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

Food preferences of the multi-mammate mouse, Mastomys natalensis, in irrigated rice habitats in Tanzania

L.S. Mulungu[a], E.C.M. Mlyashimbi[b], V. Ngowo[c], M. Mdangi[d], A.S. Katakweba[a], P. Tesha[c], F.P. Mrosso[e], M. Mchomvu[c], B.S. Kilonzo[a] & S.R. Belmain[f]
[a] Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania
[b] Crop Science and Production, Sokoine University of Agriculture, Morogoro, Tanzania
[c] Rodent Control Centre, Ministry of Agriculture, Food Security and Cooperatives, Morogoro, Tanzania
[d] MATI-Ilonga, Kilosa, Morogoro, Tanzania
[e] Ilonga Agricultural Research Institute, Kilosa, Tanzania
[f] Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, United Kingdom
Published online: 16 Jan 2014.

To cite this article: L.S. Mulungu, E.C.M. Mlyashimbi, V. Ngowo, M. Mdangi, A.S. Katakweba, P. Tesha, F.P. Mrosso, M. Mchomvu, B.S. Kilonzo & S.R. Belmain (2014) Food preferences of the multi-mammate mouse, Mastomys natalensis, in irrigated rice habitats in Tanzania, International Journal of Pest Management, 60:1, 1-8, DOI: 10.1080/09670874.2013.871759

To link to this article: http://dx.doi.org/10.1080/09670874.2013.871759

International Journal of Pest Management, 2014
Vol. 60, No. 1, 1–8, http://dx.doi.org/10.1080/09670874.2013.871759

Taylor & Francis
Taylor & Francis Group

Food preferences of the multi-mammate mouse, *Mastomys natalensis*, in irrigated rice habitats in Tanzania

L.S. Mulungu[a]*, E.C.M. Mlyashimbi[b], V. Ngowo[c], M. Mdangi[d], A.S. Katakweba[a], P. Tesha[c], F.P. Mrosso[e], M. Mchomvu[c], B.S. Kilonzo[a] and S.R. Belmain[f]

[a]*Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania;* [b]*Crop Science and Production, Sokoine University of Agriculture, Morogoro, Tanzania;* [c]*Rodent Control Centre, Ministry of Agriculture, Food Security and Cooperatives, Morogoro, Tanzania;* [d]*MATI-Ilonga, Kilosa, Morogoro, Tanzania;* [e]*Ilonga Agricultural Research Institute, Kilosa, Tanzania;* [f]*Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, United Kingdom*

(*Received 25 July 2013; final version received 1 December 2013*)

We investigated the composition of the diet of the multi-mammate mouse, *Mastomys natalensis*, within irrigated rice and fallow field habitats at set time periods related to rice crop growth stages. In both habitats, vegetative plant material, i.e. leaves, stems and seeds, were the most abundant components of the rodent's diet, while other food types (invertebrates, fruits) were observed only in low quantities. We conclude that vegetative plant material and seeds were the main types of food consumed not only due to their relatively higher abundance in the environments under study but also because of the highly specialised herbivorous/granivorous nature of the dominant rodent species, *M. natalensis*. Thus, the introduction and expansion of continuous rice-cropping using irrigation in Tanzania is likely to be severely constrained by the presence of *M. natalensis*. In our opinion, field hygiene, including the removal of alternative food resources and nesting sites for *M. natalensis* near cropping areas, may help to both lower rodent population numbers and reduce immigration potential. Non-chemical rodent control methods such as trap barrier systems developed for lowland irrigated rice in south-eastern Asia should, we argue, be evaluated for their effectiveness under African conditions.

Keywords: breeding; diet; irrigated rice; management; rodents

1. Introduction

Rodents are important agricultural pests due to the economic losses they cause in agriculture and their role as reservoirs of human and animal diseases (Meerburg, Singleton, & Kijlstra 2009; Makundi & Massawe 2011). Estimates of annual crop loss and post-harvest contamination by rodents in Africa suggest an extra 200 million people could be fed if such losses could be prevented (Meerburg, Singleton, & Leirs 2009). Farmers often view rodent losses as uncontrollable due to the frequent failure of management activities, particularly in developing countries, which lead to apathy, acquiescence and acceptance of rodent pests in the environment (Posamentier 1997; Singleton et al. 1999; Mwanjabe et al. 2002; Brown et al. 2008). Rapid rodent population expansion caused by biotic and abiotic phenomena has repeatedly led to rodent outbreaks and total crop destruction in many parts of the world (Singleton et al. 2010).

