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International Journal of Pest Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ttpm20

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Version of record first published: 07 Jan 2013.

To cite this article: M. Mdangi , L.S. Mulungu , A.W. Massawe , S.J. Eiseb , V. Tutjavi , F. Kirsten , T. Mahlaba , P. Malebane , E. von Maltitz , A. Monadjem , N. Dlamini , R.H. Makundi & S.R. Belmain (2013): Assessment of rodent damage to stored maize (Zea mays L.) on smallholder farms in Tanzania, International Journal of Pest Management, 59:1, 55-62

To link to this article: http://dx.doi.org/10.1080/09670874.2012.744495

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International Journal of Pest Management, 2013
Vol. 59, No. 1, 55–62, http://dx.doi.org/10.1080/09670874.2012.744495

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Assessment of rodent damage to stored maize (*Zea mays* L.) on smallholder farms in Tanzania

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(*Received 2 March 2012; final version received 24 October 2012*)

This study examined rodent damage, loss and contamination in stored maize on smallholder farms in East Africa. Different, novel techniques for assessing rodent damage, namely open and closed storage structures (cribs and sacks), were employed in a treatment-control trial design replicated across different households and hamlets within the Berega community of Central Tanzania. Significant correlations were observed between the monthly rates of rodent-damaged maize seeds, maize weight loss and the number of rodent droppings. Significant differences in damage, loss and contamination occurred between different storage structures (open and closed cribs and sacks). The mean monthly rate of damage was 40.4%, 7.9%, 17.7% and 0% percent in open cribs, closed cribs, open sacks and closed sacks, respectively. Our results suggest that reducing rodent infestation through the use of improved storage structures could lead to major savings in the amount and quality of stored food available to households, thus increasing food security.

Keywords: contamination; post-harvest; rodent damage; storage structures; weight loss

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1. Introduction

In most African countries, maize is one of the most important staple foods (FAO statistics 2009). However, the crop is produced on a seasonal basis, and in many places there is only one harvest per year. Drought-related crop failure and pest damage often cause regional shortages in Africa (Greaves 1980). Low and unpredictable productivity means more must be done to conserve and store the harvest for longer than 9 months (Justice and Bass 1979; Makundi et al. 1991). Grain storage is a key component in the economies of developed and developing countries alike; however, developing countries suffer severe post-harvest pest problems due to the lack of appropriate structures and technology that keep pests out of household food stores (Sarangi et al. 2009).

One of the main functions of storage in the economy is to even out fluctuations in market supply, both from one season to the next and from one year to the next (Justice and Bass 1979). Rodents are major pests in grain stores, causing both direct and indirect effects (Taylor 1968; Leirs 1992; Leung et al. 1999). Stored maize is attacked by a range of rodent species (Makundi et al. 1991; FAO 1994) depending on the region and whether they are found in domestic or peri-domestic areas.

In Tanzania, rodents contribute to high losses in terms of quantity and quality due to their consumption and contamination of maize (Mdangi 2009). Loss of quality is typically through deterioration, contamination and changes in the composition of nutrients (Sashidhar et al. 1992). The most common causes of damage by rodents in maize storage are (1) eating of the germ of seeds, which reduces the nutritive content and causes germination failure when the seeds are used for planting, and (2) contamination of the grain with faeces, hair and urine, which results in lower market values and potential disease transmission (Justice and Bass 1979; MoAFS 1984). Severe rodent damage to grain contributes to food shortages in rural communities of Tanzania as well as resulting in financial losses. In India, rodent-caused post-harvest losses have been reported to be c. 2.5% (Harris and Linblad 1978). In Tanzania, the degree of rodent damage to maize seeds in stores has been reported to be up to 35% (Makundi et al. 2006). This implies a loss of around 1.3 million tonnes per year of the actual yield (FAO statistics 2009). This amount of lost maize seed would be enough to feed 7 million people for a year at a rate of 0.5 kg/day/person with an estimated value of 141.7 million US dollars (at US$ 11.1 per 100 kg bag of maize) (Mulungu 2003). The loss could be even higher in years experiencing rodent population outbreaks. Kilosa District in Central Tanzania experiences regular rodent outbreaks that can severely cause losses of

