EVALUATION OF ON-FARM STORAGE METHODS FOR PEARL MILLET [*Pennisetum americanum* (L.) LEEKE]

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ABSTRACT

Three traditional on-farm storage methods for pearl millet (*Pennisetum americanum* (L.) Leeke) were simulated using 75 l plastic garbage cans. The storage units were infested with maize weevils (*Sitophilus zeamais* (L.)) or with a dual infestation of maize weevils and red flour beetles (*Tribolium castaneum* (Herbst)). Storage units were infested at rates of 0.9 insect species per storage unit for grain storageand 0.67 for kernel storage. After a 14-week storage period, insect populations and grain losses were measured. Under controlled conditions, pearl millet stored on-head in ventilated containers (simulating woven seed storage units) was less damaged than when millet on-head was stored in non-ventilated containers (simulating mud-plastered storages). Both on-head systems offered more protection against insect population increase than bulk storage in non-ventilated storage bins.

Keywords : Millet, storage, maize weevil, flour bestle, Bénin.

RESUME

EVALUATION DES MÉTHODES DE STOCKAGE EN PLANTATION DU MIL PERLÉ
[Pennisetum americanum (L.) LEEKE]

*Trois méthodes traditionnelles ont été simulées à l'aide des containers en polysthène d'une capacité de 75 l pour le stockage du mil (*Pennisetum americanum *(L.) Leeke). Les unités ont été infestées à des taux respectifs de 0,9 par espèces d'insectes (*Sitophilus zeamais *(L.)) ou* Tribolium castaneum *(Herbst) pour le stock grain et de 0,67 pour le stock en épis. Après 14 semaines de conservation, les populations d'insectes et les pertes en grain sont évaluées. Les résultats traduisent qu'en conditions non contrôlées, les stocks de mil en épis, en containers aérés, sont moins attaqués que ceux du système aéré. Cependant, les deux systèmes de stockage en épis testés semblent offrir plus de protection contre la pullulation des insectes que le stockage des grains de mil en conditions non aérées.*

***Mots clefs** : Mil, stockage, charançon, tribolium, Bénin.*

INTRODUCTION

In developing countries, there is an increasing awareness in the need to improve on farm storage systems to insure a supply of durable foods-grains, legumes, nuts, tubers-from harvest to harvest. Except in years of extreme weather conditions, the production of cereal grains is sufficient and could even be increased, but indigenous preservation methods in many areas are satisfactory for only a few months (Kossou *et al.*, 1992 ; 1993). Farmers store the quantity of grains they hope to preserve adequately, sell the remainder at harvest, or early in the postharvest season, and then purchase food grains until the next harvest. Storage facilities operated by buyers and merchants from government agencies and the private sector are often unsuitable and poorly managed. Low quality grain and high prices characterize the "hungry season".

The assessment of postharvest losses, particularly at small farm level in developing countries, has received much attention during the last decade and a methodology for measuring postharvest losses is emerging (Adams, 1976 ; Harris and Linblad, 1978 ; Markham, 1981 ; Golob, 1981). At the same time, the advantages of modifying traditional techniques and storage bins over the substitution of a new, often expensive, storage technology have become evident.

Better understanding of storage systems used by small farmers is necessary before appropriate changes can be recommended. Traditional storage methods are difficult to evaluate in the field (Pantenius, 1988 ; Kossou *et al*, 1992). Generally, each farmer uses just one method. Storage units are of different sizes. Harvest often extends over a long period of time so that storage units contain grain with varying field damage. Initial insect infestation is unknown. Grain is removed for use during the storage period.

An experiment was designed to simulate three traditionnal storage systems which integrated both internal and external insect grain feeders. The results presented here form the initial phase of a comparative laboratory study whose aim is to evaluate those on-farm practices for further improvement.

MATERIALS AND METHODS

Storage containers

Ventilated storage containers designed to simulate traditional woven reed storage units with thatched covers, were made from 75 l plastic garbage cans. Eight vertical openings were cut in each of the five cans. Four 4 x 12 cm, measuring , were evenly distributed around the lower 2/3 of the cans and four others, measuring 4 x 4 cm, were spaced in the upper 1/3 between the lower openings. Two 7.6-cm diameter openings were cut in each lid of 180^0 apart. All openings were fitted with a 60-mesh brass strainer cloth fixed in place with an epoxy cement.

Ten 75 l cans were fitted with ventilated lids prepared as described above to simulate mud-covered storage units with thached roofs.

Pearl millet

A bulk population of about 10,000 heads from a 1997 crop, was hand harvested after in-field drying at INA, Northern agricultural research center in Benin. The millet was stored, in jute bags in a room at 4 °C until use.

