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Rodent control in India

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Abstract

Eighteen species of rodents are pests in agriculture, horticulture, forestry, animal and human dwellings and rural and urban storage facilities in India. Their habitat, distribution, abundance and economic significance varies in different crops, seasons and geographical regions of the country. Of these, *Bandicota bengalensis* is the most predominant and widespread pest of agriculture in wet and irrigated soils and has also established in houses and godowns in metropolitan cities like Bombay, Delhi and Calcutta. In dryland agriculture *Tatera indica* and *Meriones hurrianae* are the predominant rodent pests. Some species like *Rattus meltada*, *Mus musculus* and *M. booduga* occur in both wet and dry lands. Species like *R. nitidus* in north-eastern hill region and *Gerbillus gleadowi* in the Indian desert are important locally. The common commensal pests are *Rattus rattus* and *M. musculus* throughout the country including the islands. *R. rattus* along with squirrels *Funambulus palmarum* and *F. tristriatus* are serious pests of plantation crops such as coconut and oil palm in the southern peninsula. *F. pennanti* is abundant in orchards and gardens in the north and central plains and sub-mountain regions. Analysis of the information available on the damage and economic losses caused by rodents in rice, wheat, sugarcane, maize, pearl millet, sorghum, oil seed, legume and vegetable crop fields, horticulture and forestry, poultry farms, and rural and urban dwellings and storage facilities clearly shows that chronic damage ranging from 2% to 15% persists throughout the country and severe damage, sometimes even up to 100% loss of the field crop, is not rare. Several traditional and modern approaches and methods of rodent control are being used. The existing knowledge of the environmental, cultural, biological, mechanical and chemical methods of rodent control in India is reviewed. Considerable variations exist in the susceptibility of the pest species to different methods, particularly to rodenticides and trapping, their field applicability, efficacy and economics in different crops, seasons and geographical regions, behavioural responses of the pest species to these methods in different ecological conditions and their adoption by farmers in different regions of India. Environmental and cultural techniques, such as clean cultivation, proper soil tillage and crop scheduling, barriers, repellents and proofing which may reduce rodent harbourage, food sources and immigration have long lasting effects but are seldom adopted. However, their significance in relation to normal agricultural practices, intensification and diversification are discussed. Rodenticides, which provide an immediate solution to the rodent problem, form the major component of rodent control strategies in India. Poison baiting of rodents with zinc phosphide and burrow fumigation with aluminium phosphide are common in agricultural fields and recently Racumin (coumatetralyl) and bromadiolone have been introduced for the control of both agricultural and commensal rodent pests in India. Methods and timings of campaigns and successes and problems in implementation of rodent control are also reviewed.

Introduction

India has emerged self-sufficient in food production in the 1990s from a deficit condition in the 1950s. During these four decades Indian agriculture has shifted from a natural, subsistence type farming to a managed, intensive agricultural practice involving remarkable changes in the pattern of land use, the development of an infrastructure for the production and storage of agricultural produce, the adoption of improved crop production and protection technologies and changes in the socio-economic perceptions of farmers (Sidhu and Sidhu 1994). These developments, commonly referred to as the ‘Green Revolution’, have on one hand made an enormous contribution to alleviating poverty and malnutrition but on the other have disturbed the natural ecological balance thus aggravating certain pest problems. The subsistence farming system was self-regulating, self-perpetuating and maintained natural flora and fauna, the intensive system has replaced the original communities of animals living in a steady state by more opportunistic species of insects (Dhaliwal and Arora 1993), birds (Dhindsa 1984) and rodents (Parshad 1984). For example, as a result of the developments in agriculture and urbanization during the last 3–4 decades in Punjab (India), the population of herbivorous mammals such as deer, antelope and wild boar and of carnivorous mammals such as cats, foxes, jackals and mongoose have dwindled while those of the grainivorous opportunistic rodents have tended to increase (Parshad 1984). One of the important reasons for this change in the balance of the mammalian fauna is the high rate of reproduction and population growth of rodents combined with a high degree of adaptability in the agro-ecosystem, in contrast to the low rate of fertility and lower degree of adaptability to a changed habitat of other wild mammals.

The tropical and sub-tropical climates are conducive to reproduction and population explosions of rodents (Parshad et al. 1989). Frequently they maintain high population levels in agricultural and rural situations in the Indian sub-continent where large scale outbreaks still occur and chronic annual damage continues unabated. Rodent damage ranging from 2% to 15% is common in agricultural crops and occasionally 25% to even 100% damage occurs during conditions of rodent outbreak (Malhi and Parshad 1990, Sridhara 1992, Islam et al. 1993, Jain et al. 1993a). A realistic estimate of the damage caused by rodents is difficult to make due to the varied approaches and methods used in evaluating damage in crops and storage and sometimes quantitative estimates of the damage are not possible. However, according to a conservative estimate about 5–6% of the total food grains being produced are lost annually at the preharvest stage due to rodents (Parshad 1992). During a recent resurgence of plague in India about 4000 persons suffered its infection with about 100 deaths in the months of September and October 1994 and the resulting panic lead to tremendous loss of agricultural and industrial production (Ramalingaswami 1994).

As a result of the magnitude of the rodent problem in agriculture and public health in India, research into different aspects of the biology and management of rodents received the attention of scientists and research organizations in the 1960s and gained momentum with the implementation of the All India Coordinated Research Project by the Indian Council of Agricultural Research in 1978. Now this project has 10 centres carrying out research and training on rodent control in different agro-ecological regions in India. Through this project and several other individual studies, considerable information on the distribution, ecology, behaviour and management of rodents in different agro-ecological regions has been generated which formed the basis of several previous reviews and articles (Roonwal 1987, Parshad et al. 1989, Prakash and Ghosh 1992, Rana et al. 1994). The purpose of this review article is to integrate and discuss the existing knowledge related to rodent pest problems and their control including integrated pest management (IPM) approaches and their implementation in different pest situations.

Rodent pest species and their distribution

The rodent fauna of the Indian sub-continent is represented by 46 genera and 128 species (Ellerman 1961, Roonwal 1987). Of these 18 species are commensal and agricultural pests (Table 1). Some species are widely distributed while others are locally important. The lesser bandicoot rat, *B. bengalensis*, is predominant in irrigated crop fields and grassland throughout the country except in the Indian desert and the Lakshadweep and Andamans Islands. It has turned commensal and inhabits godowns and other premises in metropolitan cities like Bombay, Calcutta and Delhi (see Chakraborty 1992a). The other species which are widespread in both irrigated and dry farming systems in the country are the Indian gerbil, *T. indica*, the soft-furred field rat, *R. meltada*, and the house mouse, *M. musculus*. However, both *T. indica* and *R. meltada* have not been reported from north-eastern hill regions (Singh et al. 1994). The Indian Crested porcupine, *H. Indica*, is widely distributed in South Asia in forest, rocky, moist or arid habitats (Agrawal and Chakraborty 1992). Occassionally, it inflicts severe damage in crops, orchards and reforestation plantations.

Table 1. Major rodent pests, their habitat and distribution in India.

Scientific and common names	Habitat*	Distributions*	Remarks and reference
Family Sciuridae			
Funambulus pennanti (Wroughton 1905), Five-striped or northern palm squirrel	Holes and nests in trunks and branches of trees in orchards and gardens; also in crevices in walls of buildings, window sills etc.	Himalayan foot hills, Indo-Gangetic plains, North-Western desert and extend towards South; also occurs in Pakistan and Nepal.	Common pest of fruit and vegetable crops (Prakash et al. 1992, Parshad and Malhi 1994).
F. palmarum (Linnaeus 1766), three-striped or southern palm squirrel	Nests in trees and crevices in walls of buildings.	Southern peninsula and also in Sri Lanka.	Common pest of cocoa, arecanut, cashewnut, cardamom and coffee (Bhat 1992, Chakravarthy 1993).
F. tristriatus (Waterhouse 1837), western ghat squirrel	Nests in canopy of trees in orchards and on rafts of tiled or thatched buildings.	Western coast (Ghats) of India.	Pest of cocoa, cashewnut and arecanut (Bhat 1992).
Family Hystricidae			
Hystrix indica (Kerr 1792), the Indian-crested porcupine	Burrows in moist, arid, sandy and rocky areas below bushes and rocks in deciduous forests and reforestation plantations.	Throughout the Indian sub-continent from river valleys to 2750 meters altitude.	Generally low population; damages tuberous crops and debark trees (Agrawal and Chakraborty 1992, Sharma 1994).
Family Muridae			
Meriones hurrianae (Jerdon), the desert gerbil	Burrows under and around bushes in rocky and sandy plains, sand dunes, interdune areas and earthen and bushy fences around crop fields and dwellings.	Indian desert in northern Gujarat, western and north-eastern Rajasthan and parts of Haryana and Punjab and occur in Pakistan, Afganistan and Iran	Serious pests of agriculture and grasslands (Prakash 1981).
Tatera indica (Hardwicke 1807), the Indian gerbil	Burrows in sandy, gravel and rocky soils in crops fields, wastelands and around dwellings in arid and sub-humid habitats.	Throughout the Indian Sub-continent; its range extends upto the Arabian peninsula.	Major pest of dry farming agriculture, and in new areas opened to irrigated cultivation (Jain 1992).
Gerbillus gleadowi (Murray 1886), the hairy-footed gerbil	Burrows in sand dunes and uncultivated patches.	Indian desert in Rajasthan and Gujarat.	Occasional serious pest of agriculture (Tripathi et al. 1992).
Nesokia indica (Gray 1830), the short-tailed bandicoot rat	Burrows in mesic soils with good vegetation cover.	North-western India and its range extends towards Pakistan and West Asia.	Damages cereal and vegetable crops (Ramesh 1989).
Bandicota indica (Bechstein 1800), the larger bandicoot rat	Burrows in humid soils in croplands and in marshes.	Southern and eastern parts of India and extends in Bangladesh and south-east Asia.	Common pest of field crops and affect fish and prawn culture (Chakraborty 1992a)

Table 1. (*Continued*).

