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Original Article

Small rodent communities and their associated damage to wheat-groundnut agriculture systems

Pequenas comunidades de roedores e seus danos associados aos sistemas de agricultura de trigo e amendoim

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Abstract

Rodents can cause significant damage to wheat-groundnut crops in developing countries, as well as to stored produce and infrastructure, affecting food security and income of small-holder farmers. Wheat (*Triticum aestivum*) and groundnuts (*Arachis hypogea*) are important cash crops for local farmers in Pakistan. Field experiments were performed to assess the extent of rodent damage to wheat-groundnut crops throughout their growth stages (i.e, germination, flowering/peg formation and maturity) in the agro-ecological zones of Pothwar Plateau, Pakistan. We used a quadrat method to record the number of damaged crop plants. On the basis of the trapping data four rodent species were captured from wheat-groundnut cropping systems which were responsible for causing damage, i.e., lesser bandicoot rat (*Bandicota bengalensis)* was the main species, followed by the short-tailed mole rat (*Nesokia indica*), the Indian gerbil (*Tatera indica*) and the bush rat (*Golunda ellioti).* In both crops, the maximum damage was recorded at crop maturity (10.7 and 14.4%, respectively). The lowest reported damage to wheat and groundnuts was at the germination stage (3.5% and 6.0%, respectively). The lower damage reported at germination could be due to availability of non-crop vegetation at field borders that may be a potential factor influencing damage. Our findings clearly show the considerable amount of damage caused by rodents to wheat-groundnut at maturity across all the agro-ecological zones of Pothwar and indicated that the small mammal composition was more related to maturity stage/season of crops, when the availability of food and climatic condition were favorable and having security under crop shelter. More detailed studies are needed to fully understand the population and breeding ecology of the relevant rodent pest species in relation to damage patterns to optimize management beyond individual structural measures.

Keywords: *Arachis hypogea*, crop damage, groundnut, Pakistan, rodents, sustainable agriculture, *Triticum aestivum*, wheat.

Resumo

Os roedores podem causar danos significativos às culturas de trigo e amendoim nos países em desenvolvimento, bem como aos produtos armazenados e infraestrutura, afetando a segurança alimentar e a renda dos pequenos agricultores. O trigo (*Triticum aestivum*) e o amendoim (*Arachis hypogea*) são culturas comerciais importantes para os agricultores locais no Paquistão. Experimentos de campo foram realizados para avaliar a extensão dos danos de roedores às culturas de trigo e amendoim ao longo de seus estágios de crescimento (ou seja, germinação, floração/formação e maturidade) nas zonas agroecológicas de Pothwar Plateau, Paquistão. Usamos um método de quadrat para registrar o número de plantas de cultura danificadas. Com base nos dados de armadilhagem foram capturadas quatro espécies de roedores de sistemas de cultivo de trigo-amendoim que foram responsáveis por causar danos, ou seja, o rato-bandico-pequeno (*Bandicota bengalensis*) foi a espécie principal, seguido pelo rato-toupeira-de-cauda-curta (*Nesokia indica*), o gerbilo-da-índia (*Tatera indica*) e o rato-do-mato (*Golunda ellioti*). Em ambas as culturas, o dano máximo foi registrado na maturidade da cultura (10,7 e 14,4%, respectivamente). O menor dano relatado ao trigo e ao amendoim foi no estágio de germinação (3,5% e 6,0%, respectivamente). O menor dano relatado na germinação pode ser devido à disponibilidade de vegetação não cultivada nas bordas do campo, que pode ser um fator potencial que influencia o dano. Nossos resultados mostraram claramente a quantidade considerável de danos causados por roedores ao trigo-amendoim na maturidade em todas as zonas agroecológicas de Pothwar e

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indicaram que a composição de pequenos mamíferos estava mais relacionada ao estágio de maturidade/estação das culturas quando a disponibilidade de alimentos e as condições climáticas eram favoráveis e com segurança sob abrigo de cultivo. Estudos mais detalhados são necessários para entender completamente a ecologia populacional e reprodutiva das espécies de pragas de roedores relevantes em relação aos padrões de danos para otimizar o manejo, além das medidas estruturais individuais.

Palavras-chave: *Arachis hypogea*, danos nas culturas, amendoim, Paquistão, roedores, agricultura sustentável, *Triticum aestivum*, trigo.

