



Efficacy of PVC coated fabric bag for on-farm storage of wheat (*Triticum aestivum*)

SUNIL KUMAR¹, DEBABANDYA MOHAPATRA², NACHIKET KOTWALIWALE³ and
KRISHNA KUMAR SINGH⁴

ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh 462 038, India

Received: 27 June 2018; Accepted: 23 July 2019

ABSTRACT

A PVC coated fabric bag was evaluated for on-farm storage of wheat for 8 months without fumigation. It was compared with fumigated samples stored in a metal bin. Temperature, relative humidity (RH) and carbon dioxide (CO₂) of the bag and surroundings were monitored throughout the storage period. The interstitial temperature, RH and CO₂ in bag were in the range of 15.2–37.7°C, 28.5–40.6% and 406–5764 ppm respectively. After 2 months of storage, no significant difference was observed between the quality parameters of samples stored in both structures; however, at the end of 8 months of storage, thousand kernel weight (57.8 g), mold count (39.8×10¹ CFU/g), moisture content (10.7%), besatz (5.3%) and bored grain (1.6%) were significantly higher in the bag samples compared to the control samples, whereas germination percentage was reduced to 76.7% from 96.7% in bag. Nevertheless, the quality of grain was within the acceptable consumable quality limit as per codex standards due to bored grains less than 1.5% for 6 months in bag.

Key words: Insect infestation, Metal bin, PVC coated fabric bag, Store wheat

Postharvest loss is the most important agro-economic issue throughout the world. A surfeit postharvest loss of 4.65–5.99% in cereals was estimated under a survey in India. Out of which, 0.75–1.21% of total production is lost annually due to unavailability of proper storage structures (Jha *et al.* 2015). Indian farmers store 60–70% of their production using indigenous storage structures (Kumar *et al.* 2015). These storage structures are normally constructed using the locally available raw materials (Paddy straw, wheat straw, wood, bamboo, bricks etc.) without any scientifically proven design. Some of these structures are neither airtight nor moisture and rodent proof, thus susceptible to insect and mould contamination, besides been attacked by rodents (Kumar and Kalita 2017). In addition, these storage structures require chemical fumigation to remain pest free, thereby causing issues like environmental pollution, development of insect resistance and the threat to health of consumers (Somavat *et al.* 2017).

Hermetic bags can be used for on-farm storage of food grains, to belittle the use of fumigants and costly infrastructures (Kumar *et al.* 2015). The need of adequate

airtightness, pest damage to the bag, condensation and limited manufacturers across the world are the major impediments in popularity of the hermetic technology in India (Kumar *et al.* 2017). The present experiment was carried out in Bhopal, India to ascertain the effectiveness of velcro fastened and silicon sealed PVC coated fabric bag for wheat storage.

MATERIALS AND METHODS

Freshly harvested Wheat (cv. HI-8498 Malavashakti) grown in the ICAR-CIAE Farm (Bhopal, Madhya Pradesh, India) during November 2015–April 2016 was used in the study. The wheat was cleaned and stored with fumigant (10 g Celphos/tonne) in metal bins till experimentation.

The flexible PVC coated fabric bag (2.36 m × 2.14 m × 1.28 m) was manufactured (SRF Ltd., Chennai, India) with Hook-and-loop fastener mechanism for three sides of the bag. In the last week of September 2016, 40 jute gunny bags of 50 kg capacity were stacked up to 84 cm height inside the structure over wooden dunnage. Use of dunnage is recommended under IS: 6151 (Part-II)-1971 to allow free movement of the air to avoid moisture condensation. After loading the bags, silicone glue was used as a sealant on fastener strips for providing better airtightness. The seaming by using the silicone glue was able to sustain the ozone in the storage ecosystem (12.7 tonnes metal bin) and resulted in 92–100% elimination of insects (Kells *et al.* 2001). Control sample was stored in the metal bin with

Present address: ¹Assistant Scientist (sunilciae@gmail.com), CCS Haryana Agricultural University, Haryana, India; ²Senior Scientist (debabandya@gmail.com), ³Head (nachiket.kotwaliwale@gmail.com), ⁴Director (singh_ciae@yahoo.com), ICAR-Central Institute of Agricultural Engineering, Bhopal, India.

phosphine fumigation (10 g Celphos/tonne) as per the existing practice among the Indian farmers.

