

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/267724516>

Efficacy of the Multiple-Layer Hermetic Storage Bag for Biorational Management Of primary Beetle Pests of Stored Maize

Article · February 2012

CITATIONS

43

READS

1,425

5 authors, including:



Jacob Paarechuga Anankware

University of Energy and Natural Resources

27 PUBLICATIONS 284 CITATIONS

SEE PROFILE



Oluwole Fatunbi

Forum for Agricultural Research in Africa (FARA) Accra Ghana

94 PUBLICATIONS 949 CITATIONS

SEE PROFILE



Kwame Afreh-Nuamah

University of Ghana

95 PUBLICATIONS 767 CITATIONS

SEE PROFILE



D. Obeng-Ofori

Catholic University College of Ghana

148 PUBLICATIONS 3,451 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Impact of the removal of black wattle (*Acacia mearnsii*) in the Tsomo Valley in Eastern Cape: Consequences on the water recharge and soil dynamics [View project](#)



Edible insects [View project](#)

Efficacy of the Multiple-Layer Hermetic Storage Bag for Biorational Management Of primary Beetle Pests of Stored Maize

¹P.J. Anankware, ²A.O. Fatunbi, ^{1,3}K. Afreh -Nuamah, ^{1,3}D. Obeng-Ofori and ³A.F. Ansah

¹African Regional Postgraduate Program in Insect Science,
P.O. Box: 59, University of Ghana, Legon, Ghana

²Forum for Agricultural Research in Africa (FARA), PMB 173 Cantonments, Accra, Ghana

³Department of Crop Science, School of Agriculture,
College of Agriculture and Consumer Sciences, University of Ghana, Legon, Accra, Ghana

Abstract: This paper reviews the destructive effects of *Prostephanus truncatus* and *Sitophilus zeamais* on maize grain and the effectiveness of the triple-layer hermetic bag storage system as a control measure. Maize (*Zea mays* L.) is the most important cereal in Ghana and is the staple food for over 90% of the population. The availability and safety of this important food crop is threatened by insect pests, rodents and fungal attacks due to inappropriate storage methods. Infestation by insect pests accounts for between 20 to 50% of post-harvest losses in maize. Pesticides and other artificial gaseous techniques are no longer acceptable due to food quality and environmental related issues. In the light of the foregoing, the hermetic storage techniques have recently been revisited as a way to control insect pest and other microbial attack in maize grain. The system creates an air tight environment to rapidly exterminate insect development and suppress micro flora activity. A recent development is the invention of the triple layer hermetic bag using biodegradable plastic materials. This is being investigated to determine its efficiency as a storage technique that prevents insect attack and yields product with good food quality and market acceptability. Quantitative figures are needed about the current distribution and losses caused by insect pests especially *P. truncatus* and *S. zeamais*. There is also the need to fill the knowledge gaps and provide adequate information needed to inform decisions for the use of the use of hermetic storage technology and its further refinement.

Key words: Larger grain borer % *Prostephanus truncatus* % Maize weevil % *Sitophilus zeamais* % Triple layer hermetic bag % IAR4D

INTRODUCTION

Maize (*Zea mays* L.) is an important staple crop in West Africa providing food and income to farmers [1]. In Ghana, maize is generally harvested late to facilitate drying. It is stored as cobs with or without the husk cover either in wooden granaries, under the roof or on the floor inside the houses, or as grains in clay containers such as mud silos or in polyethylene bags [1, 3]. Significant research and development efforts have concentrated on increasing food production in Sub Saharan Africa (SSA), but the effects of these efforts are cut short by lack of efficient post-harvest system especially those that prevent deterioration and destruction from both pathogens and insects. For many inhabitants of SSA (the smallholder farmers), changes in the quantity and

availability of maize grains represent the difference between a good year and a lean year. Maize is a strategic crop in sub-Saharan Africa. With increasing populations, urbanization, changing diets and availability of new varieties, maize consumption and production are likely to continue to increase in the region. At the same time, insect pests like the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) and the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) are spreading and threatening the productivity of the maize based future system [4]. The future spread and effects of these insect pests may depend strongly on climate change and the efficiency of the post-harvest storage facilities. Research priorities should take good cognizance of these realities and consider further development of effective options.

