

Population Frequencies and Proportional Efficacies of Acute and Anticoagulant Rodenticides Formulated Baits and Fumigant Against Rodent Pests of Wheat Crop

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ABSTRACT

The use of rodenticides is one of the most common approaches to control rodents in agricultural, urban and rural environments, while successfulness of a poison depends upon choice of suitable chemical, its formulation, and method and timing of applications. An investigation was carried out to detect the population frequency of rodent (Rodentia: Muridae) pests in wheat at various growth stages of crop and control operation against them. For evaluating the effectiveness of chemicals in pests control operation, two acute rodenticides (aldicarb, zinc phosphide), an anticoagulant rodenticide (racumin), and a fumigant (phostoxin), were applied at three growth stages (dough, maturation and pre-harvesting) of crop. A spot-baiting technique was adopted to apply poison baits to the rodent's burrows according to randomize complete block design of field. In all replications, the efficacy of rodenticides was assessed by recording the damaged wheat tillers and comparing the numbers of active burrows in the treated and uncontrolled fields fortnightly throughout the trial. During the crop growing season, amongst the trapped and identified pests, lesser bandicoot rat *Bandicota bengalensis* Gray was the primary species in wheat fields followed by Indian gerbil *Tatera indica* Hardwicke, house mouse *Mus musculus* L., soft-furred field rat *Millardia melitana* Gray and short tailed mole rat *Nesokia indica* Gray and Hardwicke. These different pests began to raid and damage the wheat crop right from sowing, depredation increased during booting stage and peaked up to the time of harvesting. Such damage was likely influenced by a number of factors, such as relative abundance of different growth stages of crop and their relative nutritional contents, palatability, tastes, and availability of other foods in the locality. The products tested demonstrated satisfactory efficacy in controlling of rodents in protected wheat plants compared to unprotected fields. During dough stage, the maximum percent of cut stems of wheat were 6.95% in the control field which was significantly ($P < 0.05$) greater from fields receiving rodenticide treatments (1.06% for aldicarb, 0.82% for zinc phosphide, 0.67% for phostoxin and 0.40% for racumin). Whereas, perusal of results on overall average numbers of active burrows revealed the maximum numeral were in control fields (6.80) and it displayed statistically significant results from aldicarb (1.33), zinc phosphide (1.03), phostoxin (0.90) and racumin (0.63) products. Biological efficacy indicates that the use of poison baits containing rodenticides, and fumigant could provide an economical and effective method of controlling the rodents in wheat fields.

INTRODUCTION

A diverse group of vertebrate pests possessing a backbone inflict economic damage to agricultural crops

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(Sarwar, 2018, 2019, 2023). Rodents (rats and mice) are very destructive pests and become a nuisance when they come in adjacent vicinity to humans, crops and storages. As well as spreading diseases to both humans and household pets, rodents can also cause destruction of goods and infect food sources in certain localities. These are one of the most important vertebrate pests that directly relate to the production, storage and utilization of field crops by man and livestock at the global level. The tropical climate enhances breeding and flare-up of rodents, and recurrently they continue to build extraordinary population levels in agricultural habitat (Sarwar, 2015a). At the worldwide level, rodents have been identified as the most successful

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Authors' Contribution

MS performed research work in field and laboratory, compiled the data of research work, and writeup of the manuscript for publication. AJ, MZ, MFS and MHS helped in lab works and field operations.

Key words

Rodenticides, Rat, Mouse, Muridae, Wheat, Pest control, Rodent baits, Aldicarb, Racumin, Zinc Phosphide, Phostoxin

mammalian agricultural pests. The effect of rodent damage causes huge amount of crop losses and food shortages in some parts of the world (Fayenuwo *et al.*, 2007). Among the rodents, most of the harmful and notorious recognized as pests are members of the family Muridae. As a result, a large number of crops during pre- and post-harvesting periods is being lost every year (Meerburg and Kijlstra, 2008).