Sensors and data acquisition system: The temperature and RH were monitored at three places across the length of the bag using a DHT-22 sensor (AM2302, Aosong Electronics Co., Ltd). Carbon dioxide (CO₂) sensor (GC-0016, COZIR, Ormond Beach, FL) was installed in the centre of the bag. All sensors were kept in a sensor rod made of perforated pipes and fittings. Sensors, LED indicators and LCD with a data logger were mounted on the microcontroller (Mega 2560, Arduino, Ivrea, Italy). Power was supplied to the system using the SMPS (Switch Mode Power Supply) (6-12V, 1A). The outputs of DHT-22 and COZIR-GC0016 were verified by Hygrometer (Testo 622, Testo, Germany) and headspace gas analyzer (GS3/P, Systech Instrument, UK), respectively.

Sampling method: Samples were collected thrice during 8 months storage period (December, March 2016 and May 2017). Star shaped sampling was followed to collect samples from all corners, levels, and center of the structure. Collected samples were thoroughly mixed to make representative sample (approx. 3 kg each). The sample was then divided into subsamples for further quality analysis.

Quality parameters

Moisture content: As per ASAE (2001), 10 g sample of wheat was kept in an air oven at 130°C for 19 h. The weight difference was divided by the initial sample weight to obtain moisture content (m.c.) on wet basis.

Germination percentage: The samples of wheat were placed over a Whatman filter paper in the Petri dish with sterile water for 6 days in an ambient condition at a darker place. Germination percentage was calculated as a ratio of the number of germinated seeds to total number of seeds (Manmathan and Lapitan 2013).

Mould count: Serial dilution of 1 g of wheat sample in 9 ml sterilized distilled water was prepared in a sterile tube. One ml of 10⁻¹ dilution was poured into a Petri dish containing potato dextrose agar media and incubated at 25°C for 72 h. Colonies were counted visually and expressed as CFU/g×101 of wheat (Beneke 1962).

$$\text{CFU/g} = \frac{\text{Count of Colony} \times \text{Dilution factor}}{\text{Weight of sample taken}}$$

Bored grain: Hundred grains of the sample were analysed visually for the number of bored grains as followed by Golob *et al.* (2002).

$$\text{Bored grain, \%} = \frac{\text{Number of bored grains}}{\text{Total grains inspected}} \times 100$$

Thousand kernel weight (TKW): 1000 grains of the sample was weighed on the balance (CX- 265, Citizen, India) to obtain the TKW in grams (Golob *et al.* 2002).

Besatz: The grain and black dockage were separated from the normal basic variety. Weed seeds, ergot, unsound grains, smutty grains, impurities and chaff are the black

dockage. The besatz was obtained in percentage by dividing total dockage to the total sample (ICC 1972).

Insect density: Samples (2 kg each) were sieved to extract the adult insects and the extracted insects were counted. This method is valid only for the external infestation (Hagstrum and Flinn 2014).

Statistical analysis: Two independent factors (Type of storage structure and time duration) multi-level analysis was conducted to see effect on responses (Quality parameters and environmental parameters) using General Linear Model with Duncan Multiple Range Test using SAS software (version 9.3) at 5% level of significance.

RESULTS AND DISCUSSION

Temperature and RH of the bag and ambient were continued to record in SD card at 1 min interval. Whereas, CO₂ level of bag was recorded at an interval of 3 days.

Environmental parameters of bag and atmosphere

Carbon dioxide changes in storage: The interstitial CO₂ in bag was in the range of 406–5764 ppm; although the bag was opened thrice for sampling in 8 months. The increasing trend of the CO₂ was observed up to December and similar increasing trend was after January (Fig 1). The maximum CO₂ level (5764 ppm) was reached in May 2017. This level corresponded to the high level of ambient temperature during that period (Fig 1a), which was favourable for CO₂ generation by the insects, pests and grains. As per Neethirajan *et al.* (2010), CO₂ level ranging between 3500–5000 ppm is an indicator of high insect infestation or higher infection by microorganisms in stored grains. In this case, a high insect activity was expected as the conditions were favorable for insect and microorganism proliferation. High initial m.c. (>17%) of wheat favours CO₂ production and degraded the quality via germination reduction and dry matter loss (Karunakaran *et al.* 2001).