Preparation of grain for storage

(i) On-head storage in five ventilated and five non-ventilated containers

About 4,200 millet heads were spread out and preconditionned to equilibrate grain mass conditions in the test room at 26 ± 1 °C and 68 ± 3 % RH for two weeks, and moisture content was determined. Ten sets of 400 well-filled heads were assembled and weighed. Each container was carefully packed in the test room with all heads in a layer having the same base-tip orientation to allow uniform insect migration. The base-tip arrangement was alternated layer by layer. In each container the bottom layer (10-11 heads) was fitted in place, then removed and weighed. The heads were marked and replaced. A similar procedure was carried out on the 15-cm layer from the bottom (12-17 heads) and the top layer (13-19 heads). Thus, top, middle and bottom layers were materialized. The packed containers were weighed.

(ii) Threshed grain storage in five non-ventilated containers

Millet was threshed in a hand-fed seed thresher. Grain was cleaned on a commercial 0.2 cm round-hole sieve ; then re-cleaned on a 16-mesh screen, and overs were combined. Six 100-g lots were inspected to determine percent damaged kernels. Threshed grains were spread in thin layers and allowed to equilibrate in the test room for two weeks. Moisture content was measured and containers were filled with 25 ± 0.1 kg of pearl millet and weighed.

Insect infestation

Stock cultures maintained in pearl millet under controlled conditions (27 ± 1 °C and 67 ± 3 % RH) for at least two generations produced 1-2 week old adult maize weevils (*Sitophilus zeamais* (L.)) (MW). Red flour beetle [*Tribolium castaneum* (Herbst)] (RFB) cultures were maintained on whole wheat flour with 5 % brewer's yeast. The infestation rate per species per 50 g of grain on dry weight basis was 0.9 for threshed grain and 0.67 for on-head millet. These rates, derived from stored grain were based on previous results (Kossou,1981). Two containers of threshed grain, were infested with 400 unsexed MW's and two with 400 MW plus 400 RFB. For both on-head storage systems, two cans were infested with 100MW's and two with 100 MW plus 100 RFB. Insects were released at the top of each container. The fifth container, prepared for each storage method, was used as a check.

Sampling

After 14 weeks, containers were weighed, and samples were taken for evalution. Sampling was done in the test room.

(i) On-head storage

The marked top, middle (15 cm above bottom), and bottom layers from each container were carefully removed and weighed. Insects in each layer were dislodged by shaking heads over a sieve and counted. Samples for moisture content determinations were taken. Then, heads were hand threshed, and the grain was cleaned as previously described. Threshed grain (about 100 g/layer) was evaluated by tests described below. The remaining heads were put into a large plastic bag and tranferred to a cool room (4 °C) for several days to slow down insect activity.

(ii) Threshed-grain storage

Grain samples from the top and bottom of the five containers were collected from five evenly spaced points with a compartmentalized probe and combined by layer. The top and bottom samples from each container were weighed, and two 10 g subsamples were taken for moisture content determinations. Each sample was sieved using 12-mesh and 16-mesh sieves to remove insects and collect fines. Adult insects were counted. Fines were examined for RFB larvae and then weighed. The cleaned grain (about 400 g/ layer) was evaluated for losses. The containers with the remaining grain were transferred to a cold storage room for several days.

Moisture content

To determine on-head moisture content, several thin slices were cut from randomly chosen sections of each head in the sample. Sections were mixed together and three replicates of 15-20 slices were dried. For threshed grain, duplicate 10 g samples were used. Samples were dried at 120 °C for 18 hr in a forced air oven.

Total adult insect

Insects in on-head storages were collected by shaking each head over a sieve. The numbers obtained were added to those obtained previously from the three layers. The entire contents of threshed grain storages were sieved, and the number of insects recovered was added to that found in the probe samples.

Count-and-weigh loss determination

Grain collected from on-head and bulk storage containers was randomly divided by coning and quartering method to yield two subsamples of about 50 g each (Boxall,1986). Grain was observed under low magnification, and kernels with visual insect damage (emergence holes) were removed. Percent weight loss on dry weight basis was calculated by the count-and-weigh method of Adams and Schulten (1978). Undamaged kernels were saved.

Germination test

Six 100-seed lots of undamaged kernels from each subsample were placed on wet paper towels and enclosed in aluminium foil folders. Seeds were kept at room temperature. A count was made when at least 50 % germination was observed in controls (from 48-72 hours) ; a second count was made the next day. Non-germinated kernels were dissected and examined under magnification. Numbers of infested and non-infested kernels were recorded.