Among farmers practicing wheat growing, there is considerable fear that rodents can become a serious problem from the seedling to crop maturity owing to increased vegetation cover. Rodents damaged 6.32-8.15% wheat tillers and the maximum damage has been recorded when the crop is at maturity stage. Lesser bandicoot rats *Bandicota bengalensis* Gray hoarded on an average about 0.486 kg ear-heads per burrow system (Sheikher and Jain, 1991). During the wheat growing season locally, various rodents species are involved in damaging to crop, but variations in their predominance have been detected. Of the trapped and identified pests, the lesser bandicoot rat *B. bengalensis* is the mainly crucial species in the wheat fields approached by Indian gerbil *Tatera indica* Hardwicke, house mouse *Mus musculus* L., soft-furred field rat *Rattus meltdada* Gray and short tailed mole rat *Nesokia indica* Gray and Hardwicke. These different pests begin to damage the wheat crop right from sowing, depredation increases during the booting stage and peaks up to the time of harvesting. Rodents directly damage to wheat grain and carry infection to the storage by posing a food safety risk. Rodents urinate on grain posing a food contamination threat and contaminated grain is unacceptable for consumption. The increase in rodent populations and economic damage they cause in a specific wheat field is influenced by several conditions. The species of rodent concerned, its reproductive condition, phase of its population cycle, type of edge surrounding the wheat field, history of the field, weather situations and all other factors around the field upset the potential for rodent damage (Sarwar, 2015b).

Rodenticides are commonly used for rodents control in residential, business and agricultural settings. Their effectiveness depends upon the selection of an appropriate compound, its formulation, and the method and timing of applications. Such lethal approaches, particularly the use of rodenticides provide an immediate solution to the problem and are considered the most practical, economical and effective method of combatting rodents (Buckle, 1994). Rodenticides are commonly used for rodent control, removal and to help get rid of in home, business site or field. A variety of lethal and non-lethal practices, comprising elimination, habitat adaptation, and trapping are existing that could successfully control these pests. However, investigations on rodent pests in the tropical farm

fields are of utmost importance as the crops losses due to rodents are reported high (Balakrishnan, 2004). Because, at the worldwide level, rodents have been identified as the most important mammals, the aim of present investigation is therefore to study proportional field efficacy of some acute, anticoagulant rodenticides formulated baits and fumigant against rats and mice pests of wheat crop.

MATERIALS AND METHODS

Study area

Study area of current research was comprised of about 50 acres of wheat fields in the vicinity of village 26/E.B., Arifwala in Sahiwal District (now included in District Pakpattan) in the Punjab province of Pakistan. It is located to the southwest of Pakpattan at latitude 30° 17' 38 N, longitude 73° 4' 25 E and altitude 252 m. The climate of Arifwala is extreme, reaching up to 50 °C (122 °F) in summer and down to 0 °C (32 °F) in winter, and the soil of the suburbs is very fertile. The experimental area was divided into 5 replications including check (untreated) each having an area of 10 acres arranged in randomized complete block design. Study program for controlling of the rodents problem in wheat fields was started after crop growing and continued till harvesting. The fields around study area were of heterogeneous type vegetation-ally in which wheat, fodder and some other crops together with a small tract of uncultivated sandy area were present. There were buffer areas between rodenticide treated fields that could minimize movement of rodents (immigration, emigration) among untreated plots.

Rodent's population in wheat fields

Before carrying out any control operation, all the replications were studied for rodent's damage, during seedling, tillering, booting, dough, maturation and pre-harvesting growth stages of wheat. To study the rodent's damage pattern to growing wheat, the data were recorded fortnightly from the wheat fields. To identify the pest specimens and their population dynamics, 10 acres of randomly selected wheat fields of the experimental area were trapped from the seedling to maturity periods. On each field of the selected wheat at each growth stage, four snap traps (16 × 10 cm metallic trap) supplied daily with food baits consisted of bread pasted with butter oil were operated per plot (2 acres) for three consecutive nights per fortnight.

Rodent control program

For managing of rodent pests, four different rodenticides representing three different groups were applied as control agents in wheat field. (1) Acute (single dose, fast acting) poisons, in which baits were prepared

by mixing zinc phosphide and aldicarb with suitable cereals and other materials. (2) Chronic (multiple doses, anticoagulant, death occurs one to two weeks after ingestion of the lethal dose) poison, in which baits were prepared by mixing of racumin (coumatetralyl) along with suitable cereals and other materials. (3) Fumigant, fumigation of live burrows with tablets of aluminum phosphide (i.e., phostoxin 3.0 g tablet). For evaluating the effectiveness of chemicals in pest control operation, the rodenticides were applied at three growth stages of wheat crop i.e., dough (75-90 days of sowing), maturation (105-120 days of sowing) and pre-harvesting (135-150 days of sowing). The following ready-to-use rodenticide baits were used on the experimental site of wheat during experimentation.

Acute rodenticides

To prepare the poison baits of acute rodenticides the basic grain used were wheat and maize, wherein only the healthy grain of both cereals were used during bait preparation. The ingredients of various rodenticides used in reducing rodent populations and damage in wheat crop for 2% zinc phosphide, aldicarb and racumin are given in the ensuing section.