In Tanzania and sub-Saharan Africa, a large proportion of potential crop yield is lost to rodents (Makundi & Massawe 2011). The multi-mammate mouse (*Mastomys natalensis* Smith) is the most abundant and important rodent pest of field crops across eastern and southern Africa and constitutes the greatest threat to crops in the region (Massawe et al. 2011; Mulungu et al. 2013). Like many rodent species *M. natalensis* demonstrates feeding preferences for high-energy resources such as seeds, and together with its natural adaptation to savannah grasslands, the species predominates in agricultural landscapes where cereals are grown across south-eastern Africa. The annual breeding pattern of *M. natalensis* in Tanzania is reported to be directly linked to rainfall patterns in maize-dominated cropping and farm-fallow mosaic landscapes consisting of a fragmented patch-work of natural, semi-natural and low-input cropping/grazing habitats (Leirs et al. 1989; Workneh et al. 2004). Seasonal variation in the onset of rains affecting vegetative productivity has been shown to trigger *M. natalensis* breeding (Leirs et al. 1994), whilst Mulungu et al. (2011) and Odhiambo et al. (2008) have shown that *M. natalensis* is an opportunistic feeder consuming a variety of food types (invertebrates, wild grass seeds, vegetative plant material, fruits, cereal grain crops) dependent upon availability, habitat and season.

Sicard and Fuminier (1996) reported that reproduction by *Mastomys huberti* is continuous in wild habitats where food is available throughout the year, whilst a similar species, *Mastomys erythroleucus*, seasonally reproduces in wild habitats where food is seasonally available (e.g. semi-arid habitats). Semi-arid natural habitats where food is seasonally differential appear to drive reproductive cycles for many sylvatic rodent species (Leirs et al. 1996). Similarly, the seasonality of crop production can drive rodent breeding; for example, Duque et al. (2005)

*Corresponding author. Email: mulungu@suanet.ac.tz, lothmulungu@yahoo.co.uk

observed that the onset of breeding in *Rattus tanezumi* Temminck is linked to specific developmental stages of the rice crop.

In irrigated rice cropping systems in Tanzania, breeding of *M. natalensis* occurs throughout the year (Mulungu et al. 2013), where food and water availability is not limited due to seasonal variations. However, little is known about the food preferences of *M. natalensis* within this continuous rice production area and whether/which foods may influence breeding. Understanding what potentially triggers breeding in *M. natalensis* and its food preferences in such habitats could serve as potential tools for planning and developing management strategies for the pest (Singleton 2002). Therefore, the aim of the study is to establish the dietary categories that may contribute to the observed continuous breeding of *M. natalensis* at different stages of rice growth over time in irrigated rice systems found in eastern Tanzania.

2. Materials and methods

2.1. *Study area*

This study was conducted at Hembeti village (06°16′S, 37°31′E), in Mvomero District, Tanzania. The study area has a bimodal rainfall pattern with a short rainy season from October to December and long rainy season from March to June. Farmers in the study area produce two rice crops per year. The first cropping season is during the wet season from January to June and the second crop is grown during the dry season from July to December, exclusively under irrigation (Table 1). For wet and dry seasons, respectively, land preparation and rice transplanting are done in January and July, the rice booting stage is in April and October, and the rice crop reaches physiological maturity in May and November, and farmers harvest in June and December.

2.2. *Trapping of rodents*

A removal study was carried out from June 2010 to May 2012. Two 70 × 70 m permanent trapping grids were established (one in a rice field and the other in a fallow field which had not been used for over a year or more). The distance between rice and fallow grids was approximately 300 m. The total local area suitable for rice cultivation is approximately 500 ha. The area planted with rice during the study period was approximately 350 ha with approximately 150 ha of fallow fields. Each grid consisted of seven parallel lines, 10 m apart, with seven trapping stations per line, also 10 m apart, making a total of 49 trapping stations per grid. One Sherman LFA live trap (8 × 9 × 23 cm, H.B. Sherman Traps Inc., Tallahassee, FL) or Victor kill trap (1.0 × 20.3 × 30.1 cm, Animal Trap Co., Lititz Pennal) was used per station, with trap type alternating. A total of 25 kill traps and 24 live traps, baited with peanut butter mixed with maize bran/flour, were placed at alternate stations and set for three consecutive nights at intervals of four weeks. Traps were placed in the afternoon and inspected the following morning. During flooding, the traps were placed on top of dried grass mounds in the same grid locations.

Table 1. Farmers' cropping calendar for rice production in the study area.

Rice crop growth stage	Season: Wet	Season: Dry
Transplanting	January	July
Vegetative	February–March	August–September
Booting	April	October
Harvesting	May–June	November–December

2.3. *Processing of captured animals*

All the captured animals were taken to the field laboratory, sexed and identified to species level as described by Kingdon (1997). Live animals were sacrificed and killed humanely according to regulations set out by the government of the Republic of Tanzania and international bodies, and all captured specimens were dissected to remove their stomachs. Individual stomachs were labelled and preserved in containers (20 ml, glass bottle, HiSupplier®.com) containing 70% ethanol. The analysis of stomach contents was carried out in a laboratory by removing and evenly spreading the contents of each stomach in a Petridish (65 mm in size, Tools and Carbide Plastics (Pty) Ltd.) and categorised using a binocular dissecting microscope under 25× and 50× magnification as described by Smith et al. (2002). The contents were identified and sorted out into the following categories: seeds, fruits, vegetative plant materials (roots, stems and leaves), invertebrates, animal hairs and other unidentified matter. Lugol's iodine solution was used to confirm the presence of seed starch (Smith et al. 2002).