Cracking-flotation test

A modified version of the AOAC Method 44.037 (Anonymous, 1980) was used the test was performed on duplicate sub-samples of about 50 g of visually undamaged kernels from each sampling layer. Modification included (a) 10 min stirring after addition of heptane (lead-free gasoline), (b) 30 min settlement time, (c) before filtration, collection of grain "trash" floating in the trapped-off layer on a 10-mesh wire screen and (d) examination of trash for head capsules (Kossou, 1998). Only head capsules with both mandibles présent were scored. Results were calculated per 50 g, dry weight basis.

RESULTS

Moisture content

Equilibrium moisture content at the beginning of the storage period was 12.8 % for on-head and threshed millet. Final moisture content dropped to 9.3, 11.1, and 12.7 % in control and infested containers of millet stored ventilated on-head, non-ventilated on-head, and non-ventilated threshed, respectively. The non-ventilated grain appeared unaffected by the RH drop (50-60 %) observed during the last week of the experiment. However, it is unlikely that either insect population increase or kernel damage was affected.

On-head millet storage

Fewer adult weevils and immature forms were found in the marked layers of millet heads when storage was done in simulated woven reed baskets than when millet heads were in solid-wall containers with small ventilation holes over the lid. In both systems, MW infested more seeds in the bottom layer than in the middle or top ones. When RFB was associated with MW, a decrease in the adult population of the two species was found in all layers in ventilated storage units and in top and middle layers of non-ventilated units but not in the bottom. Fewer RFBS were found in the millet heads sampled at the end of the storage period. The highest number was 4.2/100 g fines under non-ventilated storage.

The tests for internal-developing insects did not give the same results. Enumeration of head capsules, isolated in the cracking flotation test, indicated a slower population increase than did the score of insect-infested, non-germinated kernels. Both tests showed that infestation was highest at the bottom of the storage units indicating bottom site being in favour of insect activities.

Weight loss determined on initial an final weights of the marked layers was greater than that found by the count-and-weigh method as shown in tables 1 and 2. After the 0.5 % handling loss determined from controls was deduced, weight loss in the ventilated on-head storages infested with MW averaged 0.6, 4.3, and 4.3 % for top, middle, and bottom layers, respectively. Similar losses in non-ventilated units were higher (1.6, 4.0, and 5.3 %). When MW plus RFB infested on-head pearl millet, losses were 2.6, 1.4, and 2.8 % in ventilated and 2.1, 3.8, and 7.1 % in non-ventilated storage containers.

Threshed millet storage

Maize weevil females deposited more eggs in millet kernels near the insects' point of entry than deeper in the grain bulk of. Weight loss, kernel damage, and loss of germination of undamaged (i.e., no emergence holes) kernels were significantly greater in samples collected from the top of the bulk compared to samples from the bottom.

Although adult MW recovery from samples indicated a higher total population in threshed millet when RFB was a co-infestor, the two estimates of internal infestation showed reduced MW population in the presence of RFB. Red flour beetles recovered from threshed grain samples had a mean weight of 17.0/50 g from top samples and 7.5/50 g from bottom ones.

Dust sieved, from top and bottom samples from containers infested with MW comprised 3.9 % and 1.6 %, respectively, of sample weight. When RFB was present with MW, the top samples contained 18 % dust by weight and the bottom 1 %.

Comparison of storage systems

The extent of MW and RFB infestations and losses produced in simulated traditional storage unito were compared on the basis of measurements made on the entire grain lot in each storage unit and on estimates made from sampling the unit. From total insect count, threshed millet was more infested by MW than millet stored on-head with an increase of more than 200/50 g compared to 99 and 130/50 g for ventilated, on-head and non-ventilated, on-head storage, respectively.

When the contents of the storage units was examined, few RFB were recovered compared with the number of MW. However, RFB infestation limited MW increase by about 50 % in on-head storage but had little effect in threshed grain.

The weight loss per storage unit determined by the count-and-weigh technique underestimated weight loss obtained by weighing grain before and after storage when millet was infested by MW alone. When RFB and MW were co-infested, the count-and-weight loss estimated for the storage units was equal to or slightly greater than loss measured by direct weighing.

Internal infestation was measured in samples only. On a system basis, the estimates showed that threshed millet was more suitable for the MW than millet stored on-head.

Reduced germination, the sum of changed kernels (i.e., kernels with emergence holes), and the apparently undamaged kernels which failed to germinate, were not all due to internally developing MW's. In fact, dissection and microscopic examination of the non-germinated, visually undamaged, millet kernels detected immature MW's in fewer than 5 % kernels in any on-head samples and fewer than 8 % in samples from threshed millet. Control millet from all three systems had 98.7 % germination at the end of the storage period.