1. Introduction

In Asia, rodents are a major agricultural pest that inflicts substantial loss pre-and post-harvest (John, 2014; Singleton et al., 2010). Pre-harvest damage to agricultural crops are well documented and there are methods to considerably minimize loss (Brown et al., 2017), which entails strategies not only to increase productivity but also to minimize losses. Wheat (*Triticum aestivum*) and groundnut (*Arachis hvpogea*) are the staple food across Asia (World Bank, 2007) and therefore, highly relevant for food security. Wheat-groundnut are the major cash crops grown by the farmers in the Pothwar Plateau, an uneven, rain-fed landscape in Pakistan. These are the most important cereal crops and about 70% of the total groundnut production in Pakistan occurs in the Pothwar in northern Punjab Province (Brooks et al., 1988). These crops are immensely important for the national economy and also highly vulnerable to rodent damage from sowing until harvesting (Shafi et al., 1991). Five species of field rodents (*Bandicota bengalensis, Nesokia indica, Tatera indica, Golunda ellioti* and *Mus musculus*) have been reported in the agriculture fields of Pothwar (Hussain et al., 2003). The majority of the rural communities of the Pothwar are dependent on farming (i.e., wheat, groundnut, millet/maize and sorghum) where 90% of their farm sizes are less than two hectares and the majority of farming is conducted by small-holder farmers (Munawar et al., 2018).

Net cereal production needs to be increased by 50% from 2000 to 2050 to satisfy the food requirements of the growing global population (World Bank, 2007), especially in Asia where 578 million people are undernourished (UN, 2011). In Asia, under traditional rice farming systems, rodents typically cause chronic losses to rice in the order of 5-10% per annum (Singleton et al., 2003), while episodic population outbreaks cause severe losses that place at risk the food security of entire communities. Brooks et al. (1988) reported 10% loss of wheat crop and 3.4% of the groundnut in Pothwar area due to rodents, with a resultant mean yield loss of 43 kg/ha. Pre-harvest losses in 11 countries in Asia range from 5 to 17% annually, with Indonesia sustaining the highest damage nationally, although some districts in Bangladesh reported > 50% loss (Singleton et al., 2003). In Africa, total crop losses for maize, rice and wheat were reported to be around 15%, however seedling losses were much higher, at about 50% (Swanepoel et al., 2017). To put this in perspective, a 5% loss could feed 181 million people per year (Singleton et al., 2003).

Rodents are responsible for eating or spoiling enough food to feed approximately 280 million people for a year (Meerburg et al., 2009). They are problematic in terms of agriculture and public health since they can inflict considerable economic damage (John, 2014), because of their abundance, diversity, generalist feeding habits and their high reproductive output (Buckle and Smith, 2015). The presence of rodents around homes, food storage facilities and agricultural areas are associated with human risks of exposure to allergens that can trigger asthma and increase exposure to potentially infectious organisms (i.e., *Salmonella*) and parasites like tropical rat mites and fleas (Easterbrook et al., 2007). Management approaches are often aligned to the principles of ecologically-based rodent management (EBRM) (Singleton et al., 2003). EBRM includes a suite of techniques based on sound knowledge of the target rodent species as well as ecological, social and economic aspects.

Without thorough knowledge of the composition of small mammal species in agriculture and of the extent of damage caused, there is a weak foundation to develop evidence-based management strategies. Measures need to be aligned to the pest species present to identify the optimal timing to intercept immigration to fields or to food storage facilities. Suitable and effective management is required to reduce damage and to determine if the extent of damage justifies the cost of specific actions. In this study, we identified the small rodent species composition in agro-ecological zones of Pothwar based on systematic trapping and estimated related damage to wheat-groundnut agriculture system at various growth stages.

2. Materials and Methods

2.1. Study area

Our study was carried out in the rural areas of Pothwar Plateau (33° 30′ 0″ N and 73° 0′ 0″ W), located in the north part of the Punjab province, which is the 5th largest ecological zone of Pakistan. The total area of this region is 22,255 km^2 which includes four districts (Attock, 6,857 km^2; Chakwal, 6525 km^2; Jhelum, 3587 km^2; Rawalpindi, 5,286 km^2) and some parts of the Islamabad capital territory are also included (Bhutta, 1999) (Figure 1). The Pothwar Plateau is at the elevation of 330 – 1,000 m and the climate is semi-arid to tropical, with mean rainfall of 380 – 510 mm per annum, mostly in the months of July and August. The mean average summer high temperature is 45° C, dropping to below freezing in winter (Mahmood et al., 2019). The agriculture systems on the Pothwar Plateau encompass uncultivated areas such as range land and dry scrub forest used for livestock grazing and timber production and important cultivated dryland farmland (wheat, groundnut, millet and maize). Agriculture is scattered along dissected