2.4. *Diet analysis*

Food categories were quantified as described by Smith et al. (2002), where the average percentage volume (PV, the contribution of each item to the volume of the particular stomach content) was estimated to the nearest 10%, with an additional category of 5% where an item was present but contributed <10% to the stomach content volume. Diet variety was the number of dietary items recorded per individual, and diet diversity was calculated according to Ebersole and Wilson (1980) as Levins' index (Levins 1968) as

$$\frac{1}{\sum p_i^2},$$

where $P\ (=PV)$ is the percentage value of each of the diet category. Levins' index ranges from 1 to n (n = total number of food item categories) and was used to calculate seasonal samples of *M. natalensis*. Diversity was standardised to a scale of 0–1 using Hurlbert's method (Krebs 1989):

$$B_s = \frac{(B-1)}{(n-1)},$$

where B_s is Levins' standardised niche breadth, B is Levins' measure of niche breadth, and n is the number of possible resource states.

The combination of PV and percentage contribution (PC; percentage of the total number of stomachs in which a particular food item has been detected) was used to calculate an importance value (IV = PV × PC/100) for each dietary item (Cooper & Skinner 1978). The relative importance (RI) value of a particular item was taken as the importance value of that item expressed as an average percentage of the sum of the importance values for all items (100 × IV/PIV).

3. Results

3.1. Percentage occurrence

A total of 220 stomachs of *M. natalensis* were collected from rice fields (28 during transplanting, 94 during the vegetative stage, 74 during booting and 24 during maturity/harvesting). Likewise 253 stomachs were obtained from fallow fields (62 during transplanting, 84 during the vegetative stage, 67 during booting and 40 during maturity/harvesting). After analysing the contents it was found that vegetative plant materials, i.e. leaves/stems, and seeds predominated in the diet of *M. natalensis* in both habitats and across all growth stages of the crop (Figure 1). Other food categories comprised 21–50% of the diet in both habitats and crop growth stages (Figure 1). An analysis of variance using the explanatory variables of habitat (rice, fallow) and season (transplanting, vegetative, booting, harvesting) indicated that there were no significant differences in the proportion of the different stomach components (leaves/stems, seeds, fruits, invertebrates, hairs, other) of rodents captured across the two habitats (ANOVA, $F = 0.44$, $P > 0.05$). However, there were some differences according to season where the analysis of variance showed that rodents consumed more leaves and stems during the booting and vegetative stages (>83%) in comparison to the harvesting stage (<45%, ANOVA with LSD, $F = 3.68$, $P < 0.01$). The percentage of seeds, fruits, invertebrates and other materials found in the stomachs did not significantly vary across the crop stages, and there were no interactive effects between habitat and season ($P > 0.05$). A large percentage of the food material (67–70%) was unidentified due to the digestive process and categorised as 'other'.

3.2. Percentage contribution

Leaves/stems and seeds comprised 20–30% of the diet of *M. natalensis* in both habitats and all crop growth stages of the crop (<15% and <30%, respectively) (Figure 2). Invertebrates and unidentified matter also substantially contributed to diet in both habitats and all stages of crop growth (Figure 2). Other food categories comprised less than 10% of the diet in both habitats and all stages of crop growth (Figure 2).

3.3. Relative importance

Leaves/stems and seeds were more important than other food categories in the diet of *M. natalensis* in both habitats and all crop growth stages (Figure 3). Vegetative material had an RI value of >7% in both habitats and across all crop stages, whilst seeds were >15% in both habitats at the booting stage. Other food categories had RI values below 5% across both habitats and all growth stages of the crop (Figure 3).

3.4. Niche breadth

In the study area, food diversity was lowest during the booting stage in the rice field and during harvest in the fallow land. During these periods, rice completely dominated the diet of *M. natalensis* (Table 2). Food diversity was highest within rice fields during harvesting and within fallow lands during rice transplanting (Table 2).

4. Discussion

This study shows that *M. natalensis* feeds on all food categories investigated but largely depends on vegetative plant material and seeds. Such observations are consistent with other reports from similar studies (Monadjem & Perrin 1998; Odhiambo et al. 2008; Mulungu et al. 2011). It has been reported that dietary information is essential for understanding breeding activities of rodents (Field 1975; Leirs & Verheyen 1995; Monadjem 1998). According to Leirs and Verheyen (1995) and Field (1975), seeds are an important food category during the breeding season and are required to meet the high energy needs of a reproducing organism. In Swaziland, both seeds and invertebrates have been shown to increase in the diet of *M. natalensis* during breeding seasons (Monadjem 1998). Such observations are consistent with the findings in the current study where seeds comprise substantial proportions of the diet of *M. natalensis* in both habitats during all growth stages of the rice crop.

