



Design and Development of Environmental Friendly Sub-Baric Storage Bin

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Developments in vacuum storage technology present an opportunity to achieve significant improvements on protection, preservation and storage of agricultural commodities for residential and commercial use. Sub-baric storage is an environmental friendly, non-residue organic technology which provides chemical-free and insect contamination-free products. Due to creation of vacuum, there is a change in the environment inside the storage structure. This study therefore contributes an important knowledge and method in the development, fabrication and application of a sub baric storage bin (SBSB) as a best alternative to the commonly used traditional and modern storage structure. In its embodiment, the work focuses on the design and fabrication of the sub-baric storage bin to provide efficient storage of food grains by preventing the use of pesticides and insecticides and to reduce material loss during storage, a sub-baric storage bin of 500 kg capacity was designed and developed. The developed storage bin consists of storage chamber (500 kg), Vacuum pump, suction blower, grain inlet with pipe for loading, grain outlet for unloading, vacuum gauge, thermocouple, control panel, agitator, air filter, two inlet valves for gas infusion, vacuum release valve and SS mobile skid. The designed sub-baric storage bin is cylindrical in geometry with conical shape at bottom side and flat circular plate on top side and the storage bin has

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capacity of 500 kg to store food grains with hopper angle of 60°. The storage bin was designed in such a way that, it has provision for both bulk and bag storage and to work from 0-650 mm Hg vacuum. The developed SBSB was subjected to hydraulic pressure test and vacuum drop test to ensure a safe operation. It was observed that there was no implosion (compression) or explosion confirming to the fact that the design was adequate and also safe to operate. Also, there were no signs of bulging, buckling or any deformations observed in any of the components or the pipe lines, connections, fixtures or fasteners. Hence, it was concluded that the designed equipment could be operated safely at 650 mm Hg vacuum pressure satisfying all the applicable safety assurances and standards relevant to the industry.

Keywords: Finite element analysis; food grain storage; sub-baric.

1. INTRODUCTION

The demand for food grains is 'inelastic', which means that large changes in the market price lead to relatively small changes in the amount of grains which people purchase [1]. Most of the developing countries are already facing issues of hunger and food insecurity. Increasing urbanization, climate change and land use for non-food crop production, intensify these concerns of increasing food demands. However, postharvest loss (PHL), a critical issue, does not receive the required attention and less than 5% research funding has been allocated for this issue in previous years [2-5] Approximately one-third of the food produced (about 1.3 billion ton) is lost globally during postharvest operations every year [6]. Therefore, proper post-harvest management can play key role in mitigating these problems.

Storage is an important marketing function, which involves holding and preserving goods from the time they are produced until they are needed for consumption. Grain storage plays an important role in preventing losses which are caused mainly due to weevils, beetles, moths and rodents [7]. Every year, million tons of grain losses are caused due to improper storage conditions. Traditional storage of which construction and digging are laborious, grains can acquire a fermented smell after long storage and also inspection of the grain is difficult [8].

Factors like humidity, heat, pests and aeration which are effective on storage conditions affect the quality and quantity of grain and shorten the storage period [9]. The effect of climate change on the major components of stored-grain ecosystems and the system as a whole is an important point to be considered in storage. In general, the effects of climate change on the quality of stored grain can be considered direct or indirect. Direct effects include role of climate

change on the growth and developmental cycles of biotic components and indirect effects include the effect of rising global temperatures on grain drying conditions that would ultimately affect stored grain quality [10]. In this aspect, proper storage practices are among the most important elements in food supply chain of grain which is a significant nutritional source. Moreover, the effect of using toxic chemicals like Methyl bromide and phosphine fumigants on seed and grain include: germination ability, seeding viability and dietary risk. Ozone depletion, insect resistance and residues on grain surface are the other problems with the use of chemical fumigants. The effects of chemicals range from minor discomfort to cancer, endocrine, organic disorder which includes disruption of activity of organs in the body, e.g., kidney, liver or digestive tract [11]. Considering above mentioned demerits, inclusion of vacuum technology enhances the efficacy of storage.