Scientific and common names	Habitat	Distributions	Remarks and reference
Bandicota bengalensis (Gray 1835), the lesser bandicoot rat	Burrows in wet soils in croplands in plains and hills, land near canals, roads, dwellings, godowns etc.	Throughout India, occurs widespread in south and south-east Asia except in arid conditions.	Most common pest of irrigated agriculture and commensal in metropolitan cities like Bombay, Calcutta and Delhi (Chakraborty 1992b).
Golunda ellioti (Gray 1837), the Indian bush rat	Ground nests in scrubland with thorny and bushy plantations and hedges around crop fields.	North-western region of India and its range extends towards Pakistan.	Minor pest of agriculture (Saini and Parshad 1993, Prakash et al. 1995).
Rattus (Millardia) meltada (Gray 1837), the soft-furred field rat	Burrows in irrigated croplands, hedges, scrub grasslands in foothills and plains.	Throughout India excepts in north-eastern states.	Common pest of agriculture (Rana 1992).
Rattus rattus (Linnaeus 1758), the house, roof or black rat	Commensal and occurs in dwellings, storage facilities and wild in plantation crops.	Commensal throughout the Indian sub-continent and in plantation crops in southern peninsula and Lakshadweep and Andamans islands.	Most common commensal pest and also serious pest of plantations crops such as coconut and oil palm (Parshad et al. 1987a, 1994, Subiah and Shamsuddin 1992).
R. r. brunneusculus (Hodgson 1845), the Sikkim or Hodgson rat	Burrows in crop fields particularly in the rice fields.	North-eastern hill region of India in states of Sikkim, Assam, Mizoram, Meghalaya, Nagaland and Manipur.	Pest of rice and vegetables in areas of shifting cultivation (*Jhums*); its outbreak related to bamboo flowering (Chauhan and Saxena 1992).
R. r. wroughtoni (Hinton 1919), Wroughton's rat	Nests or holes on trees in forests, plantation crops, generally prefer tree canopies and also inhabit houses.	Southern India in Kerala, Karnataka, Andhra Pradesh and also Maharashtra.	Major pest of coconut, cocoa and oil palm (Bhat et al. 1990).
R. nitidus (Hodgson 1845), the Himalayan rat	Croplands and bamboo plantations.	North-eastern region upto 2000 m altitude.	Damages rice, maize and pineapple (Singh et al. 1994).
R. norvegicus (Berkenhout 1769), the brown or Norway rat	Commensal and occurs in sewers.	Occurs in major ports only.	Pest in godowns and stores (Jain et al. 1993a).
Mus musculus (Linnaeus 1758), the house mouse	Commensal in houses, storage facilities and also occurs in wild in croplands.	Throughout the Indian sub-continent including the islands.	Common commensal and agricultural pest (Rao and Balasubramanyam 1992).
M. booduga (Gray 1837), the Indian field mouse	Burrows in croplands on edges of cultivation and prefer sandy soils.	Throughout India	Common pest of agriculture (Rao and Balasubramanyam 1992).
M. platythrix (Bennet 1832), the brown spiny mouse.	Burrows in sandy and gravel plains and rocky habitats; prefers dry soil and occurs on edges of cultivation.	Throughout India	Common pest of agriculture (Rao and Balasubramanyam 1992).

*From Roonwal (1987) and Agrawal and Prakash (1992).

Species with a restricted distribution are: the desert gerbil, *M. hurrianae* and the hairy-footed gerbil, *G. gleadowi*, in the Indian desert; the Himalayan rat, *R. nitidus* in north-eastern hill region; the short-tailed bandicoot rat, *N. indica*, in north-western plains; the three-striped palm squirrel, *F. plamarum*, in the southern peninsula and the Western Ghat squirrel, *F. tristriatus*, in the west coast of the southern peninsula (Table 1).

The house rat, *R. rattus*, and the house mouse *M. musculus*, are the major commensal pests (Roonwal 1987, Parshad et al. 1987a, Parshad et al. 1994). *R. norvegicus* is restricted mainly to ports (Jain et al. 1993a). In the southern part of the country, *R. rattus* is a serious pest of orchards (Bhat 1992) and in central India it also occurs in rice, sugarcane and other field crops (Khatri et al. 1987, Patel et al. 1992). At least, 14 subspecies of *R. rattus* have been reported from India (Biswas and Tiwari 1969). Of these *R. r. rufescens* Gray, *R. r. alexandrinus* Desmarest and *R. r. arboreus* Horsefield occur in premises throughout the country while *R. r. wroughtoni*, Hinton and *R. r. blanfordi* Thomas are restricted to plantation crops (coconut, oil palm, cashew) in southern peninsula (Bhat 1992), *R. r. andamanensis* Blyth in Nicobar and Andaman islands (Subiah and Mathur 1992) and *R. r. brunneusculus* is common in north-eastern hill region (Chauhan and Saxena 1985).

Damages and economic losses

Rodents in India are a food source for several tribal communities in the states of Uttar Pradesh, Bihar, Andhra Pradesh, Tamil Nadu, Kerala and the north-eastern hill region (Ahmed 1992, Jain et al. 1993b) and are the object of worship to be protected and cared for in temples as at Bikaner in Rajasthan, but for the majority of people they are serious agricultural, storage and household pests throughout the country. They cause direct damage to various commodities by gnawing and feeding and indirect damage by spoilage, contamination, deterioration and enhancing susceptibility to fungal and bacterial infestations during pre- and post-harvest stages. Knowledge of the characteristics, extent of damage and the situations vulnerable to attack by rodents in different crops and regions is important in planning management strategies.

Pre-harvest damage

Almost all field crops are affected by rodents. The pattern and the extent of damage, depending upon the species and the intensity of infestation, vary in different crops and geographical regions (Tables 2, 3 and 4). Most of the estimates of damage relate to the mature or pre-harvest stages of the crop but rodents cause damage at almost all stages of the crop from sowing to harvesting.

Rice

Rodents are the major production constraint of rice. Irrespective of the type of rice production system, that is: irrigated, lowland or upland, dry farming or deep water, rodents cause considerable damage to rice crops in India (Table 2) and other South Asian countries (Fulk and Akhtar 1981, Ahmed et al. 1986, Islam et al. 1993, Karim 1994). Occasionally, they wipe out the crop in a field. Periodic outbreaks of rodents associated with bamboo flowering cause severe damage ranging from 30% to 98% in Mizoram and 75% to 100% in Arunachal Pradesh (Srinath 1980, Jain et al. 1993a). These cause famine like conditions. Rangareddy (1994) has reported some fields with 100% damage from West Godavari district in Andhra Pradesh.

In South Asia, the commonest species infesting rice fields is *B. bengalensis* and other species like *R. meltada* and *M. booduga* are also frequent (Table 2). The number of rodents trapped/100 traps/day from rice fields was 45.6 with the *B. bengalensis* being most common (Parshad et al. 1986) and from 108/hectare to 446/hectare (Chakraborty 1975). Ownership boundaries, bunds and embankments made for water management are often riddled with rodent burrows from where the rodents begin to attack rice plants within a few days of transplantation (Malhi and Parshad 1992b). The growth period of the rice crop coincides with the monsoon rains during which period the rodents show peak breeding activity (Parshad et al. 1989) causing the build up of large rodent populations which inflict severe damage to the crop at the ripening stages. During the heading and ripening stages, the rodents obliquely cut the thickened and hardened tillers to bring down the panicles which they may hoard in their burrows (Sridhara 1992). With asynchronous planting schedules with different varieties of varying maturity periods in the same area, food and shelter from the rice crop become available to rodents for longer periods and plots of early maturing varieties also suffer more damage (Singh et al. 1983) even upto 100% (Singh et al. 1994). Under such conditions synchronous planting of rice varieties with similar maturity period may help to reduce damage by rodents.

Table 2. Estimates of losses due to damage by rodents in major agricultural crops in India.

Crop and location	Field/damage description	Percent damage/ yield loss (kg/ha)	Predominant species	Reference
Wheat				
Himachal Pradesh	Pre-harvest	7.3 (6.3–8.2)	Bb, Rm	Sheikher and Jain (1991a)
Punjab	Pre-harvest	3.9–5.2 YL 105–216	Bb, Ti	Malhi and Parshad (1989)
	Pre-harvest	3.9–12.0	Bb, Rm	Parshad (1991)
Uttar Pradesh	Pre-harvest	8.0–10.0 YL 256–573	Bb	Rana et al. (1994)
	Pre-harvest	6.2	Bb	Sheikher and Malhi (1989)
Madhaya Pradesh	Pre-harvest	YL 100–200	Rm	Rana et al. (1994)
Gujarat	Pre-harvest	2.7–20.9	Bb, Ti	Rana et al. (1994)
Rajasthan	Seedling to maturity	5.93	—	Singh and Saxena (1989)
	Pre-harvest	18.7–21.3	Mh, Ti, Rm	Jain et al. (1993a)
Rice				
Punjab	Pre-harvest, irrigated	5.0 (1.1–17.5) YL 2.3 (46–528)	Bb, Rm	Anonymous (1991)
Uttar Pradesh	Pre-harvest, irrigated	YL 98–213	Bb	Rana et al. (1994)
Madhaya Pradesh	Pre-maturity dry farming	1.3–6.7 YL 60.8	Bb, Rr	Patel et al. (1992)
West Bengal	Cutting and hoarding of ripe tillers	YL 261.0	Bb	Chakraborty (1975)
Meghalaya	Pre-harvest low land	12.5	Rn, Bb	Singh et al. (1994)
	up land	10.0	Rn, Bb	Singh et al. (1994)
Mizoram	up land	4.3	Rn, Bb	Singh et al. (1994)
Andhra Pradesh (Godavari delta)	Pre-harvest survey	2.68–100 YL 60–2345	Bb, Mb	Rangareddy (1994)
Karnataka (hill region)	Different varieties	1.1–44.5	Bb, Mb	Chakravarthy et al. (1992)
	Different varieties	62–79.7	Bb	Prakash et al. (1986)
Sugarcane				
Punjab	Partially damaged canes	8.6 (2.1–21.6)	Bb, Ti, Rm, Mm	Ahmad and Parshad (1985a)
	dried canes (full loss)	3.2 Total YL = 3833		Parshad (1987)
Uttar Pradesh	Field without lodging	6.8	Ti, Bb	Singh et al. (1988)
	Field with lodging	18.9	Ti, Bb	Singh et al. (1988)
	Trash-mulched ratoon fields	15.0–30.0	—	Brar and Avasthy (1982)
Karnataka (Malnad region)	Gnawing and then lodging of canes	YL 520–1300	Bb	Chakravarthy (1993)
Maize				
Himachal Pradesh	Cobs	9.8	—	Kumar and Misra (1993)
Punjab	Winter crop, seedling stage	10.7	—	Anonymous (1995)
Meghalaya	Cobs	9.1	Rn, Bb	Singh et al. (1994)

Table 2. (*Continued*).

Crop and location	Field/damage description	Percent damage/ yield loss (kg/ha)	Predominant species	Reference
Pearl millet				
Rajasthan	Seedling stage	100, fields resown	Gg	Tripathi et al. (1992)
	Milky grain stage	Not assessed, considerable loss	Ti, Mh	Tripathi et al. (1992)
Cotton				
Gujarat	Bolls damaged	3.2–23.2	Ti, Rm	Rana et al. (1994)
Tamil Nadu	Plants with damaged bolls	55.0	Bb	Neelanarayanan et al. (1994a)
Groundnut				
Punjab	Plants and pods	3.9 (19.0 max.)	Ti, Rm, Bb, Mm, Mb	Parshad et al. (1987b)
Gujarat	Pod setting	4.5	Bb, Ti, Rm	Mittal et al. (1991)
	Pod maturity	6.9		
	Harvesting	7.3		
	During rodent outbreak	2.9–85.4		
Soybean				
Madhaya Pradesh	Green pods	YL 44.8 (0–94.0)	Rm	Awasthi and Agarwal (1991)
Bengal gram				
Madhaya Pradesh	Pods	2.5	Rm	Dubey et al. (1992)
Andhra Pradesh	Plants and pods	11.0, YL 48	Bb	Rana et al. (1994)

Bb, *Bandicota bengalensis*; Gg, *Gerbillus gleadowi*; Mb, *Mus booduga*; Mh, *Meriones hurrianae*; Mm, *Mus musculus*; Rm, *Rattus meltada*; Rn, *Rattus nitidus*; Rr, *Rattus rattus*; Ti, *Tatera indica*; YL, Yield loss in kilograms/hectare.