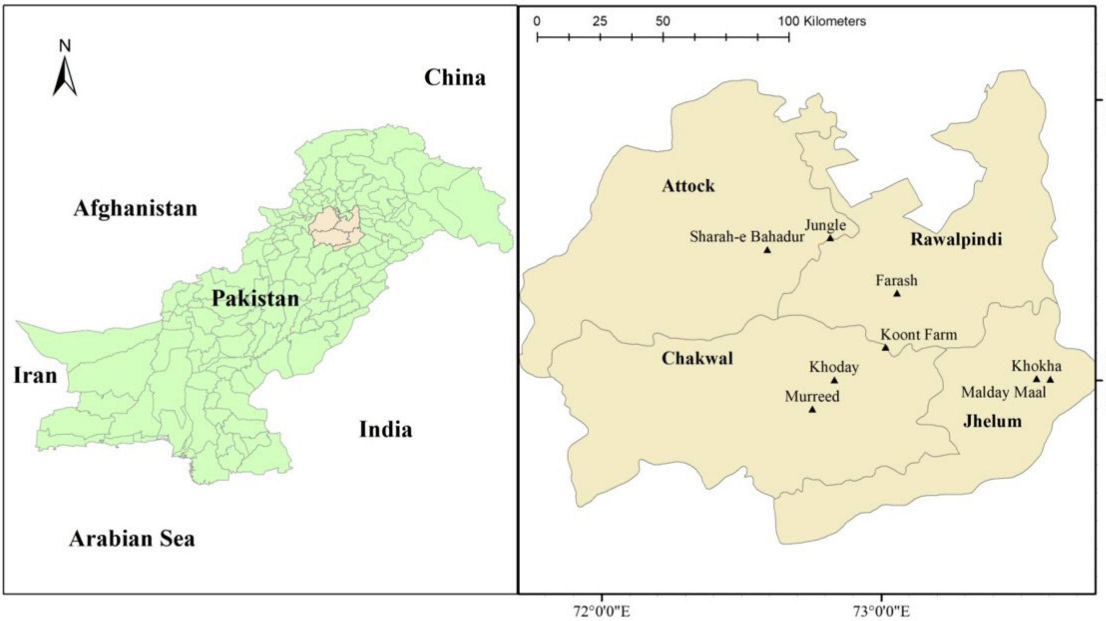

Figure 1. Map of the Pothwar Plateau in northern Punjab, Pakistan, showing the sites where the study was conducted.

zones of undulating settings, valleys, less fertile lands that exhibit irregular precipitation.

2.2. Study design

Eight study sites were selected (two in each district) to evaluate the extent of rodent damage and their compositions in wheat-groundnut agriculture systems. The sites were chosen after consultation with local farming authorities, landowners, stakeholders and growers/farmers. Selected sites had good access by roads, rotational field crops such as wheat, groundnut, millet, maize and sorghum and historically high rodent infestation. Each experimental site was approximately 3.0 ha in size, with continuous farmland ecosystem and was separated by 4-5 km, making each study site independent. In each study site we chose 40 plots inside the field for sampling. These types of habitats are regularly mowed and maintained free of debris that could otherwise provide refuge or food resources for rodents. Rodent control practices however ceased six months before our study began.

2.3. Trapping for small rodent species composition

During 2018 and 2019, snap / kill traps were set in eight selected study sites in both wheat-groundnut crop fields, on fortnightly basis for three consecutive nights. These traps were made of locally, stamped out sheet metal, they are more effective and easier to set and adjust. All the traps were baited with guava and peanut butter smeared piece of chapatti (bread) cut in to small slices of about 3-5 gram and equipped on traps. Before setting the traps, it was ensured that they were in good working order, that trigger plates work freely and release easily. Forty traps were set in the evening and checked the following morning for three consecutive nights in several trapping sessions until at least 50 rodent species were caught per crop fields. Traps were placed at 10 m intervals alongside the burrows and field borders or where signs of rodent movements were observed. Trapped rodents were mainly morphologically identified based on the key in Aplin et al. (2003).