Vacuum technologies such as vacuum packaging and sub-baric storage technology are the emerging new generation storage technologies. The disadvantages of vacuum packaging are low mechanical strength of package, small quantity storage, in the process of vacuuming of vacuum package the food inside faces pressure and if not being carefully curated the food may lose its initial integrity and gets crushed. Above mentioned requirements are fulfilled by sub-baric storage technology. Sub-baric storage is defined as the storage condition which is maintained at extreme levels of vacuum between 0-650 mm Hg. Sub-baric storage is a technique which helps in depletion of oxygen in the storage systems through the application of negative pressure, which causes slower metabolic rate and finally cessation of basic metabolism and death of insects in a few days [12]. Lack of oxygen had a significant impact on the mortality of insects and inhibits the development of fungi and yeast [13]. The

anaerobic environment of vacuum storage prevents the growth of micro-organisms especially aerobic ones which are responsible for nutritional loss, off- odour and texture changes [14].

Sub-baric storage technique as a pest management tool represents a potential non-chemical alternative to fumigants such as methyl bromide and phosphine for controlling the weevil and related bruchids [15]. It is a non-residue organic technology which provides chemical-free and insect contamination- free products [16]. Sub-baric storage technology will emphasize greater control, longevity of grains, cleanliness with respect to collected grain and provision for ease of loading and unloading of grains. In order to provide efficient storage of food grains by preventing the use of pesticides and insecticides and to reduce material loss during storage, a sub-baric storage bin (SBSB) of 500 kg capacity was designed and developed.

2. MATERIALS AND METHODS

The procedures followed in the design and development of SBSB are as follows; optimisation of wall thickness of sub-baric storage unit using finite element analysis (FEA) method, selection of hardware materials, fabrication and assembly as per FDA c-GMP and 3A hygiene standards [17], testing of an assembled unit for leak proof and safety and performance evaluation of developed storage bin.

2.1 Optimisation of Wall (shell) Thickness of Sub-baric Storage Unit using Finite Element Analysis (FEA) Methods

The mechanical strength of the chambers as determined by the thickness of the metal sheet (wall thickness) used in its fabrication was considered the critical design parameter. The following design steps elaborate the procedures adopted to arrive at the optimal thickness of the vacuum chamber wall for the sub-baric storage unit [18].

2.2 3-D Model Generation

Sub-baric storage bin is cylindrical in geometry with conical shape at bottom side and flat circular plate on top side. The material of construction was decided as AISI-316 SS and both units were

designed to work in full vacuum of 5 kPa with outside operating pressure of 101.1 kPa (NTP). Computer Aided Design/Engineering (CAD/CAE) and FEA analysis were used to determine the Von Mises stress, deformation and factor of safety. [19- 20]. The 3-D model of the unit was developed using Pro/ENGINEER software as shown in Fig. 1. This graphical model was then saved in IGES-(Initial Graphics Exchange Specification) neutral format and imported to ANSYS-14 workbench for stress analysis. The operating parameters, material properties and boundary conditions were fed to ANSYS-14 work bench for stress analysis.

2.3 Steps Involved in Thermal Stress Analysis

In order to optimize the wall thickness, the stress analysis was conducted using different design software (Pro/E, ANSYS) by following the procedures as detailed by Kraan et al., [19] [21] as shown in Fig. 2.

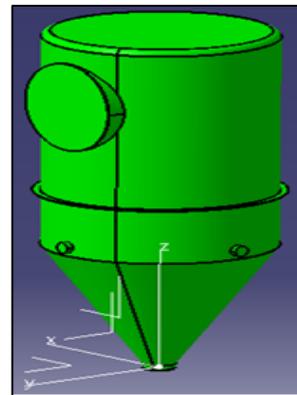


Fig. 1. 3-D model of bin

2.4 Design of Components of Sub-baric Storage Bin

After completion of theoretical design of sub-baric storage bin in design software and complete stress analysis, the fabrication work was carried out as per FDA c-GMP and 3A hygiene standards [17]. The various components of fabrication process are described hereunder.

2.5 Selection of Material of Construction: Selection of Stainless Steel

The machine components were fabricated from FDA and 3A approved cold drawn AISI-316 SS as per FDA c-GMP and 3A hygiene standards.