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maize during storage (Singleton et al. 2010). Precise crop damage and loss estimates caused by rodents in stores are generally not available in Africa; however, this information is required to develop cost–beneficial strategies for rodent control. Our working hypothesis is that improved storage structures may reduce rodent damage to stored maize. The aim of our study was to assess the level of infestation of rodents to stored maize and associated losses and compare potential damage in different types of storage structures with a view to develop optimised storage structures.

2. Material and methods

2.1. *Study location and duration*

The study was carried out at Beregga village (06°10′S; 37°5′E, 840 m.a.s.l.) in the Kilosa District of Central Tanzania during the storage season of October 2007 to May 2008. In general, the crop is harvested in July and dried on raised platforms for approximately three months before threshing. Farmers generally begin storing their harvested maize in October with most supplies depleted by April or May the following year. The duration of storage depends on the amount harvested and the family needs. Our trial was set up in October 2007, with the first sampling interval in November 2007 and the last in May 2008.

2.2. *Population of rodents in farmer's houses*

To estimate rodent populations in houses, removal trapping was done monthly for three consecutive nights for a period of seven months with the first trapping in Nov-07 and the last in May-08. Five hamlets of the village were selected randomly and from each hamlet one farmer was also selected randomly. Equal numbers of live traps (i.e. five locally made traps, each consisting of a wooden box 12 × 15 × 20 cm with a wire mesh window on one side, and five Sherman LFA live traps 7.5 × 9.0 × 23 cm (HB Sherman® Traps, Inc., Tallahassee, Florida) baited with peanut butter were placed against walls and in corners of the house, giving a total of 1050 total trap nights. Trapped animals were identified to species level following the guidelines given in Kingdon (1997). The monthly percentage trap success was calculated as described by Telford (1989).

2.3. *Damage assessment*

A factorial experiment design for damage assessment in farmers' houses was used. Two storage structure designs (cribs and sacks) and two proofing levels (open and closed) were used. Six farmers were selected randomly, each from different hamlets of Berega village. Three farmers used the sacks to store their maize while the other three used cribs; therefore, each treatment was replicated three times, that is three farmers used sacks (1 closed, 1 open) and the other three used cribs (1 closed, 1 open). For the three farmers who used sacks in the experiment, six sacks were used: three were closed and the other three were left open (Plate 1). Sacks were kept in their typical place for grain storage within the house where one sack was left open, thus resembling the farmer's typical storage situation, and the other sack was enclosed in wire mesh of mesh-size of 1.5 × 1.5 cm to protect maize grains from rodent damage. For storage in cribs, six cribs were constructed, two in each house (1 open, closed with mud) (Plate 2). Traditional crib design in central Tanzania consists of an open-topped, cylindrical woven basket that is plastered with mud. In total, three cribs were left open and the other three were closed to protect them from rodents. No rat guards were used on the legs of the crib platform. A known amount (90 kg) of dried

Plate 1. (Colour online) Open and closed sacks in farmer's house.

Plate 2. (Colour online) Open and closed crib in farmer's house.

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maize grain (moisture content of 15%) was stored in each structure placed within the normal household storage area for a period of seven months. Before the maize was placed in bags and cribs, it was treated with insecticide (Actellic Super Dust, manufactured by Syngenta) according to package's instructions to prevent insect damage. Sampling was done consecutively for 7 months at an intervals of 1 month. In each month, sampling from each replicate was done using a 0.25 kg container to sample four times, making a total of 1 kg of maize.