Wheat

Several species are involved in damage to wheat (Table 2). Variations in the predominance of species in different regions relate to the cropping patterns as *B. bengalensis* is 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 1989a, 1991). The number of rodents trapped/100 traps/day was 22.3 from a field of mature wheat (Parshad et al. 1986) and 42.2 from another field (Parshad et al. 1985). Damage occurs throughout the crop growth period but is greater at the ripening stages (Poche et al. 1982, Singh and Saxena 1989) when the rodents, particularly *B. bengalensis*, also hoard the panicles in their burrows. *B. bengalensis* hoards wheat earheads in about 60% of burrows with 390 grams of wheat earheads/burrow (Sheikher and Malhi 1983). Wheat is sown as a winter crop after the harvesting of summer crops like rice, pearl millet, maize, sorghum, groundnut or cotton, the fields generally develop large rodent populations in the summer due to enhanced reproduction during the monsoon rains combined with the abundant availability of food during the ripening stages (Parshad et al. 1989). After harvesting, if these fields are not deep ploughed and flooded to disturb the burrows and rodent control is not carried out before sowing of the winter wheat crop severe damage occurs at the seedling and early growth stages.

Maize, pearl millet and sorghum

The pattern of damage to these cereal crops is different to that in wheat and rice. The rodents attack the seeds after sowing and the seedlings more than the subsequent growth stages. Tripathi et al. (1992) reported that during severe attack of *R. gleadowi* the farmers had to resow pearl millet 3–4 times in the Rajasthan desert. *T. indica* and *R. meltada* caused 2–12.4% damage in pearl millet and 4.3–10.6% in sorghum fields at the mature stages (Rana et al. 1994). The plants of these crops are longer and thicker than wheat and rice tillers and rodents like *R. nitidus* and *Mus* spp. may climb the maize plants to gain access to the cobs and species like *B. bengalensis*, *T. indica* and *R. meltada* cut the plants at the base to fell these along with their cobs on the ground.

Sugarcane

Rodents inflict direct and secondary damage to sugarcane (Hampson 1984, Parshad 1987, Srivastava 1992). They begin to damage the canes around 90 days after planting and the damage increases with the age of the crop. Direct damage is caused mainly by gnawing through the rind of the lower internodes of canes and by damage to the roots during digging of burrows by rodents, particularly by *B. bengalensis*, and *N. indica* (Parshad 1987, Khanzada 1995), which are highly fossorial. If not properly bunched the canes may be lodged during irrigation, by the wind and as a result of gnawing of roots and loosening of soil around them by rodents during burrowing. Sugarcane fields with lodging of canes, and also of the ratoon crop, show a high incidence of rodent damage (Table 2). In two different surveys of rodent damage to sugarcane in Punjab 8.6% and 12.1% canes were partially damaged with most of damage restricted to their lower internodes and 3.2% and 1.3% canes died and had become unfit for use (Parshad 1987, Anonymous 1994). The partially damaged canes weighed about 31.5% less than healthy canes (Anonymous 1994) and also contained about 24.5% less sugar content (Gupta et al. 1968). Yield loss due to physical injury to canes is often associated with secondary losses in yield and quality because of enhanced susceptibility to a variety of fungal and bacterial diseases (Hampson 1984, Parshad 1987). The fungal disease red rot caused by *Physalospora tucamanesis* often attacks the injured canes.

The average size of cane fields in India and throughout South Asia is smaller than one hectare and these are surrounded by fields of short duration crops such as wheat, rice, oilseeds, vegetables etc. Compared to other crops the cane fields harbour higher rodent populations which increase with the age of the crop (Parshad et al. 1986). Rodents prefer to colonize cane fields because they provide an undisturbed habitat for their burrowing, feeding and breeding activities, a protective cover from avian predators and an abundant amount of high energy food for most of the year. In addition to the resident population of rodents, frequent waves of immigration from surrounding fields as a result of disturbance in these due to ploughing, harvesting and flooding with irrigation or rainfall often enhance rodent population in cane fields and they may be as high as 87–100 rodents trapped/100 traps/day in mature sugarcane compared to 20 and 45 rodents/100 traps/day in wheat and rice fields (Parshad et al. 1986).

Oil seeds

Among the oil seed crops groundnut often suffers severe attack by rodents (Table 2). The house mouse *M. musculus* and field mouse *M. booduga* are abundant in groundnut fields and major damage is caused by *T. indica* and *R. meltada* in rainfed along with *B. bengalensis* in irrigated fields (Parshad et al. 1987b). In Pakistan, of the overall 5.3% estimated damage to groundnut, *B. bengalensis* accounted for 2.4% and *N. indica* for 1% (Brooks et al. 1988). During the population outbreak of *B. bengalensis*, *T. indica* and *R. meltada* in 1976 (Shah 1979) and 1988–89 (Mittal et al. 1991) in Gujarat rodents damaged upto 85% of the crop in some parts. Rodents may damage the whole or the branches of the plant during burrowing. They damage and remove the pods at the mature and harvesting stages and take them in to their burrows (Parshad et al. 1987b).

Legumes

Determination of damage in legume crops is difficult due to the branching nature of the plants and the presence of many pods on each branch. However, incidences of moderate to severe damage to the whole plant or the shoots and pods of lentil, arhar, moong, soybean and Bengal gram are common. Attack of pods by rodents is often severe because of the high protein content of seeds. According to Awasthi and Agarwal (1991) the green pod stage of soybean suffers more damage than its ripening and drying stages.

Cotton

Cotton bolls provide rodents with seeds for feeding and fibre for making nests. They drag the bolls to their burrows, as a result 5–10% damage to cotton is common in India (Malhi and Parshad 1990). *R. meltada*, *T. indica* and *B. bengalensis* are the major rodent pests of cotton. 90 days after sowing *B. bengalensis* begins to damage cotton (Neelanarayanan et al. 1994a). It cuts and takes away the bolls from plants and damage is greater to unripe than the ripe bolls.

Vegetables

Rodents attack almost all vegetable crops mostly at the seedling and mature stages (Table 3). In the arid region in Rajasthan, vegetables are severely affected by rodents probably due to their high water content (Advani and Mathur 1982). Summer vegetable

Table 3. Estimates of losses due to damage by rodents in vegetable crops in India.

Crop and location	Stages of damage	Percent damage	Predominant species	Reference
Tomato				
Lycopersicum esculentum				
Punjab	Rinds of fruits	21.7 (11.1–37.3)	Bb	Malhi and Parshad (1992a)
Haryana	Maturity	13.5–16.5	Bb, Ti	Pasahan and Sabhlok (1993)
Gujarat	Maturity	2.6–35.6	Bb, Rm	Kotadia et al. (1993)
Rajasthan	Rinds of fruits	19.0	Ti, Mh, Rm	Advani and Mathur (1982)
Chilli				
Capsicum annum				
Gujarat	Fruits	3.5–11.7	Bb, Ti	Rana et al. (1994)
Muskmelon				
Cucumis melo				
Punjab	Developing and ripe fruits	7.3 (5.3–9.6)	Bb	Malhi and Parshad (1992a)
Haryana	Maturity	11.8	Bb, Ti, Rm	Kumar and Pasahan (1995)
Watermelon				
Citrullus vulgaris				
Punjab	Maturity	13.8 (9.9–19.8)	Bb, Rm	Chopra and Parshad (1986)
Summer squash				
Cucurbita moschata				
Punjab	Maturity	9.5 (5.2–18.4)	Bb	Malhi and Parshad (1992a)
Haryana	Maturity	1.4–1.6	Bb, Ti	Pasahan and Sabhlok (1993)
Bottlegourd				
Legenaria siceraria				
Haryana	Maturity	14.6	Bb, Ti	Kumar and Pasahan (1995)
Rajastan	Maturity	4.1	Ti, Mh	Advani and Mathur (1982)
Gujarat	Maturity	4.1	Bb, Ti	Rana et al. (1994)
Spongegourd				
Lufa cylindrica				
Haryana	Maturity	9.8	Bb, Ti	Kumar and Pasahan (1995)
Cucumber				
Cucumis sativa				
Haryana	Maturity	8.8	Bb, Ti	Kumar and Pasahan (1995)
Gujarat	Maturity	4.8–19.9	Bb, Ti	Rana et al. (1994)
Cabbage				
Rajasthan	Maturity	7.1	Ti, Mh	Advani and Mathur (1982)
Pea				
Punjab	Seedling	1.1	Bb, Rm	Anonymous 1995
	Pods	5.9	Bb, Rm	Anonymous 1995
Himachal Pradesh	Pods	1.8–5.6	Bb, Rm	Rana et al. (1994)

Bb, *Bandicota bengalensis*; Mh, *Meriones hurrianae*; Rm, *Rattus meltada*; Ti, *Tatera indica*.

crops, particularly the cucurbits, often suffer severe damage by rodents (Parshad and Malhi 1994) and damage to most of or the entire field of musk melons is not uncommon (Jain et al. 1993a). The bandicoots (*B. bangalensis*) extend their burrows right beneath the watermelons and make holes in these to get their seeds and pulp (Chopra and Parshad 1986). Often the rodents nibble and gnaw the rinds of vegetables, like tomatoes, melons, cucumbers etc., which quickly ferment and become unfit for human consumption (Parshad and Malhi 1994). Despite their bitter taste, chillies and bittergourd are not spared by rodents and in the arid regions (Rajasthan) gerbils have been reported to nibble and take away 15–20 kg of chillies from a field daily (Tripathi et al. 1992). Occasionally, the Indian crested porcupine, *H. indica*, causes severe damage in fields of tuberous crops like potato (Chandla and Kumar 1995).

Horticulture

Three types of damage occur to tree crops (Table 4). The first type includes damage to seeds and seedlings in nurseries by rats and squirrels. The second type involves stunted growth and drying up of trees due to gnawing and nibbling of the roots of saplings and young trees by the fossorial species mainly the bandicoots, *B. bengalensis* and *N. indica*, and sometimes by the gerbil *T. indica* and the porcupine *H. indica*. Such damage may occur in orchards of pecan, apple, peach and other fruit crops. The rats may gnaw through the collar into the crown and kill young plants of oil palm (Subiah 1983) and coconut (Kapadia 1995). The third type is the main cause of loss and it involves damage to the fruits generally by the climbing and arboreal species like *R. rattus*, *R. r. wroughtoni*, *R. r. andamanensis*, *F. pennanti*, *F. palmarum* and *F. tristriatus* (Table 4). Some fruits like the ber (*Z. mauritiana*), pomegranate and strawberries which may hang from their bushy plants close to the ground level are also attacked by the ground-dwelling rodents like *T. indica*, *R. meltada*, *M. hurrianae* and *B. bengalensis*.

Table 4. Estimates of losses of horticultural and plantation crops due to damage by rodents in India.