Table 1 : Insect populations and grain losses in pearl millet infested with maize weevil (MW) or MW plus red flour beetle (RFB) and stored on-head for 14 weeks in simulated woven reed containers (ventilated) at 26 °C and 68 ± 3 % RH.

Population d'insectes et perte en grains chez le mil infesté au charançon du maïs (MW) avec ou sans le Tribolium (RFB) et conservé en épis pour 14 semaines dans une structure aérée, maintenue à 26 °C et 68 ± 3 % H.R.

Layer Sampled	Populations (MW/50 g grain)			Losses (%)		
	External	Internal		Weight Loss[y]	Damaged Kernels	Reduced Germ. of Undamaged Kernels
		Head Capsules	Infested Non-Germ. Kernels			
Infested with MW						
Top	3.2 b	10.5 a	23.3 b	0.9 b	0.3 b	3.9 b
Middle	16.3 b	11.0 b	23.5 b	1.5 b	0.9 b	3.7 b
Bottom	103.9 a	22.0 a	111.2 a	4.9 a	2.5 a	0.6 a
PR > F	0.003	0.003	0.0002	0.0001	0.0002	0.0001
Infested with MW + RFB2						
Top	1.1 a	21.3 ab	14.5 a	0.7 b	0.4 b	7.6 b
Middle	3.6 a	17.3 b	48.6 a	1.0 b	0.6 b	9.3 ab
Bottom	62.8 a	29.0 a	80.7 a	3.5 a	2.1 a	10.5 a
PR > F	0.168	0.025	0.186	0.028	0.049	0.047

[y]Determined by count-and-weigh method.
[z]Infestation rate/species/50 g grain : 0.67
Means in the same column with same infestation followed by dissimilar letters differ significantly according to Duncan's multiple range test, $P < 0.05$.

Table 2 : Insect populations and grain losses in pearl millet infested with maize weevil (MW) or MW plus red flour beetle (RFB) and stored on-head for 14 weeks mud-plastered containers (non ventilated) at 26 °C and 68 ± 3 % RH.

Population d'insectes et pertes en grains chez le mil infesté au charançon du maïs (MW) avec ou sans le Tribolium (RFB) et conservé en épis pour 14 semaines dans une structure non aérée, maintenue à 26 °C et 68 ± 3 % H.R.

Layer Sampled	Populations (MW/50 g grain)			Losses (%)		
	External	Internal				
		Head Capsules	Infested Non-Germ. Kernels	Weight Loss[y]	Damaged Kernels	Reduced Germ. of Undamaged Kernels
Infested with MW						
Top	12.8 c	1.65 c	20.6 b	1.1 c	0.7 c	4.5 b
Middle	31.1 b	32.3 b	37.7 b	3.4 b	1.9 a	5.8 ab
Bottom	203.9 a	41.8 a	63.4 a	6.4 a	3.9 a	8.9 a
PR > F	0.0001	0.0001	0.024	0.0001	0.0001	0.046
Infested with MW + RFB2						
Top	6.4 b	28.3 b	27.8 b	0.8 b	0.5 b	4.7 b
Middle	22.6 b	27.8 b	37.5 b	2.3 b	0.8 b	6.9 ab
Bottom	262.1 a	128.3 a	89.5 a	11.9 a	6.9 a	11.1 a
PR > F	0.0001	0.0001	0.040	0.0001	0.0001	0.050

[y]Determined by count-and-weigh method
[z]Infestation rate/species/50 g grain : 0.67
Means in the same column with same infestation followed by dissimilar letters differ significantly according to Duncan's multiple range test, $P < 0.05$.

Table 3 : Insect populations and grain losses in pearl millet stored threshed for 14 weeks in infestation in simulated mud-plastered containers (not-ventilated) at 26 °C and 68 ± 3 % RH.

Population d'insectes et pertes en grains du mil infesté au charançon du maïs (MW) avec ou sans le Tribolium (RFB) et conservé en épis pour 14 semaines dans une structure non aérée, maintenue à 26 °C et 68 ± 3 % H.R.