2.4. *Data collection*

Before sampling, stored maize grains in each storage container was weighed. Samples were taken from the middle and the periphery from each storage structure. After every sampling the remaining maize in the storage container was re-weighed. The sampled maize grains were separated into two categories, damaged and undamaged seeds. Grains in each group were counted and weighed. Percentage grain damage and amount of weight loss were calculated as described by Buckle (1994). Samples taken each month were also used to assess the level of contamination, counting the number of rodent droppings in each sample.

2.5. *Data analysis*

The rodent population in houses was determined as a relative percentage trap success in each month with respect to total capture, that is the number of captures per 100 trap nights. Pair-wise linear regressions were used to observe trends in observed variables over time, and a factor analysis (maximum likelihood) was used to determine the degree of common variability among observed correlated parameters. Statistical analysis using analysis of variance (ANOVA) with Fisher's least significant difference (LSD) was performed to establish significance of the different treatments, time intervals and their interaction against weight loss, damage and contamination. All analyses were performed using XLSTAT (version 2011.2.06).

3. Results

During this study 134 small mammals were captured from a total of 1050 trap nights, comprising two rodent species and one shrew species. The dominance of *Rattus rattus* was strongly apparent in houses with only a few *Mastomys natalensis* present (Table 1). Similar trap success rates obtained each month suggested the rodent population abundance in the village remained more or less constant over the storage trial period and that any potential rodent feeding pressure on household grain stores would be relatively the same over time.

The pattern of weight loss over the sampling intervals varied, and there were no obvious correlations when comparing treatments and sampling interval with weight loss (Figure 1). There were no significant differences in weight loss, damage or contamination rates over the 7 months duration or any interactive effect between sampling interval and treatment (ANOVA, $P > 0.05$). However, there were significant differences in weight loss, damage and contamination among the treatments (Table 2). On average, open cribs suffered significantly more weight loss per month (144.5 g) than closed sacks (0.0 g), closed cribs (45.2 g) and open sacks (86.0 g). Open sacks significantly lost more grain to rodents than closed sacks, but weight loss from closed cribs was not significantly different from the observed weight loss in both open and closed sacks. For farmers adopting these different storage practices, the estimated weight loss would be 19.3 kg/tonne/year in open cribs, 6.0 kg/tonne/year in closed cribs, 11.5 kg/tonne/year in open sacks and 0.0 kg/tonne/year for closed sacks.

Table 1. Small mammal species composition in five village houses involved in the study area over seven months of trapping.

Month	Number of captures: *Rattus rattus*	*Mastomys natalensis*	*Crocidura* spp.	Percentage trap success
Nov-07	21	5	0	17.3
Dec-07	18	1	0	12.7
Jan-08	15	1	0	10.7
Feb-08	20	0	0	13.3
Mar-08	19	0	0	12.7
Apr-08	17	0	1	12.0
May-08	15	1	0	10.7
Total	125	8	1	12.8

Similar statistical trends in the percentage of damaged grain were observed between treatments with mean monthly damage rates of 40.4%, 7.9%, 17.7% and 0% observed in open cribs, closed cribs (after the rodents had damaged the cribs), open sacks and closed sacks, respectively (Table 2). All recorded variables (damage, contamination, loss) showed positive and significant correlations with one another (Figure 2). Weight loss against damage showed the strongest relationship ($r^2 = 0.64$, Figure 2a), followed by weight loss and droppings ($r^2 = 0.28$, Figure 2b) and damage and droppings ($r^2 = 0.15$, Figure 2c). These relationships among the three parameters were confirmed using a factor analysis with maximum likelihood that showed final communality values were high for weight loss (1.0) and damage (0.64) and low for contamination (0.05), indicating contamination rates did not follow the same pattern as observed for loss and damage and, therefore, suggesting contamination rates may not accurately reflect on-going damage and loss caused by rodents in grain stores.

