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COMPARATIVE EFFICACY OF READY-TO-USE BROMADIOLONE AND BRODIFACOUM BAITS IN MANAGING RODENT POPULATION IN SUGARCANE AND RICE CROP FIELDS IN PUNJAB (INDIA)

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ABSTRACT

Brodifacoum, a highly potent second-generation anticoagulant, emerges as a powerful solution for controlling rodent populations that have developed resistance to other compounds within its class. This study highlights almost similar efficacy of ready-to-use brodifacoum bait (0.005% BB) and bromadiolone bait (0.005% RB) in managing rodent infestations in both sugarcane and rice cultivation systems. In sugarcane fields, two applications of brodifacoum bait, administered at 15-day intervals each in September and November (@ 1 kg ha^{-1} each), demonstrated almost similar effectiveness to comparable bromadiolone treatments, both in reducing rodent populations and in mitigating crop damage. In rice fields also, brodifacoum applied 15 days before transplanting (@ 5 g per burrow), followed by a second application before the milky grain stage (@ 1 kg ha^{-1}), demonstrated almost similar effectiveness to comparable bromadiolone treatments in controlling rodent activity and reducing damage caused. These findings strongly reinforce the potential of brodifacoum as a reliable alternative rodent control tool, particularly in agricultural settings where conventional anticoagulants fail.

Keywords: Anticoagulant, brodifacoum, bromadiolone, ready-to-use baits, rice, rodents, sugarcane

INTRODUCTION

Rodents represent a critical threat to Indian agriculture, with species such as *Bandicota bengalensis*, *Mus* spp., *Millardia meltada*, *Tatera indica*, and *Golunda ellioti* identified as major pests across the key cropping systems (Singla and Babbar, 2012; Gogoi and Borah, 2013). Their destructive behaviour, marked by persistent gnawing, burrowing, and feeding, leads to the substantial yield losses (Singla and Babbar, 2010). Besides direct damage to the crops, rodents act as vectors for zoonotic diseases, posing serious health risks to humans and livestock (Singla *et al*., 2008; Battersby, 2015; Brar *et al.*, 2020; Mandla *et al*., 2022).

In sugarcane-growing regions of tropical and subtropical Asia, rodent infestations reach critical levels between September and early February, largely due to the field migration driven by agronomic practices. A field study in Punjab recorded average rodent-induced crop losses of 19.1% in sugarcane during this peak period (Singla and Parshad, 2010), with damage primarily resulting from gnawing through internodes and burrow excavation around the roots. Rice, a staple food for over 3 billion people globally and a dietary cornerstone for nearly 70% India's population, is similarly vulnerable to rodent attacks. Rodents attack rice crops throughout the growth cycle from seedling to harvest, resulting in 1-5% crop damage (Srinivasa Rao *et al.*, 2021).

Rodenticide use is the most widespread practical control method. Acute poisons like zinc phosphide are valued for their rapid action but often suffer from limitations like bait shyness and rapid resurgence of rodent populations (Horak *et al.*, 2018). This necessitates follow-up treatments with chronic anticoagulants to ensure long-term suppression. Anticoagulants act by inhibiting blood clotting through vitamin K antagonism (McGee *et al*., 2020). Warfarin [4-hydroxy-3-(3-oxo-1-phenylbutyl) chromen-2-one], the first widely used multi-dose 1st generation anticoagulant rodenticide, eventually lost its effectiveness due to the emergence of resistant rodent populations after prolonged exposure (Zawadjki *et al.*, 2019). Bromadiolone (3-[3-[4-(4-bromophenyl)phenyl]-3-hydroxy-1-phenyl propyl]-4-hydroxychromen-2-one), a single dose 2nd generation anticoagulant rodenticide, was developed to address warfarin resistance and has extensively been used in India for last 30 years (Mooney *et al*., 2018; Srinivasa Rao *et al.*, 2019). However, this long-term reliance has led to the signs of rodent tolerance, threatening its continued efficacy in field (Garg *et al.*, 2017; Blazic *et al*., 2018). In comparison, brodifacoum (3-[3-[4-(4-bromophenyl)phenyl]-1,2,3,4-tetrahydronaphthalen-1-yl]-4-hydroxychromen-2-one), a more potent, single-dose 2nd generation anticoagulant rodenticide, has gained global recognition for its superior efficacy, especially against bromadiolone-resistant rodent populations (Greaves and Cullen-Ayres, 1988; Berny *et al.*, 2018). Its high lipid solubility enhances tissue retention, boosting its potency and durability in rodent control efforts (Mooney *et al.*, 2018). The estimated LD_{50} value of brodifacoum in rodents is 0.16-0.93 mg kg^{-1} (Tomlin, 1994) as compared to 10-300 mg kg^{-1} warfarin (USEPA, 1981). This may be due to brodifacoum's long biological half-life (approximately 20 days) as compared to the warfarin (O'Reilly *et al.*,1963).