Temperature and RH: The ranges of monthly average of ambient temperature and RH during investigating period were 11.3–38.1°C and 7.8–91.3%, respectively; whereas, interstitial average temperature and RH ranges of bag for whole storage period were 15.2–37.7°C and 28.5–40.6%, respectively. The recorded temperature values at three horizontal places were compared for 8 months period. Ambient and interstitial temperature of the bag was similar in most of the months (difference was approximately 1°C). Ambient RH was significantly different than the RH inside the bag throughout the storage period (Fig 1b). Interstitial temperature followed the same path as ambient whereas interstitial RH was comparatively remained stable in bag. Though drop in ambient RH after February did not disturb the stability of RH in the ecosystem of the bag. RH of the bag was maintained 30–40% throughout the storage period (Fig 2b). In fact, interstitial temperature was slightly higher than the environment in October-January, which might be due to metabolic activity of grains and insect. Average interstitial RH of the bag was below 40.1%, which indicated good storage ecosystem. According to Kumar

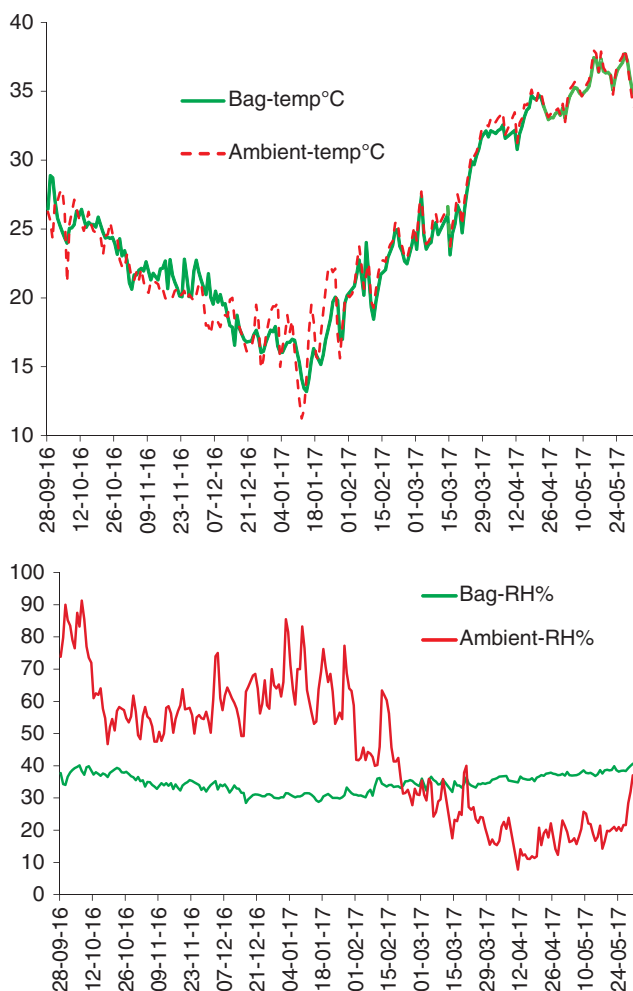


Fig 1 Temperature (a) and relative humidity (b) of the PVC coated fabric bag and ambient conditions.

and Kalita (2017), the recommended RH of stored cereals should be less than 70% to avoid the mould infestation. In the present study, lowest and highest of average RH of shed-environment were 15.5% and 91.3%, respectively. In the case of bag, minimum RH was 28.5% (Dec) and maximum was 40.6% (May). Silicone glue was observed to be adequate in providing slight sealing. It prevented the effect of ambient humidity fluctuations and resulted

negligible growth of mould (Table 1). The variation of interstitial RH was approximately $\pm 10\%$ in whole storage period. Lower RH fluctuation in the bag also blocks the spreading of mold infection to non-infected kernel also (Lane and Woloshuk 2017).

Quality changes of stored wheat in metal bin and bag

Germination percentage: It was decreased with storage period in both structures. Loss of germination was lesser in the metal bin, which is attributed to the zero insect growth and lower m.c. (Table 1). The results corroborate the fact that germination of grains is affected by ageing (Karunakaran *et al.* 2001), temperature and RH (Strelec *et al.* 2010), moisture content (Somavat *et al.* 2017), mould infection (Kumar and Kalita 2017) and insect infestation (Somavat *et al.* 2017). After 8 months, germination reduced to 83.1% and 76.7% in metal bin and bag, respectively from initial level of 96.7%. Major loss of germination was noticed in bag due to insect damage in grains and comparatively higher m.c. than the metal bin (Table 1). In India, germination percentage of certified seeds of wheat should be minimum 85% (Trivedi and Gunasekaran 2013). Germination of wheat in a metal bin qualifies limit of seed standards after 8 months as per statistical analysis (Table 1).