Research efforts should be channeled towards developing a proper storage system to deduce post-harvest losses and to create a way to meet up with the increasing demand for maize grain [5, 6]. It is estimated that between 2010 and 2015, maize demand is projected to grow at an annual rate of 2.6% [7]. This increase in demand could easily be met by reducing storage losses which could save 40% of the current production rather than expanding the hectare in an unsustainable manner. Insects attack constitutes a major cause of losses of stored maize in the tropics [8]. Recently, it has been reported that 9% postharvest losses are due to insect and mite infestation worldwide; suggesting a need to make strenuous effort to control them [9]. Stored maize are known to be infested by a variety of insects; among them, *S. zeamais* and *P. truncatus*, are the most damaging [10].

Biology and Economic Importance of *S. zeamais* and *P. truncatus*: The developmental stages (egg, larvae and pupae) of *S. zeamais* are all found within tunnels and chambers bored in the grain and are thus not normally seen. Eggs are laid throughout most of the adult life, although 50% may be laid in the first 4-5 weeks; each female may lay up to 150 eggs. The eggs are laid individually in small cavities chewed into cereal grains by the female; each cavity is sealed, thus protecting the egg with a waxy secretion (usually referred to as an 'egg-plug') produced by the female. Upon hatching, the larva begins to feed inside the grain, excavating a tunnel as it develops. There are four larval instars in 'English wheat' at 25°C and 70% RH. Pupation occurs after about 25 days, although development periods are extremely protracted at low temperatures. The newly developed adult chews its way out, leaving a large, characteristic emergence hole. Total development periods range from 35 days under optimal conditions to over 110 days in unfavorable conditions. The actual length of the life cycle also depends upon the type and quality of grain being infested [11]. In stored maize, heavy infestation by *P. truncatus* and *S. zeamais* may cause weight losses of as much as 30-40% [12]. *S. zeamais* has been found to be amongst the most important pests of maize in a number of studies; in steel silos, in sacks and barns throughout Ghana.

The larger grain borer, *P. truncatus* Horn is thought to be a native of Central America. It was first described by Horn in 1878 who named it *Dinoderus truncatus*. It is 3-4 mm long, cylindrical and dark in colour. The flattened ends of the wing and the ridges give *P. truncatus* a very square-cut end, thus distinguishing it from other bostrichids known to attack stored products i.e

Rhyzopertha dominica and *Dinoderus spp.* *Prostephanus truncatus* is a pest with a high damage potential and it poses a major problem for cob-stored maize and dry cassava chips, in all the affected countries. According to Obeng-Ofori, [8], *P. truncatus* can tolerate dry conditions and can breed on maize with 9% moisture content. The ability of *P. truncatus* to develop in grain at low moisture content may be one reason for its success [8]. So far, about 16 African countries are reportedly affected by the Larger Grain Borer [13]. According to [14], reported mean losses due to LGB are around 9%, which is twice that of all indigenous storage pests together. Besides contamination with the insect bodies and frass, the food substrate can be exposed to quinines that are released from the thoracic and abdominal defense glands [15].

Control Strategies for *P. truncatus* and *S. zeamais*: Good store hygiene plays an important role in limiting infestation by *P. truncatus* and *S. zeamais*. The removal of infested residues from last season's harvest is essential. Aeration dramatically reduces the numbers of insects compared with population levels in non-aerated maize.

Zea mays genotypes resistant to *S. zeamais* have been evaluated in the field in Benin [9]. Genetic variability for resistance to *S. zeamais* in domestic US maize germplasm has been identified. In Brazil, tests were carried out with maize cultivars to evaluate the attractiveness and oviposition preference of *S. zeamais*. In the case of the LGB, the phenolic acid content of maize grain, especially that of para-coumaric acid has been shown to be important [16].

Management of agricultural pests over the past half century has been largely depending on the use of synthetic chemical pesticides for field and post-harvest protection of crops [17].