Brodifacoum notably exhibits nearly 100 times potency of earlier anticoagulants in inhibiting vitamin K epoxide reductase (Prescott and Buckle, 2000; Prescott *et al*., 2007), with field efficacy of 90-100% even in resistant populations (Buckle *et al.*, 2012). Blazic *et al*. (2018) assessed the effectiveness of brodifacoum against mice resistant to bromadiolone and concluded that brodifacoum is a sound practical alternative for rodent control in situations where bromadiolone is no longer satisfactory. Despite its proven effectiveness brodifacoum remains unregistered for field use against wild rodents in India. Consequently, its potential remains underexplored, especially in diverse agroecosystems like rice and sugarcane. There is an urgent need for robust field evaluations to devise its optimal application strategies, assess its environmental safety, and provide clear data-driven guidance to the farmers. To address this gap, we made a comparative assessment of ready-to-use bromadiolone and brodifacoum bait treatments for rodent control in sugarcane and rice fields in Punjab, India. The present research was aimed to develop an integrated rodent management strategy and offer science-backed solutions to mitigate crop losses and enhance food security.

MATERIALS AND METHODS

The ready-to-use block bait type brodifacoum (0.005% BB) and the ready-to-use bait of bromadiolone (0.005% RB) evaluated in the present study were supplied by M/s Syngenta India Limited, New Delhi (India). The presence of different rodent species in crop fields was determined on the basis of their characteristic burrow entrances (Singla and Babbar, 2010). The Institutional Animal Ethics Committee's approval was not required for this study, as whole research work was conducted in field on wild rodent pests and did not involve capturing or transporting the animals to the laboratory.

Experimental setup and treatments in sugarcane crops

Rodent populations are usually high in sugarcane crops. Hence, for comparison of the efficacy of bromadiolone and brodifacoum in sugarcane crops, five treatment blocks, each having four replicated fields of 0.4 ha area, were selected in villages Gohavar and Chachrari of district Jalandhar (Punjab) in the year 2023-2024 (Fig. 1). Blocks I-IV were treated with rodenticide baits while block V was maintained as control where no treatment was done. Before treatment, pre-census bait consumption (%)