Some studies have reported that the presence of secondary plant compounds in vegetative plant material consumed by rodents may trigger reproduction and influence growth (Jung & Batzli 1981; Linn 1991; Neal 1996; White & Bernard 1996). The large amounts of plant materials found in the stomachs of *M. natalensis* observed in the current study could support this hypothesis, particularly as the rodents in our study ate vegetative material continuously and bred year-round. It has been reported that forage preference in microtines is enforced by the presence of secondary plant compounds that influence growth (Jung & Batzli 1981). It is also known that plant phenolics possess oestrogenic activity (Biggers 1959).

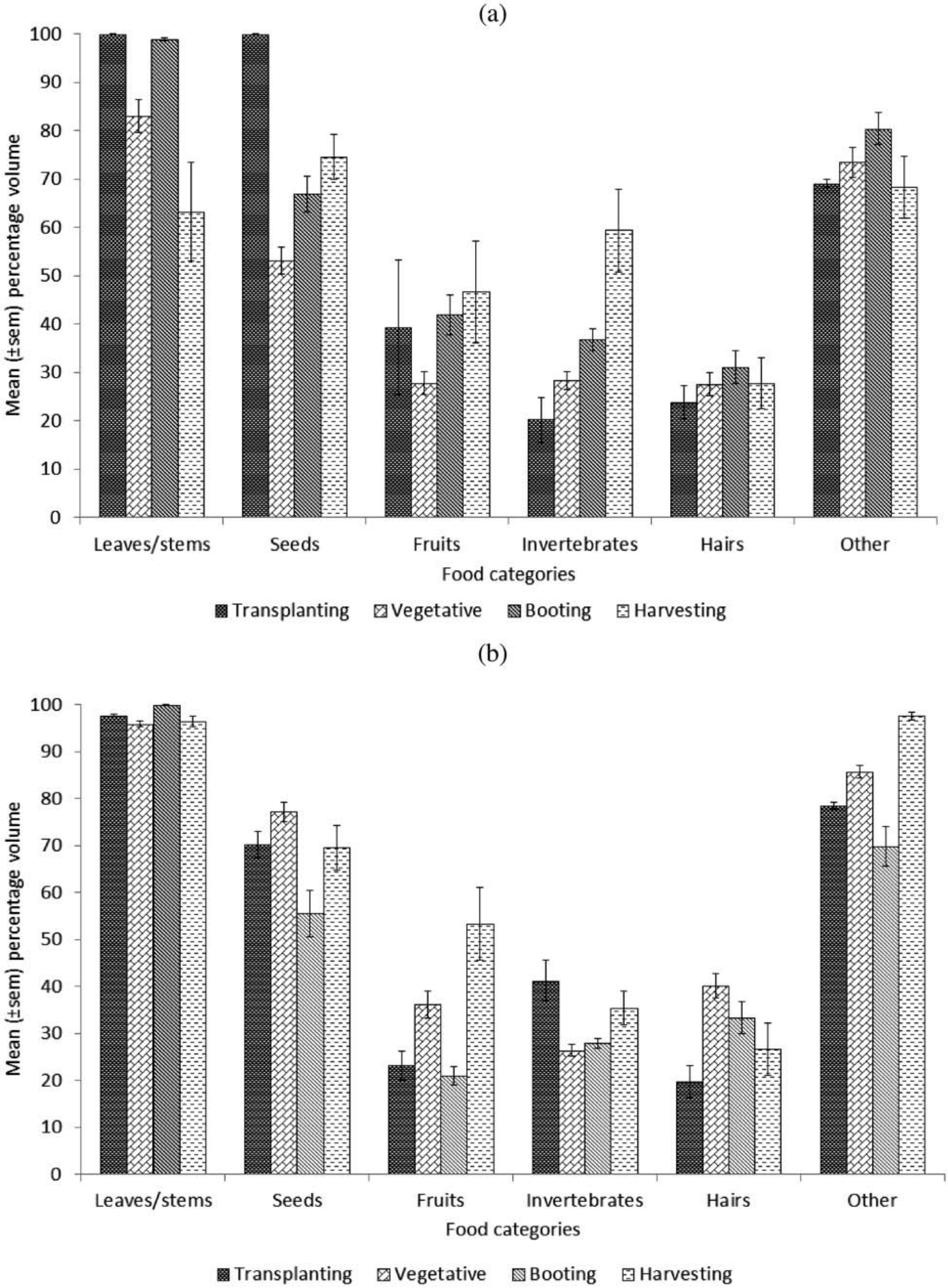
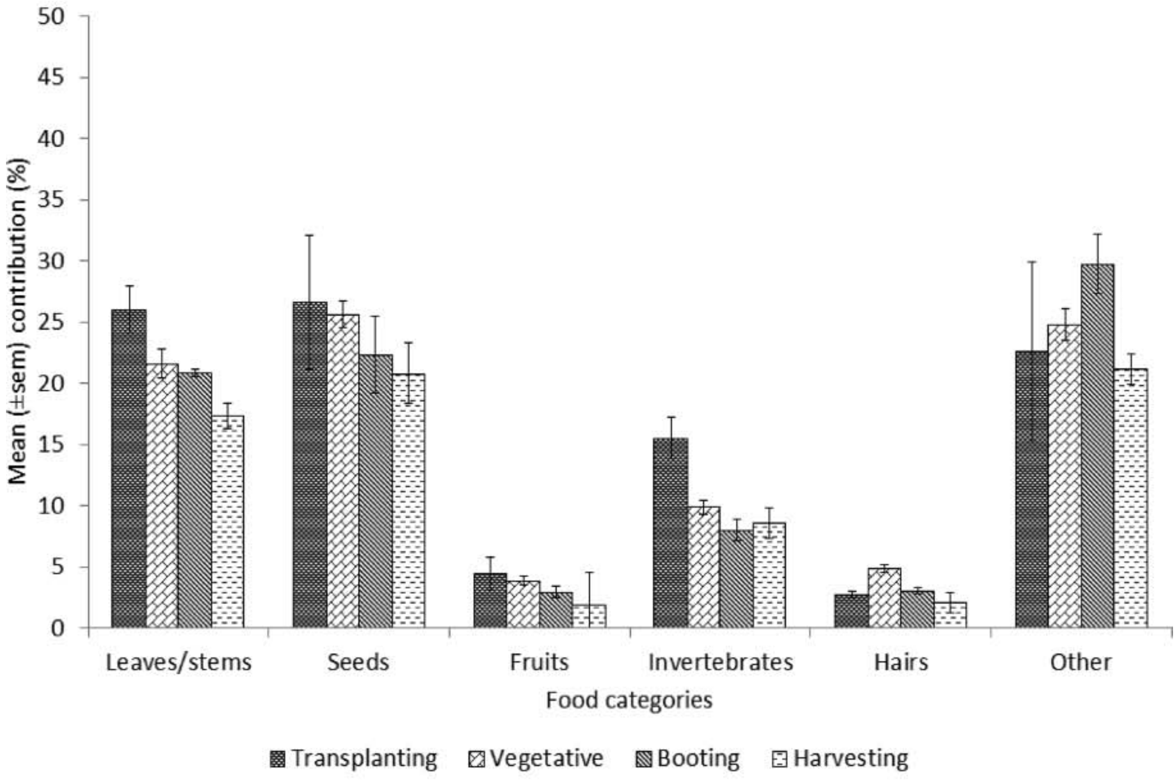