2.4. Rodent's damage to wheat and groundnut fields

We established 3 transects of variable width and length in both wheat-groundnut fields to survey for crop damage. Transects were established at the field edges and in the middle of the plot (Figure 2). The length of each transect varied according to the size of the field. All transects ran parallel with the fields' row crop plantings, and transects continued through the end cross rows to the ends of the fields. To record the data, damage estimates were conducted during the standing fields of both crops at three growth stages i.e., tillering/pre-flowering, flowering/peg formation and maturity/pre-harvesting. Corresponding climatic seasons were defined as: autumn (October, November), winter (December – February) and spring (March, April) at the tillering/pre-flowering, flowering/peg formation and maturity/pre-harvesting of wheat and groundnut crops respectively. At peg formation stage, the formation of nuts initiated, the rats started feeding on them as it is assumed to be the most favorite food for them (Munawar et al., 2018).

The data were recorded fortnightly by using a wooden quadrat of 1 m × 1 m and placing it on the standing crop at each sampling plot and the proportion of damaged crop plants present inside the quadrat were recorded. The 20 quadrats were taken in both crops separately in each experimental site. The total number of mature crop plants within the quadrat, both damaged and undamaged, were recorded and a proportion of damaged crop plants was

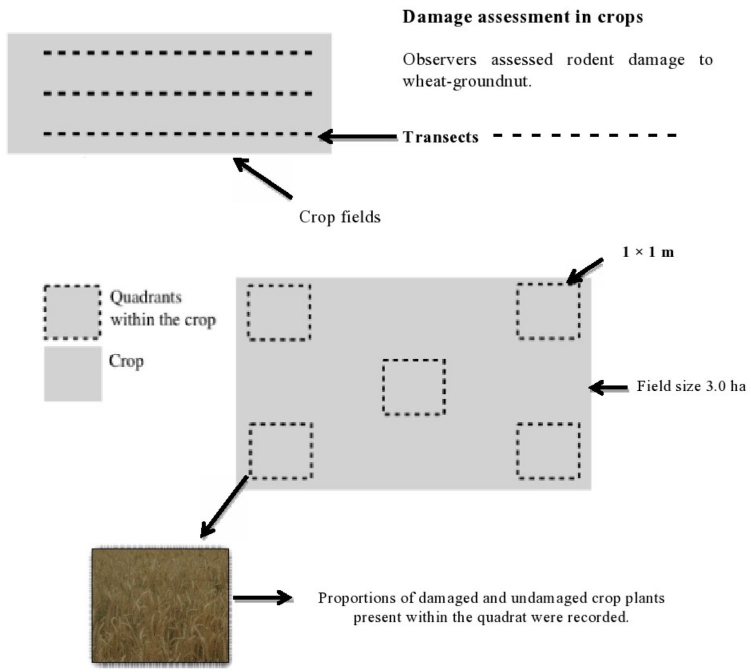

Figure 2. Lay-out of the damage assessment transects within a sampling plot.

calculated for each sampling plot. The damaged plants/stems caused by rodents were considered as either dead and dried or withered. The evidence of gnawing stems was measured by the cut off the tillers at the bottom on the sweet pulpy portion of the stem and damaged tillers were scattered fairly evenly throughout the field. Stems were felled by cutting their bases from 50 to 100 mm above ground level and the base of the panicle cut from the stem and stored underground. The fields were also searched for the identifications of responsible pest species for damage at each damage location. Rodents tend to create most of the damage nearest to their burrows, so the burrows were distinguished on the basis of the shape and size of the entrances, fecal pellets and species-specific burrowing behavior/characteristics. The burrow of the bandicoot rat was characterized by the larger soil particles, visible burrow openings, and visible runways, crops and their residues scattered about in the area, and spindle-shaped fecal droppings. The *N. indica* burrows can be differentiated from *B. bengalensis* mounds by their generally smaller soil particles pushed up from the tunnels and by the more capsule-shaped fecal droppings mixed into the mounded soil. The burrows of the *T. indica* were of simple patterns and easily identified by clear one or two surface openings, while bush rat (*G. ellioti*) construct shallow depressions in the soil for nests and shelter under thick vegetation at adjacent habitats (Munawar et al., 2018).