Fruit crop and location	Stage/nature of damage	Percent damage	Pest species	Reference
Pecan				
Carya illinoensis				
Himachal pradesh	Drying due to root gnawing	17.4	Bb	Sheikher and Jain (1991b)
Pineapple				
Ananas comosus				
Meghalaya	Semiripe and ripe fruits	8.5	Rn, Bb	Singh et al. (1994)
Mizoram	do	4.7	Rn, Bb	Singh et al. (1994)
Tamil Nadu	Semiripe fruits	44.4	Rr	Nagarajan et al. (1994a)
Arecanut				
Areca catechu				
Karanataka	Nuts	432 grams/tree	—	Chakravarthy (1993)
Coconut				
Cocos nucifera				
Karnataka	Root damage	6.8–8.0	Bb	Guruprasad and Srihari (1983)
	Tender nuts	12.0–15.0	Fpm	Chakravarthy (1993)
Kerala	Tender nuts	21.0–28.5	Rrw	Advani (1985)
Andhra Pradesh	Tender nuts	14.7	Rr	Rao and Subiah (1982)
Tripura	Nuts	15.0	Sv, Sc	Sarkar (1986)
Lakshadweep islands	Tender nuts	4.5–55.0	Rr	Advani (1984)
Andamans islands	Tender nuts	32.0	Rra	Advani (1985)
Oil palm				
Kerala	Seedlings	45.0	Rrw	Bhat et al. (1990)
Tamil Nadu	Saplings	11.2	Bb	Nagarajan et al. (1994b)
Andamans Islands	Seedlings	10.0	Rra	Subiah (1983)
	Saplings	29.5	Rra	Subiah (1983)
	Tender and ripe fruits	57.3	Rra	Subiah (1983)
Cocoa				
Theobroma cocoa				
Tamil Nadu	Pods	50.0	Rrw, Ft	Bhat et al. (1981)
Karnataka	Pods	47.6	Rrw, Ft	Bhat et al. (1981)
Cardamom				
Elettaria cardamomum				
Karnataka	Capsules	8.7–12.6	Fpm, Bb	Srihari and Chakravarthy (1992)
	70–110 days old capsules	2.5–77.7	Fpm, Bb	Chakravarthy and Gangappa (1992)

Bb, *Bandicota bengalensis*; Fpm, *Funambulus palmarum*; Ft, *Funambulus tristriatus*; Rn, *Rattus nitidus*; Rr, *Rattus rattus*; Rra, *Rattus rattus andamanensis*; Rrw, *Rattus rattus wroughtoni*; Sc, *Sciurus carolinensis*; Sv, *Sciurus vulgaris*.

Coconut and oil palm plantations are important to the economies of several states in the southern peninsula and of the Lakshadweep and the Nicobar–Andamans islands. Both suffer severe damage mainly by *R. rattus* and its sub-species (Table 4). Usually they make a single hole into the developing and tender coconuts near its point of attachment and feed on their pulp. Most of the damaged nuts fall to the ground (Shamsuddin and Abdulla Koya 1985). Subiah (1983) reports that several species of *Rattus* which are endemic in the Andamans islands cause damage to oil palm fruits on 57.3% palm trees. They generally damage the female flowers of oil palm to feed on the oil bearing tissue.

The shrub plantations of cocoa, cardamom, coffee and tea are also affected by rodents (Table 4). Squirrels and rats make irregular holes on the cocoa pods to feed on their contents. The proportion of pods with such damage is often high reaching up to 50% (Bhat et al. 1981) and the damaged pods are more susceptible to black pod disease caused by a fungus *Phytophthora palmivora* (Bhat 1978). Once injured a pod becomes unfit for use. Cardamom capsules are damaged by ground dwelling rats mainly *B. bengalensis* and the squirrel *F. palmarum*, particularly at the ripening stage when they begin to emanate typical cardamom odour (Srihari and Chakravarthy 1992). Coffee and tea plantations provide good hiding places to rodents. Chakravarthy (1993) reports 1.9% damage to berries of coffee/bush by rats and 2.8% by squirrels. The lesser bandicoot rats, *B. bengalensis*, migrate to tea gardens especially when cereal crops in the vicinities are harvested (Bhagat and Kashyap 1992). During burrowing they damage roots affecting the growth and survival of tea bushes.

Forestry

The Indian crested porcupine, *H. indica*, causes damage to tree plantations by debarking (Sharma 1994) and affects reforestation plantation programmes (Agrawal and Prakash 1992). There are reports of rodent damage in nurseries of trees such as: shisham (*Dalbergia sissoo*), teak (*Tectona grandis*), bakain (*Melia azadirachta*), and bans (*Dendrocalamus strictus*) by the short-tailed bandicoot rat *N. indica* (Kumar 1991); acacia (*Acacia nilotica* and *A. tortilis*), *Albizzia lebbek* and *Tamarindus indica* by some unidentified burrowing species (Kumar 1991); gnawing and slicing of the roots with subsequent mortality of 1–4 years old *A. nilotica* trees by *B. bengalensis*, *T. indica* (Bhadauria 1992) and *N. indica* (Tripathi and Jain 1990) and of *Prosopis juliflora* and *A. tortilis* by *N. indica* (Tripathi and Jain 1990); and debarking of the main stem and lateral branches of *A. tortilis* and *Parkinsonia aculeata* by *M. hurrianae* and *T. indica* (Tripathi and Jain 1990). These reports reflect the serious economic losses caused by rodents in Indian forestry. Bhadauria (1992) reports that *B. bengalensis* and *T. indica* attack only *A. nilotica* trees. Studies in new afforestation areas in Rajasthan and Uttar Pradesh show that rodents particularly impede afforestation programmes in arid and semi-arid environments: causing the death of 4–100 seedlings of different trees in nurseries (Kumar 1991), 4.4% of 1–4 year old trees of *A. tortilis*, 10–30% of *A. nilotica* and 10% of *P. juliflora* (Tripathi and Jain 1990, Bhadauria 1992).

Damage during harvesting

During harvesting of food grain crops rodents get easy access to their food source and have to spend less time and energy in taking away the pods, earheads and cobs for hoarding to their burrows, particularly *B. bengalensis*, *T. indica*, *R. meltada* and *M. hurrianae* (Malhi and Parshad 1987, Tripathi et al. 1992). Most of the harvesting of food grain and other crops in India and elsewhere in South Asia is done manually which takes more time and gives a longer period of exposure to pests than with mechanized harvesting such as the use of a combine harvester for wheat and rice crops. The latter is not only efficient but also reduces the time of exposure of the mature standing crop and grains to pests during harvesting. Birds and rodents during this period have been reported to cause 4.31% loss of panicles equivalent to 1.11 quintals per hectare of wheat and 4.64% loss of rice panicles equivalent to 1.72 quintals per hectare of coarse rice (Malhi and Parshad 1987). Similarly the plants or cobs of sorghum, maize and pearl millet are often piled for a number of days in the field or the threshing ground where rodents cause considerable damage (Tripathi et al. 1992). Similar damage also occurs in groundnut (Parshad et al. 1987b). According to Jain et al. (1993a) as many as 40 gerbils occur in a $15 \times 40\,m^2$ area of threshing yard. In fact threshing yards, due to the presence of abundant food and nesting material, attract both the wild and commensal rats in large numbers.

Post-harvest damage

Generally, most food stores, godowns, commercial premises such as grocery shops and grain markets and food processing units such as bakeries and floor mills are infested by the house rat *R. rattus* and the house mouse *M. musculus* throughout the country in both rural and urban situations and by the lesser bandicoot rat *B. bengalensis* in major metropolitan cities such as Bombay, Calcutta, Delhi and Madras (Table 1). These often cause serious losses during storage (Rao and Joshi 1986, Prakash and Mathur 1987). There have been many reports which demonstrate the severe infestations of rodents that can occur in some premises – 8.2 and 7.9 house rats per house from two different villages in Udaipur district (Singh et al. 1990), 10.7 rats/godown of 106 m^2 area in rural houses, shops and godowns near Hapur (Krishnamurthy et al. 1967), about 200 bandicoot rats from each godown in Calcutta (Franz 1975), 7.6–10.7 rats/warehouse of 100–300 ton capacity (Pingale 1975) and 272247 rats and mice killed in 55433 houses of 80 villages in Mehsana district of Gujarat (Chaturvedi et al. 1975). Similarly, in Pakistan the number of *R. rattus* ranged from 5 rats/grain shop in the new market in Faisalabad to 61 rats/grain shop at Lahore and in the Punjab province losses due to consumption, spillage and contamination of grains and commodities by rats came to about 4000 metric tonnes/year or about 0.3% of the total amount handled annually at 5500 shops (Ahmad et al. 1995). During storage, rats are considered responsible for 2.5% loss of the total food grains produced in India (Krishnamurthy 1968). Rodents contaminate food with their urine, faecal droppings and hair. The level of contamination varies in different situations in relation to the type of packing and storing facility. Less than 0.1% samples of wheat grains collected from gunny bags and metallic bins had signs of rodent contamination compared to 4.7% samples of spilled grains collected from floor mills, grain stores and rural houses (Parshad et al. 1994). Similarly, in grocery shops 0.6% samples of rice and 0.4% of green gram had signs of rodent contamination. Information about the damage to fruits and vegetables by rodents during storage is scanty. However, at Ludhiana (India) the house rat, *R. rattus*, is reported to have adapted to conditions in a cold store (0–4°C) of approximately 2040 metric tonnes and caused damage to fruits, vegetables and packaging materials, 81 rats were trapped in 1989 and 61 in 1991 (Ahmad et al. 1993a).

The reasons for the subsistence of large rodent populations in most of the storage premises and human dwellings is the inadequate maintenance of buildings combined with lack of hygiene, poor handling of food materials leading to spillage and serious neglect of rodent proofing. Often the food grains are stored in rural houses, stores and godowns, where the major part (60–70%) of the grains produced in India are stored for 6–10 months, in traditional storage structures made from locally available materials such as clay, wood, bamboo, straw, jute bags and bricks, vulnerable to rodent attack (Save Grain Manual 1990). Losses due to rodents and other storage pests are reported to be least in public-sector godowns and warehouses (Save Grain Manual 1990) and also on those farms where metallic bins and other proper storage techniques are being used (Girish et al. 1985).

Damage and economic losses in poultry farms

Animal houses, particularly poultry farms, provide a most favourable and stable habitat throughout the year for large rodent populations which by their burrowing, nibbling, feeding, defecation, urination and extensive movements damage the poultry farm environment and cause severe economic losses both by direct damage to poultry production and also indirectly by spreading several diseases among the birds and to poultry keepers themselves (Parshad et al. 1987a, 1991, Malhi and Parshad 1993a, 1995a). Poultry farms located in urban areas are severely infested with *R. rattus* and *M. musculus* and in rural areas wild species such as *B. bengalensis*, *R. meltada* and *T. indica* may also invade (Christopher et al. 1984, Parshad et al. 1987a, Malhi et al. 1991). A high carrying capacity of poultry farms for rodents is evident from the reports of 292 rodents/3600 sq. ft floor area (Malhi et al. 1991) and 72 rodents/100 m^2 (Ahmad et al. 1992). Damage to about 0.5% eggs is common in India (Parshad et al. 1987a) and it may reach 10% under poor storage conditions (Khatri and Veda 1984). Fibre egg trays are also gnawed and spoiled by rodents. Rats frequently attack and kill young chicks up to the age of about 30 days and with reports of 5.9% being killed in one chick house (Malhi et al. 1991). Rodents frequently scare and bite hens and effect their feeding, growth and egg laying.

Poultry feed stores are also heavily infested with rodents (Parshad et al. 1987a). According to one estimate 309–359 rodents may occur in 100 m^2 of the feed store (Ahmad et al. 1993b). On average one adult house rat eats 8.6 g of poultry feed per day (Parshad et al. 1991). Different estimates reveal that the total population of rodents in poultry farms may consume between 2 and 50 kg of poultry feed daily and also damage the gunny bags used for its storage and transport (Rosario 1987, Malhi et al. 1991). They also contaminate poultry feed with urine, droppings and hair and 0.4–3.3%

samples of feed had signs of contamination (Parshad et al. 1987a). Damage to poultry feed is a major cause of economic loss as feed accounts for 50–75% of the operational cost of a poultry farm. By causing frequent structural damage to wooden doors, windows and electric cables (by gnawing) and to floor and foundations (by burrowing) the rats increase the maintenance costs of the building.