Figure 1. Mean (±sem) percentage volume of food items in stomachs of *Mastomys natalensis* in (a) rice fields and (b) fallow fields over the rice cropping season.

(a)



(b)

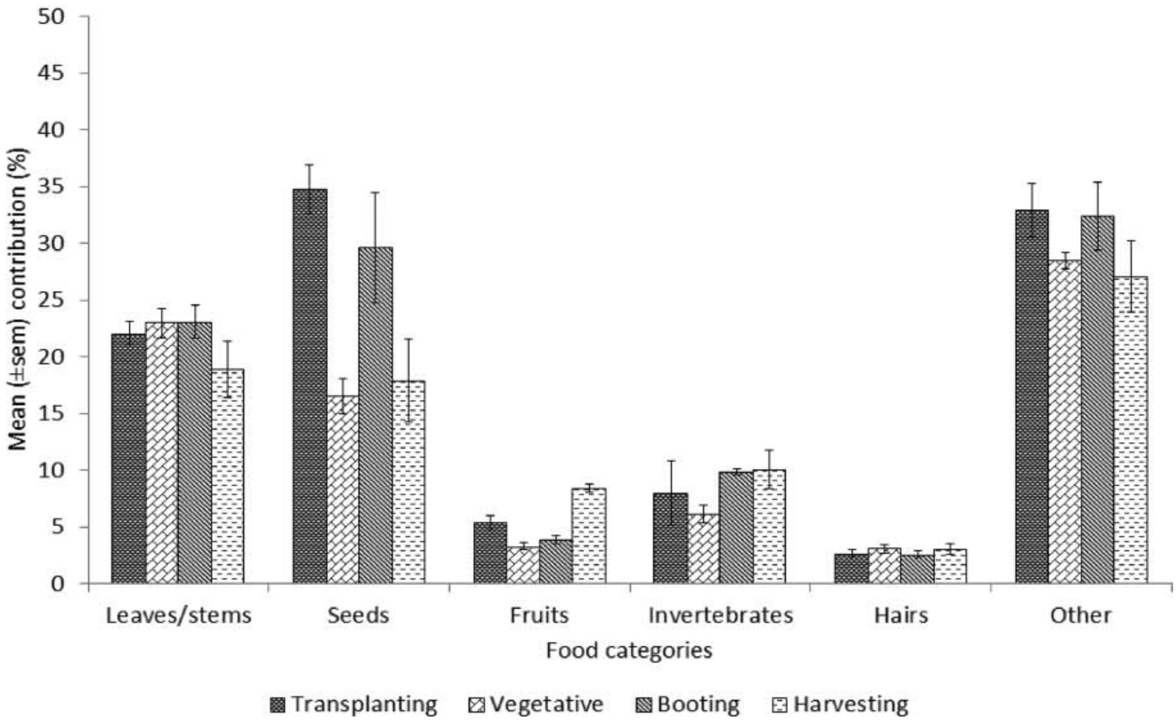


Figure 2. Mean (±sem) percentage contribution of the observed dietary components found in stomachs of *Mastomys natalensis* in (a) rice fields and (b) fallow fields.

