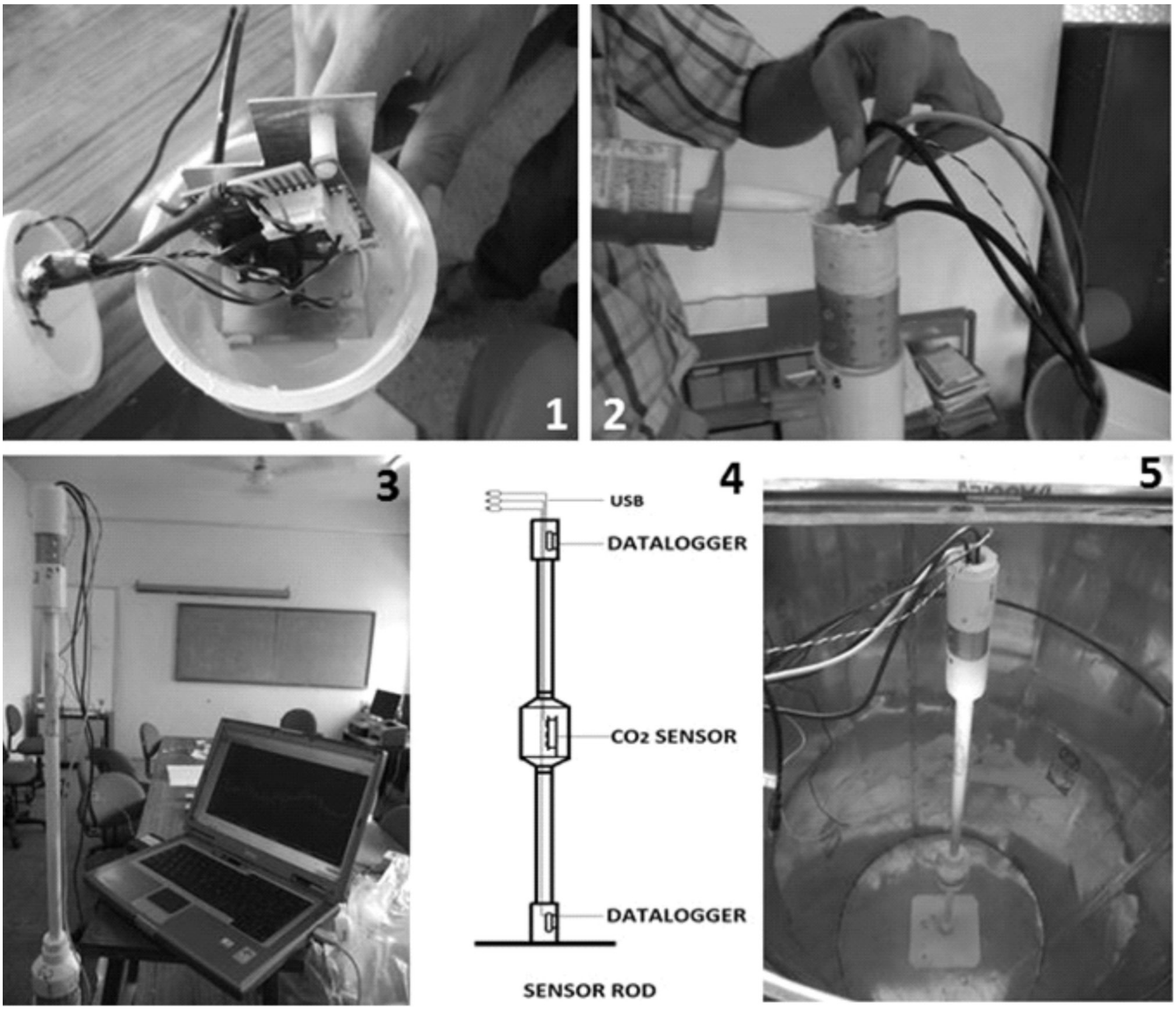

Fig. 2. Sealing middle and top section of the sensor rod[1] with silicon sealant[2], testing of sensor rod[3], schematic diagram of the sensor rod[4] and assembled sensor rod[5].

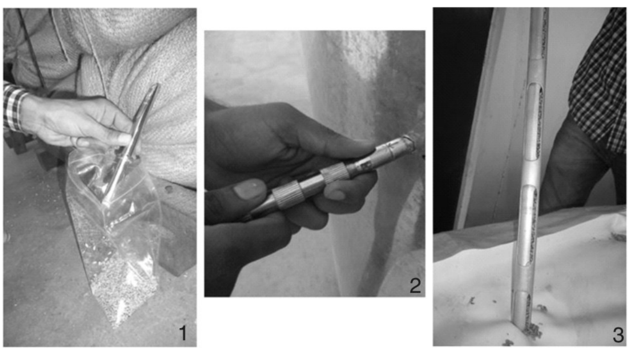

Fig. 3. Sampling probe in the gunny bag[1], steel bin[2] and hermetic bag[3]