Rodent control strategies and methods

Due to variations in geographical and climatic factors; systems of crop production and post-harvest storage; carrying capacity of the environment; biology of the pest rodent species; the nature and extent of rodent problems and the perceptions and socioeconomic conditions of the people, no single strategy or method of control is feasible or applicable in all different pest situations. Moreover, farmers use several traditional techniques for controlling rodents and several improved techniques, particularly rodenticides, have also become available during the last 2–3 decades. The available rodent control options can be grouped into two basic approaches: lethal or reductional and non-lethal or preventive. The lethal approach, particularly the use of rodenticides and trapping, which provides an immediate solution to the problem, is often considered the most practical, economical and effective method of combatting rodents while non-lethal or preventive measures involving environmental, cultural and biological methods, which may produce a more lasting effect, are seldom adopted.

Environmental and cultural methods

Several techniques are used either as part of routine agricultural and post-harvest storage operations or directly against the rodents. These directly or indirectly reduce the immigration of rodents into a habitat and/or reduce the carrying capacity of the habitat.

Harbourage reduction

A clean environment discourages rodents from establishing in an area. After removal of wild vegetation from a field, *T. indica*, *M. hurrianae* and *M. booduga* migrated to other more favourable habitats about 65–78 m away (Sabhlok and Pasahan 1985). The mechanization of agriculture has reduced wastelands and wild vegetation on crop field boundaries which otherwise provide harbourage to rodents. Bandicoot rats make extensive burrows usually in dikes, bunds and the earthen embankments of water channels. They prefer thick bunds with more height for burrowing and a reduction in bund thickness and height discourages them (Rana et al. 1994, Kumar et al. 1995a).

Garbage, junk and other hiding and nesting materials provide harbourage to rodents in animal and human dwellings and in stores and godowns. The periodic removal of rubbish and good hygiene discourage rodents in these premises (Christopher et al. 1984, Save Grain Manual 1990, Parshad et al. 1991: Malhi and Parshad 1995a). Studies of the population density of rats and mice in different systems of poultry housing show a 3–4 times higher population *R. rattus* in the deep litter system of poultry houses (29.6 rats/100 m^2 floor area) than in the California cage system of housing (Ahmad et al. 1993b). The deep litter housing system provides more harbourage sites to rats which make nests and hide below the litter bed, feeding and water hoppers and other structures. In the California cage system of poultry keeping, unlike in the deep litter system, the hanging cages of poultry birds provides minimum harbourage to rats.

Food source reduction

Weeds form an important component of the diet of rodents (Fulk et al. 1981, Malhi and Parshad 1994a) which selectively invade and cause more damage in weedy than in weeded crops as observed in experimental plots of rice in Philippines (Drost and Moody 1982) and of rice and wheat in India (unpublished observation). The practice of weed control with chemicals and other techniques, which has improved during the last 2–3 decades in India, has also reduced rodent pest problems in crop fields. Similarly, the removal of additional food sources for rats in premises and dwellings is important. For example, spilled grains in stores and godowns and food scraps left from feeding domestic animals, pets and children in houses, if not removed, attract rodents. Pen experiments using *R. rattus* show that the presence of an alternative food source reduces the performance of other control techniques such as trapping and poison baiting (Parshad et al. 1991). Controlling rats with these techniques is easier in poultry houses after shifting of feeding hoppers and chicks.

Immigration reduction

Exclusion of rodents from an area or structure depends on the physical ability and biology of the pest species. For example, *B. bengalensis* dig extensive burrows, *R. rattus* climbs trees and buildings and *M. musculus* can squeeze through a small aperture of about 1 cm diameter. These three species breed throughout the year and maintain large populations (Parshad et al. 1989) and their physical abilities allow them to disperse quickly. Different techniques, such as barriers, electric fences, repellents and rat proofing, can be used to prevent the entry of rodents, denying them access to food in agricultural fields and during post-harvest storage.

Barriers. Banding the trunk of coconut trees with metallic sheet prevents *R. rattus* climbing to the crown to get access to coconuts. About 7.5% coconut trees were reported infested with rats in an area where the tree trunks were banded compared to 25% of trees which were not banded (Guruprasad and Srihari 1978). Little work has been carried out in India on protecting crops from rodents with lethal and sub-lethal electric barriers or fences around the fields (Sreenivalu et al. 1971). However, occasionally some farmers use crude electric fences which may themselves be hazardous (Subiah 1978). Elsewhere, in Philippines (Shumake et al. 1979, Reidinger et al. 1985) and USA (Fitzwater 1972) sub-lethal electric fences are reported to be effective in protecting experimental plots of rice from rodents. This method is important in protecting high value commodities or structures.

Repellents. A few traditional methods such as the placing of screw-pine leaves along the edges of paddy fields (Subiah 1978) and flagging of palm leaves or polythene pieces on a 3–4 feet long rod in rice fields (Neelanarayanan et al. 1995a) or plant material which makes rattling sound (Sharma 1994) are used by farmers to scare away the rodents. The effectiveness of these method is not known. Ultrasonic repellers came on to the markets for use in premises in both India and other countries but there is insufficient evidence of their effectiveness (see Lund 1988 for review). Similarly, numerous chemicals have been evaluated for their repellent action (Rana et al. 1994) but in practice no single chemical is being used as a repellent. Studies of the behavioural responses of *R. rattus* and *B. bengalensis* toward the odour and taste of two fungicides, namely copper oxychloride and thiram (tetramethythiuram disulphide) have been carried out. Damage caused to treated cardboard cartons showed that surface application of 1.5% and 4.5% solutions of copper oxychloride and thiram in water and peanut oil, respectively, provided a degree of protection to the cartons and their contents from *R. rattus* for about 30 days (Parshad et al. 1993). Earlier studies (Welch and Duggan 1952) showed that thiram in vinyl film on cardboard provides good protection against damage by *R. rattus* and *R. norvegicus*.

Rodent-proofing. Rodents may enter animal houses and human dwellings, shops, stores and godowns through several routes, proofing of which with appropriate techniques is the first line of defense against them (Save Grain Manual 1990, Meyer 1994, Malhi and Parshad 1995a). Most rural and urban slum houses are made of mud and wattle with a thatched roof. Rodent proofing of such premises is not possible. The residential premises of middle class families, shops and stores may be made of bricks and concrete but still often lack rodent proofing. However, newly constructed houses in towns and cities and also public sector godowns and warehouses are generally made rodent proof, although because of the maintenance problems sometimes the established proofing is lost. In 1965, a nationwide research and extension programme called the 'Save Grain Campaign' was launched by the Department of Food, Government of India to prevent losses of foodgrains in storage (Girish et al. 1985, Save Grain Manual 1990). Popularization of metallic drums and other rodent proof storage techniques and improvements in the traditional storage structures are the most important contributions of this programme to reducing damage to stored foodgrains in farm and village houses.

Cultural practices

Crop rotation and tillage. Certain cultural practices affect the incidence of rodent pests and their damage to crops. Conventionally farmers carry out deep tillage which also destroys rodent burrows and drives away rodents. Wheat sown after mulching with rice straw and with minimum tilling after harvest of rice – which often develops large populations of *B. bengalensis* with extensive deep burrows during the ripening stages – suffer more rodent infestation and damage throughout the crop period than in the conventionally deep tilled fields (Parshad 1997). Ploughing of vacant land around wheat fields causes about a 49% reduction in the burrows of *N. indica* (Ramesh and Katiyar 1985b). In the Indo-Gangetic plains rice–wheat rotation along with fields of sugar cane is the predominant cropping system. *B. bengalensis* occurs predominantly in the rice–wheat and *R. meltada* and *T. indica* in cotton–wheat rotations (Parshad 1989a). Rice–wheat rotation appears to promote the population of *B. bengalensis*

(Parshad and Ahmad 1996) and diversification of agriculture by replacing rice with sunflower and horticulture may reduce this problem. Being a long duration crop the cane fields are frequently threatened by waves of rodent immigration related to agricultural operations in the adjoining fields of rice–wheat rotation (Parshad et al. 1986, Parshad 1989a). Puddling of fields before rice transplantation drives away rodents into adjoining sugarcane and permanent boundaries and after harvesting of rice they again tend to migrate into the sugarcane. In fact sugarcane fields are highly vulnerable to attack by rodents which cause more damage to a lodged crop (Bindra and Sagar 1975). Adoption of techniques such as bundling or bunching of the standing crop, irrigation according to wind intensity, and the use of varieties which may not lodge, indirectly help to prevent damage by rats.

Varietal resistance and crop scheduling. Rodents are sensitive in food selection and are able to discriminate between foods with subtle changes in their composition. The lesser bandicoot rat exhibits references among rice grains of different varieties (Parshad and Nijjar 1995). Several field studies suggest varietal differences in damage to rice (Singh et al. 1983, Prakash et al. 1986, Chakravarthy et al. 1992) and sugarcane crops (Prakash and Avasthy 1980). However, no true rodent resistant variety has yet been identified. Often the early maturing varieties of rice are more attacked by rodents. In sugarcane more damage occurs to varieties with a thin barrel, soft rind, low fibre and lodging habit than the varieties with a thick barrel, hard rind, more fibre and non-lodging habit. Crop scheduling is important as with asynchronous sowing or transplantation of crops in the same area the timing of ripening and hence availability of food from the same crop will vary among fields. Rodents cause more damage in fields where shelter and food has been available to them earlier and they can then shift to fields where harvesting is late or delayed (Singh et al. 1983). Severe damage due to such practices can be prevented by adopting synchronous sowing or transplantation and harvesting schedules for the same variety over a large field area.

Biological methods

Biological control involves the use of predators, parasites, pathogens and reproductive inhibitors against rodents. Environmental changes due to the over exploitation of land and forest resources and developments in transport, urbanization and agriculture in several parts of India have disrupted the natural control of rodents but its importance is well recognized and interest in biological techniques has revived in recent years.

Predators

The major predators of rodents are cats, mongeese, jackals, foxes, owls, hawks, kites, monitor lizard and snakes (Prakash and Mathur 1987). The populations of these predators have declined because of hunting and environmental reasons. Rats and mice are the principal food of the barn owl, *Tyto alba* (Neelanarayanan et al. 1994b). Farmers sometimes place tree branches or T shaped perching poles in the field to encourage predation by owls in Bangladesh (Catling 1992) and Southern India (Neelanarayanan et al. 1995a). Apart from a few attempts to breed and release barn owls for rodent control not much research has been carried out on predators.

Parasites and diseases

The potential of microparasites (viruses, bacteria and protozoans) and macroparasites (helminths and arthropods) as bio-control agents of rodents has been ignored, although these can play an important regulatory role in their host population dynamics (see Singleton and Redhead 1990, for review).

The *Salmonella* bacteria has been found to be effective against rats in Europe but is a potential health risk to livestock and humans which is a major challenge to this approach to rodent control (Singleton and Redhead 1990). Studies in India show that *Salmonella* bacterium and murine typhus fever bacterium strain-5170 are ineffective against *R. rattus* and *B. bengalensis* (Deoras l964, Bindra and Mann 1975). However, typhus bacterium strain-5170 causes 20% mortality of *M. m. bactrianus* and 40% mortality of *T. indica* in laboratory trials (Bindra and Mann 1975).

The potential of helminth parasites in regulating the population of Indian rodents is not known although a hepatic nematode *Capillaria hepatica* has been considered important for controlling mouse plagues in Australia (Singleton and McCallum 1990). However, a trichostronglid nematode *Hepatojarakus bandicoti*, which occurs in most species of rats and mice in crop fields in Punjab (India), causes severe pathological lesions in the bile ducts and liver and consequent death of *B. bengalensis* (Parshad and Sood 1976). Variations in the incidence of this parasite in rodents from different crop fields and seasons (Sood and Parshad 1975) suggest that certain conditions favour its infestation, these need to be identified to explore its potential for rodent control.