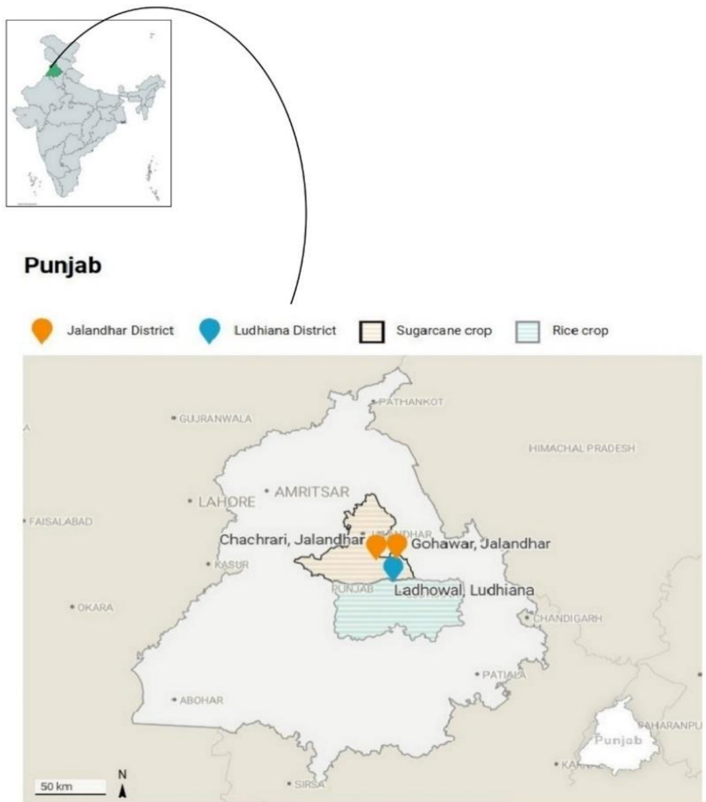

Fig. 1: The map of experimental sites in Punjab (India)

was recorded in fields of all blocks by keeping WSO bait (loose mixture of broken wheat (W), powdered sugar (S) and vegetable refined oil (O) in a ratio of 96:2:2) @ 1 kg ha^{-1} at 100 bait points covering the entire field in September and collecting and weighing the unconsumed bait material on 3rd day. After pre-census, blocks I and II were treated with brodifacoum bait and blocks III and IV were treated with bromadiolone bait (@1 kg ha^{-1} at 100 bait points) using cardboard bait stations (to avoid non-target toxicity). After 15 days of this treatment, block II was again treated with brodifacoum bait and block IV with bromadiolone bait (@1 kg ha^{-1} at 100 bait points). After 15 days of this poison baiting, post-census bait consumption (%) was recorded in all blocks as per the method described for pre-census bait consumption.

Again, in November, a pre-census bait consumption (%) was recorded for the 2nd time, and after that, blocks I and II were treated with brodifacoum bait and blocks III and IV with bromadiolone bait (@ 1 kg ha^{-1} at 100 bait points) using cardboard bait stations. After 15 days of treatment, block II was again treated with brodifacoum bait and block IV with bromadiolone bait (@ 1 kg ha^{-1} at 100 bait points). After 15 days of this poison baiting, again post-census bait consumption (%) was recorded in all blocks as per the method described above. From pre- and post-treatment census data, the percent rodent control success was determined as per the following formula (Singla and Mittal, 2012):

$$\text{Rodent control success (\%)} = \frac{\text{Pre−census bait consumption} - \text{Post−census bait consumption}}{\text{Pre−census bait consumption}}\ x\ 100$$

Rodent damage was recorded in the fields of all blocks at pre-harvest stage in January. For this, ten bundles of canes were observed at five locations per field, covering all four geographical sides and the centre, and counting the number of healthy canes and canes damaged by rodents. From this data, the percent cut canes was determined by using the below given formula (Singla *et al.*, 2023):

$$\text{Percent cut canes} = \frac{\text{Cut cames}}{\text{Healthy canes+Cut canes}}\ x\ 100$$

Experimental setup and treatments in rice crops

For comparing the efficacy of bromadiolone and brodifacoum baits in rice crops, three treatment blocks, each having four replicated fields of 0.4 ha area, were selected before seedling transplantation in village Ladhowal of district Ludhiana (Punjab), during kharif season of 2023 (Fig. 1). The fields of blocks I and II were treated with poison baits and those of block III were kept as a control wherein no treatment was given. Before seedling transplantation (June end to 1st week of July), pre-census live burrow counted in fields of all blocks by closing all rodent burrows in evening hours with loose soil and counting the reopened burrows on next day. After pre-census, all live burrows of block I were treated with brodifacoum bait and those of block II with bromadiolone bait by inserting 5 g bait 15 cm deep inside each burrow. After 15 days of treatment, post-census live burrow count was recorded in fields of all blocks as per the method described above for pre-census live burrow count. Then, in September, before milky grain stage, pre-census bait consumption was recorded in the fields of all blocks as per the method described above for sugarcane crop. After pre-census, fields of block I were poison-baited using bromadiolone bait, and that of block II with bromadiolone bait using cardboard bait stations (@ 1 kg ha^{-1} at 100 bait points). After 15 days of baiting, post-census bait consumption was recorded as per the method described above. From pre- and post-treatment census data, percent rodent control success was determined by using the below given formula (Singla and Mittal, 2012):