Grain may be protected by the admixture of insecticide. Research in Togo estimated the toxicity of deltamethrin to a number of resistant and susceptible populations of *S. zeamais* in traditional maize stores. The toxicity of deltamethrin, fluvalinate, chlorpyrifos-methyl, etrimfos and malathion against *S. zeamais* and topical application bioassays of DDT has also been evaluated [18].

P. truncatus can be controlled chemically by using permethrin, deltamethrin and a combination of pyrethroids with phosphorus acid ester compounds [19]. Even though chemicals are generally quick acting against pests, there are serious limitations to their use. Misuse or overuse of chemicals have serious repercussions, such

as the development of resistance, pollution of the environment, effect on non-target organisms, food poisoning, among others [20].

Dry heat treatment has been found to be an effective control against all developmental stages of *S. zeamais*. Local farmers in northern Ghana usually use sun-dry insect infested maize to kill larvae and to drive away adults. Treatment with 15% carbon dioxide and 5% oxygen controlled the insects in 10 days. Carbon dioxide at concentrations of 50% and 60% killed all life stages of the weevil after 10 days of exposure. Under sealed storage (hermetic) conditions in maize, insects and fungi both deplete the oxygen supply, creating an unfavorable atmosphere for their own survival [11, 21].

A good number of plant extracts are toxic to adults of *S. zeamais* and *P. truncatus*. Garlic oil is toxic to adults and oils of coconut, sunflower, sesame and mustard, alone and in combination with eucalyptol, eugenol or camphor have been found to be toxic to *S. zeamais* in wheat and maize-treated grains [22]. Botanicals currently constitute 1% of the world's insecticide market, despite the knowledge that plants constitute an effective alternative to regular insect control agents. Other plant extracts have exhibited toxicity to *S. zeamais*. These include: *Ocimum suave*, *Ocimum kenyense*, *Ocimum kilimandscharicum* [23]; *Tagetes minuta*, *Capsicum annum* etc.

The effect of different isolates and formulations of *Beauveria bassiana* on *S. zeamais* in stored maize are reported. The bionomics of the pteromalid parasitoid *Lariophagus distinguendus* and its controlling effect on *S. zeamais* has been evaluated. *L. distinguendus* was found to have five generations each year in the laboratory, with final-instar larvae of the parasitoid overwintering in larvae of *S. zeamais*. The parasitoid *Theocolax elegans* has also been recorded to attack *S. zeamais*.

The histeride beetle *Teretrius nigrescens* has been identified as the most effective natural antagonist of *P. truncatus* [8]. It feeds on eggs, larvae and sometimes even on adults of *P. truncatus*. *T. nigrescens* though effective, has not been able to entirely eradicate the grain borer. Besides, it is even feared that the *T. nigrescens* may even be a pest in disguise. There is even some evidence that *T. nigrescens* imagines can feed on plants with high starch content, such as maize, wheat, sorghum and cassava. It is for this reason that the search for other control measures especially those intended to mitigate post harvest losses and to complement *T. nigrescens* became necessary; hence the hermetic storage technology.

The Hermetic Storage Technology: Hermetic simply means 'airtight'. The origin of hermetic storage dates back to antiquity. Hermetic storage (HS) technology has emerged as a significant alternative to other methods of storage that protect commodities from insects and molds. Hermetic storage is based on the principle of generating an oxygen-depleted, carbon dioxide-enriched interstitial atmosphere caused by the respiration of the living organisms in the ecological system of a sealed storage structure [9, 24, 25, 26]. Pioneering modern hermetic storage, [27, 28] has resulted in the broad use of safe, pesticide-free hermetic storage suitable for many commodities and seeds, particularly in hot, humid climate. Hermetic storage takes three distinct forms. 1) "Organic-Hermetic storage", relies on the metabolic activity and respiration of insects, microflora and the commodity itself to generate a modified, non-life sustaining low oxygen atmosphere, 2) "Vacuum-Hermetic Fumigation" (V-HF) - uses a vacuum pump to rapidly create a very low pressure atmosphere for accelerated disinfestations of non crushable commodities through asphyxiation; and 3) Gas-Hermetic Fumigation (G-HF) uses an external gas source (usually CO₂) for crushable commodities, such as dried fruit, prior to shipment [29].