Mould count: Higher mould count was observed in the bag than samples stored in a metal bin. High m.c. and trespassing of gases (low airtightness) in the bag were the reason of mould activity. In the case of metal bin, no significant mould activity was noticed on completion of storage period (Table 1). However, in between the storage period there was significant variation in mould count of metal bin after 2 months of storage (Table 1). On that time, ambient RH was comparatively higher and assisted with lower temperature (Fig 1). The m.c. of the food grains in drier months was reduced and made an unfavourable ecosystem for mould proliferation. In the case of bag, mould count decreased to 39.8×10^1 CFU/g (8 months) from 60.8×10^1 CFU/g (2 months) (Table 1). The final mould count of bag was higher than metal bin and initial sample too. Maximum limits of mould count for wheat were 12.6×10^4 CFU/g for wheat grown in dry and wet climate and 10.0×10^5 CFU/g for wet climate (Galeas 2014). Wheat was innocuous for

Table 1 Quality parameters of metal bin and PVC coated fabric bag

Quality parameter	0 months	Metal Bin			PVC coated fabric Bag		
		2 months	6 months	8 months	2 months	6 months	8 months
Germination Percentage (%)	96.7 ^a $\pm$ 2.1	87.1 ^b $\pm$ 8.6	84.47 ^{b,c} $\pm$ 9.0	83.1 ^{b,c} $\pm$ 6.4	83.5 ^{b,c} $\pm$ 7.3	78.3 ^{b,c} $\pm$ 5.3	76.7 ^c $\pm$ 5.7
Mould Count $\times 10^1$ CFU/g	22.8 ^c $\pm$ 3.7	36.8 ^b $\pm$ 4.9	28.6 ^c $\pm$ 3.2	22.3 ^c $\pm$ 5.9	60.8 ^a $\pm$ 7.2	38.0 ^b $\pm$ 1.6	39.8 ^b $\pm$ 6.1
Bored Grain (%)	0.0 ^d $\pm$ 0.0	0.2 ^{c,d} $\pm$ 0.4	0.0 ^d $\pm$ 0.0	0.0 ^d $\pm$ 0.0	0.8 ^{b,c} $\pm$ 0.4	1.2 ^{a,b} $\pm$ 0.2	1.6 ^a $\pm$ 1.1
Thousand kernel weight (g)	56.4 ^{a,b} $\pm$ 0.7	49.9 ^c $\pm$ 0.9	49.4 ^c $\pm$ 1.9	51.1 ^c $\pm$ 1.2	58.6 ^a $\pm$ 1.7	55.3 ^b $\pm$ 1.3	57.8 ^a $\pm$ 2.5
Moisture content (%)	10.1 ^{b,d,c} $\pm$ 0.3	11.2 ^{ab} $\pm$ 0.7	8.1 ^d $\pm$ 0.9	9.9 ^{a,b,c} $\pm$ 0.3	11.5 ^a $\pm$ 0.3	9.1 ^{c,d} $\pm$ 0.7	10.7 ^{a,b} $\pm$ 0.2
Besatz (%)	3.2 ^b $\pm$ 0.8	3.3 ^b $\pm$ 1.5	4.1 ^{a,b} $\pm$ 0.6	4.2 ^{a,b} $\pm$ 0.5	3.3 ^b $\pm$ 1.8	5.2 ^a $\pm$ 0.4	5.3 ^a $\pm$ 0.4
Insect Density (live adult insects/kg)	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	-	15.9 $\pm$ 14.3	8.1 $\pm$ 6.8

Values are mean $\pm$ S.D; Same alphabets (Horizontally) denotes non-significant difference

consumption, as mould count was less than the maximum limits in both structures after 8 months of storage. Generally, moulds were visible on storage of high m.c. (>17%) wheat at 25°C. High m.c. increases the respiration rate of the grains hence produces water as well as heat helps in proliferation of moulds (Karunakaran *et al.* 2001). In spite of infection, there was no visible mould appeared on the grain surface.