The AISI-316 SS is austenitic grade stainless steel and has good weldable and forming properties. It is resistant to both acid and alkali and has good corrosion-resistant properties. Non-contact parts like structure skid, fasteners etc. were fabricated from AISI-304 SS.

2.5.1 Sub-baric storage bin

The storage bin was fabricated from FDA and 3A approved cold drawn AISI-316 SS. Sub-baric storage bin was designed and developed having cylindrical in geometry with conical shape at bottom side and flat circular plate on top side and has capacity of 500 kg to store food grains with hopper angle of 60° as shown in Fig. 3. The physical properties of grains like grain pressures, packing behaviour and flow behaviour include the bulk density of the grain (W), the ratio of lateral to vertical pressure (k), the internal angle of friction (ϕ) and the coefficient of friction of grain on the bin wall (μ) were considered while designing the storage chamber. It has length, diameter and thickness of 1638, 750 and 4 mm, respectively. The four legs were fixed to the storage chamber with size of

1268 × 65 mm (LxD) to ensure smooth functioning and operation. The storage bin was designed in such a way that, it has provision for both bulk and bag storage. Due to creation of vacuum, there was change in climatic condition inside the storage bin.

2.5.2 Vacuum pump

The sub-baric storage bin is designed to work from 0-650 mm Hg vacuum. The capacity of vacuum pump was designed based on time required to evacuate total volume of air present in the designed SBSB. Vacuum pump will suck all the air inside the storage chamber but before that valve 2 (Fig. 6) need to be closed. After the suction the pressure sensor will indicate 0.0 bar and the regulator will trigger indicating there is no more air inside the system then the pump will be turned off. In order to create high vacuum and considering noise less operation, an oil immersed vacuum pump with 1 Hp capacity was chosen to create vacuum in the sub-baric storage bin. A valve provided at front facing of the sub-baric storage bin with hand operated lever to release the vacuum before unloading food grains.

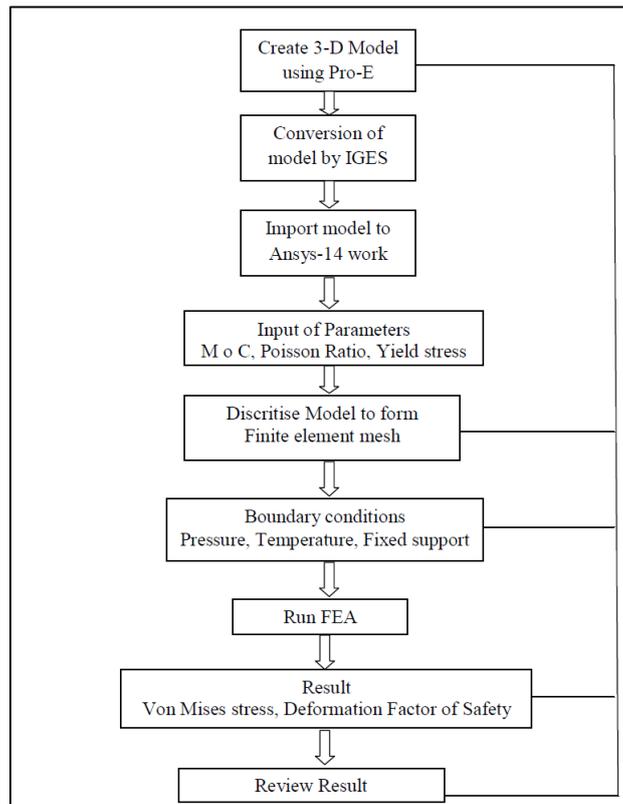


Fig. 2. Stress analysis cycle

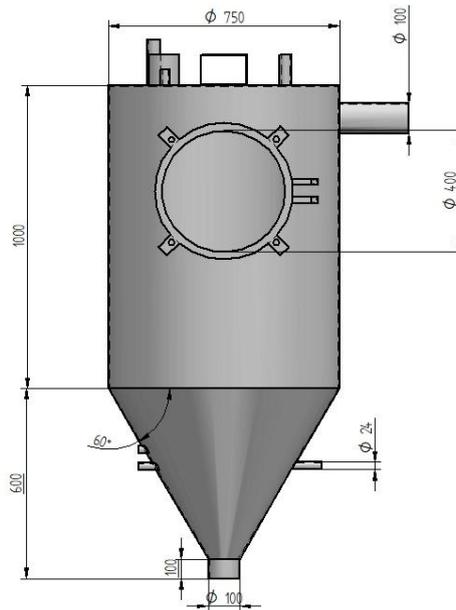


Fig. 3. Sub-baric storage bin

2.5.3 Suction blower

The suction blower was used to suck food grains into sub-baric storage bin by creating negative pressure. The blower was of high discharge and low vacuum type and it has capacity to rotate 20,000 revolutions per minute.