A more recent but increasingly popular form of hermetic storage system is the triple layer bag [30]. This system utilizes a thin, transparent and low permeability co-extruded multi layer plastic as a liner to a conventional jute or polypropylene bag. The triple bag consists of 2 layers of polyethylene bags which are expected to be as hermetic as possible and both are included in a protective polypropylene woven bag [30]. Prior to the introduction of these bags in West Africa, farmers lacked appropriate polyethylene bags and so they often use insecticides or combination of insecticides with solar heating for grain storage [31]. Triple-bagging prevents the development of mycotoxins such as aflatoxins and ochratoxin [27, 32]. It also prevents quality loss due to increase of Free Fatty Acids (FFAs) in the low oxygen environment [24, 33, 34]. Finally, the method is suitable for long-term storage of maize, rice and high value commodities such as coffee, cocoa, peanuts and spices in addition to permitting long-term seed preservation without refrigeration [35, 36]. The triple-bagging technology was disseminated in Cameroon in the 90's [37]; it has also been used in Niger, Burkina Faso and Northern Nigeria for successful storage of cowpea under the Purdue University PICs project [31, 38].

The triple-bag technique can be easily adopted by farmers since low-grade polyethylene bags allowing low oxygen permeability is available and affordable. Furthermore, polyethylene bag storage is a flexible

technique that fits with the West Africa commodities trade [39]. Triple layer bag capacities range from 5kg to 1,000 kg, with 43-60 kg capacity being the most common. At the individual small farm level they can be protected from rodents by storage in empty 55-gallon drums. By preventing the entry of water vapor into a hermetically sealed container, adequately dried commodities are protected from external humidity, preventing a rise in their moisture content beyond their critical moisture level of 14% [40]. Many studies in various countries have shown that triple-bagging maintains germination of 85% or more for periods up to 9 months, while conventional storage in jute bags reduces germination down by 14% to 76% within 3 months [14]. This has led to the adoption of hermetic storage by some leading seed producers.

Research Needs: Many knowledge gaps need to be filled in order to support farmer's decision with respect to management of beetle pests on stored maize. More quantitative figures are needed about the current distribution of beetle pests (especially *S. zeamais* and *P. truncatus*), the importance of individual species and the extent to which they are responsible for huge post-harvest losses in the sub-region. This information, combined with historical data and future predictions of maize production and long-term storage ability, as well as data on the economic importance of different beetle pest's species could provide more solid evidence on which to base priority setting for concerted research and development efforts on triple-bagging technology in the sub-region. Current knowledge of triple-bagging and its availability is very limited. Why for example, is triple-bagging in use in South America and Asia for so long and not in common usage in Africa? Then again why has triple-bagging been proven effective in controlling the cowpea beetle *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) and still not been used in managing major pest of maize which is rather a staple food crop in the sub-region. Further studies should include investigations on effects of climate and increased temperatures on the effectiveness and longevity of the three layer hermetic bag. The development of biodegradable triple-layer bags that combines different defense mechanisms with other desirable traits such as resistance or tolerance against rodents and other biotic and abiotic factors should also be considered. More detailed information on the effectiveness of the triple bag in managing common storage insect pests and cost-effectiveness of its usage needs to be well communicated to the final consumers (farmers, middlemen/women and market women). Participatory approaches and videos could help to raise

awareness about the efficacy and cost-effectiveness of the three layer bag among farmers and stimulate information exchange between stakeholders. This in turn could result in the identification/realizations of farmer's interest and innovations. Adult learning tools such as the Farmer Field School developed by FAO, or Participatory Learning and Action Research (PLAR) [41] and the use of learning videos [42] would also be effective methods to demonstrate to farmers how effective removal of air and tying of the triple-bags can be used to increase effectiveness and avoid detrimental effects by puncturing. A more effective way to communicate this technology would be its integration within the innovation platforms established within the Integrated Agricultural Research for Development Concept (IAR4D). This concept will often achieve a hundred percent technology adoption by farmers on the innovation platform. The suitability of the IAR4D concept has been reported elsewhere [43].

