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Development of portable modified atmospheric packaging (MAP) unit for grain disinfestation

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ABSTRACT

A portable modified atmospheric packaging (MAP) unit was developed for grain disinfestation. The developed MAP unit consisted of a grain holding unit and cover, sealing unit, flushing nozzle, pressure regulator, solenoid valve with timer, working table and carbon dioxide cylinder. The operational parameters of the developed MAP unit, viz. flushing pressure and flushing duration, was optimized for Bengal gram (*Cicer arietinum* L.). The flushing pressure of 5 kg/cm^2 for 10 s was found to retain the maximum concentration of CO_2 (94.8%) and minimum of O_2 (0.1%) in Bengal gram packages of one kg capacity, with highest desirability of 97.8%. The results on storage of Bengal gram showed no incidence of infestation and the highest germination (%) in PET packages compared to PE and PP at the end of nine months. Similarly, CO_2 retention was observed to be for longer period in PET compared to PE and PP. The estimated cost of the developed MAP unit was found to be ₹ 8350 and the cost of packaging was worked out to be ₹ 2.90 for PET followed by PE and PP each of ₹1.90.

Key words: Disinfestations, MAP of Bengal gram, Modified atmospheric packaging unit

Agriculture is an important sector of Indian economy, contributing about 17% to the GDP and provides employment to over 60% of the population (Kekane, 2013). Indian agriculture has registered impressive growth over last few decades and helped India to mark its global presence. Grain production has been steadily increasing owing to advanced production technologies, but improper storage resulted in high losses. During storage, quantitative as well as qualitative losses occur due to insects, rodents and micro-organisms. Grain storage plays an important role in preventing losses which are caused mainly due to weevils, beetles, moths and rodents (Kartikeyan et al., 2009). It is estimated that 60–70% of food grain produced in the country is stored at home level in indigenous storage structures; however, they are not suitable for storing grains for very long periods (Mishra et. al., 2012). Here in lies the significance of improved and scientific storage of grains. Many studies have shown that modified atmosphere (MA) of elevated CO_2 and depleted O_2 is lethal to pests and obligate aerobe micro-organisms during the storage. Modified atmospheric storage is a well-proven technology for preserving natural quality of food products in addition to extending the storage life (Jayas and Jeyamkondan, 2002). At the same time, consumers today expect the food products to be chemical and pesticide free or with lower levels of residues. Hence it is necessary to develop alternative methods that are economically feasible and ecologically adjusted to control storage grain insects and fungi (Moreno-Martinez et al., 2000). Though modified atmosphere packaging is a effective method for storing the grains without spoilage and it may help improve the shelf life of the grains effectively, still it has some limitations like higher initial cost. Hence an attempt is made to develop a small-scale portable modified atmospheric packaging unit.

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MATERIALS AND METHODS

Selection of food grains

Survey was conducted to know the major food grains grown in the region, their production and shelf life. Based on the study, bengal gram (*Cicer arietinum* L.), rice (*Oryza sativa* L.) and sorghum were selected for design of the modified atmospheric unit.

Physical properties of selected food grains

The physical properties of grains relevant to the design of portable modified atmospheric packaging unit, viz. bulk density, true density and porosity, were determined. The bulk density was determined as the ratio of mass of the sample and volume occupied by it (Mangaraj and Singh, 2005). The true density was determined by toluene displacement method as suggested by Mohsenin (1986). Porosity was computed from the value of particle density and bulk density using the equation given by Mohsenin (1986).

Selection of packaging material

The commonly available packaging materials, viz. polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) having 100 µ thickness, were used. The dimension was selected based on bulk density and headspace required for filling gas. Five kg capacity packaging material was used for designing the MAP unit and one kg capacity for studying the quality parameters of packaged food grains.

Development of portable modified atmospheric unit

A portable modified atmospheric packaging (MAP) unit was designed, developed and tested for disinfestations of Bengal gram. The developed unit consists of a grain holding unit, top cover, sealing unit, nozzle, pressure regulator, solenoid valve with timer, working table and carbon dioxide cylinder.