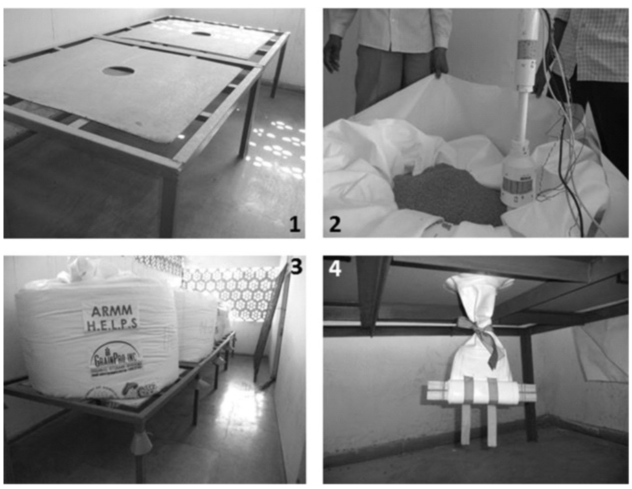

Fig. 4. Table shaped metallic frame[1], sensor rod installation[2], final experimental set up with rat cone[3] and drain tube[4] of the hermetic bags.

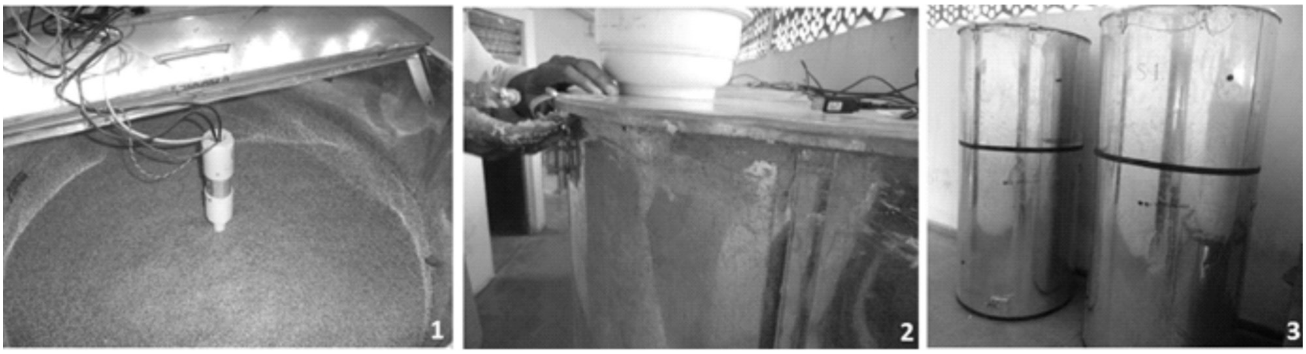

Fig. 5. Sensor rod installation[1], sealing of leak points - joints with wheat flour paste[2] and final experimental setup[3] of the steel bins.

Fig. 6. Sensor rod installation in a gunny bag[1], Gunny bags piles on wooden crates[2] and manual insect infestation[3] of the hermetic bag.

germination. Insect infestation was carried out by identifying the damaged grains found in one hundred kernels by visual inspection and the results are shown as a percentage.

RESULTS

Carbon dioxide (CO_2) concentration was recorded by the sensors inside all the structures. The CO_2 buildup behavior of all hermetic structures was almost the same. Carbon dioxide started building during August and September, but then a fall was experienced until January in all four hermetic bags. It again started building in February and reached the highest CO_2 concentration of 9.696%, 8.702%, 9.843% and 9.295% inall four hermetic bags respectively. The average CO_2 concentration was 3.81%, 3.46%, 4.53% and 4.56% in all four hermetic bags, respectively in nine months.

The highest CO_2 concentration was 10.58% and 15.59% in metallic bins (Fig. 1). The starting concentration was about 2.5% (October) but later it increased due to development of the insects inside the structure. Gunny bag piles were exposed to the outside environment, so the maximum CO_2 concentration was 1.956% and 1.368% in gunny bag piles respectively (Fig. 1).

Effect of storage on moisture content of wheat in structures

The initial m. c. of hermetic bags 11.7%, 11.8%, 13.4% and 13.4% reduced to 8.1%, 8.5%, 9.2% and 9.3% in all the hermetic bags respectively (Fig.1). Moisture content reduction was greater in wheat with initial high moisture content.The first three months showed the maximum drop in the m. c. but with the onset of winter, the level stabilized. Moisture content changes in steel bins and gunny bag piles respondedto changes in ambient relative humidity. This change was greater in gunny bag piles than the steel bins (Fig. 4) The m. c. of gunny bag piles was 12.2% and 12.3% on filling, which was reduced to 8.3% in both piles in nine months. Initial m. c. of steel bins was 12.2% and 12.3% on July, which came down to 8.3% in both bins at the end of experiment .