1. zinc phosphide, 100 g; wheat flour, 2.5 kg; cracked wheat, 2.5 kg; butter oil, 100 g
2. aldicarb 10 G, 100 g; wheat flour, 2.5 kg; cracked maize, 2.5 kg; full cream dry milk, 100 g
3. racumin, 150 g; broken rice, 5 kg; vegetable oil, 100 g

For the preparation of baits of acute poisons, the flour and grains were mixed well with zinc phosphide/aldicarb separately. Then butter oil or full cream dry milk was added and mixed well accordingly. After that water was added and mixed well until a stiff barter formed. The baits so prepared were stored in a cool dry place until used.

Chronic rodenticide

To prepare racumin baits, the grains were coated with vegetable oil and then mixed while stirring, slowly racumin was added and blended till the grains coated evenly. The baits so prepared were used in the loose grain form.

Fumigant

The fumigation was done by applying one tablet of phostoxin per burrow. Immediately after that the treated burrows were plugged with grasses or leaves and then sealed with soil. They were rechecked next morning and burrows found open were again treated as mentioned above.

Application of poison baits

Pre-baiting was undertaken with the baits prepared according to above cited procedure, but without use of

poisons. Pre-baiting was undertaken on the spots where the rodents were likely to visit, in order to encourage feeding on the baits before the poison baits were applied. The poison baits were placed on the same spots where pre-baiting was done. Baits were applied by placing them on polythene paper near the active burrows. The extent of pre-baits consumed was considered as a rough indication about the amount of poisonous baits required. At spots where all the baits had been consumed, twice the amount previously used was placed. On the wheat fields, baiting was started about 9 weeks after sowing, when wheat crop was at its booting stage, during the middle of January. Likewise, second and third baitings were done during the middle of February and middle of March, respectively. Within each replication (10 acres each), each block of 5 treatments (control + 4 rodenticides) replicated 5 times were treated with zinc phosphide, aldicarb, racumin, phostoxin and untreated check according to randomization (2 acres each). The first application of rodenticides was confined to bunds and irrigation embankments. About 4 to 6 bait pieces weighing approximately 10 to 12 gm (zinc phosphide and aldicarb) for each baiting point were placed along each field edge and at every intersection of bunds. Second and third baitings were made inside the fields by spot baiting as well as along the bunds. This was done by walking 3-4 m from the intersection of bunds and making transect line inside the field. All active burrows were treated along this transect line and in each field three or four such transects were made and lively burrows treated accordingly.

Racumin baits were applied in loose grain form, weighing about 25 gm, for each baiting point. These were placed along with bunds and embankments at about 15-20 m intervals and also inside the fields near the active burrows along transect lines made in the same fashion as in the case of zinc phosphide and aldicarb baits placement. Cares were taken if the rain was anticipated, the baiting application avoided shortly for 2 to 3 days. The baiting was also avoided 2 to 3 days before or after irrigating the fields. The baits were placed at left or right side of active burrows and not in front of the open hole as these were likely to be buried by fresh dirt pushed out of the burrow mouth by the rodents. Normally, baits were placed throughout the infested area at points where there were signs of rodent's activity, such as fresh pest's feeding places, droppings and runways, and presence of tillers inside burrows.

Rodenticides evaluation

The results of all the treatments of four rodenticides used as rodents control agents in the wheat fields were recorded fortnightly. In all replications, the efficacy of the rodenticides was assessed by recording the damaged wheat

tillers and through comparing the number of active burrows in the treated and control fields. To count the damaged and undamaged tillers, 1×1 m quadrat delineated by iron frames was used as the sampling unit. Within each field (2 acres) the nearest corner in the first field was chosen and observation taken, then a diagonal line followed in the second field to the opposite corner of first field, observation drawn near this corner, and third sampling was drawn in the centre of both fields along predetermined diagonal (3 quadrates) line to count both damaged and undamaged tillers. Then total stems, cut stems and average percent damage of three samples were calculated. As the damage data were to be recorded fortnightly, therefore, after each interval only the fresh damaged tillers recorded. The criteria used to distinguish fresh rat's damage from old damage were: (1) Tillers with fresh rat damage were green, without or with decay at an early stage. (2) Tillers with old rat damages were turned brown or dry, with the decay at an advanced stage.

To distinguish potential rodents and other pests damaged tillers from each other, cut portion of wheat plant was observed. Though rats, mice and parrots (Psittaciformes: Psittacidae) cut wheat stem at the top near the base of ear, but rodents damage was scattered throughout the field and not clumped along the edges as the parrot injury happened. Furthermore, the teeth marks on damaged portion were noted when cut by rodents and they either left the half eaten ears or carry to the burrows, while parrots transfer it away.