CONCLUSION

The use of hermetic storage is now becoming widespread using modern low permeability plastic materials which are light-weight, which can be used indoors or outdoors, have long lifespan and are now, in the case of triple layer bags, transportable when full.

Pesticide-free three layer bag technology has already been found suitable for a number of markets. This is especially true where conventional storage, such as in hot humid climates, fails to adequately protect the stored commodity for the desired time and this results in large losses in quantity and quality [35, 36]. Studies show that hermetic storage of cowpea for 8 months in triple layer bags maintains constant moisture and germination rates [38].

Triple-bagging is a sustainable, cost effective, user-friendly and environmentally benign technology that makes the use of pesticide and fumigants in post harvest and seed storage unnecessary. The technology has already been adopted for the protection of many different commodities in quantities ranging from that of conventional grain bag size to many thousands of tones. Applications of triple-bagging technique is likely to expand even more rapidly in the future, as the available forms of hermetic storage continue to increase and more users experience and understand the advantages of this "green" technology. By a commitment to community engagement with local traditional leaders and district councils, researchers and extension workers, the triple-bagging technologies will grow to take over the less efficient indigenous storage systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of the Forum for Agricultural Research in Africa (FARA), Concern Universal, Ghana (NGO), Grainpro Inc, Food and Agriculture Organization of the United Nations, Statistics Division, The College of Agriculture and Consumer Sciences, University of Ghana, Ghana Cocobod, for their different support to this study.

REFERENCES

1. Komi, A., F. Schulthess, M. Tamò, K. Hell and V. Stefan, 2010. The importance of *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) as a post-harvest pest in different storage structures in Benin. *J. Stored Products Res.*, 46(2): 81-86.
2. Hell, K., K.F. Cardwell, M. Setamou and H.M. Poehling, 2000. The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *J. Stored Products Res.*, 36: 365-382.
3. Hell, K., Y. Lamboni and K. Cardwell, 2002. Role of insects in the propagation of mycotoxigenic fungi in stores in Benin. In: P.F. Credland, D.M. Armitage, C.H. Bell, P.M. Cogan and Highley E, Editors, *Advances in Stored Products Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July, York, UK, CABI International*, pp: 330-338.
4. Boxall, R.A., 2002. Damage and loss caused by the larger grain borer, *Integrated Pest Management Reviews*, 7: 105-121.
5. Grolleaud, M., 2002. Post harvest losses; discovering the full story. *FAO Corporate Document Repository, FAO Agro Industries and Post-harvest Management Service (AGSI)*.
6. Weinberg, Z.G., Y. Yan, Y. Chen, S. Finkelman, G. Ashbell and S. Navarro, 2007. The effect of moisture level on high-moisture maize (*Zea mays* L.) under hermetic storage conditions-*in vitro* studies. *J. Stored Products Res.*, 44(2): 136-144.
7. Food and Agriculture Organization of the United Nations, Statistics Division. *Maize, rice and wheat; area harvested, Production Quantity and Yield, 2009: 23*.
8. Obeng-Ofori, D., 2008. Major stored product arthropod pests. In: E.W. Cornilius and D. Obeng-Ofori, (Eds), *Post-harvest Science and Technology, Smartline Publications, Accra, Ghana*, pp: 1-46.
9. Vachanth, M.C., K.M. Subbu Rathinam, R. Preethi and M. Loganathan, 2010. Controlled Atmosphere Storage Technique for Safe Storage of Processed Little Millet. *Academic J. Entomol.*, 3(1): 12-14.
10. Meikle, W.G., R.H. Markham, C. Nansen, N. Holst, P. Degbey, K. Azoma and S. Korie, 2002. Pest management in traditional maize stores in West Africa: a farmer's perspective. *J. Economic Entomol.*, 95: 1079-1088.
11. Moreno-Martinez, E., S. Jiménez and E. Mario Vázquez, 2000. Effect of *Sitophilus zeamais* and *Aspergillus chevalieri* on the oxygen level in maize stored hermetically. *J. Stored Products Res.*, 36: 25-36.
12. Mao, L. and G. Henderson, 2010. Evaluation of potential use of nootkatone against maize weevil (*Sitophilus zeamais* Motschulsky) and rice weevil [*S. oryzae* (L.)] (Coleoptera: Curculionidae). *J. Stored Products Res.*, 46(2): 72-75.
13. Obeng-Ofori, D., 2011. Protecting grains from insect infestations in Africa: Producer perceptions and practices. *Stear Postharvest Review*, 3(10): 1-8.
14. Omondi, B.A., J. Nanqing, J. Van Den Berg and F. Schulthess, 2011. The flight activity of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) in Kenya. *J. Stored Products Res.*, 47(1): 13-19.
15. Kabir, B.G.J., M. Lawan and F.M. Gambo, 2011. Efficacy and Persistence of Raw Diatomaceous Earth Against *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) on Stored Maize, Sorghum and Wheat. *Academic J. Entomol.*, 4(2): 51-58.
16. Sabio, G.C., J.V. Dator, R.F. Orge, D.D.T. Julian, D.G. Alvindia, G.C. Miranda and M.C. Austria, 2006. Preservation of Mestizo 1 (PSB Rc72H) Seeds Using Hermetic and Low Temperature Storage Technologies. *GrainPro Document #SL2329GCS1206*.
17. Kamel, A.M., 2010. Can we use Moringa Oil as Botanical Insecticide Against Spodoptera frugiperdia? *Academic J. Entomol.*, 3(2): 59-60.
18. Greater grain weevil (*Sitophilus zeamais*). www.plantwise.org/?dsid=109268loadmodule (accessed on 24.02.12).
19. Pöschko, M., 1994. Research into the biology and host specificity of *Teretriosoma nigrescens*, a potential natural antagonist of *Prostephanus truncatus*. *GTZ, GmbH, Eschborn, Germany*, pp: 1-12.