For wheat crop the percentage (%) damage was estimated by the given formula (Equation 1).

$$(\%)\ Yield\ loss = \frac{\text{No. of plants damage}}{\text{Total no. of plants}} \times 100 \qquad (1)$$

Similarly, in groundnut crop percentage (%) damage was calculated by using the following formula (Equation 2).

$$Pod\ damage\ (\%) = \frac{b + c}{a + b + c} \times 100 \qquad (2)$$

Where a = No. of undamaged pods; b = No. of scratched pods; c = No. of freshly bitten pods.

2.5. Statistical analysis

The composition of small rodent species and to analyze the (%) damage data in both crops was calculated as means and compared among crop stages and seasons by two factor factorial design of ANOVA using (MSTAT-C®; version 1.42, Michigan State University, East Lansing, MI, USA). When F-ratio was significant ($P < 0.05$), post-hoc comparison between the means was carried out through Fisher's protected LSD test.

3. Results

The data on trapping rodents in wheat-groundnut based cropping systems carried out agro-ecosystem of Pothwar Plateau, are summarized in Table 1. The results showed that the study area was composed of four rodent species; the dominance among species was found in the following descending order: *B. bengalensis* > *N. indica* > *T. indica* > *G. ellioti.* The most common species in both crops in all stages/seasons were *B. bengalensis.* The *G. ellioti* was caught only from adjacent habitats nested under non-crop vegetation. This rat species is very rare and shy in nature and mostly constructs nest-like burrows under

Table 1. Species composition of rodents trapped in wheat-groundnut agriculture systems over three consecutive nights (n = 30) of Pothwar Plateau, Pakistan.

Agriculture system	Crop stage	Species composition (Mean ± S. E)			
		B. bengalensis **N (%)**	***N. indica*** **N (%)**	***T. indica*** **N (%)**	***G. ellioti*** **N (%)**
Wheat	Germination	5 (16.6)	3 (10)	1 (3.33)	1 (3.33)
	Flowering	6 (20)	2 (6.66)	2 (6.66)	0 (0)
	Maturity	8 (26.6)	5 (16.6)	4 (13.3)	1 (3.33)
Sub-total		19 (21.1)	10 (11.1)	7 (7.77)	2 (2.22)
Groundnut	Germination	3 (10)	4 (13.3)	2 (6.66)	0 (0)
	Peg formation	6 (20)	3 (10)	3 (10)	0 (0)
	Maturity	8 (26.6)	5 (16.6)	4 (13.3)	2 (6.66)
Sub-total		17 (18.8)	12 (13.3)	9 (10)	2 (2.22)
*(**Mean ± S. E)**		5.5 ± 0.69^{A}	2.5 ± 0.52^{BC}	2.1 ± 0.27^{CB}	1.2 ± 0.53^{CB}

*The values superscript by same letters are not significantly ($P > 0.05$) different from each other.

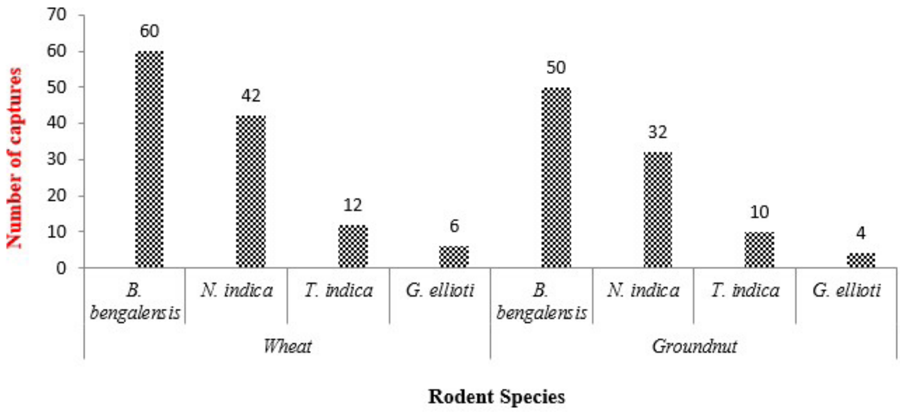

Figure 3. The number of different rodent species observed in all growth stages of wheat-groundnut cropping system.