The experimental site was also surveyed to record burrows distribution of the rats and mice, and for this purpose, study spots for all the burrows in the fields were observed. It was also noted whether a given burrow was located at the margin of the field, in field embankments separating two fields, on the embankment of water courses, or inside the fields. The observations on active burrows were recorded by walking along the straight lines 4 m apart from each other both within treated and control fields. Efforts were also made to know whether a given burrow system was active or abandoned. To meet these requirements, the following procedure was followed: (1) All the burrows which evidenced sign of recent digging activities of rodents such as soil at the opening were considered as active burrows having rodents inside. (2) Burrow systems which carried no fresh dirt in front of the burrow mouth, presence of web and dry leaves at burrow entrance and absence of foot prints, were considered signs of inactive burrows. (3) Filled in the mouth of all the rats or mice holes found, then again re-examined next day and all reopened holes indicated that a rodent was present and considered as active burrows otherwise inactive.

Safety precautions

The main expected hazards either directly or indirectly concerned with rodents and their control operation were the possibility of occurring the rodent-borne diseases and the risk of accidental poisoning to non-target species or man. By observing the important safety precautions, no any hazards were observed under the field conditions. Rodenticides, like all other pesticides, were handled responsibly and used in accordance with the label's instructions.

Data analysis

Data counts collected during sampling periods were defined as the percent damaged wheat tillers, the number of active burrows and number of rodents within treated and control sites. Pre- and post-treatment data were used to compute the efficacy of rodent baits containing rodenticides. All data were analyzed using SPSS (statistical product and service solutions) statistics version 15.0 for Windows (IBM, China). Differences between pre- and post-treatments, and within the treated and control sites, at fortnightly sampling periods were assessed using a LSD post-hoc test after the ANOVA, at $P=0.05$.

RESULTS

During the crop growing season, several rodents species were involved in damaging to wheat, but variations in their predominance were detected. The effectiveness of poison products displayed the highest variations in their efficacies, but the baits significantly reduced the prevalence of rodents in infested crop.

Rodent's population frequency

Of the trapped and identified rodent pests, the lesser bandicoot rat (*Bandicota bengalensis*), the Indian gerbil (*Tatera indica*), the house mouse (*Mus musculus*), soft-furred field rat (*Millardia melitada*) and short-tailed mole rat (*Nesokia indica*) constituted the numbers viz., 32, 17, 14, 7 and 1, respectively, from seedling to crop maturity (Standard error 0.553; critical value 1.2339; DF 14). This comparison on captures of the different species of rodents was at different growth periods of crop in wheat farmland during seedling, tillering, booting, dough, maturation and pre-harvesting stages. Bandicoot rat was the primary rodent pest of wheat; it invaded the wheat fields in appreciable numbers when the crop was in dough growth stage. In the subsequent stages of growth of the crop, this outnumbered the other species. The bandicoot rats began to damage the wheat crop right from sowing, their destruction increased during the flowering stage and peaked at the time of harvesting. Wheat fields also harbored the gerbils in good numbers during all growth stages, but the pest attained

maximum abundance during the dough stage, after which its numbers were continually decreased as the bandicoot rats became increasingly predominant. Corresponding to gerbil, the house mouse infested the wheat crop in almost all the stages of growth and fairly in good numbers too. This was observed that only during the pre-harvesting season its number dwindled considerably. The field rats infested the wheat fields in rather lower numbers than bandicoot, gerbil and house mouse in all growth stages of the crop. Their numbers remained relatively stable and did not fluctuate like those of all the other three pests species. This species was noted in the wheat fields maximum, when the crop was in booting and dough stages. However, they were scarce during the ripening and pre-harvesting stages. A single specimen of short-tailed mole rat was trapped in the investigational zone and it observed just earlier to harvest at crop maturation (Fig. 1). Generally, the incidence of rodents damage to the wheat-growing area was patchy.

The frequency of occurrence of stem density varied from 117-359/m² for all the wheat fields sampled from seedling to harvest. In general, it was observed that as the stem density per unit area increased, rats damage increased concomitantly. However, the damage distribution among fields having dense population of wheat stem per m² was very severe than surrounding fields. Virtually no damage was recorded for fields with less than 117 stems/m², but as the stem density approached 359 stems/m², pest's damage increased up to greater extent.

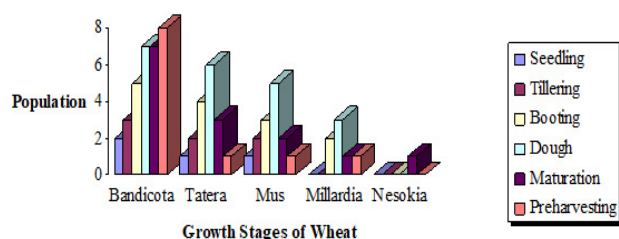


Fig. 1. A comparison of densities of different rodents species recorded at different growth stages of crop in wheat farmland.