A cost–benefit analysis of the different storage options was carried out based on the average market prices of maize in Tanzania and the local construction costs (labour and physical inputs) of the different storage options. Maize prices were considered in terms of two quality variables: (1) high quality maize with little rodent damage or faecal contamination – \$1.25/kg; (2) low quality maize with many grains damaged with the germ removed by rodents and visible faecal contamination – \$0.63/kg. We proceeded on the expectation that grain marketed from open sacks and cribs would obtain the lower market price and that closed sacks and cribs would obtain the higher market value. Crib construction requires little in terms of physical input (wood, grass, mud) but is labour intensive. Based on a labour cost of \$0.63/hour and discussion with farmers, we estimated an open crib would cost \$4.69/crib and a closed crib would cost \$6.25/crib. Woven polyethylene sacks commonly used for grain storage typically cost \$0.94/sack, that is the price of an open sack as used in the trial. Closed sacks have the additional input cost of buying wire mesh (\$1.88/m^2) and paying for the labour involved in shaping the mesh. We estimated closed sacks would cost \$3.75/sack. We considered that this cost could be considerably lower if several sacks were stored together within a single mesh compartment as well as if larger sized cribs were constructed. However, disregarding economies of scale in storage construction and using 90-kg storage units as trialled, we estimated that open cribs would provide a profit of \$62.36/90 kg unit maize sold, closed cribs would provide a profit of \$97.36/unit, closed sacks would profit by \$108.75/unit and open sacks would profit by \$91.65/unit (subtracting the observed amounts of grain consumed by rodents and the container construction costs in each case). Therefore, the net benefit of improved grain storage can be directly measured in terms of improved household food security through preventing rodent consumption as well as increased profitability of grain sold, particularly when using closed cribs and sacks where the additional proofing costs are outweighed by the increased quality and quantity of grain sold.

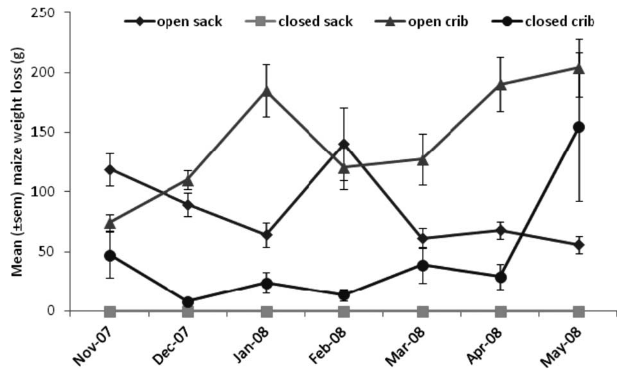

Figure 1. Mean ($\pm$ standard error of the mean) weight loss (g) per treatment ($n = 3$) per month ($n = 7$). Closed sacks and cribs were more rodent proof than their open comparisons, with sacks better than cribs at preventing losses of grain caused by rodents.

4. Discussion

Kilonzo (2006) found the most common rodent pests in food stores in Tanzania to be *R. rattus*, *R. norvegicus*

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Table 2. ANOVA with Fisher's Least Significant Difference (LSD) comparison of experimental treatments for the observed variables of monthly weight loss, damage and contamination over 7 months.[a]

Treatment	Mean weight loss (g)/month	Mean percent damage (%)/month	Mean number of droppings/month
Open crib	144.5 ± 38.35 a	40.4 ± 9.05 a	39.0 ± 18.22 a
Open sack	86.0 ± 23.39 b	17.7 ± 3.47 b	20.2 ± 6.21 a,b
Closed crib	45.2 ± 22.57 b,c	7.9 ± 2.99 b,c	6.9 ± 2.31 b
Closed sack	0.0 c	0.0 c	0.0 b

[a]Mean values (± standard error of the mean) in each column followed by different letters are significantly different from each other ($P < 0.05$). ANOVA showed no differences across sampling intervals for any variable and no interactive effect between treatment and interval ($P > 0.05$).