Grain holding unit: The dimensions of grain holding unit are designed based on the quantity of grains to be packed, dimension of sealing unit and space to accommodate other accessories. Based on the water capacity of the packaging material and volume of the grains, the dimension of the packaging material was selected. The unit was designed for packing of 5 kg grain capacity.

Standard packaging material size for 5 kg capacity:
450 mm × 300 mm

Length of the grain
holding unit (L) = Length of packaging material + width of the sealing unit + length of the nozzle
= 450 + 100 + 50 = 600 mm

Width of the grain
holding unit (W) = Length of the sealing unit space + Free board
= 400 + 50 = 450 mm

Height of the grain
holding unit (H) = Height of the packaging machine + Free board
= 140 mm + 60 mm = 200 mm

The final dimensions = L × W × H
= 600 mm × 450 mm × 200 mm

Plywood of 8 mm thick was used as construction material considering its durability and cost.

Top cover of grain holding unit: Transparent fibre sheet of 5 mm thick was used as top cover, so as to make sure the operation of gas flushing and sealing are visible to avoid the possible errors. Accordingly, the dimensions of cover were selected as 615 mm and 465 mm based on grain holding unit.

Sealing unit: The sealing machine was selected based on dimensions of packaging material and the standard sizes of sealing machine available in the market. The sealing unit of SEPACK brand (model-300 DELTAS) with seal dimensions of 300 mm × 1.6 mm was used.

Nozzle: The nozzle was used for flushing the gas and dimensions were selected based on the standard sizes available in market. Nozzle of 50 mm length with 2 mm of orifice was selected.

Pressure regulator: It was provided for regulating the pressure and flow volume. The commercially available gas regulator with maximum pressure range of 16 kg/cm^2 with orifice of 6 mm was used.

Solenoid value with timer: Timer controlled solenoid valve was used to control the flow of gas. Commercially available solenoid valve of 2/2-way midget direct acting normally closed and energized to open type with 6 mm orifice was used with digital timer ranging 0.5–45 min.

Working table: The MAP unit was placed on a portable working table made of cast iron angles. Dimensions of table are designed based on the dimensions of the MAP unit and operators ergonomics. The dimensions designed are 620 mm × 470 mm × 850 mm for L × W × H.

Carbon dioxide cylinder: The commercially available carbon dioxide cylinder having 30 kg capacity with a total volume of gas equal to 47.4 m^3, was used for the experiment.

Performance evaluation of developed MAP unit

The performance of developed MAP unit was evaluated after optimizing the operational parameters of MAP unit in terms of quality of packaged grains/seeds during storage period.

The optimization of operating parameters, viz. flushing pressure and flushing duration, for the developed MAP unit was carried to achieve target composition of gases in the grain packages using statistical software Design Expert with two responses (CO_2 maximization >60% and O_2 minimization <3%) in the range. The target gas concentrations considered for insect toxicity were 3% or less of O_2 and 60% or more of CO_2 (Mbata et al., 2004). The flushing of gas was carried out at four different pressures, viz. 2, 3, 4 and 5 kg/cm^2, and flushing durations, viz. 5, 10, 15 and 20 s for Bengal gram based on trial experiments. The leakage test was performed by bubble immersion testing method as described in IS 9902:2004.

Gas composition in package

The gas concentration in package was measured using gas analyzer (Model-Check point; Make-PBI Dansensor, Denmark) at monthly interval during storage period.

Quality parameters of packaged grains/seeds

The quality parameters, viz. per cent insect damage and germination percentage, for packaged grains/seeds were estimated for nine months at monthly intervals during storage. Pulses suffer a great damage during storage due to insect attack and Bengal gram is one of the important pulse crop of the HK region. Hence Bengal gram was selected for storage study and is severely attacked by bean beetle resulting losses in quantity and nutritional quality (Muhammad Sarwar, 2012).