thick vegetation and did not occur in the intermediate zone. While the *N. indica* and *T. indica* were trapped on field boundaries as well as from inside the crop fields. Rats were usually trapped during all the growth stages of the wheat-groundnut, but the trap success was higher at maturity stage of respective crops due to availability of food and cover/shelter. The cumulative rodent population abundance indices in wheat crop in all growth stages were *B. bengalensis* (21%), *N. indica* (11.1%), *T. indica* (7.77%) and *G. ellioti* (2.22%). The mean abundance of rodents trapped in wheat differed significantly between crop growth stages ($F_{2,6} = 13.02$, $P = 0.0002$). The *N. indica* and *T. indica* could also be considered as abundant, but was more sporadically and irruptive. In groundnut crops the overall capture success of *B. bengalensis* was (18.8%), *N. indica* (13.3%), *T. indica* (10%), and *G. ellioti* (2.22%) (Table 1). Species richness was higher during the months of crop maturity (Figure 4).

In wheat, an analysis between damage levels at different crop stages showed significant differences, the overall rodent damage was highest at maturity with (10.74%) followed by flowering (6.4%) and tillering (3.5%). An overall significant difference in damage was observed between growth stages ($F_{2,6} = 52.10$, $P = 0.0001$) as well as rodent species which revealed that *B. bengalensis* damaged significantly more ($F_{2,6} = 79.20$, $P = 0.003$) crop seedlings at maturity. In groundnut crop damage at maturity, damage (14.38%) was significantly higher than at both peg formation (7.4%) and tillering (6%) (Figure 3). No significant difference was identified between tillering and peg formation ($F_{2,6} = 4.9$, $P = 1.000$). Further statistical comparisons highlighted that the *B. bengalensis* significantly inflicted more damage ($P \leq 0.05$) than did the other rodent species.

4. Discussion

Farmers in Pakistan who attempt to grow wheat-groundnut crops are faced with a multitude of pest problems and a long vulnerable period between flowering, early nut formation and maturity until harvest because

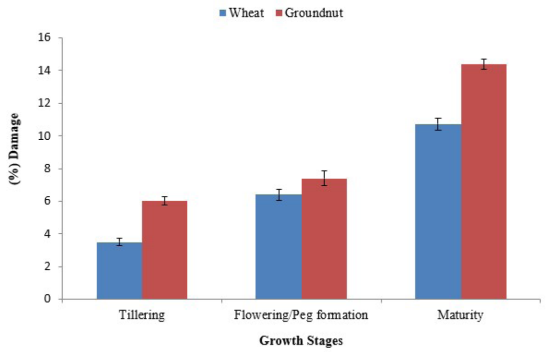

Figure 4. Comparison of (%) damage in wheat-groundnut farmland by different rodent species at various growth stages (Mean ± SE).

they lack viable strategies for controlling rat infestations (Brooks et al., 1988). Rodent populations fluctuate with different crop seasons and growth stages in the agricultural ecosystems and they are known to damaging seedlings and mature crops (Sarwar, 2015). Crop stage was an important factor influencing damage levels. In our study the highest damage was recorded during maturity stages in both wheat and groundnut fields. Similar findings were observed by Miller et al. (2008) for *R. tanezumi* in the rice terraces of Banaue, in northern Luzon, Philippines.

During maturity stage of both wheat-groundnut crops, a trend of maximum damage towards the center of the fields was evident during sampling periods when there were sufficient crop plants for food intake by rodents (Munawar et al., 2020a). Jones et al. (2017) reported that rodent damage is greater in the middle of croplands due to lower perceived risk of predation (falcons, eagles) and several large animals (foxes, jackals etc). The perception of predation risk (or fear) increased towards the field edge and was greatest on the edges, where there was no vegetation cover. This provides a preliminary insight into the rodent "landscape of fear" (Laundre et al., 2010) within crop field habitats. These findings supported by Fall (1977) that the low level of damage by *R. tanezumi* to rice near to the margins of the crop may reflect high (human) disturbance. In the present study the mean damage was significantly higher in the wheat fields at maturity as compared to rest of the stages although in groundnut we found no difference in mean number of damage between tillering and peg formation. Rodent damage in agriculture fields may have been influenced by crop growth stages, previous experience of feeding, lower risk of predation, environmental conditions and human activities in the area, or a combination of these factors (Brown et al., 2005). Mian et al. (2007) reported a similar finding in Pothwar damage to wheat due to Indian porcupine was 0.96%. According to (Hafeez et al., 2011) the survey conducted in Punjab, damage to wheat was 1.14 to 4.58% in Faisalabad, and 1.53% in Sheikhupara, Pakistan. Islam (1987) estimated that vertebrate pests caused 17% yield reduction in Pothwar and Brooks et al. (1988) estimated 3.4% loss of the groundnut crop due to rodents, with mean yield loss of 43 kg/ha. This study has highlighted that pest rodents do indeed have a significant negative effect on small-holder farming communities of Pothwar. Even though damage estimates varied considerably between crop stages, in the methods used to estimate damage, and in geographical scope, there appears to be considerable support that total crop losses due to rodent pests remain around 10-15%.