and *Mus musculus*. However, Fiedler (1994) stated that *M. natalensis* may also cause damage during smallholder storage. The dominance of *R. rattus* was apparent from our trapping in houses and few *M. natalensis* were present. It has been reported that *R. rattus* is the main commensal rodent pest in Tanzania (Kilonzo 1984), and it is widely considered the most abundant rodent residing inside houses across

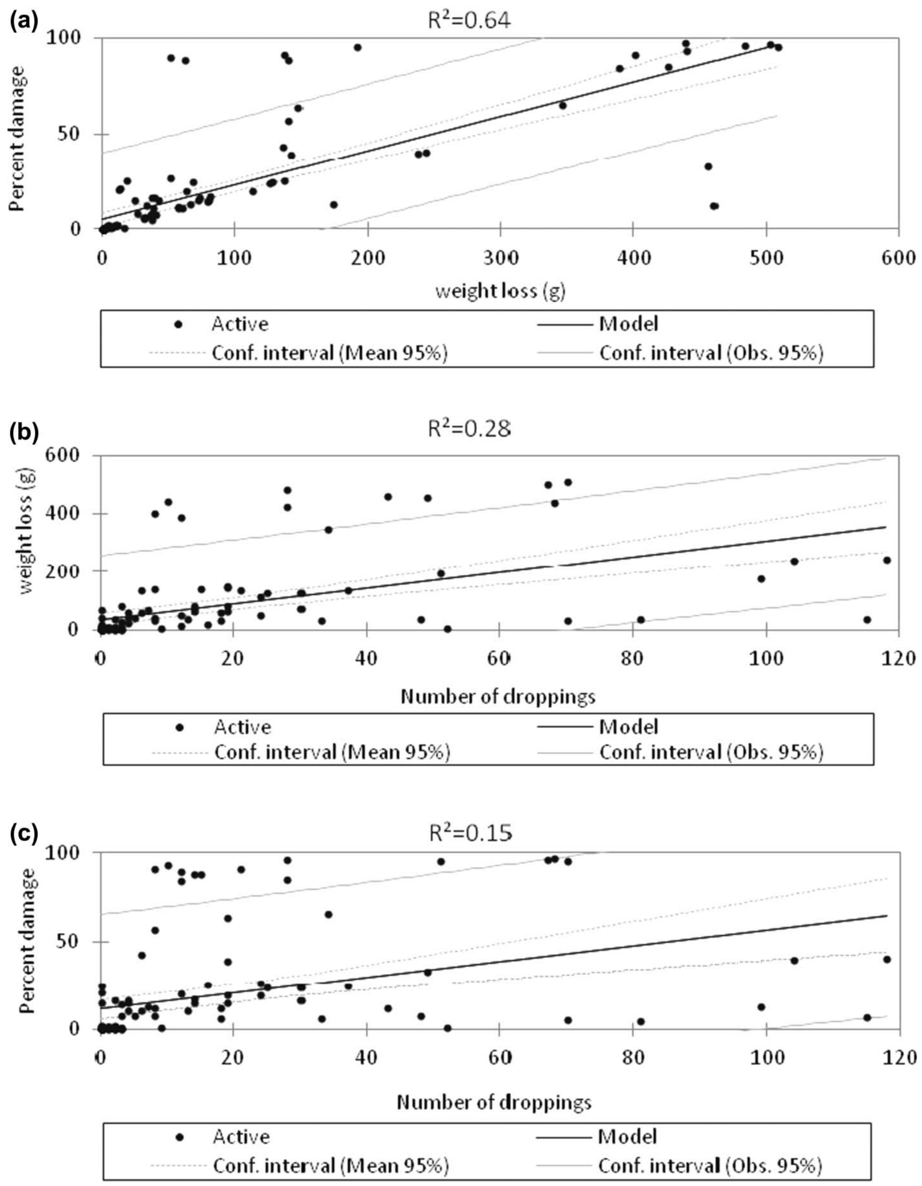

Figure 2. Linear regressions between (a) percentage damage and weight loss of grain, (b) weight loss and number of droppings and (c) percentage damage and the number of droppings.