Effect of storage on germination of grains

Germination test is the best indication of seed viability. A gradual reduction in germination percentage was observed for all the three structure in this study but the reduction was more in gunny bag piles and steel bins as compared to hermetic bags. During storage of nine months, there was a significant loss in the germination of grains in all structures. Initial germination percentage was 96 which decreased to 87, 88, 87 and 86 in hermetic bags respectively, but it was 80, 82, 75 and 72 in steel bins and gunny bags piles, respectively. The minimum standard germination recommended for wheat is 85%. Hermetic storage was the only structure where germination remained in this limit. The germination of high and low moisture hermetic wheat storage remained the same in nine months. The reduction in germination percentage was more rapid in warmer months of storage under all storage techniques.

Effect of storage on insect infestation inside the structure

During storage of nine months, not a single insect was found alive in the four hermetic bags of low and high initial moisture content. In the gunny bags piles and steel bins, infestation of *Rhyzopertha dominica* was detected in September and October respectively. The insect infestation intensity was calculated by visual inspection of damaged grain. The infestation rate was higher in August and September during the storage period. The damaged grain percentage was greater in gunny bag piles in comparison with steel bins. The damaged grain percentage was 2.33, 2, 8.33 and 7.6 in metallic bins (two) and bags (two) respectively. No damaged grain was found in the hermetic bags.

DISCUSSION

The effect of ambient temperature and relative humidity (RH) decreased with grain depth. The temperature of all layers in all structures corresponded to the changes in the ambient temperature. The middle and bottom layers of hermetic bags were cooler than the ambient temperature. But in steel bins and gunny bag piles the middle and bottom layers were warm in comparison with ambient conditions, most probably due to insect infestation and microbial contamination. The CO_2 level is a function of respiration rate of the grains and airtightness of the structures. The respiration rate of grain is governed by water availability, temperature, oxygen concentration, microbial contamination, mechanical damage andthe conditions and period of previous storage and by mite and insect infestation (Lacey et al. 1990; Abalone et al. 2011).

Wheat is a hygroscopic bio-material, tends to move into equilibrium with the ambient atmosphere, which may cause increase or decrease in the moisture content of the stored grains. But ambient conditions affected only the gunny bag piles and steel bins in comparison with hermetic bags. Hermetic storage is an airtight structure and it prevented interaction of wheat with ambient atmosphere. The values of moisture content remained lower than safe level during the complete storage period. After three months of storage, the moisture content of the wheat in hermetic storage tried to be in equilibrium with the air in the head space and it became constant till April.

Gaston et al. (2009) reported that major moisture difference was experienced in April due to highest ambient temperature (39.48%) which provided drive for moisture migration and condensation towards the peripheral layers of the hermetic bags. During sampling in March and April, water accumulation was observed on the inner surface of the patching material,which proved condensation of moisture in peripheral layers of hermetic structures. During prolonged storage, extreme variations in grain temperatures (e.g. exceeding 50º C and falling below 0ºC) can lead to grain moistures drying out by over 1% and moistening up to 3% in hermetic storage.

The stored wheat in gunny bag piles and steel bins maintained equilibrium moisture content with the ambient air condition (Lukow et al., 1995). In April the temperature was highest and r.h. was less as compared to the last months of storage, this caused the grain to lose moisture from the kernels. The germination capacity of stored wheat grain reduces with time (Sawant et al., 2012). Seed germination during storage was not only influenced by temperature, grain moisture content, relative humidity and insect infestation, but also by the type of structures (Villers et al., 2008; Navarro, 2012).

Generally with each 1% increase in moisture content, between 5 and 14% m. c. there is a halving of seed life, also for each 5°C increase in temperature, from 0 to 50°C, seed life is halved (Lukow et al., 1995). In this study moisture content difference was up to 2% inside hermetic bag storage but there was no difference on the germination percentage. Germination was almost the same after nine months duration in all the bags under hermetic storage. Rapid reduction in germination of gunny bags piles and steel bins in warmer months revealed that higher temperature and higher relative humidity increases the insect activity and resulted in a reduction of germination percentage. In hermetic bags, constant moisture content of wheat after three months storage and modified atmosphere preventing insect infestation were the reasons formaintaining good germination.Literature states that carbon dioxide (CO_2) concentration, air tightness, exposure time, insect species, type of structure, temperature and relative humidity are the primary factors that influence the mortality of insects in storage (Driscoll et al. 2000; Darby and Caddick, 2007; Villers et al. 2008; 2010). This was the reason behind the absence of insects in the hermetic bag without manual insect infestation and of 100% mortality in hermetic bags withmanual insect infestation.

Steel bins and gunny bag piles had severe insect infestation because these structures provide a favourable environment for proliferation. Populations of all insect species will develop at grain temperatures between 15° and 35°C approximately (Driscoll et al., 2000). The reduced insect infestation in steel bins was due to some modified atmosphere achieved by restricting air infiltration.

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