Layer Sampled	Populations (MW/50 g grain)			Losses (%)		
	External	Internal		Weight Loss[y]	Damaged Kernels	Reduced Germ. of Undamaged Kernels
		Head Capsules	Infested Non-Germ. Kernels			
Infested with MW[x]						
Top	278.4 a	351.8 a	317.8 a	16.5 a	7.3 a	18.a
Bottom	36.7 a	108.8 b	97.0 b	3.7 b	2.0 b	11.8 b
PR > F	0.078	0.0001	0.005	0.0003	0.003	0.027
Infested with MW + RFB[y]						
Top	354.0 a (17[z])	284.3 a	115.1 a	29.6 a	17.0 a	17.3 a
Bottom	28.6 b (7.5)	68.0 b	93.9 b	2.1 b	1.0 b	7.0 b
PR > F	0.021	0.0001	0.003	0.0001	0.0003	0.025

[x]Determined by count-and-weigh method
[y]Infestation rate/species/50 g grain : 0.9
[z]Numbers in parentheses are RFB

Means in the same column with same infestation followed by dissimilar letters differ significantly according to Duncan's multiple range test, P < 0.05.

Table 4 : Comparison of insect population and grain losses, measured by in-out totals and by sampling in simulated on-forages of pearl millet infested with maize weevil (MW) and MW plus red flour beetle (RFB).

Comparaison des populations d'insectes et des pertes en grain dérivées de l'échantillonnage des formes traditionnelles simulées de stockage du mil infesté de charançon (MW) et ou de Tribolium (RFB).

Storage system and infestation[v]	Populations (MW/50 g grain)				Losses (%)			
	Increase in Adults		Internal Stages		Weight		Damaged Kernels	Reduced germination[w]
	Total	Samples	Head capsules samples	Infected non-germ. Kernels samples	Total	Samples	Samples	samples
On-head ventilated[x] MW	99.4	61.4	14.5	53.3	3.2	1.2	2.4	8.6
MW + RFB	44.5 (1.9[z])	33.6	22.5	48.3	2.0	1.1	1.7	9.8
On-head[y] non-ventilated MW	130.1	123.4	30.2	40.6	4.3	2.2	3.6	10.0
MW + RFB	77.6(2.8)	144.8	61.5	51.6	2.4	2.8	5.0	12.5
Threshed on-ventilated [y] MW	215.7	175.0	230.1	207.4	8.6	4.6	10.1	25.4
MW + RFB	196.0	212.5	176.2	104.5	8.2	8.9	15.8	27.9

[v]Infestation rate/species/50 g grain : on-head = 0.67 ; threshed 0.9
[w]Reduced germination of undamaged kernels plus damaged kernels
[x]Simulated woven reed containers
[z]Simulated mud-plastered containers
[z]Numbers in parenthesis are for RFB

DISCUSSION

Over a 14-week period, the increase in maize weevils in stored pearl millet and red flour beetle populations was significantly influenced by the storage method employed. Under controlled conditions pearl millet stored on-head in ventilated containers was less damaged by MW and MW plus RFB infestations than when on-head millet was stored in non-ventilated storage units. Both on-head systems offered more protection against insect population increase than did bulk storage of threshed grain. The advantage of on-head storage as a deterent to infestation by MW and by RFB was previously demontrated (Kossou, 1981).

The three systems ranked the sa me whether evaluated by measurements made on the entire contents of the storage unit or on samples from the containers. There were some advantages to both bases of evaluation. The influence of fluctuating ambient relative humidity and the eve of repeated infestation were not addressed in this study.

Although weight loss as measured samples taken from layers in the storage containers underestimated weight loss determined by in-out weight of the stored millet, the weight in-weight out method failed to account for various other losses affecting the value and use of the grain. Samples taken from several levels in the storage units although subject to the inherent errors in sampling, provided information on insect dispersal and/or losses due to damaged kernels and reduced seed germination.

Tests to detect internal infestation were useful to relate location of live insects to preferred sites for MW oviposition. The cracking-flotation method generally gives a lower estimates of internal infestation for the on-head millet storages than was found by examining non-germinated seeds. The reverse occured with threshed grains.

A 50-g sample was examined in the cracking-flotation test ; germination tests using 500 seeds (~6 g) of which fewer than 8 % were infested in any sample. Infestation estimates were more subject to sampling error. Germination tests provide an estimate of seeds quality. We found that non-germinated seeds gave a good estimate of internal infestation by MW and by *Rhyzopertha dominica* Fabr. (Kossou, 1998). Non-germinated pearl millet kernels without internal larval or pupal forms were probably damaged by MW female seeking oviposition sites and by adult insect feeding (Howe, 1973).

Experiments, designed to simulate pearl millet storage methods, can be used to determine which, among several traditional pratices, gives highest protection against common infestors, done and in combination. The information then can help to facilitate the selection of on-farm practices that can be targeted for use and/or modification with reasonable expectation of extending the on-farm storage period and reducing storage losses. Evaluation of traditional storage pratices under controlled conditions may aid interpretation of survey findings in loss assessment studies and suggest sampling procedures which would give better indication of actual losses.

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