Rodent control success (%) =

$$\frac{\text{Pre−census bait consumption/burrow count − Post−census bait consumption/burrow count}}{\text{Pre−census bait consumption=burrow count}} \ x\ 100$$

Rodent damage was recorded in each treatment block at the pre-harvest stage in October. For this, five samples of 1 m^2 crop area were observed at five locations per field, covering all four geographical sides and the centre, and counting the number of healthy tillers and tillers damaged by rodents. From this data, the percent cut tillers was assessed as per the formula of Singla *et al.* (2023).

$$\text{Percent cut canes} = \frac{\text{Cut tillers}}{\text{Healthy tillers+Cut tillers}} \ x\ 100$$

Statistical analysis

The experiment was performed under a completely randomized design. Values are expressed as mean ± SE. Data was analysed by using one-way analysis of variance in SPSS 20.0 software. Pairwise treatment comparisons were made using Tukey’s test at a 5% level of significance.

RESULTS AND DISCUSSION

Comparative efficacy in sugarcane crops

The sugarcane crop fields had high rodent infestation with pre-census bait consumption ranging from 54.25 to 71.25% in September. *Bandicota bengalensis* was the major rodent species inhabiting these fields, followed by *Mus* spp., *Millardia meltada, Tatera indica,* and *Golunda ellioti*. In September, single and double baiting with brodifacoum bait in treatment blocks I and II resulted in 40.72 and 59.81% rodent control success, respectively. However, single and double baiting with bromadiolone bait in treatment blocks III and IV resulted in 27.99 and 56.37% rodent control success, respectively. There was significant difference in percent rodent control success between blocks I and II treated once and twice with brodifacoum bait and between blocks III and IV treated once and twice with bromadiolone bait. However, no significant difference in percent control success was observed between blocks I and III treated once and blocks II and IV treated twice with brodifacoum and bromadiolone baits, indicating almost similar efficacy of both the rodenticide baits (Table 1).

Pre-census bait consumption in November revealed 70 to 100% consumption in the fields of all the blocks, indicating rodent population build up. Single and double baiting with brodifacoum bait in treatment blocks I and II resulted in 37.32 and 52.62% rodent control success, respectively. Single and double baiting with bromadiolone bait in treatment blocks III and IV resulted in 25.96 and 32.38% rodent control success, respectively. There was a significant difference in percent rodent control success between blocks I and II treated once and twice with brodifacoum bait and between blocks III and IV treated once and twice with bromadiolone bait. There was no significant difference in percent rodent control success between treatment blocks I and III treated once and treatment blocks II and IV treated twice with brodifacoum and bromadiolone baits, again indicating almost similar efficacy of both the rodenticide baits (Table 1).

Rodent damage in terms of percent cut canes in blocks I and III treated once with brodifacoum and bromadiolone was 6.00 and 5.30%, respectively, while it was 1.50 and 2.60% in blocks II and IV

Table 1: Comparative efficacy of ready-to-use brodifacoum and bromadiolone treatments in rodent control in sugarcane crop