Nothing is known about the role of arthropod parasites in regulating rodent populations. However, Mittal et al. (1991) attributed drastic reductions in the population of rodents, after an outbreak in Gujarat (India) in 1989–90, to heavy parasitization by a blood sucking lice, *Polyplax spinulosus*.

Reproductive inhibitors

A major cause of the abundance and post-control resiliency of rodent populations is their high rate of reproduction (Parshad et al. 1989). Because of the potential of chemical inhibition of reproduction in integrated rodent control programmes, a number of chemicals have been evaluated against several species of Indian rodents. These include: clomiphene, tetradifon, furadantin and colchicine, glyzophrol (see Barnett and Prakash 1975, Prakash and Mathur 1987), ethyl methanesulphonate (Kaur and Parshad 1997) and alpha-chlorohydrin (Saini and Parshad 1988, 1991, 1993). Alpha-chlorohydrin is toxic at higher doses to both males and females and causes permanent sterility at low doses in males (Ericsson 1982, Saini and Parshad 1988). Of the 15 species and strains of rodents tested for the toxic and antifertility effects of alpha-chlorohydrin, *B. bengalensis*, the most predominant species of field rodents in India, is most susceptible (Saini and Parshad 1988). A 0.5% cereal bait is accepted by the rat which ingests a dose of the active ingredient equal to or more than the LD_{50} value (82 mg/kg) in a single day's feeding (Saini and Parshad 1991). Application of 0.5% bait in sugarcane field caused 63.7–82.9% mortality of rodents including *B. bengalensis*, *G. ellioti* and *R. meltada* (Saini and Parshad 1993). Most of the survivors, which had ingested a sub-lethal amount of alpha-chlorohydrin both in the laboratory (Saini and Parshad 1991) and the field (Saini and Parshad 1993) become permanently sterile. Though alpha-chlorohydrin is widely marketed it is yet to be introduced in South Asia where it can be useful for control of *B. bengalensis*.

Compounds that produce mutagenetic effects and also reduce fertility in both male and female animals may be useful in future strategies of rodent pest management. Recently, a germ cell mutagen, ethyl methanesulphonate (EMS), has been found to affect the differentiation, structure and function of spermatozoa of *R. rattus* with 500 and 625 mg/kg body weight doses (Kaur and Parshad 1997). EMS acts by alkylayion of testicular DNA inducing dominant lethal or specific locus mutations and heritable translocations (Topham 1980). Its potential for rodent control needs to be explored.

Mechanical methods

Mechanical techniques such as hunting, killing and trapping often involve high labour costs and are less practicable over large areas. However, these can be integrated with chemical control techniques to achieve better control success or can replace chemical control in areas where the use of rodenticides may cause health and environmental problems.

Physical killing

Bandicoot rats can be hunted and killed with sticks during ploughing of fields and flooding of burrows with rain or irrigation water during the period between crops (Anonymous 1995). After harvesting of the crop the bandicoot rats persist within the field on grain hoarded in their burrows. The rats begin to come out when their burrows are flooded during irrigation of the field and can be killed with sticks or by employing rat dogs. The tribals who eat rats retrieve them from their burrows by digging or by smoking the burrows by burning cow dung cake or rice straw on one opening to drive out the rats from another opening of the burrow (Ahmed 1992, Jain et al. 1993b).

For controlling *R. rattus* in coconut plantations in Lakshadweep islands the villagers are reported to organize 'yeli nayatu' which means rat hunts with participation of the entire community (Kidavu Koya 1955, Shah and Subiah 1978). During the hunt, the climbers climb a group of coconut trees and after cleaning their crowns they continuously shake them, as a result the rats run helter skelter and on to the ground below the trees to be killed by another group of people. These hunts have been an annual event in the past killing about 3000–4000 rats every year on the island.

Trapping

Trapping rodents in fields and premises is a common old practice (Fitzwater and Prakash 1989). Two basic types of traps are being used, the snap or kill trap and the live trap. Among the snap traps the Tanjore Bow trap, a low cost bamboo trap generally used by professional trappers in rice fields (Neelanarayanan et al. 1995b); the wooden snap trap, a locally fabricated trap using timber splinters (Srihari and Chakravarthy 1992); the *urang* or arrow trap (Prakash and Mathur 1987) and the break-back spring loaded snap traps with wooden or jawed iron base (Prakash and Mathur 1987) have been used traditionally. Among these the break-back snap trap is most popular. Glue boards are effective for trapping indoor rodents (Srivastava and Srivastava 1985). However, these have not become popular so far because of the cost, hygiene problems and cruel method of killing.

For live trapping of rodents, different types of traps are used which include the primitive type pit fall or pot trap (Neelanarayanan et al. 1994c), foldable iron sheet boxes with a spring loaded shutter commonly called as Sherman traps (Rana 1982), small sized $9 \times 4 \times 4''$ wooden boxes, also called single-rat traps (Pasahan and Sabhlok 1981) and multi-catch wonder traps of different sizes and shapes (Prakash and Mathur 1987, Parshad et al. 1987a, 1991, 1994, Sheikher and Jain 1992, Kumar et al. 1995b). Pre-baiting the rats in wonder traps for 2–3 days by keeping its door off reduces the effects of neophobic reaction on trapping. The use of traps in crop fields is generally limited due to the more widespread distribution of rodents than in premises. However, live trapping of *B. bengalensis* and *B. indica* in flooded deep water rice fields in Bangladesh (Islam and Karim 1995) and of *B. bengalensis*, *G. ellioti*, *R. meltada*, *R. rattus* and *Mus* spp. in vegetable crop fields in Himachal Pradesh, India (Sheikher and Jain 1992) are reported to be effective for their control. Studies in poultry houses show that the maximum number of rats is trapped on the first and second days of trapping and thereafter trapping declines as the remaining rats tend to become trap-shy (Parshad et al. 1987a). Unlike *B. bengalensis* and *R. meltada*, *R. rattus* and *T. indica* normally live in social groups and trapping of one individual may facilitate that of others in the group as observed in case of *R. rattus*. Often rat families consisting of the mother and 4–10 immature individuals of *R. rattus* are caught in one trap (Parshad et al. 1987a). The population pressure of *R. rattus* affects its trapping as trapping is more successful in heavily infested areas where as a few scattered individuals are difficult to trap. The use of rodenticides or other techniques for control of *R. rattus* in complex situations such as cold stores can involve environmental problems but trapping after insulating the entrance and body of traps with paper, is effective (Ahmad et al. 1993a).

Chemical methods (rodenticides)

The use of rodenticides is the common approach to rodent control in agricultural, rural and urban environments in South Asia. Their effectiveness depends upon the selection of an appropriate compound, its formulation, and the method and timing of application. The commonly used/recommended rodenticides in India are zinc phosphide, aluminium phosphide, warfarin, racumin and bromadiolone. Along with these compounds several others have been evaluated for rodenticide action against the predominant pest species. The mechanism of action of different compounds is reviewed by Buckle (1994) and the following information relates to their evaluation and use in India.

Acute rodenticides

The acute rodenticides whose toxicity and efficacy have been tested against Indian rodents are zinc phosphide, aluminium phosphide, barium carbonate, arsenic trioxide, strychnine alkaloid, thallium sulphate, alphanapthyl thiourea (ANTU), norbormide, scillirocide (red squill); sodium fluroacetate, vacor (RH-787) and a gophacide (see Subiah and Mathur 1985, Prakash and Mathur 1992, for reviews). Apart from zinc phosphide, aluminium phosphide and barium carbonate, none of these is used in India because of toxicity and efficacy problems. Occasionally, a phosphorus based rodenticide labelled as ‘Ratol’, containing inorganic phosphorus, is used in the fields. Despite being hazardous to the user its bait has low acceptance and efficacy as determined against house rats (Malhi and Parshad 1991). Because of low toxicity, barium carbonate is used at high concentration, that is 10–20% in the bait, and mortality of rodents is generally variable and erratic (Prakash and Mathur 1992, Malhi and Parshad 1994b). Some rats die at low dosages while others survive its higher doses. Fumigation of burrows with aluminium phosphide is generally effective in damp soils (Sridhara and Srihari 1979) but its importance is limited by toxicity hazards, cost of application and low efficacy against species like *B. bengalensis* which may plug the tunnels of their burrows.

Among the acute rodenticides, zinc phosphide is most commonly used in South Asia and forms the basis of 80–90% of rodent control operations, particularly in agricultural situations (Parshad 1992). This is a broad-spectrum rodenticide with LD_{50} ranging from 25 to 40 mg/kg in different species of Indian rodents, it can easily be used in different bait formulations generally at 2% concentration in cereal bait, it rapidly detoxifies in carcasses and baits and thus is relatively safe in use, and it is economical (see Prakash and Mathur 1992, Parshad 1992). The major problems with the use of zinc phosphide include its antidotable character, quality problems and bait aversion among sub-lethally poisoned rodents. Analysis of commercially available zinc phosphide from Bangladesh showed that only 2 out of 23 samples contained 80% of the active ingredient while 14 had 15% to non-detectable zinc phosphide content (Bruggers et al. 1995). Such a lack of quality control not only discourages farmers from adopting rodent control with zinc phosphide but its use complicates rodent management as the sub-lethally poisoned rodents tend to develop poison bait aversion.

Extensive studies have been carried out on the problem of poison bait aversion in *T. indica* (Prakash and Jain 1971), *M. hurrianae* (Prakash and Jain 1971), *G. gleadowi* (Rana et al. 1975), *R. rattus* (Bhardwaj and Khan 1978, 1979); *B. bengalensis* (Sridhara and Srihari 1978, Sridhara 1983, Parshad 1989b, Parshad and Kochar 1995), *M. musculus* (Rao and Prakash 1980) and *M. platythrix* (Sridhara and Srihari 1980). Because of this problem rodents will continue to reject the zinc phosphide bait for 6–170 days. With repeated exposures to it the period of rejection may go up to 484 days, that is almost throughout their life in the case of *B. bengalensis* (Parshad and Kochar 1995). According to Sridhara (1983) aversive rats become more neophobic towards novel food and thus avoid the bait. Sometimes, farmers do multiple treatments of zinc phosphide at short intervals in the same field and this enhances aversive responses of rodents to poison baits and their control with zinc phosphide in such situations become extremely difficult. To prevent this problem the rodents are encouraged to eat the lethal amount of zinc phosphide bait by pre-baiting with plain bait material and leaving a sufficient time gap, equivalent to the memory of rats for poison stimulus, between its two consecutive treatments. In case of *B. bengalensis* that is about 58 days (Parshad and Kochar 1995). If bait aversion develops in rodents, its effect can be reduced by changing the cereal base and its texture (Bhardwaj and Khan 1979) or by the addition of 0.4% conspecific urine to the poison bait (Prakash 1986).

