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Eco-friendly management of rice weevil (*Sitophilus oryzae* Linnaeus) on sorghum during storage

AR Bhargude, SK Patil and DR Kadam

Abstract
Among different plant products evaluated for their efficacy against rice weevil, *Sitophilus oryzae* Linnaeus for six months stored sorghum seeds, sweet flag rhizome powder @ 5% was found significantly superior in reducing 100 percent adult mortality, no seed damage, no seed weight loss and higher seed germination (85.67%) followed by neem seed kernel powder @ 5% with significant maximum adult mortality (85.00%), least seed damage (13.00%), lowest seed weight loss (5.16%) and higher germination percentage (74.33%). The effectiveness of next treatments *viz*., karanj seed powder @ 5%, neem leaf powder @ 5%, custard apple leaf powder @ 5% and karanj leaf powder @ 5% which shows less mortality (61.67, 51.33, 43.33 and 40.00%), less seed damage (28.67, 42.00, 51.33 and 54.00%), less weight loss (16.19, 22.50, 28.08 and 31.03%) and less germination (67.33, 60.67, 58.00 and 55.67%), respectively. Seed treated with tulsi leaf powder @ 5% and turmeric rhizome powder @ 5% was not found effective against rice weevil, which showed the least adult mortality (30.00 and 26.67%), more seed damage (64.33 and 67.33%), more weight loss (37.19 and 38.60%) and least germination (48.33 and 44.67%), respectively.

Keywords: sorghum, plant powders, rice weevil, adult mortality, seed damage

Introduction
Sorghum (*Sorghum bicolor* L. Moench) is an important food crop valued both for grains as well as fodder. It is also considered to be the fifth most important leading cereal crop in global production and is the dietary staple food for more than 500 million people of more than 30 countries. It is grown in Asia, Africa, Oceania and the U.S.A. (Kumar *et al*., 2010) [12]. In India area under grain sorghum were 4.96 million hectares and production at 4.95 million tones with national average productivity of 997 kg/ha. Maharashtra stands 1st in terms of area (2.17 M.ha.), production (1.81 M.t.) and productivity (834 kg/ha) (Anonymous, 2018) [1].
The grain is mostly used for food purposes (55%).
This grain is commonly eaten with the hull, which retains the majority of the nutrients. The fiber is used in wallboard, fences, biodegradable packaging materials and solvents (Bhandari *et al.*, 2015) [4]. It has a rich source of energy, containing about 75% complex carbohydrate, zinc, iron and rich in vitamin 'B' complex. Also an excellent substitute for wheat to meet gluten-free needs for those with celiac disease or gluten-intolerance and also a terrific substitute for traditional grain diets. Phenolic compounds present in grains possess antioxidant properties that are associated with the health benefits of grains and grain products (Kamatha *et al*., 2004) [9].
In recent years the storage problem has assumed importance in the case of high yielding varieties and hybrids of sorghum. The average loss of food grains in storage due to biotic and abiotic factors accounts for 10 per cent annually of which insects contributed about 2.5 to 5.0 per cent. Nearly 15 per cent grain stored after each harvest is believed to be lost due to attacks of rats, insects, mites and microbial agents (Walter, 1971) [20]. Major pests of storage sorghum are rice moth (*Corcyra cephalonica* Stainton), rice weevil (*Sitophilus oryzae* Linnaeus), maize weevil (*S. zeamais* Motschulsky) and angoumois grain moth (*Sitotroga cerealella* Olivier).
Rice weevil is the most destructive insect pest that originated from India and now it has cosmopolitan. Both, adults and grubs damage the grain on which they feed voraciously so the grain is rendered unfit for human consumption as well as for seed purposes. The grub stage is more injurious than an adult, it makes small hole into the grain, enters inside and feeds on the starchy content of the grain leaving only shell intact.

Rice weevil remains active throughout the year; however serious damage is caused from July to November. The important factor is moisture for its development. Under favorable condition, it can multiply in a large number. In case of heavy infestation there is a mass of broken grains. Sometimes black fungus also develops (Ghosh and Durbey, 2003) [1]. The losses of grains due to weevils are estimated to an average of 25 to 40 per cent after 100 days of storage (Ladang *et al*., 2008) [13]. Seed weight loss was reported to be the best indicator of economic loss from damage by rice weevils (Teshome *et al*., 1999) [19]. It has been found that rice weevil infestation alone resulted in sorghum grain damage upto 83.5 per cent for six months (Kudachi and Balikai, 2014) [11].

Larvae and adults are internal feeders affecting the quality and quantity of grains. Thus, unless control measures are taken, heavy infestations may take place. Additionally, the kernel damage caused by *S. oryzae* larvae enables other species, the external feeders, which are not capable of infesting sound grain, so increase the damage rapidly. Chemical control measures are accompanied by inherent risks such as toxic residues contaminating the grains, development of resistance by insects, toxicity to consumers and pollution of the environment.