Per cent insect damage

Insect damage was assessed by counting method as described by Wambugu et al. (2009). It was estimated by drawing 100 seeds from each replication at random and damaged seeds due to insects (with holes, eggs or both) were recorded and expressed in percentage on number basis.

Germination percentage

Germination test was conducted with three replicates of 100 seeds each in the paper medium and kept in the walk-in germinator maintained at 25 ± 1°C and 90 ± 2% r. h. At the end of sixth day, the number of normal seedlings in each replication was counted and the germination was calculated and expressed in percentage (ISTA, 2013).

Economics of developed unit

The economic analysis is an important part of any technology, since it determines the cost : benefit ratio and adoptability of the technology. The cost of the developed MAP unit and the cost of packaging were computed.

Table 1 Physical properties of the selected grains

Parameter	Commodity		
	Bengal gram	Rice	Sorghum
Bulk density (kg/m^3)	818	838	821
Particle density (kg/m^3)	1330	1428	1304
Porosity (%)	38.47	41.29	37.03

RESULTS AND DISCUSSION

Physical properties of selected food grains

Grain properties relevant to the design of MAP unit were determined for rice, Bengal gram and Sorghum and results are presented in Table 1.

The mean values of bulk density for Bengal gram, rice and sorghum were 818, 838 and 821 kg/m^3, respectively, with highest value for rice followed by sorghum and Bengal gram (Table 1). The average values of particle density were 1330, 1428, 1304 kg/m^3 for Bengal gram, rice and sorghum respectively. The calculated porosity was 38.47, 41.29 and 37.03% for Bengal gram, rice and sorghum respectively. Similar results were reported by Kanchana et al. (2012), Jambamma et al., (2011) and Nikoobin et al. (2009).

Selection of packaging material

Based on bulk density of grains and water capacity of packages, the commercially available packaging materials of one kg capacity with 203 mm × 305 mm, 100 μ were selected for the performance study. The dimensions of packaging materials are presented in Table 2.

Table 2 Dimensions of one kg capacity packaging materials

Packaging material	Size (mm^2)	Thickness (μ)	Water capacity (cm^3)
Poly ethylene (PE)	203 × 305	105	1890
Polypropylene (PP)	203 × 305	101	1740
Polyethylene terephthalate (PET)	203 × 305	103	1770

Design of modified atmospheric packaging unit

The specifications of the developed portable MAP unit are presented in Table 3 and the schematic diagram in Fig. 1.

Performance evaluation of developed MAP unit

The recorded and analyzed data for performance evaluation of MAP are presented below.

The data on average of replications for gas

Table 3 Design specifications of portable modified atmospheric packaging (MAP) unit

Parts of MAP	Specifications
Grain holding unit	L × W × H : 600 mm × 450 mm × 200 mm
Top cover	L × W × T : 615 mm × 465 mm × 5 mm
Sealing unit	L × W × H : 400 mm × 90 mm × 140 mm Seal dimensions : L × T - 300 mm × 1.6 mm
Nozzle	L × D : 50 × 8 mm, Orifice - 2 mm
Solenoid valve	2/2-Way Midget Type, Normally Closed Size : 6mm (1/4"), Orifice - 3.0 mm, Max. Pressure – 12 bar
Pressure regulator	Model - OR Mini (1/4'), Pressure (Max) P1 - 16 kg/cm^2
Working table	L × W × H : 620 mm × 470 mm × 850 mm

composition in Bengal gram packages immediately after flushing are presented in Table 4. It was observed that, flushing pressure and duration had significant effect on concentration of flushed gas. The solutions provided by optimization tool showed the flushing of CO_2 at 5 kg/cm^2 for 10 sec had 97.8% desirability for Bengal gram.