During this study, wheat plants were found to possess a large potential for compensatory recovery from rat and mouse damage that occurred during the early growth stages. Beyond the vegetative or tillering stage, however, this potential disappeared rapidly. At the tillering stage, the secondary tillers were as productive as the original intact tillers and growth compensation offset the early damage. In the booting stage some plants compensation was observed, but panicle size was condensed because the grain had less time to mature fully. At the dough stage

there was no measurable plant compensation and panicles did not form before harvest. There was no opportunity for tillering's development when damage was caused at the mature stage, so losses at this time may be found to be very high.

Rodenticides evaluation

Table I shows the percent cut stems recorded before treatments during various growth stages viz., seedling, tillering and booting. It is clear from the results that seedling stage with 0.83% and tillering stage having 1.11% cut stems differed statistically from booting stage with 1.48% cut stems, while seedling (0.83%) and tillering stage (1.11%) reflected non-significant results. A perusal of the results on the percent cut stems recorded before treatments during various fortnights depicted that the crop damage started from first fortnight (15 days after crop sowing) and increased through second fortnight (30 days after sowing), which differed non-significantly. However, damage increased continuously up to the third to fourth fortnights (45-60 days after sowing), and cut stems differed significantly from first and second fortnights.

Table I. Pre-treatment data on comparative effectiveness of rodenticides in reducing rodents damage and burrows at different growth stages of wheat crop within the treated and control sites.

Wheat growth stage	Days after crop sowing	Percent cut stems of wheat	Number of active burrows
Seedling	15	0.83 b	1.40 b
Tillering	30	1.11 b	2.20 b
Booting	45-60	1.48 a	4.20 a
Standard error		0.129	0.400
LSD value		0.298	0.922

Means within columns followed by the same letters are not significantly different ($P = 0.05$).

The data recorded on the number of active burrows before treatment during various fortnights are also given in Table II. The results of statistical analysis depicted that the number of active burrows enhanced abruptly from seedling (1.40), tillering (2.20) and booting (4.20) stages, therefore, seedling and tillering growth stages differed significantly from booting stage. Perusals of these results indicate that the number of active burrows during third and fourth fortnights differed significantly, while in case of first and second fortnights these showed non-significant differences with each other. Though the numbers of active burrows increased tenuously, yet the abrupt activity of rodents had been recorded during third and fourth fortnights.

Table II. Comparative effectiveness of rodenticides in reducing rodents damage and numbers of active burrows in wheat fields.

Treatments	Growth stages of wheat crop					
	Dough (75-90 days of sowing)		Maturation (105-120 days of sowing)		Pre-harvesting (135-150 days of sowing)	
	Percent damage	Active burrows	Percent damage	Active burrows	Percent damage	Active burrows
	First baiting program		Second baiting program		Third baiting program	
Zinc phosphide	0.65 b	0.90 bc	0.97 b	1.00 bc	0.86 c	1.20 b
Aldicarb	0.84 b	1.30 b	1.06 b	1.50 b	1.28 b	1.20 b
Racumin	0.28 c	0.60 c	0.42 c	0.60 c	0.52 d	0.70 b
Phostoxin	0.57 bc	0.90 bc	0.79 bc	0.80 bc	0.66 cd	1.00 b
Control	4.78 a	5.80 a	6.75 a	6.80 a	9.34 a	7.80 a
St. error	0.152	0.325	0.237	0.354	0.125	0.431
LSD. value	0.308	0.657	0.480	0.716	0.254	0.872

Means within columns followed by the same letters are not significantly different ($P = 0.05$).

The data reflecting the comparison of test rodenticides on the average percent cut stems after each treatment at dough stage of wheat (75-90 days of sowing), indicated that maximum percent cut stems of wheat were recorded in control fields (6.75%) and it differed significantly from all other treatments. Whereas, the treatments of racumin (0.42%), phostoxin (0.79%), zinc phosphide (0.97%) and aldicarb (1.06%), provided non-significant results with one another. The results of statistical analysis given on the average percent cut stems recorded during maturation (105-120 days of sowing) growth stage depicted that all the treatments viz., zinc phosphide (0.65%), aldicarb (0.84%), racumin (0.28%) and phostoxin (0.57%) differed significantly from control fields (4.78%). All the treatments, zinc phosphide, aldicarb, racumin and phostoxin gave non-significant results with each other. But, the mean damage in racumin treatment evidenced lower level with that of phostoxin, zinc phosphide and aldicarb. The percent cut stems recorded after pre-harvesting (135-150 days of sowing) period and results of statistical analysis given depicted the racumin (0.52%), phostoxin (0.66%), zinc phosphide (0.86%) and aldicarb (1.28%) losses resulted after second fortnight of application. A perusal of these results revealed that all the treated areas differed significantly in injury from control fields (9.34%) damage.