In Asian countries, rodents are the pre-harvest pest in rice crops (Brown et al., 1999), causing 5-15% loss in production in traditional rice farming systems (Rao, 2003). In Indonesia, the rice field rat (*Rattus argentiventer*) is ranked number one pest (Leung et al., 1999), causing pre-harvest losses of approximately 17% enough to feed 25 million Indonesians for one year (Singleton et al., 1999). The current study revealed that the rodent abundance and damage inside the field of both crops was higher at maturity ($F_{2,6}$ = 4.30, P = 0.060), may be due to plenty of food, good shelter/crop cover and the breeding activities of rodents were at peak that corresponds with moderate temperature and photoperiod, which directly and indirectly determined crop damage. Munawar et al. (2020b) reported that the breeding activity of summer season is correlated with the environmental factors (rainfall, day-length and temperature), which provides moist soil and good stands of wild vegetation for shelter and cover. While in autumn season there was less vegetative cover inside the fields due to early growth stage of wheat crop, the rodents preferred the naturally occurring food available in the shape of seeds of herbs/ grasses or shrubs (Munawar et al., 2018). In Malaysia, breeding of *R. argentiventer* was confined to the reproductive stage of rice, both for the wet and dry seasons (Lam, 1983). Uria et al. (2013) also reported that the rodent activity can depend on weather conditions as can population dynamics driven by food availability (Andreassen et al., 2020) synchronized by cropping seasons (Htwe et al., 2012) or other resources that are regulated by weather (Heisler et al., 2014; Imholt et al., 2011; Krebs et al., 2004). Significant difference was found between the number of rats captured during maturity and non-crop fallow fields ($P < 0.05$) while the difference in between the population density of rodents were not significantly different in both wheat and groundnut fields. At maturity stage, the trap success inside the crop fields was higher, however, in the un-ploughed/non-crop fallow fields, overall trap success was relatively low, but much more number of rodent species was observed on the boundaries compared to those inside the fields.

Rodents have adapted well to the diversity of agricultural habitats created by human. Almost 42% of all mammalian species are rodents with at least 10% are significant agricultural pests (Khan et al., 2022). Rodents are the ultimate Mammalia living in almost every habitat on earth, some of the ecological roles include soil mixing and aeration, seed and spore dispersal, influences on plant species composition and abundance, and serving as a prey base for many predatory vertebrates and therefore the non-pest species need to be protected (Witmer and Singleton 2010). The use of non-chemical rodent control measures is intended to minimize pest rodent population abundance and associated damage. In addition, environmental issues related to the use of rodenticides (van den Brink et al., 2018) and other compounds to reduce rodent-related health risks (Hinds et al., 2021; Jacob et al., 2021) could be mitigated. Several zoonotic pathogens that are present in rodents and their ectoparasites (Böge et al., 2021; Gamage et al., 2017) pose serious health risks to people and livestock that should be managed. Hence, rodent control should have high priority for farmers, agricultural and health authorities to improve livelihoods and environmental safety alike.

5. Conclusion and Recommendations

In the context of the current study, this would suggest that rodents would be reaching maximum abundance during the December and April sampling periods (maturity stage of wheat-groundnut) and this was precisely when maximum damage was found to occur. The timing of peak rodent abundance however varies among different habitats depending on the pattern of resource availability occurring within that habitat. Our results concluded that the increased utilization of wheat-groundnut crops as they approached maturity can cause damage and heavy losses. It is recommended to determine the implications of management of adjacent habitats on rodent populations. Future studies should therefore be aimed at identifying any seasonal patterns occurring within agricultural systems in rodent abundances as well as rodent damage and nut resource availability. We speculate that the information generated in this study will allow farmers, growers, wildlife managers/researchers, and agriculture administrators to understand the dimension of the rodent's distribution, behavior and its damage and adapt such ecologically based rodent management practices to minimize crop damage.

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