20. Musa, A.K., A.A. Oyerinde and F.O. Owolabi, 2009. Evaluation of the Efficacy of Mixed Leaf Powders of *Vernonia amygdalina* L. and *Ocimum gratissimum* Del. Against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Academic J. Entomol.*, 2(2): 85-87.
21. Conilh De Beyssac, B., J.T. Arnason, J. Gale, A. Sen, S.S. Miller, B.J.R. Philogene, J.D.H. Lambert, R.G. Fulcher, A. Serratos and J. Mihm, 1992. Role of phenolics in resistance of maize grain to the stored grain insects, *Prostephanus truncatus* (Horn) and *Sitophilus zeamais* (Motsch.) *J. Stored Product Res.*, 28(2): 119-124.
22. Moreno, E., C. Benavides and J. Ramirez, 1988. The influence of hermetic storage on the behaviour of maize seed germination. *Seed Science and Technol.*, 16: 427-434.
23. Obeng-Ofori, D. and C.H. Reichmuth, 1999. Plant oils as potentiation agents of monoterpenes of stored grains against damage by stored product pests. *International J. Pest Management*, 45(2): 155-159.
24. Obeng-Ofori, D., 1995. Plant oils as grain protectant against the infestation of *Cryptolestes pusillus* (Schorr.) and *Rhyzopertha dominica* (Fab.) in stored grain. *Entomologia Experimentalis et Applicata*, 77: 133-139.
25. De Bruin, T. and V. Murali, 2006. Quality Preservation of Stored Cocoa Beans in the Tropics. (unpublished). GrainPro Document Number SL2299TB0905. GrainPro, Inc. Concord, MA USA.
26. Donahaye, E.J., S. Navarro, G. Sabio, M. Rindner, A. Azrieli and R. Dias, 2001. Reflective covers to prevent condensation in sealed storages in the tropics. Executive Printing Services, Clovis, CA, U.S.A., pp: 227-230.
27. Navarro, S., S. Finkelman, G. Sabio, A. Isikber, R. Dias, M. Rindner and A. Azrieli, 2002. Enhanced Effectiveness of Vacuum or CO₂ in Combination with Increased Temperatures for Control of Storage Insects. Presented in: Advances in Stored Product Protection, Proceedings of the 8th International Working Conference on Stored Product Protection (IWCSPP), pp: 818-822.
28. Donahaye, E.J., S. Navarro, S. Andales, Angelita M. Del Mundo, F. Caliboso, G. Sabio, A. Felix, M. Rindner, A. Azrieli and R. Dias, 2001. Quality preservation of moist paddy under hermetic conditions. In: E.J. Donahaye, S. Navarro and J.G. Leesch, 2001. Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, Fresno, CA. 29 Oct.3 Nov. 2000, Executive Printing Services, Clovis, CA, U.S.A., pp: 209-225.
29. Navarro, S., E.J. Donahaye and S. Fishman, 1994. The future of hermetic storage of dry grains in tropical and subtropical climates. In: Proc. 6th Int. wkg. Conf. Stored-Product Protection, 17-23 April Canberra Australia, 1: 130-138.
30. Navarro, S. and E.J. Donahaye, 2005. Innovative environmentally friendly technologies to maintain quality of durable agricultural products. In: S. Ben Yehoshua, Editor, Environmentally Friendly Technologies for Agricultural Produce Quality, CRC Press, Boca Raton, FL, USA, pp: 204-260.