The results obtained from statistical analysis regarding number of active burrows recorded during various growth stages viz., dough, maturation and pre-harvesting are given per plot in Table II. The perusal of the data in the relevant Table II revealed that number of active burrows during dough (75-90 days of sowing), were maximum in the control fields (5.80) and it differed significantly from all the rest of treatments, racumin (0.60

phostoxin (0.90), zinc phosphide (0.90) and adicarb (1.30) and showed statistically related results. The number of burrows recorded after maturation (105-120 days of sowing) of wheat of each treatment area indicated that the total active burrows were negligible in the treated areas, while maximum in untreated (6.80) fields. However, the data revealed a significant difference among control and all other treatments. As far as the treated area is concerned, the active burrows were maximum in aldicarb (1.50), followed by zinc phosphide (1.00), phostoxin (0.80) and racumin (0.60), which did not show any significant difference among themselves. The average numbers of active burrows recorded at pre-harvesting stage (135-150 days of sowing) presented in this table revealed that number of active burrows in the control area (7.80) were the maximum as compared to treated areas and showed significant results among each other. The aldicarb (1.20) and zinc phosphide (1.20) indicated good control of rats and mice, and the number of active burrows in these treatments differed non-significantly from that of racumin (0.70) and phostoxin (1.00).

The overall average percent cut stems recorded during dough, maturation and pre-harvesting stages after all the treatments are depicted in Figure 2. The maximum percent cut stems of wheat were in control fields (6.95%) and it differed significantly from all other treatments. Whereas, results of aldicarb (1.06%), racumin (0.40), zinc phosphide (0.82%) and phostoxin (0.67%) did not differ statistically (standard error 0.795; critical value 1.834; DF8). The overall average number of active burrows recorded at various growth stages after all treatments are also given in Figure 2, the perusal of results revealed that the number of active burrows were maximum in control fields (6.80) and

it differed significantly from all other treatments. However, zinc phosphide (1.03), aldicarb (1.33), racumin (0.63) and phostoxin (0.90) showed statistically non-significant results for each other (standard error 0.358; critical value 0.827; DF 8).

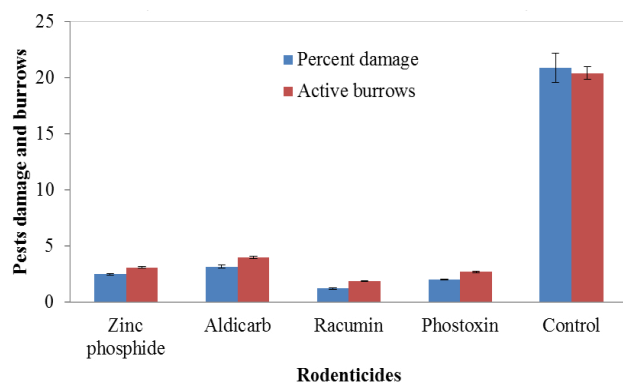


Fig. 2. Comparative effectiveness of rodenticides in reducing rodents populations and damage in wheat fields (Error bars= $\pm$ standard error of Mean).

DISCUSSION

Present study observations made in the wheat fields reported the damage inflicted on the crop by the guild of 5 rodents species belonging to family Muridae namely *B. bengalensis*, *T. indica*, *M. musculus*, *M. meltada* and *N. indica* with *B. bengalensis* being the most prevalent species from sowing to harvesting. In fact, the surveys in the same locality revealed that the sugarcane crop was found infested with six species of rodents including five as mentioned above plus a squirrel *Funambulus pennanti* L. (Sarwar *et al.*, 2011). Furthermore, results revealed that guild of four rodent species viz., the lesser bandicoot rat (*B. bengalensis*), the soft-furred field rat (*M. meltada* Gray), the short-tailed mole rat (*N. indica*), and the house mouse (*M. musculus*) was observed damaging in the rice fields (Sarwar, 2015c). Such information on the presence of rodents in disturbed and primary habitats agrees with other earlier observations (Cabello *et al.*, 2006), confirming the wide ecological tolerance (niche breadth) of these pest species. However, abundance variations in the different biotopes suggest the importance of several environmental parameters, such as food, cover and predators of pests. These different responses of mice and rats, and also variations in their densities, highlight the importance of monitoring of targeted pests species during control operations (Bennett *et al.*, 2002). These findings also emphasize the importance of monitoring the densities of mouse populations, particularly prior to sowing, to