Insect infestation and density: Some bored grains were detected after 2 months of storage, but in subsequent sampling no bored grains were detected in the metal bin (Table 1). The phosphine performed well in preserving grains against insect and quality change in metal bin. In the case of bag, bored grains were detected after the 2 months of storage and it continued to increase significantly ($P < 0.05$). After 6 months, bored grain in bag was 1.2%, which was increased to 1.6% in next sampling after 2 months. Lack of proper airtightness and fumigation in bag could have helped in proliferation of the insects. The detected adult insects in bag were *Rhyzopertha dominica* (RD) and *Tribolium castenum* (TC) at a density of 16 adult insects/kg (after 2 months). The ratio of RD and TC was 10:1. It clearly indicated that RD (15 insects/kg) was dominating insect over TC (2 insects/kg). Later on, adult insect density was reduced to 8 insects/kg after the storage of 8 months. More larvae and pupae were observed than adult in last sampling. The adult of RD died after completing the life cycle in 58 days (Koehler *et al.* 1992). Dead or inactive adult insects were found below the dunnage. Therefore, less adult population was observed in the last sampling. During last 2 months of storage, the conditions were not highly favorable (33.0–35.7°C and 36.6–38.2% RH) for insects' growth. Unfavorable environmental condition prolonged the hatching stage of insect's eggs. Therefore eggs could not contribute to the insect density after 8 months of storage. The favorable condition for insect proliferation is 25–30°C and 60–70% RH (Hayma 2003). During sampling in bag, movement of insects was also observed towards cool and moist places. Therefore, insects were higher in number in gunny bags at the bottom and darker side (shaded side) of the bag. Navarro and Noyes (2001) reported insect movement is not random. They tend to aggregate in favorable environment for their development away from the sunlight, along the temperature and gas gradient, towards the aggregation and attraction pheromones.

The phosphine inhibited the growth of insects in metal bin and influence was continued throughout the storage period. Instead of insect infestation in bag, the level of bored grains was in acceptable limits (1.5% max.) for the commercial sale and consumption after 6 months of storage (As per Codex Standard for wheat).

Thousand kernel weight: After storage, significant difference was observed in TKW of metal bin against the initial. TKW was reduced to 51.1 g (after 8 months) from 56.4 g (initial) in metal bin (Table 1). Significant difference in TKW for bag occurred after 6 months, but again regained TKW similar to initial. Almost similar pattern was noticed with m.c. of grains. Therefore, gain in TKW after 2 months

was because of the gain in m.c. of grains due to higher humidity of the environment. The gain in moisture again reduced to 10.7% (bag) and 9.9% (metal bin), because of subsequent drier months after January. In case of bag, non-significant change in TKW was noticed after completion of the storage period. TKW of stored wheat in bag was higher than the metal bin. Results of both structure showed decreasing trend of TKW with storage time. Moreover, the grains respire and that accompanies loss of weight of the sample. Dry matter loss becomes worse at higher m.c. and produces 14.7 g of CO₂ by 1% dry matter loss (Karunakaran *et al.* 2001).

Moisture content: During storage, m.c. of stored commodities depends upon environmental conditions and level of airtightness of storage structure. Grains absorb or desorb moisture from environment to comply hygroscopic nature of biological materials (Somavat *et al.* 2017). Ambient RH was reduced in subsequent months after December. At this time, grains desorbed moisture to attain an equilibrium state in both structures. The significant difference in m.c. of stored grains in bag was observed after 2 and 6 months (11.5% and 9.1%). After 8 months, m.c. again reached back to the same to 2 months old stored grains. Moisture of samples stored in the bag was higher as compared to the control sample. In addition, insect infestation in stored wheat of bag produced heat and moisture due to biological respiration, that caused significant and comparatively more variation in m.c. than metal bin. Strelec *et al.* (2010) reported a 4% decrease in m.c. of stored wheat at 40°C than 1% at 4°C on a constant RH (45%). It is apparent that decrease in m.c. of stored wheat was due to temperature. Higher temperature caused more moisture loss in both structures.

Besatz: The insignificant change was observed in besatz of wheat stored in metal bin during the whole storage period. Storage of 2 months in bag also had insignificant influence on besatz. In a subsequent sampling of bag, besatz increased to 5.3% (after 8 months) (Table 1). The increase in besatz happened due to insect and mould infestation. However, mould infestation was negligible in our case as per the codex norms for the minimum mould count due to safe m.c. (12%) of stored grain in both structures. Bored grains were detected in samples after 2 months in bag and it continued to increase. Mass of bored grains as well as other defected grains was also added to besatz (Bettge *et al.* 1989). It resulted increase in besatz of wheat in bag. In both of structures, the besatz increased with the storage time. However, besatz (3–5.5%) was below the permissible limit of maximum 12% foreign matter (As per Prevention of Food Adulteration Act, India) by weight in both structures.