31. Sanon, A., L.C. Dabiré-Binso and N.M. Ba, 2011. Triple-bagging of cowpeas within high density polyethylene bags to control the cowpea beetle *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). *J. Stored Products Res.*, 47(3): 210-215.
32. Rickman, J.F. and E. Aquino, 2004. Appropriate Technology for Maintaining Grain Quality in Small Scale Storages. CAF2004 International Conference on Controlled Fumigation in Stored Products 8-13 August Gold Coast, Australia.
33. Moussa, B., 2006. Economic Impact Assessment of Cowpea Storage Technology. Master of Science thesis, Purdue University, West Lafayette, IN, USA.
34. Navarro, S., H. Navarro, S. Finkelman and W.A. Jonfia-Essien, 2010. A novel approach to the protection of cocoa beans by preventing free fatty acid formation under hermetic storage. 10th International Working Conference on Stored Product Entomology, Lisbon, Portugal., 425: 390-395.
35. De Bruin, T., 2006. A User's Introduction to Hermetic Storage - How it Works. (unpublished). GrainPro Document Number SL2322TDB0506-4. GrainPro, Inc. Concord, MA USA.
36. Finkelman, S., S. Navarro, M. Rindner and R. Dias, Transportable hermetic storage and vacuum equipment for disinfestation of durable commodities. International Conference on Methyl Bromide Alternatives. Lisbon, Portugal.
37. Murdock, L., D. Seck, G. Ntoukam, L. Kitch and R.E. Shade, 2003. Preservation of cowpea grain in sub-Saharan Africa. *Bean/Cowpea CRSP contributions, Field Crops Res.*, 82: 169-178.
38. Moussa, B., J.L. DeBoer and D. Barisbusta, 2010. Adoption of Hermetic Storage for Cowpea in Niger and Burkina Faso. Poster presented during the 5th World Cowpea Conference, 27 September to 1 October, Saly, Senegal.
39. Genest, C., A. Traoré and P. Bamba, 1990. Guide pratique de protection des grains entreposés, ACIDI (1990) p. 105.

40. Villers, P., T. De Bruin and S. Navarro, 2006. Development and Applications of the Hermetic Storage Technology. Published in Proceedings of the 9th International Working Conference on Stored Products Protections (IWCSP), Sao Paulo, Brazil, October.
41. Defoer, T., M.C.S. Woperreis, P.A. Idinoba, T.K.L. Kadisha, S. Diack and M. Gaye, 2004. Curriculum for Participatory Learning and Action Research (PLAR) for Integrated Rice Management (IRM) in Inland Valleys of Sun-Saharan Africa: Facilitators' Manual. WARDA, Cotonou, Benin/IFDC, Muscle Shoals, USA.
42. Van Mele, P., 2006. Zooming-in zooming-out: a novel method to scale up local innovations and sustainable technologies. *International J. Agric. Sustainability*, 4: 13-25.
43. Adekunle, A.A. and A.O. Fatunbi, 2012. Approaches for Setting-up Multi-Stakeholder Platforms for Agricultural Research and Development. *World Applied Sciences Journal*, 16(7): 981-988.