determine if management is warranted (Brown *et al.*, 2007). The variations in the predominance of species in different regions also relate to the cropping patterns of a locality as *B. bengalensis* predominant in fields of paddy-wheat rotation, *R. meltada*, *T. indica* and *Mus* spp., in cotton and groundnut-wheat rotations, and *B. bengalensis*, *R. meltada* and *T. indica* in millet and maize-wheat rotations (Parshad, 1991). The rodenticide treatments conducted in farmer's fields revealed that to protect the sugarcane crop from rodent's damage during the months of December-January, the rodenticide treatment may be applied either by double-baiting with 2% zinc phosphide followed by 0.005% bromadiolone after 15 days at 1 kg/ha each, or by single-baiting with 0.005% bromadiolone at 2 kg/ha. Likewise, the impact of rodenticide treatments in cane fields was also evident in the adjoining wheat crop fields where the incidence of rodent damage was less (0.97-3.24%) than in the fields surrounding untreated cane fields (3.53-6.22%) (Singla and Parshad, 2010). Hereafter, the rodent populations, which generally ceased to breed during the winter season, were forced to move from one crop to another following their harvesting at different times of the year. Consequently, the pest populations dispersed and then concentrated in certain fields where they could be easily destroyed using an appropriate rodenticide concentration in the vegetable, fodder and sugarcane fields (Durr-i-Shahwar *et al.*, 1999).

Our results indicate that the average numbers of cut stems and active burrows recorded during dough, maturation and pre-harvesting stages showed non-significant differences, yet all the treatments differed significantly from the control designating that losses caused by rodents and measures taken for their control during various growth stages had non-significant differences i.e. crop stages have no effect on rodent's damage, though the data of treatments differed significantly from control. Henceforth, when growers are engaged in rodents control in the wheat fields, a jointly concentration on their destroying through poison baiting in other minor and major crops of the area is utter most worthy before these pests start migrating to the wheat fields. If necessary, during October or November the poison baiting in these crops might be reiterated, earlier to the rodents begin to infest the wheat fields. Through this tactic, the rat and mouse individuals persisting in the October and November control actions can have not an opportunity to build up their populations for the reason that throughout the winter months these pests turn into reproductively quiescent, or else significantly slow down the practice of reproduction. When the food and shelter circumstances in the wheat cropland are momentarily refining above a massive range, then the probability of migration of rodents resulting from

lack of diet and housing can be very little or the chances of immigration from outside the protected area may be very negligible. In this context, pest management program in wheat may be operated on the fundamental concepts of the economic injury level and the action threshold value. However, in integrated cropping systems, pesticides may be used to control pests only when a risk of damage is established, and pesticide usage can be reduced as much as possible by using other cropping practices aiming at reducing the occurrence of pests e.g., resistant cultivars, minimum tillage and lower nitrogen fertilizer rates (Loyce *et al.*, 2012).

The present investigations assessed the efficacy of poison bait formulations in the wheat land using acute and anticoagulant rodenticides, and fumigant. During the crop growing season, the products tested demonstrated satisfactory efficacy in controlling of rodents in wheat crops, while product racumin displayed the highest efficacy. Rat activity was significantly reduced in poisoned compared with non-poisoned areas after bait stations were stocked. At present, most commonly used rodenticides are available in various formulations for control of rats and mice, thus facilitating as one component of an integrated pest management program. Most commercial poison baits are registered for rats and mice, and their level of susceptibility to the toxicants as well as the attractiveness and palatability of the bait formulation varies between the pests species and even between individuals of the same species. No rodent bait ingredient is universally highly acceptable, so, to achieve good control of rodents using rodenticides, selection of the appropriate toxicant and formulation (grain or attractant) as well as bait placement, are important considerations (Jokic *et al.*, 2010; Sakthivel and Neelanarayanan, 2014).

