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Design and development of hermetic storage bin for de-hulled Kodo millet

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Abstract
Hermetic storage is sealed airtight non-chemical based storage system used to preserve the quality of grain, protect from pests, insects, and minimizes the storage losses. A hermetic storage bin was designed with a capacity 200 kg for de-hulled kodo millet. To design the hermetic bin the physical properties of de-hulled kodo millet such as bulk density, true density, porosity, angle of repose and co-efficient of friction were studied. The bulk density, true density, porosity, and angle of repose of de-hulled kodo millet were found to be 685.42 kg/m^3, 1250 kg/m^3, 45.16% and 26.1°. The co-efficient of friction of de-hulled kodo millet against the mild steel was found to be 0.781. The lateral pressure exerted on the wall surface for was 123.45 kg/m^3 at the height of 0.6m. Pressure decay test was performed to check the air tightness of the hermetic bin. This hermetic bin can advocated to farmers and processors for value addition of small millets.

Keywords: Hermetic, storage, de-hulled, Kodo

Introduction
Hermetic storage is a sealed airtight storage system in which reduced oxygen level and elevated carbon dioxide were produced based on the result of respiration effects. It is non-chemical based storage system which reduces the cost of chemicals, insect's resistance, residues/poisoning in stored products, hazard associated with handling. This storage was primarily used in South and Central America, Africa, and Asia for medium and high value commodity (Villers, De Bruin et al., 2006) [23]. The synergistic effect on combination of reduced oxygen (reduced from 21% to less than 5%) and higher CO_2 levels helps in controlling insects and maintain the quality of grains. (Bibwe Bhushan 2017) [4], reported that the insect activity cessation occurs at 8-9% O_2 levels and complete mortality occurs when O_2 level drops below 2%. The loss in post-harvest of grain was estimated as 15% in the field, 13-20% during processing, and 15-26% during storage. The loss during storage is one of the main contribution in post-harvest losses of grains (Manandhar, Milindi et al., 2018) [13]. The losses due to post-harvest are by both in terms of quantitative and qualitative. Quantitative losses is due to infestation of insects, rodent's, pests, and birds whereas qualitative losses is due infestation of molds, mycotoxin and decrease in their nutritive value of the grains. When compared to conventional storage structure and using of synthetic pesticide, hermetic metal bin storage would be the effective one (Chigoverah and Mvumi 2016) [7]. To check the efficacy of hermetic bin pressure decay test is important to maintain the air-tightness inside the bin (Cardoso, Bartosik et al., 2012) [5]. Farmers can get higher profit due to seasonal price fluctuations when stored in hermetic storage (Baributsa and Njoroge 2020) [3].

Millets are drought resistance crop cultivated in rainfed regions of the country which contributes 60% of the total area. Madhya Pradesh is the India's leading producer of minor millets with 1, 44,000 tonnes per year followed by Uttarakhand. Tamil Nadu is the third largest leading producer from an area of 25,260 hectares with production of 31,280 tonnes (INDIASTAT 2018). Minor millets which may also called as small millets comprises of Foxtail millet (*Setaria italica*), Pearl millet (*Pennisetum glaucum*), Kodo millet (*Paspalum scrobiculatum*), little millet (*Panicum sumatrense*), Proso millet (*Panicum miliaceum*), and Barnyard millet (*Echinochloa esculenta*) (Seetharam, Riley et al., 1989) [18].

Kodo millet (*Paspalum scrobiculatum*) which is also known as Indian Crown Grass cultivated in the regions of India, Indonesia, Pakistan, Philippines, Thailand, Vietnam, and West Africa. In India it is a major food in Karnataka, Gujarat, Odihsa, Maharashtra, West Bengal, Uttar Pradesh and Rajasthan (Deshpande, Mohapatra et al., 2015) [9]. Kodo millet is highly nutritious when compared to other cereals. (Shahidi and Chandrasekara 2013) reported that the protein content in kodo millet was 8% in which the major protein fraction was glutelin.