Subacute rodenticides

Rodenticides with subacute action, that is where death is delayed for several days after ingestion of a lethal amount, are bromethalin, flupropadine, calciferol (ergocalciferol, vitamin D_2) and cholecalciferol (vitamin D_3). Reports of their testing against South Asian rodents are scanty. Bromethalin is reported to be effective against *B. bengalensis* in Bangladesh at 0.005% or 0.01% concentration in bait (Mian et al. 1993). Feeding poison baits containing 0.1% calciferol, 0.1% calciferol plus 0.025% warfarin (Arora et al. 1982) and 0.075% cholecalciferol for 1–2 days (Saini and Parshad 1992) caused 100% mortality of *R. rattus*. Most of the rats died after between 3 and 5 days of treatment. After ingesting lethal amounts of cholecalciferol in 1–2 days of feeding, the rats lose appetite and stop feeding (Saini and Parshad 1992). The advantages of this 'stop feed' action caused by a lethal dose is that the rats do not consume excessive overdoses thus reducing bait requirements and the risk of secondary poisoning (Saini and Parshad 1992). Moreover, vitamin D compounds pose less toxicity hazards to non-target animals and their accidental poisoning is symptomatic with cortisone and sodium sulphate (Saini and Parshad 1992, Buckle 1994). However, Buckle (1994) indicates that in some cases sub-lethal ingestion of subacute rodenticides may cause 'stop feed' action leading to failure of these compounds.

First-generation anticoagulants

All anticoagulant rodenticides are either hydroxycoumarins or their related indane-dione compounds. The first-generation anticoagulant rodenticides are characterized by their chronic and multi-dose effects. Several compounds including warfarin, fumarin, coumatetralyl, diphacinone and chlorophacinone are effective against most of the species of Indian rodents (see Mathur et al. 1992 for review). Among these are warfarin and fumarin (Ratafin) which are generally used at 0.025% concentration in cereal baits or sometimes as ready-to-use wax bound cakes as of fumarin (Ratobar). These have long been available in India but have not gained popular acceptance for rodent control because they become effective only after several ingestions of small doses over a number of days, ranging 4–28 in different species (Prakash and Mathur 1987, Mathur et al. 1992). The long period of treatment involves operational problems, a high cost of baits and labour and more importantly patience. Moreover, the problem of resistance to warfarin and other first-generation anticoagulant rodenticides as reported in the case of *R. rattus* (Deoras 1967, Arora and Lal 1979) and *B. bengalensis* (Fernando et al. 1967) impedes their usefulness for effective rodent control.

Recently, 0.75% Racumin (coumatetralyl) has been commercialized in India to be used as 0.75% tracking powder or 0.0375% cereal bait. It is more potent than other first-generation anticoagulant rodenticides. Species-specific differences in its toxicity occur as *B. bengalensis* is more susceptible to its lethal effects than *T. indica* and it is least effective against *R. rattus* (Chopra and Parshad 1985, Parshad and Malhi 1995).

In fact, the susceptibility of *B. bengalensis* to Racumin approaches that of the second-generation anticoagulant rodenticides while that of other species is typical of first-generation anticoagulants rodenticides. In fields, 50–70% control of *B. bengalensis* is achieved by placing the racumin bait in burrows (Parshad and Malhi 1995); or at 10 m distances throughout the crop field for 3–5 days (Malhi and Parshad 1995b); or by dusting burrows or the runways of rats with racumin tracking powder (Parshad and Malhi 1995). Continuous baiting for 10–12 days is required to achieve the same level of control of *M. hurrianae*, *T. indica* and *G. gleadowi* (Mathur and Prakash 1984a) and of *R. rattus* (Arora et al. 1984). Because of its low toxicity, chronic action, antidotability with vitamin K and high susceptibility of the most predominant pest species (*B. bengalensis*), Racumin can be widely used in crop fields in India.

Second-generation anticoagulants

The development of second generation anticoagulant rodenticides, namely difenacoum, brodifacoum, bromadiolone, flocoumafen and difethiolone, has improved our rodent control capabilities. Of these, bromadiolone has been commercially available in India since 1988 for the control of agricultural and commensal rodents. This compound, along with other second-generation anticoagulants, has been tested extensively against rodents in both laboratory and field studies in India (Mathur and Prakash 1981, Chopra et al. 1983, Parshad et al. 1985, Parshad and Chopra 1986, Balasubramanyam and Purushotham 1987, Parshad 1986, 1988, 1994a,b, Arora et al. 1994) and several other countries (Dubock 1980, Garforth and Johnson 1987, Jackson and Ashton 1992, Gill 1992). Compared to first-generation anticoagulant rodenticides, the second-generation are more toxic and effective and thus are used at low doses at 0.005% concentration in the bait, and 0.0025% in case of difethiolone, and are generally effective after a single dose or day's ingestion and thus require a shorter feeding period and less bait. Also they are generally effective against rodents resistant to first-generation anticoagulant rodenticides (Greaves 1994). Studies using *R. rattus*, *B. bengalensis* and *T. indica* have revealed that 80–100% mortality occurs after ingestion of 0.005% brodifacoum and flocoumafen baits equivalent to just 10–20% of the daily food intake and with 2–3 h of exposure to the poison baits (Parshad et al. 1985, Parshad 1986). Bromadiolone is less toxic and rats must eat more bait for a longer period, usually for 24–48 h for complete mortality (Parshad 1986). Generally, the toxic effects of second-generation anticoagulants begin after 2–3 days after ingestion of the poison bait and most deaths occur between 4 and 10 days after treatment. Sub-lethally poisoned rats, in contrast to acute rodenticides, eat sufficient poison bait for a complete kill as they do not develop an aversion to it (Parshad and Kochar 1995). Because of their broad spectrum lethal effects against most of the rodent species (Parshad et al. 1985, Parshad 1986,1988,1994a,b, Mathur et al. 1992), the second-generation anticoagulants can be used successfully for rodent control in different pest situations.

The practical value of second-generation anticoagulants has been proved in numerous field studies against agricultural and commensal rodent pests (Mathur and Prakash 1984b, Parshad et al. 1987b, Sarker and Jaeger 1997). Results varying from 30% to 100% rodent control are reported with single and multiple applications of freshly prepared loose cereal bait or ready-to-use wax cake formulations (Table 5). These variations are related to: differences in the pest species and density of the pest species, ecological factors such as, the size of the baiting area (Parshad et al. 1986, Parshad 1989a, Ahmad and Parshad 1987, 1989a,b), climatic and agronomic changes (Parshad et al. 1986, Parshad 1989a), type of the harbourage and availability of alternative food sources for rodents (Parshad et al. 1991, Parshad 1994b), behavioural responses toward poison baits (Parshad 1994a,b), method of bait application (Ahmad and Parshad 1989b, Malhi and Parshad 1995b), timing of treatments (Ahmad and Parshad 1991a, Malhi and Parshad 1993b), post-control reinfestation (Parshad et al. 1986, Ahmad and Parshad 1991a) and also the method of determining the field efficacy (Mathur and Prakash 1984b). The second generation anticoagulant rodenticides are suitable for sustained and multiple or pulse baiting of rodents (Parshad et al. 1985, 1987a,b, Parshad 1988, Malhi et al. 1986, Ahmad et al. 1989). Treatment of large sized fields is more effective and economical (Ahmad and Parshad 1989a). The intrinsic palatability of the second generation anticoagulants is evident in several studies of their laboratory evaluation using cereal baits but the introduction of ready-to-use paraffin wax cakes, for safety reasons, reduces the palatability of the poison baits particularly by *B. bangalensis* (Parshad 1994a,b) and also the acceptance and efficacy in fields (Conway 1984, Parshad et al. 1987b, Ahmad and Parshad 1989b,1991b). The commonly used cereals for bait formulation are pearl millet, sorghum, rice and wheat, among these pearl millet is generally preferred by rodents (Parshad

Table 5. Field efficacy of second-generation anticoagulant rodenticides in India.

Rodenticide crop/premises	Predominant species	Formulation, number and method of treatment	Percent control	Reference
Brodifacoum 0.005% bait				
Wheat	Bb, Ti, Rm	FB, 1 GB	61.4	Parshad et al. (1985)
		FB, 2 GB	93.0	Parshad et al. (1985)
		FB, 3 GB	96.1	Malhi et al. (1986)
		RUC, 1 GB	68.0	Ahmad et al. (1989)
		FB, 1 GB	70.6	Malhi and Parshad (1995b)
		FB, 1 BB	56.0	Parshad et al. (1985)
Rice	Bb, Rm, Mb	FB/RUC, 1 BB	74.0	Balasubramanyam et al. (1985)
		RUC, 1 BB	91.1	Bhadauria and Mathur (1995)
		RUC, 1 GB	54.3	Malhi and Parshad (1995b)
		FB, 1 GB	67.3	Malhi and Parshad (1995b)
Groundnut	Bb, Rm, *Mus*	FB, 1 GB	67.0	Parshad et al. (1987b)
		FB, 1 GB	42.3	Parshad et al. (1987b)
	Ti, Rm, *Mus*	FB, 2 GB	72.4	Parshad et al. (1987b)
		RUC, 1 GB	26.1	Parshad et al. (1987b)
Sugarcane	BB, Rm	FB, 2 GB	86.1	Ahmad and Parshad (1989b)
		FB, 3 GB	47.2	Parshad et al. (1986)
		RUC, 1 GB	58.0	Ahmad and Parshad (1991b)
		RUC, 2 GB	61.8	Ahmad and Parshad (1989b)
		RUC, 2 BR	45.4	Ahmad and Parshad (1989b)
Fodders	Mh, Ti, Gg	FB, 1 GB	90.5	Mathur and Prakash (1984a)
Coconut	Rr	RUC, 1 CB	73.5	Advani (1986)
	Rrw	—	100.0	Rangareddy (1995)
Cocoa	Rrw	FWC, 1	76.0	Bhat and Sujatha (1989)
		FWC, 2	95.0	Bhat and Sujatha (1989)
Rural houses	Rr, Mm	—	91.0	Rao (1986)
	Rr, Ti, Mm	—	92.5	Advani and Prakash (1987)
	—	RUC, 1 or 2 BB	71.0	Sarker and Jaeger (1997)
Urban premises	Rr, Bb	—	98.9	Deobhankar (1985)
Poultry farms	Rr, Mm	FB, 1 PB	56.2	Parshad et al. (1987a)
		FB, 2 PB	88.8	Parshad et al. (1987a)
Flocoumafen 0.005% bait				
Wheat	Bb, Ti, Rm	FB, 1 GB	67.4	Parshad (1988)
Rice	Bb, Ti	FB/RUC, 1 BB	87.1	Bhadauria and Mathur (1995)
Sugarcane	Bb, Ti, Rm	FB, 1 GB	65.7	Parshad (1988)
		FB, 2 GB	85.6	Parshad (1988)
		RUC, 1 GB	54.6	Ahmad and Parshad (1991b)
		RUC, 1 BR	41.1	Ahmad and Parshad (1991b)
Houses	Rr, Mm	–	100.0	Srivastava et al. (1989)
Bromadiolone 0.005% bait				
Wheat	Bb, Rm Ti, Mm	FB, 1 GB	58.8	Sinhgal and Pasahan (1995)
		FB, 1 GB	52.5	Ahmad and Parshad (1989a)
		FB, 2 GB	78.8	Ahmad and Parshad (1989a)
		FB, 3 GB	97.5	Malhi et al. (1986)
Rice	Bb, Rm, Mb	FB, 1 GB	79.1	Christopher et al. (1984)
		RUC, 1 GB	71.8	Christopher et al. (1984)
		FB, 1 GB	67.7	Balasubramanyam et al. (1985)
	Bb, Ti	FB/RUC, 1 BB	91.1	Bhadauria and Mathur (1995)

Table 5. (*Continued*).