During this study, the data examination based on the average numbers of cut stems and active holes, and rodenticide efficacy measured in three stages of wheat crop displayed the products tested demonstrated satisfactory efficacy in controlling of rodents. This is due to the fact that anticoagulants are more toxic because these bind more tightly to the enzyme that makes blood clotting agents, can also interfere with other steps in Vitamin K recycling, are not easily excreted from the body, and they can be stored in the liver (Watt *et al.*, 2005; Mchomvu *et al.*, 2013). This information on the biological efficacy of chemicals for controlling of rats and mice in wheat-based fields is in compliance with the previous findings (Durr-i-Shahwar *et al.*, 1999; Pervez *et al.*, 2005; Singla and Parshad, 2010), wherein the researchers for controlling of rodents depredations in the croplands, used common rodenticides and the products tested demonstrated satisfactory efficacy for pests control. Thus, regular control and sustainable

operations are essential if rodents pest populations are to be kept within tolerable limits (Mulungu *et al.*, 2006). However, as the pesticides manufacturing is fairly vigorous, therefore the participation and contributions of several stakeholders in making rodenticides can be overemphasized.

During most of the session, the variations in the densities of rodents recorded in different trapping periods can be associated with the fluctuations in population size in the pests wherein there were more rodents in the wheat than in other networks harmoniously. Correspondingly, it is emphasized that rodent control programs could be more effective if applied during the pre-breeding season, which also coincides with the reproductive phase of the vegetation communities around (Workneh *et al.*, 2004). Further, as rodents get shelter in areas of natural vegetation around farmlands throughout the seasons, it is guided to follow up clean farming practices by clearing shrubs and rock piles in areas around farmlands, as an environmental means of rodent's control. Moreover, as the relative abundance of rats and mice varied significantly between pre- and post-harvest sessions, Jacob and Brown (2000) have emphasized that harvesting not only results in food scarcity for pests, but also exposes rodents to predators, leading to increased predation risk. Naturally, they move away from such areas to have more suitable areas, thus resulting in decreased population density in farmlands after harvest.

Conversely, there are numerous significantly undesirable aspects to the usage of rodent poisons. For the reason of the overuse of rodenticides, some rats and mice populations have developed resistance to the toxicants. Furthermore, the practice of rodenticides can be a dangerous exercise for the environment, thus, aim of integrated pest management (IPM) is to decrease two special things, the pest population and the quantity of pesticides desirable to achieve that objective. With the exception of emergency circumstances, entirely other existing control approaches must be used before using of a pesticide. Prior to use of any rodenticide in an IPM package, sanitation, maintenance and other less toxic control methods must be operated. Some of the most effective methods of prevention using sanitation and maintenance are by limiting rats and mice access to their nesting sites, and food and water supplies. Detection and monitoring are important in controlling of mouse and rat problems by observing nesting areas, food sources, water sources, access points, signs of rodent activity, and removal of individuals by trapping. For monitoring, rodent traps fall into three main categories including snap traps, live traps and glue boards. When mice and rats persist and other management techniques are insufficient, then it warrants control of pests problem

via chemical pesticides to handle emergency situations. For future rodents control operation, keep record of all chemicals applied in IPM logbook including name of the applicator, date of application, formulation used and the brand name of the chemical used (Sarwar, 2015d, 2016).

CONCLUSION

The key objective of this study is to advance an operational strategy for employment of rodent's management program by the use of rodenticides in wheat ecosystem and its implementation in diverse pest locations. The outcomes signpost the usage of poison baits containing rodenticides, and fumigant to deliver an economical and effective method of controlling the rodents in wheat fields. The picture of overall average percent cut stems and average numbers of active burrows recorded during dough to harvesting stages reflected that the maximum damage of wheat was in uncontrolled field and it differed significantly from other treatments i.e., aldicarb, zinc phosphide, phostoxin and racumin. On the other hand, the development of an operative controlling approach to reduce damage due to rodents necessitates an understanding of the exploitation and collaborations among the diverse habitat elements of the ecosystem. After the wheat is harvested from fields, the field populations of rodents may become markedly less abundant or evidence little change. When most of the wheat fields are harvested, the mouse can use the sheaves of the harvested plants for food and shelter. Further, the bandicoot rat, undoubtedly in consequence of its subterranean mode of life and grain storing habits, can be able to continue infestation of the harvested fields. Undoubtedly, such type of behaviors of rat and mouse enable the pests to continue their numbers in the harvested wheat fields. Soon after harvesting, flooding of the fields for the duration of irrigation and succeeding ploughing can have devastating effects on the bandicoot and mouse populations. This sort of rodent's disturbance can arise to wheat fields much earlier to prepare soil for the sowing of rice crop that is helpful to control pests without using of rodenticides. Feasibly, this can be done in the agroecosystem through restriction of the length of the harvesting and sowing periods of the gramineous crops. The fundamental hint in it, is to withdraw shelter and food for the rodents to make them more defenseless to predation and the mortality components. The future of rodents control permits the effectiveness and precision with the practice of using strategies, software and other progressive technology to help growers for no longer depends on products that can threaten the health of people and wildlife.

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Statement of conflict of interest

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