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Africa (Kilonzo 2006). The results of this study would support the hypothesis that R. rattus is confined to residing inside dwellings. Although a few individuals of M. natalensis were caught inside houses, we would argue that this behaviour is uncommon and caused by an absence of food in fields after harvest, whereby M. natalensis is attracted to the grain stored within houses. Taylor et al. (2012) showed that M. natalensis only entered smallholder African houses in large numbers when R. rattus was completely absent from the regional environment.

Significant differences between storage structures were recorded, whereby open sacks and open cribs had higher levels of damage, grain removal and contamination when compared to closed sacks and cribs. These results suggest that there is a need to use rat guards on the platform legs to prevent rodent access when using cribs for grain storage. MoAFS (1984) pointed out that to prevent rodents from jumping onto grain storage structures; rat guards should be fixed one metre above ground on the supporting legs of cribs. The low level of damage in closed sacks would indicate there was limited access by rodents. In some sampling intervals there were relatively high levels of variability among replicates and this could be due to local changes in rodent populations resulting from differences in type of household storage, type and proximity of habitat around the perimeter of houses and spillage around food sources in households. For example, some houses used in this study had thatched roofs and were closely surrounded by high grass whereas other houses were constructed with corrugated metal roofs and were generally further from crop land with higher levels of hygiene (unpublished observation). Future research should try to take more account of these environmental variables to reduce potential sources of variation affecting rodent abundance. In order to reduce high numbers of rodents in houses, MoAFS (1984) suggested that farmers should use the following methods: (a) keeping an area around the house clean and free of vegetation; (b) not piling firewood and other things next to the walls; (c) maintaining the house by blocking holes in the walls with small stones and mud or clay, (d) plastering the walls so that the surface becomes smooth; (e) making doors fit tight; (f) cleaning up inside houses and removing piles of items (e.g. empty used bags and boxes) not in use, (g) always keeping food in closed containers like tins and clay pots covered with sheet metal lids and put something heavy on top; (h) using locally made traps or other traps if available. Our research cannot confirm whether these practices have directly affected the results presented, but it is likely that variation in household implementation of them has driven some of the variation in our study variables.

The observed total weight loss in the treatments was relatively low compared with the potential feeding capacity of rodents reported by Meyer (1994), who found that rodents need to consume approximately 10% of their body weight per day. According to Nowak (1999), R. rattus consumes about 15 g/day of food and 15 mL/day of water (an adult of 150 g). Therefore, given the observed number of rodents (15 to 21) in the study area, a loss of 47.25–66.15 kg would be expected for the whole storage time of seven months per farmer. The lack of a clear trend of post-harvest loss over time indicates that rodent feeding pressure at a given household is more or less constant due to relatively stable rodent populations in African village environments. Our rodent trap success data support this hypothesis. High rates of variation may be due to low replication or local fluctuations in availability of other food resources in and around different households and/or rodent migration.

Rodents cause direct damage and spoilage to stored food with their droppings, urine, saliva and hair, which leads to deterioration, potential disease transmission and enhances susceptibility of the grain to fungal and bacterial infestations during storage (Gregory 2002). In our study, the closed sacks were protected from rodent attack, showing no evidence of contamination, loss or damage. Our analyses showed that higher weight loss was associated with higher percentages of damaged grain and contamination. This relationship will depend on the rodent species involved. Meyer (1994) observed that Rattus species can produce about 40 droppings a day. However, contamination rates will be affected by rodent behaviour whereby rodents removing grain to be hoarded or eaten elsewhere will be less likely to contaminate the grain compared to rodents which sit in the grain store, partially eating grains over a period of time, before leaving the store. The regression and factor analysis of the data presented would support the hypothesis that faecal contamination rates are likely to be a more variable reflection of individual rodent behaviour and species traits and a poor reflection of the rates of grain damage and loss incurred by rodents. The potential lesson for farmers is that the absence of or low level of faecal contamination present in a grain store may underestimate the amount of grain being eaten by rodents. As smallholder maize farmers cannot easily observe the loss of maize in their store over time, we would advise the better proxy for measuring grain loss is the percentage of grain damaged as opposed to faecal contamination. Further research is required to develop reliable models linking rodent damage to loss and which can estimate the amount of grain removed from farmer stores based on maize damage rates.