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Kodo millet consists of 66.6g of carbohydrate, 1.4% fat 2.6% mineral content and 25.86 to 36.90 ppm of iron content (Girish, Meena *et al.,* 2014) [10]. Kodo millet contains high amount of anti-nutritional factors such as phytates, tanins and phosphorous. These anti-nutritional factors forms complexes with iron, zinc and calcium and reduce their bioavailability. De-hulling of kodo millet reduces the phytic contents by 25% (Balasubramanian 2013) [2]. Due to lack of storage structure the de-hulled kodo millet exhibits high storage losses by insects, birds, rodents and nutritive grain loss. In chemical based storage methods the insects develop resistance and chemical residues will form that may hazard to human beings while consumption. Hence, this research was proposed and the main objective was to design and develop an airtight storage metal bin for de-hulled kodo millet an alternative to chemical based storage to ceases insects and pests, to minimize the storage losses and to preserve the quality of grain during storage.

Materials and Methods
De-hulled Kodo Millet
Kodo millet (variety CO 3) used in this research were obtained from Tamil Nadu Agricultural University, Agricultural College and Research Institute, Eachangkottai, Thanjavur. Kodo millet was de-hulled using TNAU model multigrain de-huller shown in Figure 1. This de-huller consists of hopper, grain outlet, husk outlet, casing, impeller, aspirator and power transmission unit. During the operation, the millet hit the hard casing surface and due to impact force the husk splits from the grain. Millet is collected in the grain outlet and husk is collected by means of aspirator.

Fig 1: TNAU model multigrain de-huller

Moisture content
The moisture content of the grain was determined using standard oven-dry method by placing 5g of grain in hotter oven at 130 °C. The moisture content was calculated using this formula by the following equation (AACC 2000)

$$Mc\ (w.b.) = \left(\frac{Wi - Wf}{Wi}\right) \times 100$$

where, MC (w.b.) is the moisture content on wet basis (%), W_i is the initial weight of the sample (g), W_f is the final weight of the sample (g).

Bulk density
Bulk density of the grain was determined by filling the grains in a measuring cylinder to a certain level with constant height. Bulk density was calculated using the following formula (Mohsenin 1986) [14].

$$Bulk\ Density = \frac{Mass}{Volume} \left(\frac{kg}{m3}\right)$$

True density
True density was determined by taking 50ml of toluene into the measuring jar and a known weight of millet poured into measuring jar and raise in toluene level were recorded. The true density was calculated using the following equation (Sunil, Venkatachalapathy *et al.,* 2016) [22].

$$True\ Density\ (kg/m^3) = \frac{Weight\ of\ grains\ (kg)}{Volume\ of\ grain\ excluding\ void\ space\ (m^3)}$$

Porosity
Porosity of kodo millet was calculated by using the earlier value obtained from bulk and true density in accordance with the following equation (Mohsenin 1986) [14].

$$Porosity\ (\%) = \left(1 - \frac{Bulk\ density}{True\ density}\right) \times 100$$

Co-efficient of friction
Co-efficient of friction for de-hulled kodo millet was determined by (Sahay and Singh 1996) [17] against mild steel surface by the following formulae

$$f = \frac{F}{W}$$

Where, f is the co-efficient of friction, F is the force of friction and W is the force normal to the surface contact.

Angle of repose
It is the angle between the base and slope of cone formed when the millet is allowed to free fall vertically on the horizontal plane. Angle of repose was determined by using the following formulae given by (Sahay and Singh 1996) [22].

$$\theta = \tan^{-1} [2H/D]$$

Where, θ is the angle of repose, H is the height of cone formed and D is the diameter of the platform.

Silo classification
Depending on the relative dimension of the container the silo was classified into deep bin and shallow bin. The plane of rupture decides whether the silo is deep bin or shallow bin based on at what extent the diameter, width and relative dimension of its structure. The following equation given by (Gökalp and Bundy 2010) [11], determines the structure of bin. If $h < L \tan\left(\frac{90+\varphi}{2}\right)$ the structure can be taken as shallow bin and,

If $h > L \tan\left(\frac{90+\varphi}{2}\right)$ the structure can be taken as deep bin silo, were h and L are the depth and breadth of the structure and φ is the angle of internal friction.