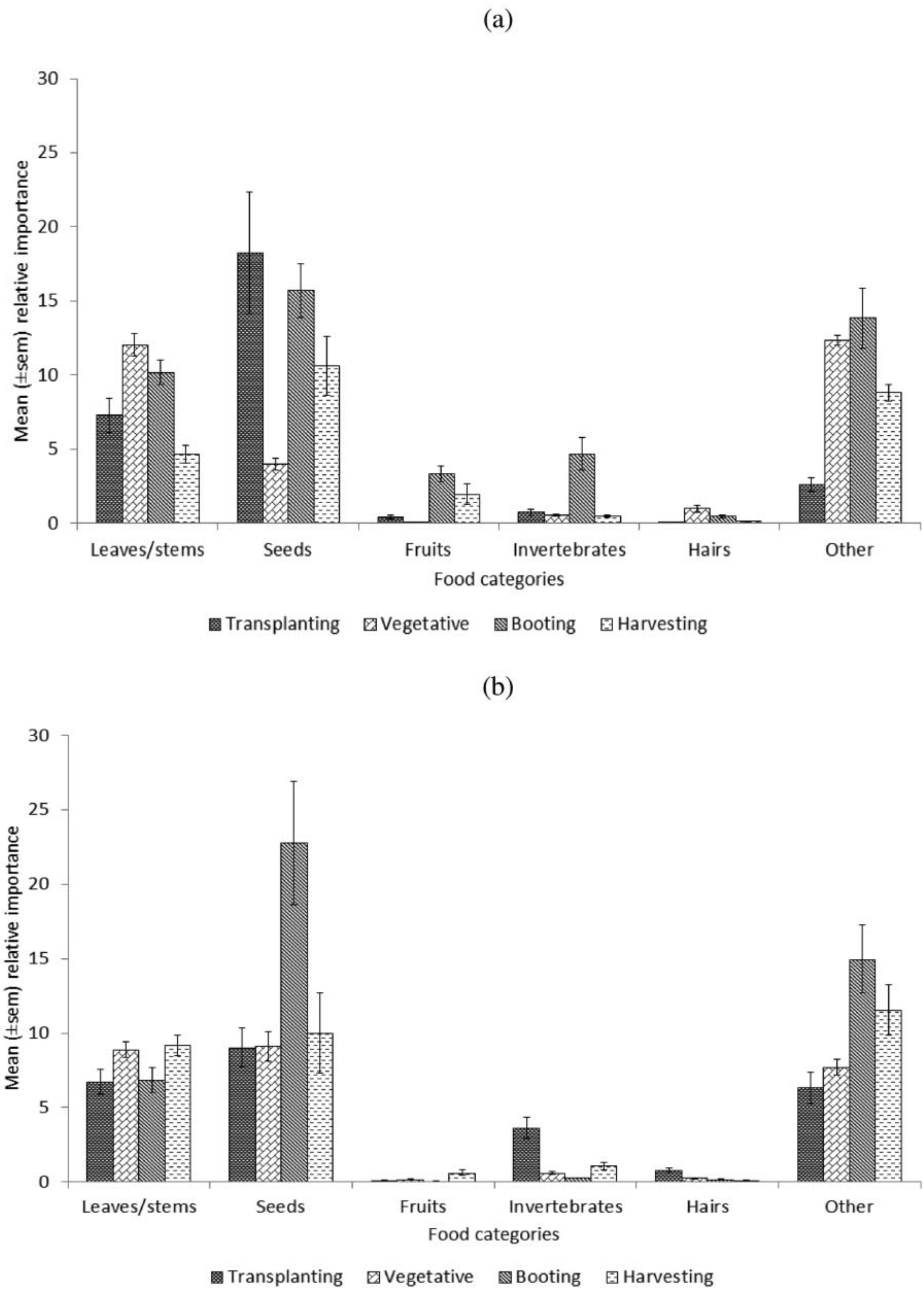


Figure 3. Mean (±sem) relative importance of the observed dietary components found in stomachs of *Mastomys natalensis* captured in (a) rice fields and (b) fallow fields.

Similarly, it has been reported that the phytohormone gibberellic acid has a similar action in *Mus musculus* (Olsen 1981). Another chemical, 6-methoxy-2-benzoxazolinone, is reportedly present in large quantities in sprouting grass and acts as a trigger for reproduction in several rodents (Negus & Berger 1987; Korn 1989).

In view of these findings and the fact that seeds and vegetative plant material comprised the largest

Table 2. Levins' index for food diversity (± sd)[1] from two habitats and different crop growth stages of the rice crop.