6. Conclusions

A full understanding of rodent damage to crops is vital to the design of cost-effective management strategies. Our study has shown that more severe rodent damage, weight loss and contamination occurs in open storage structures (sacks and cribs), which unfortunately conforms to the majority practice of smallholder farmers in Kilosa District as well as other parts of Africa and Asia. Our data support the hypothesis that improved storage structures can reduce rodent damage to stored maize. In this study, no loss was observed in closed sacks because rodents were unable to obtain access. Although closed sacks showed better control of rodent damage to stored maize, it is more expensive for farmers to implement as they must buy wire mesh. However, there are clear net benefits to using sacks protected by wire mesh through improving the quality and quantity of grain conserved. Further research is required to determine whether these additional costs associated with improved storage structure design can be reduced through scaling up the grain volume protected, making it more affordable in the short and long term for small scale farmers. Considering the amount of stored grain saved and the cost–benefits calculated at a relatively small scale, we can hypothesize that the cost–benefits of improved large-scale storage will be highly favourable. Future research trials are needed to investigate the costs and benefits of improved grain storage versus other rodent management practices. The 11 dollar difference in profit between using closed sacks ($108.75) and closed cribs ($97.36) is significant for a rural farming family, and the large scale adoption of mesh-protected sacks could lead to the erosion of traditional African granaries and the loss of their aesthetic and cultural values. Further socio-economic analyses on post-harvest systems would be required before any policy recommendations could be made.

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Acknowledgements

This work was supported by the ECORAT Project, financed by the European Union and the Southern African Development Community (SADC) Secretariat through the Implementation and Coordination of Agricultural Research and Training (ICART) programme. The contents are the sole responsibility of the authors and can under no circumstances be regarded as reflecting the position of the SADC Secretariat or the European Union. We appreciate the excellent field assistance from Mr Khalid S. Kibwana of the Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania.

References

Buckle AP. 1994. Damage assessment and damage surveys. In: Buckle AP, Smith RH, editors. Rodent pests and their control. Wallingford (UK): CAB International. p. 219–248.

FAO [Food and Agricultural Organisation]. 1994. *Grain storage techniques: Evolution and trends in developing countries*. Proctor DL editor. Rome, Italy. p. 289.

FAO statistics [Food and Agricultural Organisation]. 2009. Maize production in Tanzania [Internet]. Available from: http://www.pps.fao.Org/ (cited 11 December 2009).

Fiedler LA. 1994. Rodent pest management in East Africa. Plant production and protection paper No. 123. Rome: FAO [Food and Agriculture Organization of the United Nations]. p. 83.

Greaves JH. 1980. Rodent loss determination by population assessment and estimation procedures. In: Harris P, Linblad CJ editors. Post-harvest grain loss assessment methods. St. Paul (MI): American Association of Cereal Chemists. p. 109–115.

Gregory K. 2002. Information on common pests [Internet]. Available from: http://www.statistics of common pests.htm/ (cited 16 March 2002).

Harris KL, Linblad CJ, editors. 1978. Preamble to the methodology of standard measuring techniques. In: Post-harvest grain loss assessment methods. St. Paul, MN: American Association of Cereal Chemists. p. 77–82. 193 pp.

Justice OL, Bass LN. 1979. Principles of seed storage. Beccles and London: Castle House Publications. p. 275.

Kilonzo BS. 1984. Studies on the present status of endemicity, mammalian reservoirs and flea vectors of plague in Tanzania. PhD thesis, University of Dar es Salaam. p. 369.