Grain pressure calculation

The grain pressure exerted on the silo can be determined by using Airy theory. To calculate grain pressure, first it should require determining whether the silo is deep bin or shallow bin by above formulae. The lateral pressure at static equilibrium inside the bin was calculated using hydrostatic formula

$$P_l = wh \qquad (1)$$

Where,
P_l -lateral pressure exerted by storage grain on the bin wall (Pa);
w – bulk density of grain (kN/m^3);
h – depth of stored grain (m).

The formulae (1) has been modified and incorporated with a factor k because many structure buckled the vertical load arising from friction of grain on bin wall.

$$P_l = kwh \qquad (2)$$

where, k – Rankine co-efficient

The lateral pressure exerted by granular material stored inside bin against the retaining wall in shallow bin was determined by (Singh and Moysey 1985) in accordance with the following equation

$$P_l = wh\left(\frac{1}{\sqrt{\mu(\mu+\mu')}+\sqrt{1+\mu^2}}\right)^2 \qquad (3)$$

where, μ - co-efficient of friction of the grain on grain
$\mu = \tan\varphi$, $\varphi -$ angle of internal friction;
$\mu' = \tan\varphi$,$\varphi -'$angle of wall friction
h – height of the stored grain

Pressure decay test

The pressure decay test is used to check the air tightness of the silo. To check the silo air tightness it is pressurized by connecting to a fan or compressor and increase the pressure above the atmospheric level to a certain level. The air supply was then disconnected and the air pressure inside the silo was measured using manometer. (Navarro and Zettler 2001) [5, 15, 16], reported that the recommended time elapsed for pressure decay test is 6 min.

Results and Discussion

The physical properties of de-hulled kodo milled were measured at a moisture content of 10% (w.b.). Each property were measured at five replication and the mean values were taken. The bulk density of de-hulled kodo millet was found to be 685.42 kg/m^3. The true density, porosity and angle of repose were found to be 1250 kg/m^3, 45.16% and 26.1°. The results obtained for bulk density, true density, angle of repose and porosity were close to the findings of (Sunil, Venkatachalapathy *et al.,* 2016) [22]. The co-efficient of friction against the mild steel was 0.781 and these result was closer to the value obtained by (Chandan Kumar V.b 2018) [6].

Design of hermetic bin

The hermetic bin was designed with a capacity of 200 kg for de-hulled kodo millet. Based on the bulk density obtained the volume of the bin was found to be 0.283 m^3. The total height of the bin was 1.2 m and the breadth of the bin was 0.6 m. The frustum height was 0.3 m. To measure the temperature and relative humidity inside the bin two thermocouples and one rh probe were attached at equidistant to each other. Since it was a hermetic type storage system it is important to measure the gas concentration inside the bin. The gas concentration was measured with help of placing septum at three points equidistant to each other. The schematic representation of the designed bin was given in Figure 2.
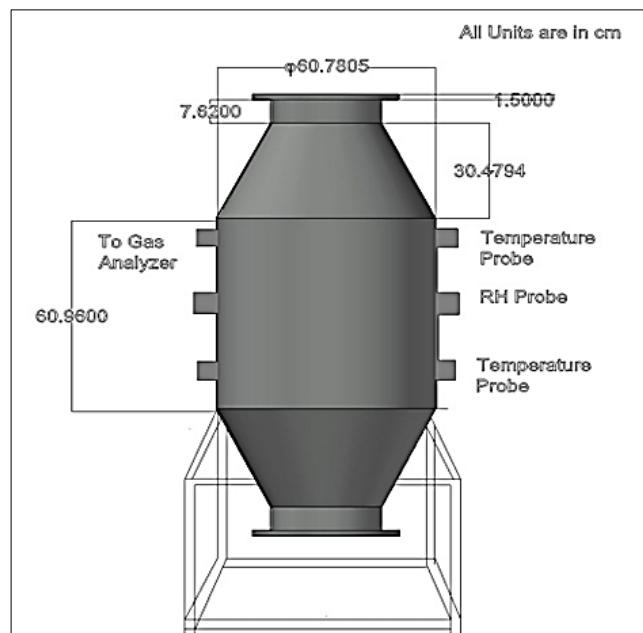

Fig 2: Schematic representation of storage bin

Structure of designed bin

To determine the designed bin is deep bin silo or shallow bin silo the length and depth of bin is substitute in the equation given by (Gökalp and Bundy 2010) [11]. The result obtained is h < l (0.6 < 0.96 m), the breadth of the bin is greater than its depth then the structure of bin can be taken as shallow bin silo.