Treatments (n = 4 fields each)	Timings of application	Pre-census bait consumption (%) (Sep)	Control success (%) (Sep-Oct)	Pre-census bait consumption (%) (Nov)	Control success (%) (Nov-Dec)	Cut canes (%)
Brodifacoum 0.005% BB	Single baiting each in Sep and Nov	68.50 ± 3.34[a]	40.72 ± 10.14[a]	100.00 ± 0.00[a]	37.32 ± 8.12[a]	6.00 ± 1.30[a]
Brodifacoum 0.005% BB	Double baiting each in Sep and Nov	71.25 ± 2.25[a]	59.81 ± 7.54[b]	100.00 ± 0.00[a]	52.62 ± 6.58[b]	1.50 ± 0.59[b]
Bromadiolone 0.005% RB	Single baiting each in Sep and Nov	54.25 ± 5.87[a]	27.99 ± 6.37[a]	70.05 ± 1.87[a]	25.96 ± 7.75[a]	5.30 ± 1.20[a]
Bromadiolone 0.005% RB	Double baiting each in Sep and Nov	64.50 ± 5.68[a]	56.37 ± 7.80[b]	98.12 ± 1.04[a]	32.38 ± 5.70[a]	2.60 ± 0.60[b]
Control	-	65.25 ± 8.41[a]	-	94.25 ± 1.08[a]	-	15.06 ± 1.30[c]

The values are mean ± SE, Values with different superscripts (a-c) along a column represent significant differences at $P<0.05$
BB - Block bait type formulation, RB- Ready-to-use formulation

treated twice with brodifacoum and bromadiolone baits, respectively. Rodent damage in control block V was 15.06%. There was a significant difference observed in percent rodent damage to sugarcane crops between the blocks given single and double treatments with both rodenticides, but no significant difference was observed in percent damage caused in fields treated once or twice with brodifacoum and bromadiolone baits, indicating almost similar efficacy of the two rodenticides. Damage in control block was significantly higher than all the four treated blocks. Overall, from all the treatments in sugarcane crops, it is evident that double poison baiting at 15-day intervals each in Sep and Nov is required for managing rodent populations and reducing the damage caused, and brodifacoum bait can be used as an alternative to bromadiolone bait.

Comparative efficacy in rice crops

The rodent burrows ranged from 9.25 to 14.00 in number per 0.4 ha area in fields of all three treatment blocks before the crop transplantation, indicating moderate infestation. *B. bengalensis* was the major rodent species inhabiting the rice fields, followed by *Mus* spp., *M. meltada* and *T. indica.* Treatment of burrows in fields of block I with brodifacoum bait and those of block II with bromadiolone bait 15 days before transplantation resulted in 82.0 and 72.6% rodent control success, respectively, with no significant difference between the two treated blocks (Table 2).

The pre-census bait consumption in fields of all the blocks before the milky grain stage revealed consumption ranging from 42.06 to 65.62%. Treatment with brodifacoum bait resulted in 73.30% rodent control. However, treatment with bromadiolone bait resulted in 56.65% rodent control. Significant difference in rodent control was observed between ready-to-use brodifacoum and bromadiolone baits, indicating higher efficacy of brodifacoum bait at the milky grain stage (Table 2).

The percent cut tillers by rodents in treatment blocks I and II, treated with brodifacoum and bromadiolone baits, respectively, were 0.3 and 0.4%, with no significant difference between the two. However, in control block 1.85% cut tillers were observed, which were significantly higher than other treatment blocks, indicating that rodenticide treatment is required both before transplantation and before milky grain stage in rice crop to reduce rodent population and damage. It is evident that the use of brodifacoum 0.005% bait @ 5 g per burrow 15 days before rice transplantation and a second application @400 g per 0.4 ha before the milky grain stage is more effective for the management of rodent populations and can be used as an alternative to bromadiolone bait.

The 2nd generation anticoagulants are most effective mean of controlling bait-shy and resistant rodent populations. Their extended persistence in the environment raises concerns regarding non-target toxicity, and consequently research efforts are increasingly directed toward identifying and

Table 2: Comparative efficacy of ready-to-use brodifacoum and bromadiolone treatments in rodent control in transplanted rice crops