Kilonzo BS. 2006. Rodent pest and their management in Tanzania. Compendium I, Pest Management Centre, Sokoine University of Agriculture, p. 64.

Kingdon J. 1997. The Kingdon field guide to African mammals London: Academic Press. p. 460.

Leirs H. 1992. Population ecology of *Mastomys natalensis* (Smith, 1834) Multimammate rats: possible implications for rodent control in Africa. PhD Thesis. University of Antwerp, Belgium. p. 263.

Leung LKP, Singleton GR, Sudarmaji, Rahmini. 1999. Ecologically–based rodent management of the rice field rat in Indonesia. In: Singleton GR, Hinds LA, Leirs H, Zhang Z., editors. Ecologically–based rodent management of rodent pests. ACIAR Monograph No. 59. Canberra, Australia. p. 305–318.

Makundi RH, Massawe AW and Laswai HS. 2006. Storage and protection of Durable Food crops and their products in Tanzania. In: Makundi RH, editor. Management of selected crop pests in Tanzania. Dar es Salaam: Tanzania Publishing House. p. 185–204.

Makundi RH, Mbise TJ, Kilonzo BS. 1991. Observations on the role of rodents in crop losses in Tanzania and control strategies. Beiträge zur tropischen Landwirtschaft und Vertirinärmedizin. 29(4):465–474.

Mdangi M. 2009. Assessment of rodent damage to maize (*Zea mays* L.) in the field and stores at Berega village, Kilosa District, Tanzania. MSc dissertation, Sokoine University of Agriculture, Morogoro, Tanzania, p. 71.

Meyer AN. 1994. Rodent control in practice: food stores. In: Buckle AP, Smith RH, editors. Rodent pests and their control. Wallingford (UK): CAB International. p. 273–290.

MoAFS [Ministry of Agriculture and Food Security]. 1984. Trainer's guide to improved rat control, Ministry of Agriculture, Tanzania, p. 27.

Mulungu LS. 2003. Assessment of maize (*Zea mays* L.) damage and yield loss due to rodent in the field. PhD Thesis, Sokoine University of Agriculture, Morogoro, Tanzania, p. 178.

Nowak R. 1999. Walker's mammals of the world (6th edition) [Internet]. Baltimore(MD): Johns Hopkins University Press. Available from: http://animaldivesty.ummz.umich.edu/site/account/information/Rattus rattus.htm/ (cited 25 August 2008).

Sarangi SK, Singh R, Singh KA. 2009. Indigenous method of rat proof grain storage by Adi tribes of Arunachal Pradesh. Indian J Trad Knowledge. 8(2):230–233.

Sashidhar RB, Ramakrishna Y, Bhat RV. 1992. Moulds and mycotoxins in sorghum stored in traditional containers in India. J Stored Prod Res. 28(4):257–260.

Singleton GR, Belmain SR and Brown PR. 2010. Rodent outbreaks: an age-old issue with a modern appraisal. In: Singleton GR, Belmain SR, Brown PR and Hardy B, Editors. *Rodent outbreaks: ecology and impacts*. Los Banos, Philippines: International Rice Research Institute. p. 289.

Taylor KD. 1968. An outbreak of rats in Agricultural areas of Kenya in 1962. East Afr Agric Forest J. 34:66–67.

Taylor PJ, Downs S, Monadjem A, Eiseb SJ, Mulungu LS, Massawe AW, Mahlaba TA, Kirsten F, Maltitz EV, Malebane P, Makundi RH, Lamb J, Belmain SR. 2012. Experimental treatment–control studies of ecologically based rodent management in Africa: balancing conservation and pest management. Wildlife Res. 39(1):51–61.

Telford SR Jr. 1989. Population biology of the multimammate rat, *Praomys* (*Mastomys*) *natalensis* at Morogoro, Tanzania, 1981–1985. Bull Florida State Museum Biol Sci. 26(6):249–288.

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