Retention of carbon dioxide and oxygen in grain packages

The variations of CO_2 and O_2 concentration for Bengal gram packets during storage, presented in Table 5, showed that CO_2 composition reduced and attained atmospheric condition within one month of storage in PE and PP packets, whereas PET retained higher levels of CO_2 up to three months. Similarly, oxygen composition turned to atmospheric condition within one month for all packaging materials. This might be because of higher permeability PE and PP for CO_2

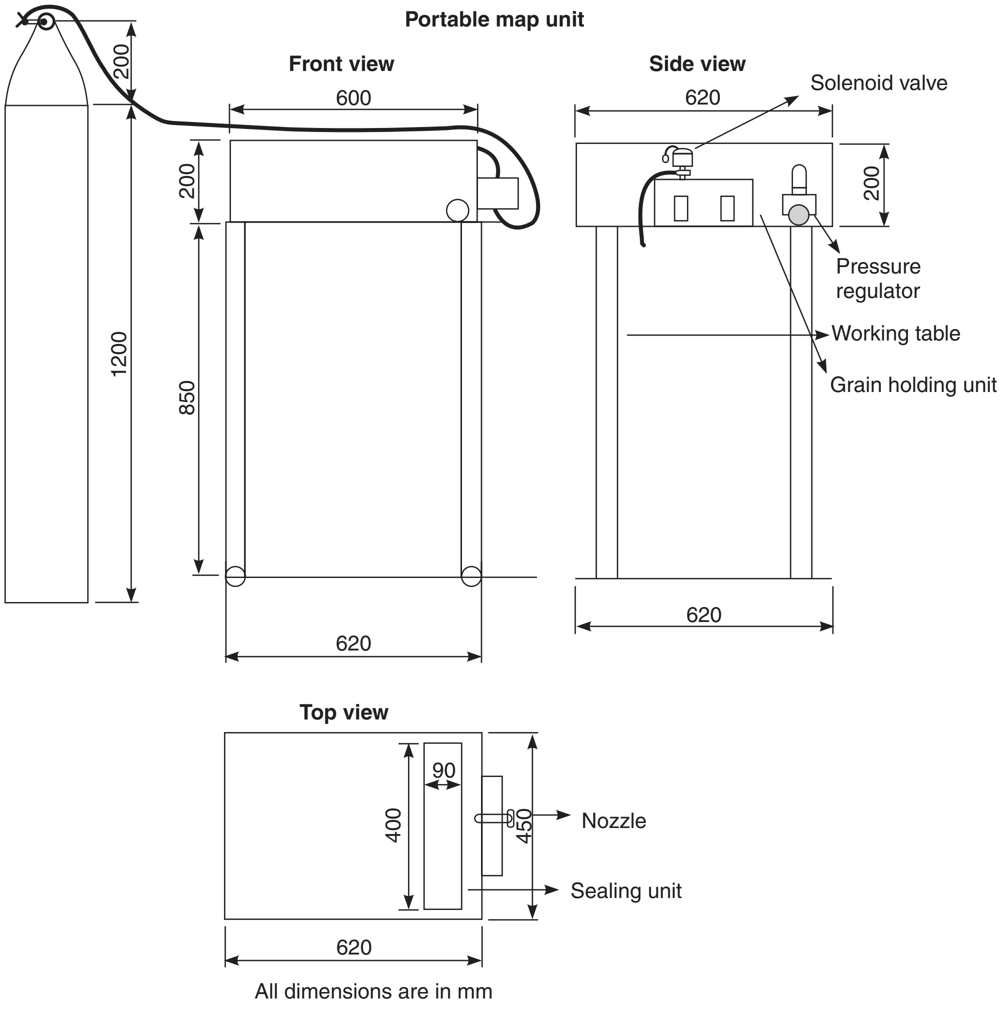

Fig. 1. Schematic presentation of modified atmospheric packaging unit

Table 4 Average data on composition of gas in bengal gram packages

Pressure	2 kg/cm^2				3 kg/cm^2				4 kg/cm^2				5 kg/cm^2			
Time, s	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
CO_2, %	91.6	92.6	92.3	94.8	85.0	92.7	91.6	92.5	91.9	94.5	91.0	94.6	90.5	94.8	93.1	93.8
O_2, %	0.5	0.6	0.7	0.1	2.1	0.6	0.7	0.6	0.6	0.1	0.9	0.1	1.0	0.1	0.4	0.3