Treatments (n = 4 fields each)	Timings of application	Pre-census burrow count before transplantation	Control success (%) (July)	Pre-census bait consumption (%) (Sep)	Control success (%) (Sep)	Cut tillers (%)
Brodifacoum 0.005% BB	15 days before transplanting + Before milky grain stage	12.25 ± 0.41[a]	82.02 ± 2.88[a]	42.06 ± 5.50[a]	73.30 ± 2.53[a]	0.30 ± 0.07[a]
Bromadiolone 0.005% RB	15 days before transplanting + before milky grain stage	9.25 ± 0.41[a]	72.64 ± 5.04[a]	64.50 ± 1.50[a]	56.65 ± 3.61[b]	0.40 ± 0.06[a]
Control	-	14.00 ± 0.61[a]	-	65.62 ± 5.18[a]	-	1.85 ± 0.30[b]

The values are mean ± SE. The values with different superscripts in the same column are significantly different at $P < 0.05$
BB-Block bait type formulation, RB- Ready-to-use formulation

using the chemicals with minimal impact on ecosystems and non-target organisms. Brodifacoum exhibits rapid toxicity upon brief exposure, with acute median lethal doses against rats and mice significantly lower as compared to the other anticoagulants (Patocka *et al.*, 2013). As a result, the need for continuous feeding, a common trait of anticoagulants, is alleviated. This feature is advantageous in reducing environmental exposure and mitigating non-target toxicity. Naik *et al.* (2013) demonstrated 80-100% mortality in *B. bengalensis* within 2-3 days of exposure to 0.005% brodifacoum bait. Bhattacharyya and Borah (2016) evaluated the efficacy of 0.005% wax blocks of four anticoagulant rodenticides *viz*., brodifacoum, flocoumafen, difenacoum and bromadiolone against *B. bengalensis* and *Mus musculus* under no-choice and choice feeding trials and observed 100% mortality with brodifacoum and bromadiolone in no-choice test within 4-9 days, but significantly lower mortality with flocoumafen (80%) and difenacoum (60%). This showed the effectiveness of both brodifacoum and bromadiolone against rodent species. Suárez *et al.* (2018) reported higher efficacy of bromadiolone-based baits in the individuals fed on grain baits than on wax blocks. Padonou *et al.* (2021) compared the efficacy of three types of formulations of brodifacoum-based baits on the wild domestic mouse strain (*Mus musculus*) and observed 72% efficacy of block formulation.

Blazic *et al.* (2018), based on a series of laboratory experiments, assessed the effectiveness of brodifacoum against mice resistant to bromadiolone and concluded that brodifacoum is a sound practical alternative for rodent control in situations when bromadiolone is no longer a satisfactory solution. Our previous *in vitro* study has also revealed 100% mortality of *B. bengalensis* within 2-3 days following ready-to-use brodifacoum bait treatment in no-choice tests (Sharma *et al*., 2024). The treatment schedules evaluated in the present study in two crops were as per the recommendations of PAU, Ludhiana, India (Anonymous, 2025). In rice crop, there is a recommendation of burrow baiting in lean period after harvest of wheat crop and paper/grid baiting before the milky grain stage. In sugarcane crops, there is a recommendation of paper/grid baiting twice with double rodenticide baiting at 15-day intervals to control high rodent infestations. The present study revealed almost similar efficacy of ready-to-use 0.005% brodifacoum and bromadiolone baits in managing rodent populations in sugarcane and rice crop fields. Buckle *et al.* (2012) conducted field trials to check the efficacy of 0.005% brodifacoum bait against anticoagulant-resistant rats in Europe. The applications in the form of pulse baiting observed 99.2-100% mortality of resistant rats, hence recommending the use of brodifacoum as an effective rodent control method. A recent study in Pakistan has revealed 92% reduction in rodent activity in poultry farms with 0.005% brodifacoum bait (Shahwar *et al.*, 2024).

Conclusions: The present study highlighted the potential of ready-to-use brodifacoum bait as an effective tool for rodent population management, offering a viable alternative to other 2nd generation anticoagulant rodenticides such as bromadiolone.

Ethical statement: Institutional Animal Ethics Committee approval was not required for this study, as all research was conducted in the field on wild rodent pests and did not involve capturing or transporting animals to the laboratory.

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