2.5.4 Inlet and outlet of bin body for loading and unloading of grains

The storage bin was designed in such a way that, it has provision for both bulk and bag storage. For loading of bulk grains, the grain inlet pipe with hand operated lever was provided. A pipe with length adjustment coupling was attached to grain inlet mouth for easy loading of food grains. Circular glass door with suitable frame work was provided for loading of grains into the bin and bags could be placed on circular platform. A grain outlet provided at the bottom of developed sub-baric storage bin with 5 kg capacity container for unloading of food grains with 200 mm height and 260 mm diameter. Bulk grain unloading (>5 kg) is attained by dismantling the container which is provided at the bottom of bin.

2.5.5 Vacuum gauge

The developed sub-baric storage bin has a dual scale vacuum gauge to measure vacuum level

inside the bin. Vacuum gauge is mounted on the bin which shows vacuum level in both mm Hg and inches Hg. The vacuum gauge ranges from 0-650 mm of Hg.

2.5.6 Thermocouple

A thermocouple is inserted at one side of sub-baric storage bin in such a way that the sensing front of thermocouple should touch grains to sense temperature of food grains.

2.5.7 Electrical control panel

Control panel has main switch of developed storage bin and also includes switches of suction blower, vacuum pump, light, agitator and agitator speed regulator.

2.5.8 Agitator for grain mixing

Agitator is provided in the center of storage chamber for mixing of food grains which are stored in the bin to prevent the accumulation of respiratory gases released by insects, food grains and also used in easy unloading of food grains as shown in Fig. 4. It is having 1500 mm length and 25 mm diameter and it has two attached plates with dimensions 300 × 100 mm (L × W) for proper rotations of the grains. A motor with 0.5 Hp capacity was placed at the top of bin to provide power.

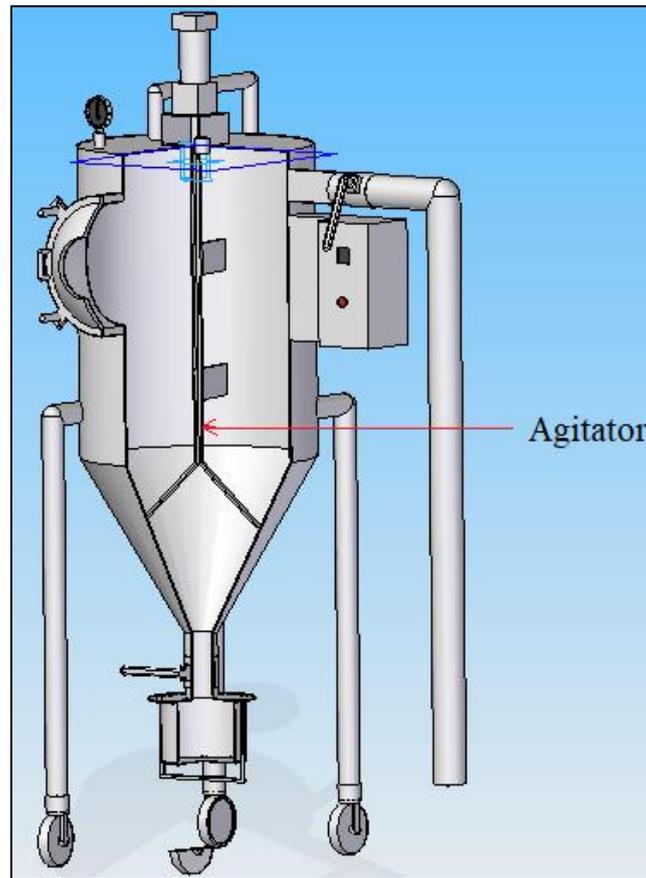


Fig. 4. Cross sectional view of developed sub baric storage bin

2.5.9 Two inlet valves for gas infusion

The sub-baric storage bin has two inlet valves for impregnation of gases which can be used in modified atmospheric storage for future use by providing a gas mixer for mixing of desired gases.