The velcro fastened bag with silicone sealing did not obtain sufficient airtightness for sustaining insecticidal level of CO₂ concentration. The level of CO₂ (>3000ppm) inside the PVC storage structure clearly indicated the higher insect infestation after two months. CO₂ generation per unit time in warmer months was higher than cooler months. For quality parameters, metal bin with phosphine fumigation performed better than bag. As per codex standards, wheat stored in

bag was still consumable and marketable, even after 6 month's storage. Mould count ($39.8 \text{ CFU}/10^1$), germination percentage (76.7%), bored grains (1.6%) were within the acceptable limits of national (FCI) and international (Codex) standards. Density of *Rhizopertha dominica* was higher over *Tribolium castaneum*. Use of sealant with velcro fastening increased the airtightness and offer advantage to store food grains on-farm without chemical fumigants for six months, however, use of fumigant can extends the storage life beyond six months.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to M/S SRF Ltd for providing PVC coated fabric bag for field evaluation.

REFERENCES

- ASAE. 2007. Moisture measurement-unground grain and seeds (S352.2 ASAE Standards). In *American Society of Agricultural Engineering* 567–68.
- Beneke ES. 1962. Medical Mycology Lab. Manual. Minneapolis, Minnesota: Burgess Pub. Co.
- Bettge A, Rubenthaler GL and Pomeranz Y. 1989. Air-aspirated wheat cleaning in grading and in separation by functional properties. *Cereal Chemistry* 66(1): 15–8.
- Galeas L S. 2014. 'Understanding the Factors Affecting Microbiological Quality of Wheat Milled Products: From Wheat Fields to Milling Operations'. MSc Thesis, University of Nebraska. Lincoln, USA.
- Golob P, Farrell G and Orchard J. 2002. Crop Post-Harvest: Science and Technology, Perishables, 3, John Wiley & Sons.
- Hagstrum D W and Flinn P W. 2014. Modern stored-product insect pest management. *Journal of Plant Protection Research* 54(3): 205–10.
- Hayma J. 2003. *The Storage of Tropical Agricultural Products*. 4th Edn. Agromisa Foundation, Wageningen, The Netherlands.
- ICC. 1972. *Standard Methods of the International Association for Cereal Chemistry*. Method No. 102/1 Verlag Moritz Schafer: Detmold, West Germany.
- Jha S N, Vishwakarma R K, Ahmad T, Rai A and Dixit A K. 2015. Report on assessment of quantitative harvest and post-harvest losses of major crops and commodities in India. All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET.
- 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 Products Research* 37(3): 303–12.
- Kells S A, Mason L J, Maier D E and Woloshuk C P. 2001. Efficacy and fumigation characteristics of ozone in stored maize. *Journal of Stored Products Research* 37(4): 371–82.
- Koehler P G, Kern W H and Castner J L. 1992. Stored Product Pests. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Retrieved June 13, 2017, from <https://edis.ifas.ufl.edu/pdf/IN/IN02700.pdf>
- Kumar S, Mohapatra D, Kotwaliwale N and Singh K K. 2017. Vacuum hermetic fumigation: A review. *Journal of stored products research* 71: 47–56.
- Kumar N, Kumar S and Garg M K. 2015. Pasting characteristics of stored wheat in hermetic bags and conventional methods. *Agricultural Engineering International: CIGR Journal* 17(3): 278–86.
- Kumar D and Kalita P. 2017. Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. *Foods* 6(1): 8.
- Lane B and Woloshuk C. 2017. Impact of storage environment on the efficacy of hermetic storage bags. *Journal of Stored Products Research* 72: 83–89.
- Manmathan H and Lapitan N L. 2013. Measuring Germination Percentage in Wheat. Bio-protocol 3(16): e866. DOI: 10.21769/BioProtoc.866.
- Navarro S and Noyes R T. 2001. The mechanics and physics of modern grain aeration management. CRC press.
- Neethirajan S, Freund M S, Jayas D S, Shafai C, Thomson D J and White N D G. 2010. Development of carbon dioxide (CO₂) sensor for grain quality monitoring. *biosystems engineering* 106(4): 395–404.
- Somavat P, Huang H, Kumar S, Garg MK, Danao MGC, Singh V, Paulson MR and Rausch K D. 2017. Comparison of hermetic storage of wheat with traditional storage methods in India. *Applied engineering in agriculture* 33(1): 121.
- Strelec I, Popovich R, Ivanisic I, Jurcovic V, Jurcovic Z, Hardi Z and Sabo M. 2010. Influence of temperature and relative humidity on grain moisture, germination and vigour of three wheat cultivars during one year storage. *Poljoprivreda* 16(2): 20–24.
- Trivedi R K and Gunasekaran M. 2013. Indian minimum seed certification standards. The Central Seed Certification Board, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, 401–402.