The growing awareness of environment hazards due to synthetic insecticides has attracted attention towards the use of plant and animal products which are biodegradable, environment friendly and safe for the human health. There is an added advantage is the pest can't develop resistance against it. Various plant products have been tried with good degree of success as protectant against many stored grain pests (Shankar and Abrol, 2012) [17]. Many products of botanical origin have been proved to show insecticidal activity against stored grain pests. Many products of botanical origin such as leaves and seeds of neem and jatropha, garlic capsules have been proved to show insecticidal activity against stored insect-pest (Onu *et al.*, 2015) [14] as plant extracts have shown ovicidal, repellant, antifeedent and toxic effect in insects (Devi and Devi, 2011) [5]. Keeping in this view, the present study was undertaken to evaluate the efficacy of different botanicals against rice weevil (*S. oryzae* L.) in sorghum.

Materials and Methods

The present studies on ''Eco-friendly management of rice weevil (*Sitophilus oryzae* L.) on sorghum during storage'' was carried out under laboratory in ambient conditions during July, 2019 to December, 2019 at Department of Agricultural Entomology, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431402 (Maharashtra), India.

Rice weevil culture

The initial culture of rice weevil, *Sitophilus oryzae* Linnaeus (Coleoptera : Curculionidae) was obtained from the Sorghum Research Station, VNMKV, Parbhani. To initiate the culture, healthy seeds of sorghum were kept in to 32 cm × 22.5 cm size cylindrical jar and 10 pairs of adult weevils were isolated and released into the jar. The mouth of the container was covered with a muslin cloth secured firmly by a rubber band. Fresh seeds were provided periodically for the development of weevils. After few days the new adult weevils emergence, the weevils were introduced into healthy sorghum seeds kept in series of cylindrical jars for building up a homogenous population. The density of population per jar was standardized to prevent overcrowding of weevils which was reported to give rise to less reproductive active forms (Sano, 1967) [16].

Treatment details

The different plant parts of various botanicals *viz*., Neem, *Azadirachta indica* A. Juss) (Leaves),Tulsi, *Oscimum basilicum* L. (Leaves), Custard apple, *Annona squamosa* L. (Leaves), Karanj, *Pongamia glabra* L. (Leaves), Neem, *Azadirachta indica* A. Juss.(Seed), Karanj, *Pongamia glabra* L. (Seed), Turmeric, *Curcuma longa* L.(Rhizome) and Sweet flag, *Acorus calamus* L. (Rhizome) with a dose of each 5 per cent evaluated for their efficacy against S. oryzae in sorghum in the present study.

Preparation of powder

The leaves of Neem, Tulsi, Custard apple and Karanj were collected and shade dried for a week then ground into powder. Kernels of Neem and Karanj were collected and made into powder using a grinder. Rhizomes of sweet flag and turmeric were procured from local market and made into bits and shade dried for a week then ground into powder.

Methodology:

The experiment was carried out in a complete randomized design (CRD) with three replications comprising 8 plant products treatments compared with untreated control in ambient storage conditions at different storage periods. Sorghum seeds of variety Parbhani Shakti were used to carry out the experiment. The seeds were sterilized at 60+2^{0}C for four hours to eliminate both apparent and hidden infestation, if any. Sorghum seeds were weighed and kept in a medium sized (250 g capacity) plastic container at the rate of 100 g each. 5 g powder of each treatment was added to the respective plastic containers and mixed thoroughly by shaking the containers. Twenty (10 pairs) newly emerged adults of rice weevil from the pure culture were released in each of the containers containing treated seeds and allowed to feed and oviposit.

Record of observations

As per the treatments, plant products that showed promising results were recorded at every month for upto six months. The purpose of the experiment was to find any change in their effectiveness against the weevil due to storage conditions. Data were recorded on adult mortality of insects released by using sieve (mesh size 10) to separate the weevils. After taking counts on dead insects, the live ones were transferred to the irrespective containers. All the adults (both dead and live) were removed and again ten pairs of adults were released each time for calculation of per cent adult mortality.

The observations on per cent damaged seeds, per cent weight loss and germination percentage was calculated on the following formulae:

$$\text{Seed damage (\%)} = \frac{\text{Initial No. of grains} - \text{Final No. of damaged grain}}{\text{Initial No. of grains}} \text{X } 100$$

$$\text{Weight loss (\%)} = \frac{\text{Initial wt. of sound grains - Final wt. damaged grains}}{\text{Initial wt. of sound grains}} \text{ x } 100$$

$$\text{Germination (\%)} = \frac{\text{Number of grains germinated}}{\text{Total number of grains used}} \text{ x}100$$

Statistical analysis

The data obtained from different treatments were subjected to statistical analysis as per the statistical guidelines by Gomez and Gomez (1984) [6]. The results were transformed to arc sine values wherever necessary. The significance of treatment was tested by critical difference (C.D.) at 5 per cent level of significance for the comparison among the treatments, for which the marginal means of each treatment were considered. Appropriate transformations were applied to the data obtained from the present studies.