Rodenticide crop/premises	Predominant species	Formulation, number and method of treatment	Percent control	Reference
Groundnut	Ti, Bb, Rm	FB, 1 GB	40.9	Parshad et al. (1987b)
		FB, 2 GB	67.3	Parshad et al. (1987b)
Sugarcane	Bb, Rm	FB, 2 GB	77.1	Ahmad and Parshad (1989b)
		FB, 2 BR	69.8	Ahmad and Parshad (1989b)
		FB, 1 × 2 GB	75.1	Ahmad and Parshad (1991a)
		FB, 2 × 2 GB	84.3	Ahmad and Parshad (1991a)
	Bb	FB	99.6	Khatri et al. (1989)
	Bb	FB, 1 BB	97.6	Mathur and Bhadauria (1985)
	Bb	RUC, 1 BB	96.4	Mathur and Bhadauria (1985)
	BB, Rm	RUC, 1 BR	82.9	Srivastava (1995)
	BB	FB, 1 GB	90.0	Bhadauria and Singh (1996)
Fodder	Mh, Ti, Gg	FB	90.5	Mathur and Prakash (1984a)
Coconut	Rr	RUC, 1 CB	75.5	Advani (1986)
	Rr	FWC, 1 CB	100.0	Rao et al. (1984)
	Rrw	FB, 2 CB	100.0	Rangareddy (1995)
Stores	Rr	FB, 1 × 4 days	87.5	Maddaiah et al. (1987)
Houses	Mm, Rr	FB, 50 g/house	86.0	Shamsuddin and Abdulla Koya (1985)
Poultry farms	Rr, Mm	FB, 1 × 5 days PB	80.8	Parshad et al. (1987a)

Bb, *Bandicota bengalensis*; BB, Bburrow baiting; BR, Bait broadcasting; CB, Crown baiting; FB, Freshly prepared cereal bait; FWC, Freshly prepared wax cakes; GB, Ground baiting in the field; Gg, *Gerbillus gleadowi*; Mb, *Mus booduga*; Mh, *Meriones hurrianae*; Mm, *Mus musculus*; PB, Protective baiting in closed containers; Rm, *Rattus meltada*; Rr, *Rattus rattus*, Rrw, *Rattus rattus wroughtoni*; RUC, Ready-to-use wax cakes; Ti, *Tatera indica*.

and Jinda1 1991, Malhi and Kaur 1995). Bait acceptance is improved by the addition of 1–2% arachis oil (Ahmad and Parshad 1985b). Depending on field conditions baits can be: placed in burrows in vacant and fallow fields; placed at equal distances of about 10 m throughout the crop as in most agricultural crops (Parshad et al. 1987b, Malhi and Parshad 1995b); broad-casted as in sugarcane (Ahmad and Parshad 1991b); placed in the coconut crown or other strategic locations in trees (Rao et al. 1984, Sadakathulla and Kareem 1993) or placed in specially designed protective bait stations as in poultry farms or other premises (Parshad et al. 1987a). All these studies show that the selection of a suitable bait formulation, method and timing of application are important for delivering the rodenticides to the target rodent pests. In fact the development of second-generation anticoagulants and sustained and pulse baiting techniques has made it possible for individual farmers to save their crops from rodents, unlike in the past when large scale rodent control campaigns were considered essential.

Timings of rodent control

There are two basic approaches, that is prophylactic or lean period and symptomatic or crop period treatments that have been adopted for the use of rodenticides in India (Parshad 1992). The months of May and June and of November and December, which fall between two major crop seasons that is summer or *kharif* season and winter or *rabi* season, are termed as lean periods. During the lean periods most of the fields are vacant and rodents occur in bunds, dykes, water channels, fallow and uncultivated lands or in fields of long duration crops such as sugarcane and tree plantations. A prophylactic treatment, which breaks the natural cyclicity of rodents and prevents population explosion during the cropping season (Barnett and Prakash 1975), is carried out during the lean period. This is the case in rodent control campaigns in most parts of the country for which the rodenticide, generally the zinc phosphide, is supplied free of cost through different Government agencies. The rodenticides are generally placed in burrows and on the activity sites of rodents in the standing crops. During the lean period, food and shelter are scarce in crop lands and the rodents easily accept the poison baits in their burrows, this approach has been studied in an orchard (Malhi and Parshad 1994a) and in fields before rice transplantation (Malhi and Parshad 1993b). Burrow application of 2% zinc phosphide bait may result in about 80% rodent control (Parshad and Malhi 1995). Studies in Bangladesh showed that baiting of burrows in bunds and along roadways early in monsoon rice is effective in reducing rodent populations and damage to the crop (Sultana and Jaeger 1992). The months of May and June are also considered to be an effective period for the control of rodents as there is minimum reproductive activity during these months as shown in case of *B. bengalensis* (Srihari and Govinda Raj 1988), *T. indica* (Govinda Raj and Srihari 1987) and *M. platythrix* (Govinda Raj 1994). Killing the non-breeding populations of rodents during these months is particularly advantageous because with the monsoon rains in July and August the availability of abundant food both from crops and wild habitat may trigger a peak of reproduction and a population explosion coinciding with the maturity of *kharif* crops, mainly rice. Control of rodents in November and December is also useful in preventing population outbreaks in *rabi* crops, particularly in wheat.

Symptomatic control is designed to control rodents which begin to threaten the crop or storage material. Rodenticide treatments or trapping of rodents in premises is carried out on seeing signs of rodent activity such as their movements, faecal pellets and gnaw marks or actual damage to food and other articles. However, in croplands certain timings are considered suitable for rodent control operations: for example 30–60 days or 42–70 days after transplantation of rice (Rao and Singh 1983, Parshad 1989a, Baskaran et al. 1995); 80–100 days after planting of peanut (Parshad et al. 1987b); the late tillering stage of wheat (Rao 1992) and July–August and October–November in sugarcane (Parshad et al. 1986, Ahmad and Parshad 1991a), this is because during subsequent ripening stages the rodents avoid poison baits due to the availability of abundant food in the cereal and oil seed crops.

Economics

The economic injury level, the point which the application of control measures becomes economically justifiable, is equivalent to a loss of potential yield of 0.5–1.0% in peanut (Parshad et al. 1987b) and sugarcane (Parshad 1987, Ahmad and Parshad 1987). The estimated cost and benefit ratios of carrying out rodent control with different rodenticides are 1 : 8–1 : 25 in sugarcane (Ahmad and Parshad 1987), 1 : 18 and 1 : 24 in rice (Sridhara 1992), 1 : 26–1 : 38 (Ahmad and Parshad 1989a) and 1 : 247 in wheat (Advani et al. 1982), 1 : 49 in peanut (Mittal and Vyas 1992), 1 : 900 in some vegetables in the Rajasthan desert (Advani and Mathur 1982). 1 : 66–1 : 90 in watermelon fields (Kumar et al. 1997) and 1 : 23 in rural residential premises in Gujarat (Chaturvedi 1978) and 1 : 220 in Rajasthan (Prakash et al. 1981). Studies of the economics of rodent control on a poultry farm by Malhi et al. (1991) show that an expenditure of Rupees 311–439 (1 US$ = 40 Rupees) on trapping and poison baiting results in 90% control of rodents which cause damage equivalent to about rupees 1250 per month. The cost of the control operation is just 25% of the monthly loss caused by rodents on the poultry farm.

Integrated pest management and implementation

Despite significant advances in our knowledge of the biology and control of rodents in agriculture and rural and urban situations, the rodent problems continue to persist unabated with occasionally devastating effects. The present review of the available information on different control methods clearly reveals that techniques are now available which will give economical and effective rodent control in most situations. However, rodent control has not yet become an important component of crop production and storage strategies in India and elsewhere in South Asia. A more serious problem is the lack of an Integrated Pest Management (IPM) approach which would require an effective integration of different techniques of rodent control in an ecologically based control system (Rao 1992, Fiedler and Fall 1994). With changes in agro-climatic conditions and cropping patterns, rodents are showing changes in the distribution and abundance of different species (Parshad and Ahmad 1996). In fact, rodents are highly responsive to environmental conditions and their population and behaviour vary with the ecological, phenological and climatic conditions of the agro-ecosystem. These parameters form an important component of an IPM programme for rodent control, but our information on these aspects of the biology of South Asian rodent species is scanty. However, based on the existing knowledge of rodent populations during different seasons, the distribution and abundance of rodents during the crop cycle and reproductive cyclicity, the concept of IPM has been introduced to rodent control by suggesting control operations during the lean period and at specific times in different crops. However, its adoption is slow, more extension and a multi-media approach needs to be introduced to speed up adoption.

The major problems in the implementation of different technologies of rodent control are general neglect, a lack of awareness of economic losses, small land holdings which make rodent control campaigns difficult to organize over large areas, the low education and economic level of farmers and discouragement due to the frequent failure of rodent control operations as a result of the adoption of the wrong procedures of bait formulation and application (Malhi and Parshad 1988, Mathur 1992, Rana et al. 1994, Malhi 1998). Moreover, when compared to the considerable trained manpower and facilities provided for the transfer of other crop production and protection technologies to the farmers, the transfer of rodent control technologies continues to be neglected (Parshad 1992). Often the farmers consider rodents as minor or unmanageable pests and this perception contributes to their lack of interest and motivation to carry out effective rodent control.

Effective implementation of rodent control in agricultural, rural and urban situations requires long-term education and training programmes. Studies in several villages of Punjab (India) reveal that education and training of farmers along with the availability of rodenticides are effective in reducing by 75–85% damage to wheat and rice (Malhi and Parshad 1988, 1992b). Compared to a 1.5–2.0 quintals/hectare loss in yield of these crops in neglected villages only 0.38–0.48 quintals/hectare yield loss occurred in villages where the rodent control operations were effectively carried out with the participation of farmers. The impact of education and training of farmers in the adoption of rodent control is also evident from several similar studies carried in other parts of the country (see Mathur 1992, for review).

Recognizing the need to transfer the technology of rodent control several training programes such as ‘apex level training’ for senior Government officials, advanced training courses in plant protection for extension specialists, ‘subject matter specialist’s training courses’ for agricultural development and plant protection officers, village level training and field demonstrations and radio and television programmes on rodent control are being organized either exclusively on rodents or as part of some other major programme. The objective of this training is to disseminate proper information about rodent control and other agricultural practises to farmers. However, rodent control is seldom considered a priority by most of the trainees who generally lack formal education in rodent control and after their training are occupied with their other more important schedules. An analysis of participation on various training programmes on rodent control reveals, unfortunately, very poor response from personnel from different states and regions (Jain and Rao 1992). A well-organized agricultural service exists which greatly helped to improve agricultural production in the country. Economic support in the form of subsidies on metallic and non-metallic rat proof storage structures and a free supply of rodenticides considerably helped to reduce the problem (Girish et al. 1985, Save Grain Manual 1990) but the problem continues to persist in serious proportions. Several biological and socioeconomic factors interact in rodent control, these include complex behaviour of rodents, their diverse adaptation in different pest situations, the potential non-target hazards of rodenticides, self-protection mechanisms and responses of rodents to control techniques, complex social and religious perceptions, rodents as food sources to certain tribes, small land holdings with difficulties in organizing village level campaigns and low economic levels. Because of this complexity, the effective implementation of rodent control technologies, which have improved significantly during the last two decades, probably requires a special task force to plan, organize and conduct rodent control campaigns in agricultural, rural and urban situations. Specific extension education programmes and multi- media campaigns need to be launched to create interest and motivation among farmers about rodent pest problems and their management.

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