Table 5. Retention of CO_2 and O_2 gas for bengal gram in different packaging materials during storage

Packaging material	Storage period, months									
	0	1	2	3	4	5	6	7	8	9
	Carbon dioxide, %									
PE	94.4	0	0	0	0	0	0	0	0	0
PP	94.25	0	0	0	0	0	0	0	0	0
PET	93.95	21.6	12.6	0	0	0	0	0	0	0
	Oxygen, %									
PE	0.14	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
PP	0.05	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
PET	0.14	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9

and O_2 gases compared to PET. Valentina (2012) also reported similar results.

Per cent insect damage

The data on per cent insect damage influenced by MAP conditions during storage revealed that, no incidence of infestation was found up to five months but, from sixth month onwards infestation was observed in PE and PP packages (Table 6) and PET packages were free from infestation even after nine months. The results are in agreement with Ramesh Babu et al., (1991) and Mbata et al., (2004).

Germination

The results of germination as influenced by MAP conditions during storage showed that, germination percentage declined with advancement of storage period. (Table 7). Germination percentage was the highest for Bengal gram stored in PET packets which was 100% at initial stage and decreased to 97.5% at the end of nine months. In PE and PP packages, it declined from 100% to 94.0% and 94.5% respectively. The probable reason for differences in longevity might be due to reduced respiration and aging of the seeds at higher concentration of CO_2. Bera et al., (2004) also

Table 6 Per cent insect damage for Bengal gram in different packaging materials during storage

Packaging material	Storage period, months								
	1	2	3	4	5	6	7	8	9
Poly ethylene (PE)	0	0	0	0	0	1.0	2.5	3.5	5.0
Polypropylene (PP)	0	0	0	0	0	0.5	1.5	3.0	4.0
Polyethylene terephthalate (PET)	0	0	0	0	0	0.0	0.0	0.0	0.0

Table 7 Germination percentage for Bengal gram in different packaging materials during storage

Packaging material	Storage period, months									
	0	1	2	3	4	5	6	7	8	9
Poly ethylene (PE)	100	100	99.3	99.0	99.0	97.0	96.5	96.0	95.5	94.0
Polypropylene (PP)	100	100	99.3	99.6	98.0	97.5	97.5	96.5	95.0	94.5
Polyethylene terephthalate(PET)	100	100	99.6	99.6	99.0	99.0	98.5	98.0	97.5	97.5

reported that, the germmination ability of wheat seed was not adversely affected by CO_2 rich atmosphere when stored for six months with 12% moisture content. Rathi et al., (2000) also reported on the germination and viability of soybean [*Glycine max* (L.) Merr.] and sorghum [*Sorghum bicolor* (L.) Moench] seeds indicate that an atmosphere containing high CO_2 does not have a detrimental effect on seeds as much as high storage temperature and higher moisture content.

Economics

The cost of developed MAP unit was estimated to be ₹ 8,350 and cost of operation ₹ 0.90/ packet. The cost of modified atmospheric packaging of Bengal gram was ₹ 2.90 for PET followed by PE and PP each of ₹ 1.90 respectively.

CONCLUSION

The developed portable MAP unit consisted of a grain holding unit, sealing unit, flushing nozzle, pressure regulator, solenoid valve with timer, working table and CO_2 cylinder. The flushing pressure of 5 kg/ cm^2 for 10 s duration was found to flush the maximum concentration of CO_2 (94.8%) and the minimum of O_2 (0.1%) in the Bengal gram packages of one kg capacity, having highest desirability of 97.8%. The performance evaluation showed no incidence of infestation in PET packages compared to PE and PP packages and germination was also highest for Bengal gram packed in PET (97.5%) compared to PE (94.0%) and PP (94.5%) packages at the end of nine months of storage. The estimated cost of the MAP unit was found ₹ 8350 and the cost of packaging ₹ 2.90 for PET followed by PE and PP each of ₹ 1.90.

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