2.6 Fabrication Processes

The various manufacturing processes involved in fabrication are: Selection of material of construction; Testing of stainless steel for different grades; Development of geometry; SS Sheet cutting; Sheet rolling to form cylinder; TIG welding and DP testing; Nozzle cutting (Door, Sight Glass, Light Glass etc.); Grinding and polishing; Hydraulic testing; Pickling and Passivation; Assembling of different components on SS mobile skid and leak testing of total unit. Optimization of wall (shell) thickness of sub-baric storage bin was carried out using Finite Element Analysis (FEA) method. Finally, the whole set-up assembly of the sub baric storage bin fabricated is as presented in Fig.5. The 2-D view of

developed SBSB with all components is shown in Fig. 6.

2.7 Testing of Assembled Unit for Leak Proofing and Safety

2.7.1 Hydraulic pressure test

Water was filled in the assembled unit and pressure was elevated to 300 kPa using hydraulic test rig. On detection of leaky joints and spots, they were plugged or welded and made leak proof. The assembled unit was held in that pressure for 24 h. Pressure drop was again measured as a check [22]. The procedure was performed again till no further drop in pressure was noticed.

2.7.2 Vacuum drop test

On completion of hydraulic test, the bin unit was subjected to vacuum drop test. Vacuum of 650 mm Hg was created within the unit using vacuum pump. All joints of the unit were tested with soap solution. Vacuum pump was stopped and

isolated by terminating suction valve. Any drop in vacuum was considered as an indication of leakage and presence of any faulty welds/joints in the unit was investigated using the soap test. The unit was held under full vacuum for 24 h and vacuum drop was measured at the end. If drop in vacuum level is less than 5- 10 mm Hg then unit was considered to be leak proof [22].

Sub-baric storage method involves (manually or automatically) placing food grains in a storage structure, removing air from inside and sealing. The intent of vacuum storage is usually to remove oxygen from the container to extend the shelf-life of food grains. Vacuum storage reduces atmospheric oxygen, limiting the growth of aerobic bacteria or fungi, and preventing the evaporation of volatile components. In this aspect, A sub-baric storage bin was designed and developed with the following components: Storage chamber (500kg capacity); Vacuum pump; Pressure indicator controller (PIC); Temperature indicator controller (TIC); Humidity indicator controller (HIC); Bin body; Inlet and outlet bin body for loading and unloading and grain discharge hopper. The developed storage bin with above components were subjected to testing of unit for leak proofing and safety.

3. RESULTS OF FINITE ELEMENT ANALYSIS

Based on stress analysis results of ANSYS-14, the sub-baric storage bin was fabricated using 4 mm stainless steel sheet. Following were the results of finite element analysis:

Permissible yield stress for stainless steel – 205 MPa

Von Mises stress – 175 MPa

Factor of safety – 1.2

3.1 Testing of Sub-baric Storage Bin

After subjecting sub-baric storage bin to 650 mm Hg vacuum and hydraulic pressure 300 kPa tests for 24 h, it was observed that there was no implosion (compression) or explosion confirming to the fact that the design was adequate and also safe to operate. The results of these quality tests are presented in Table 1. Also, there were no signs of bulging, buckling or any deformations observed in any of the components or the pipe lines, connections, fixtures or fasteners. Hence, it was concluded that the designed equipment could be operated safely at 650 mm Hg vacuum pressure satisfying all the applicable safety assurances and standards relevant to the industry [22].