	Habitats	
Rice growth stages	Rice field	Fallow land
Transplanting	0.60 ± 0.12	0.61 ± 0.20
Vegetative	0.54 ± 0.16	0.53 ± 0.17
Booting	0.30 ± 0.14	0.52 ± 0.22
Harvesting	0.73 ± 0.16	0.41 ± 0.26

[1]Index scale ranges from 0 to 1, where 1 is the highest diversity and 0 is the lowest diversity.

proportions of the diet of *M. natalensis* in the current study, it is likely that the consumption of these food categories help facilitate breeding of this rodent species in the two habitats surveyed. Taylor and Green (1976) observed that *Arvicanthis niloticus* begins breeding some two to three months after the start of rains and that weed seeds first appeared in the stomach contents at the same time. However, *A. niloticus* bred almost continuously when living in an area where cereals were grown (Taylor & Green 1976). According to Leirs and Verheyen (1995), *M. natalensis* also breeds when seeds and cereals are plentiful. Unseasonal reproduction in *M. natalensis* has been observed during an unseasonal wheat crop (Taylor & Green 1976).

In our study, *M. natalensis* consumed mainly vegetative plant materials and seeds, regardless of habitat or crop growth stage. Variation in diet mostly existed in niche breadth, which is probably attributable to the relative availability of resources. Narrow niche breadth observed during the booting stage, for example, suggests availability of fewer food categories in the rice fields. In contrast, the wider niche breadth in other crop growth stages and habitats potentially demonstrates the opportunistic and generalist feeding habits of *M. natalensis*, particularly when vegetative plant materials and seeds were not adequately available in the area.

It can be concluded on the basis of this study that rice cultivation through irrigation can generate excess food and cover, which in turn, facilitates extended breeding seasons for *M. natalensis*, generating unusually large numbers of rodent pests. Such an agricultural system provides green grasses and seeds, consequently triggering rodent breeding. The study confirms that *M. natalensis* is both granivorous and herbivorous, suggesting their management should be timed when both seeds and vegetative plant material are not available within the targeted area. Non-chemical rodent control methods such as trap barrier systems developed for lowland irrigated rice in south-eastern Asia should be evaluated for their effectiveness under African conditions (Singleton 2002).

Acknowledgements

This work was supported by the Tanzanian Zonal Agricultural Research and Development Fund (ZARDEF). We appreciate the excellent field assistance offered by Messrs Khalid S. Kibwana, Omary Kibwana, Shabani Lutea, Geoffrey Sabuni and Ramadhani Kigunguli of the Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania.

References

Biggers JD. 1959. Plant phenols possessing oestrogenic activity. In: Fairbairn JW, editor. The pharmacology of plant phenolics. New York: Academic Press; p. 51–69.

Brown PR, Yee N, Singleton GR, Kenney AJ, Htwe NM, Myintand M, Aye T. 2008. Farmers' knowledge, attitudes, and practices for rodent management in Myanmar. Int J Pest Manag. 54:69–76.

Cooper RL, Skinner JD. 1978. Importance of termites in the diet of the aardwolf *Proteles cristatus* in South Africa. S Afr J Zool. 14:5–8.

Duque UG, Joshi RC, Martin AR, Marquez LV, Sebastian LS. 2005. Rat pest species breeding patterns in the trap barrier system plus a trap crop (TBS + TC) at the PhilRice-CES farm: management implications. Int Rice Res Notes. 30:26–28.

Ebersole JP, Wilson JC. 1980. Optimal foraging: the responses of *Peromyscus leucopus* to experimental changes in processing time and hunger. Oecologia. 46:80–85.

Field AC. 1975. Seasonal changes in reproduction, diet and body composition of two equatorial rodents. East Afr Wildl J. 13:221–235.

Jung HJG, Batzli GO. 1981. Nutritional ecology of microtine rodents: effects of plant extracts on the growth of arctic microtine. J Mammal. 62:286–292.

Kingdon J. 1997. The kingdom field guide to African mammals. London: Academic Press; 464 pp.

Korn H. 1989. A feeding experiment with 6-methoxy benzoxalinone and a wild population of the deer mouse (*Peromyscus maniculatus*). Can J Zool. 9:2220–2224.

Krebs CJ. 1989. Niche overlaps and diet analysis: ecological methodology. New York: Harper and Row; 654 pp.

Leirs H, Verhagen R, Verheyen W. 1994. The basis of reproductive seasonality in Mastomys rats (Rodentia: Muridae). J Trop Ecol. 10:55–66.

Leirs H, Verhagen R, Verheyen W, Mwanjabe P, Mbise T. 1996. Forecasting rodent outbreaks in Africa: an ecological basis for Mastomys control in Tanzania. J Appl Ecol. 33:937–943.

Leirs H, Verhagen W. 1995. Population ecology of *Mastomys natalensis* (Smith 1834). Implications for rodent control in Africa. Agricultural Editions No. 35. Brussels: Belgium Administration for Development Cooperation; 268 pp.