Fig 3: Hermetic storage bin

Grain pressure calculation

During storage of grains in silo the lateral pressure developed inside the bin will act on silo wall. The lateral pressure for shallow bin silo can be determined using Airy equation. The Rankine Constant (k) can be determined by (Sun, Zhao *et al.,* 2018) [21, 22], and the constant depends on the angle of internal

friction (φ) and the angle of internal friction can be taken as natural angle of repose (Sahay and Singh 1996) [22]. He defined k as $(1 - \sin\varphi)(1 + \sin\varphi)^{-1}$. The k value was calculated as 0.39 when the angle of internal friction is 26° (for de-hulled kodo millet). The angle of friction of grain on grain (μ) was calculated as 0.487. The maximum lateral pressure exerted on the wall surface at 0.6m was calculated as 123.45 kg/m³. The lateral pressure act on wall at different depth was given in fig below:
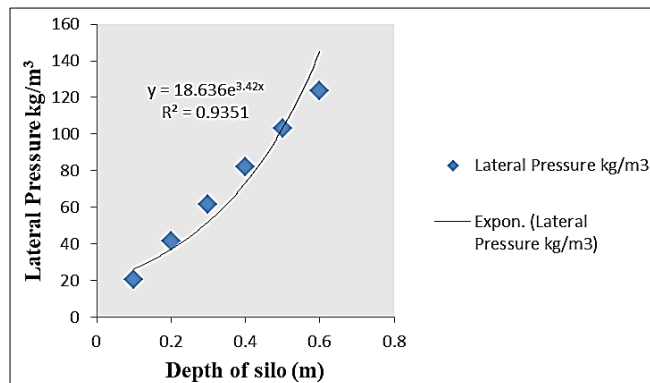

Fig 4: Lateral pressure exerted on silo wall

The hermetic shallow bin silo has maximum lateral pressure on the top of bin and it gets reduced when it reaches to the bottom of the bin. (Sun, Zhao *et al.,* 2018) [21, 22], also reported the same that the maximum lateral pressure was on the top of the silo bin.

Pressure decay test
The air tightness of silo bin was affected by any holes or damages in the material and improper sealing (Cardoso, Bartosik *et al.,* 2012) [5]. Since it was hermetic bin it is essential to maintain the air tightness inside the bin. The level of air tightness was determined by pressure decay test (Navarro 1998) [5, 15, 16]. Initially the silo was pressurized by 1300 Pa and decrease in pressure was measured for every 10 min. At the end of 1 hour the pressure was reduced to 710 Pa. (Darby JA 2007) [8] reported that the range of half pressure of 5 minutes implies high level air tightness and less than 3 minutes indicates poor air tightness. From the Figure 5. It shows clearly that the half of pressure reduced 50 minutes which shows the bin has high level air tightness.
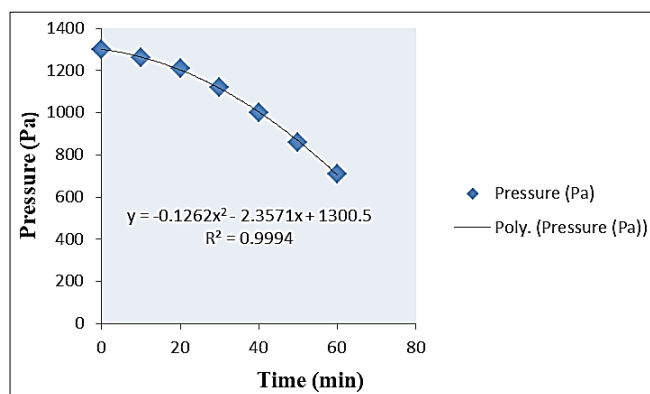

Fig 5: Pressure decay test

Conclusion
This hermetic bin is alterative to chemical based storage system which preserves the quality of the stored de-hulled kodo millet, inhibits insect infestation and pests and minimizes the losses during storage. This bin could be scaled up which might effectively store store de-hulled kodo millets without addition of any chemicals. This hermetic storage can be advocated to farmers and processors for value addition of small millets.