Fig. 5. Sub-baric grain storage bin

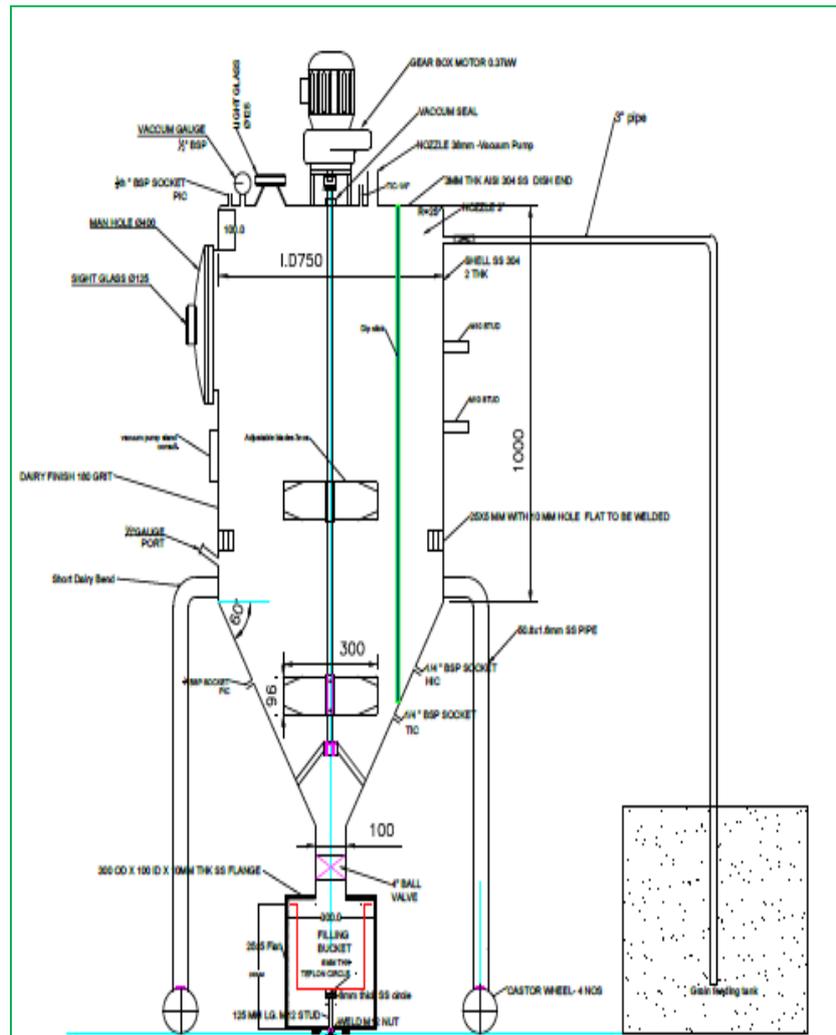


Fig. 6. 2-D view of developed sub baric storage bin with components

Table 1. Hydraulic pressure and vacuum drop testing of sub-baric storage bin

| Sl. No. | Type of test | Tested Parameter | Drop in pressure after a hold for 24 h | Result and remarks |
|---------|-------------------------|------------------|--|--|
| 1 | Hydraulic pressure test | 300 kPa | No drop | No leakages and explosion – Design and Safety Assurance ascertained |
| 2 | Vacuum drop test | 650 mm Hg | 5 mm Hg | No leakages and implosion – Design and Safety Assurance ascertained. |

4. CONCLUSION

In this study, the sub baric storage bin was designed and developed with the following components like storage chamber (500 kg capacity), vacuum pump, pressure indicator controller (PIC), temperature indicator controller (TIC), humidity indicator controller (HIC), bin body, inlet and outlet bin body for loading and

unloading and grain discharge hopper. The said machine is rigid structure and simple in operation. Due to creation of vacuum, there was a change in climatic conditions inside the storage bin. The sub-baric storage is not only used for storing of food grains in vacuum but can obtain modified atmospheric storage environment by impregnation of gases through said inlet valves. The said storage bin can also be used to store

foods, such as vegetables, meats, silage and liquids, because it inhibits bacterial growth. The sub-baric storage bin is a non-residue organic, environmental friendly and green technology which provides chemical-free, insect contamination-free products for future use. The machine was tested for its performance evaluation. This includes testing of sub-baric storage bin for leak proof and safety. For storage of food grains in processing industries, and warehouses the sub-baric storage bin can be used efficiently. The invention paves way for modernization of traditional storage, improved and modern storage structures and provides chemical-free, insect contamination-free and environmental friendly products for future use as compared to conventional storage structures.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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