Leirs H, Verheyen W, Michiels M, Verhagen R, Stuyck J. 1989. The relation between rainfall and the breeding season of *Mastomys natalensis* (Smith, 1834) in Morogoro, Tanzania. Ann Soc R Zool Belgi. 119:59–64.

Levins R. 1968. Evolution in changing environments. Princeton, NJ: Princeton University Press; 132 pp.

Linn IJ. 1991. Influence of 6-methoxybenzoxazolinone and green vegetation on reproduction of *Mastomys coucha*. S Afr J Wildl Res. 21:33–37.

Makundi RH, Massawe AW. 2011. Ecologically-based rodent management in Africa: potential and challenges. Wildl Res. 38:588–595.

Massawe AW, Mulungu LS, Makundi RH, Dlamini N, Eiseb SJ, Kirsten F, Mahlaba T, Malebane P, von Maltitz E, Monadjem A, Taylor P, Tutjavi V, Belmain SR. 2011. Spatial and temporal population dynamics of rodents in three geographically different regions in Africa: implication for ecologically-based rodent management. Afr Zool. 46:393–405.

Meerburg BG, Singleton GR, Kijlstra A. 2009. Rodent-borne diseases and their risks for public health. Crit Rev Microbiol. 35:221–270.

Meerburg BG, Singleton GR, Leirs H. 2009. The year of the rat ends: time to fight hunger! Pest Manag Sci. 65:351–352.

Monadjem A. 1998. Reproduction biology, age structure and diet of *Mastomys natalensis* (Muridae: Rodentia) in a Swaziland grassland. Z Säugetierkunde. 63:347–356.

Monadjem A, Perrin MR. 1998. Effects of food supplementation and fire on small mammal community structure in a Swaziland grassland. S Afr J Sci. 94:89–93.

Mulungu LS, Massawe AW, Kennis J, Crouwels D, Eiseb S, Mahlaba TA, Monadjem A, Makundi RH, Katakweba AAS, Leirs H, Belmain SR. 2011. Dietary differences of the multimammate mouse, *Mastomys natalensis* (Smith, 1834), across different habitats and seasons in Tanzania and Swaziland. Wildl Res. 38:640–646.

Mulungu LS, Ngowo V, Mdangi M, Katakweba AS, Tesha P, Mrosso FP, Mchomvu M, Sheyo PM, Kilonzo BS. 2013. Population dynamics and breeding patterns of multimammate mouse, *Mastomys natalensis* (Smith 1834), in irrigated rice fields in eastern Tanzania. Pest Manag Sci. 69:371–377.

Mwanjabe PS, Sirima FB, Lusingu J. 2002. Crop losses due to outbreaks of *Mastomys natalensis* (Smith, 1834) Muridae, Rodentia, in the Lindi region of Tanzania. Int Biodeterior Biodeg. 49:133–137.

Neal BR. 1996. Reproductive response of *Tatera leucogaster* (Rodentia) to supplemental food, water, and 6-methoxybenzoxazolinone. Mammalia. 60:651–666.

Negus NC, Berger PT. 1987. Mammalian reproductive physiology: adaptive responses to changing environments. Curr Mammal. 1:149–173.

Odhiambo RO, Makundi RH, Leirs H, Verhagen R. 2008. Dietary selection in *Mastomys natalensis* (Rodentia: Muridae) in the maize agro-ecosystems of Central and South-western Tanzania. Mammalia. 72:169–177.

Olsen P. 1981. The stimulating effect of a phytohormone, gibberellic acid, on reproduction of *Mus musculus*. Wildl Res. 8:321–325.

Posamentier H. 1997. Communication in national rodent management programmes. Belgian J Zool. 127:171–180.

Sicard B, Fuminier F. 1996. Environmental cues and seasonal breeding patterns in Sahelian rodents. Mammalia. 60:667–675

Singleton GR. 2002. Non-chemical control of rodents in lowland irrigated rice crops. ACIAR Research Notes #26 9/01, 8 pp.

Singleton GR, Belmain SR, Brown PR, editors. 2010. Rodent outbreaks: ecology and impacts. Los Banos (Philippines): International Rice Research Institute Press; 289 pp.

Singleton GR, Hinds LA, Leirs H, Zhang Z. 1999. Ecologically-based rodent management. Monograph No. 59. Canberra: ACIAR; 494 pp.

Smith VR, Avenant NL, Chown SL. 2002. The diet and impact of house mice on a sub-Antarctic island. Polar Biol. 25:703–715.

Taylor KD, Green MG. 1976. The influence of rainfall on diet and reproduction in four African rodent species. J Zool. 180:367–389.

White RM, Bernard RTF. 1996. Secondary plant compound and photoperiod influences on the reproduction of two southern African rodent species, *Gerbillurus paeba* and *Saccostomus campestris*. Mammalia. 60:639–650.

Workneh G, Bekele A, Belay G, Balakrishnan M. 2004. Microhabitat choice and diet of rodents in Maynugus irrigation field, northern Ethiopia. Afr J Ecol. 42:315–321.