References
1. AACC. Approved methods. American Association of Cereal Chemists. Moisture determination 44-15A, Minnasota, St Paul 2000.
2. Balasubramanian S. Processing of millets. Paper presented National Seminar on Recent Advances in processing, utilization and nutritional impact of small millets. Madurai Symposium, Thamukkam Grounds, Madurai 2013.
3. Baributsa D, Njoroge A. The use and profitability of hermetic technologies for grain storage among smallholder farmers in eastern Kenya. Journal of Stored Products Research 2020;87:101618.
4. Bibwe Bhushan KJ, Manoj Mahawar, Dukare Ajinath, Pankaj Kannaujia. Hermetic Storage: Safe and cheap technique for grain storage 2017.
5. Cardoso L *et al.* Air-tightness level in hermetic plastic bags (silo-bags) for different storage conditions. Navarro S, Banks HJ, Jayas DS, Bell CH 2012, P583-589.
6. Chandan Kumar VB, Madhusudan PV, Nayak C. Engineering Properties of Kodo Millet (Paspalum scrobiculatum): CO (3) Variety. International Journal of Agriculture, Environment and Bioresearch 2018;3(1):81-87.
7. Chigoverah AA, Mvumi BM. Efficacy of metal silos and hermetic bags against stored-maize insect pests under simulated smallholder farmer conditions. Journal of Stored Products Research 2016;69:179-189.
8. Darby JA, CL. Review of grain harvest bag. CSIRO technical report 2007.
9. Deshpande S *et al.* Kodo millet: Nutritional value and utilization in Indian foods. Journal of grain processing and storage 2015;2(2):16-23.
10. Girish C *et al.* Nutritional properties of minor millets: Neglected cereals with potentials to combat malnutrition. Current Science 2014;107(7):1109-1111.
11. Gökalp Z, Bundy DS. Analysis of lateral design pressures, vertical frictional forces and bending stresses on horizontally corrugated steel silo wall panels 2010.
12. INDIASTAT 2018. http://www.indiastat.com.elibrarytnau.remotexs.in/table/agriculture-data/2/small-millets/968772/1229930/data.aspx
13. Manandhar A *et al.* An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. Agriculture 2018;8(4):57.
14. Mohsenin NN. Physical properties of plant and animal materials 1986.
15. Navarro S. Pressure tests for gaseous applications in sealed storages: Theory and practice. Proceedings of 7th international working conference on stored-product protection 1998.
16. Navarro S, Zettler J. Critical limits of sealing for successful application of controlled atmosphere or fumigation. Proc. Int. Conf. on Controlled Atmosphere and Fumigation in Stored Products. Executive Printing Services, Clovis, CA 2001.
17. Sahay K, Singh K. Unit operations of agricultural processing. Vikas Publishing House Pvt Ltd 1996.

18. Seetharam A *et al.* Small millets in global agriculture. International Small Millets Workshop 1986: Bangalore, India). Oxford & IBH Publishing Co Pvt Ltd 1989.
19. Shahidi F, Chandrasekara A. Millet grain phenolics and their role in disease risk reduction and health promotion: A review. Journal of Functional Foods 2013;5(2):570-581.
20. Singh D, Moysey E. Grain bin wall pressures. Theoretical and experimental. Canadian Agricultural Engineering 1985;27(1):43-48.
21. Sun S, *et al.* Calculation of Silo Wall Pressure considering the Intermediate Stress Effect. Advances in Civil Engineering 2018.
22. Sunil C *et al.* Engineering properties of foxtail millet (*Setaria italic* L.): Variety-HMT 1001. International Journal of Science, Environment and Technology 2016;5(2):632-637.
23. Villers P *et al.* Development and applications of the hermetic storage technology. Proceedings of the 9th International Working Conference on Stored Products Protecfion 2006.