Results and Discussion

The data collected concerning adult mortality of *S. oryzae*, seed damage, seed weight loss and germination percentage in sorghum as influenced by various plant products at 30, 60, 90, 120, 150 and 180 days after storage and results are presented in Table 1-4 and depicted in Fig.1.

Table 1: Adult mortality of rice weevil as influenced by different botanicals in sorghum seeds

Sr. No.	Treatments	Adult mortality (%)						
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	Mean
1.	Neem leaf powder 5%	76.67 (61.12)	75.00 (60.00)	73.33 (58.91)	65.00 (53.73)	58.33 (49.80)	51.33 (45.96)	66.67 (54.74)
2.	Tulsi leaf powder 5%	36.67 (37.27)	35.00 (36.27)	33.33 (35.26)	35.00 (36.27)	31.67 (34.24)	30.00 (33.21)	33.61 (35.43)
3.	Custard apple leaf powder 5%	61.67 (51.75)	58.33 (49.80)	55.00 (47.87)	51.67 (45.96)	48.33 (44.04)	43.33 (41.17)	53.06 (46.75)
4.	Karanj leaf powder 5%	58.33 (49.80)	60.00 (50.77)	53.33 (46.91)	48.33 (44.04)	46.67 (43.09)	40.00 (39.23)	51.11 (45.64)
5.	Neem seed kernel powder 5%	100.00 (90.00)	100.00 (90.00)	98.33 (82.58)	96.67 (79.48)	93.33 (75.04)	85.00 (67.21)	95.56 (77.83)
6.	Karanj seed powder 5%	76.67 (61.12)	80.00 (56.79)	75.00 (60.00)	68.33 (55.75)	65.00 (53.73)	61.67 (51.75)	71.11 (57.49)
7.	Turmeric powder 5%	36.67 (37.27)	35.00 (36.27)	31.67 (34.24)	33.33 (35.26)	30.00 (33.21)	26.67 (31.09)	32.22 (34.59)
8.	Sweet flag powder 5%	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
9.	Untreated check	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
S.E. (m) ±		1.36	1.47	1.24	1.57	1.24	1.11	0.60
C.D. at 5%		4.08	4.40	3.72	4.71	3.72	3.33	1.80
C.V. (%)		3.88	4.22	3.72	4.92	4.09	3.95	1.86

Figures in parentheses are arcsine transformed values,
DAS- Days after storage

Table 2: Seed damage by rice weevil as influenced by different botanicals in sorghum seeds

Sr. No.	Treatments	Seed damage (%)						
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	Mean
1.	Neem leaf powder 5%	7.00 (15.34)	14.33 22.25)	20.33 (26.80)	29.00 (32.58)	34.33 (35.87)	42.00 (40.40)	24.50 (29.67)
2.	Tulsi leaf powder 5%	11.33 (19.67)	19.33 (26.08)	29.67 (33.00)	37.33 (37.66)	51.67 (45.96)	64.33 (53.33)	35.61 (36.64)
3.	Custard apple leaf powder 5%	8.33 (16.78)	15.67 (23.32)	24.33 (29.56)	31.67 (34.24)	40.33 (39.43)	51.33 (45.76)	28.61 (32.34)
4.	Karanj leaf powder 5%	8.67 (17.12)	16.33 (23.84)	25.00 (30.00)	33.33 (35.26)	42.33 (40.59)	54.00 (47.29)	29.94 (33.18)
5.	Neem seed kernel powder 5%	1.67 (7.43)	2.33 (8.79)	4.33 (12.01)	5.67 (13.77)	8.67 (17.12)	13.00(21.13)	5.95 (14.11)
6.	Karanj seed powder 5%	5.33 (13.35)	9.33 (17.79)	14.33 (22.25)	19.67 (26.33)	21.33 (27.51)	28.67 (32.37)	16.44 (23.92)
7.	Turmeric powder 5%	9.67 (18.12)	18.00 (25.10)	30.33 (33.42)	40.00 (39.23)	53.33 (46.91)	67.33 (55.14)	36.44 (37.13)
8.	Sweet flag powder 5%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
9.	Untreated check	17.33(24.60)	26.00(30.66)	32.67(34.86)	47.33(43.47)	68.67(55.96)	83.67(66.16)	45.95(42.67)
S.E. (m) ±		0.29	0.39	0.48	0.61	0.76	2.56	0.96
C.D. at 5%		0.88	1.15	1.45	1.82	2.28	0.85	0.32
C.V. (%)		6.61	4.95	4.17	3.89	3.70	3.29	2.24

Figures in parentheses are arcsine transformed values,
DAS- Days after storage

Table 3: Loss in weight due to rice weevil as influenced by different botanicals in sorghum seeds

Sr. No.	Treatments	Weight Loss (%)						
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	Mean
1.	Neem leaf powder 5%	1.50 (7.03)	5.15 (13.12)	9.76 (18.20)	14.96 (22.76)	18.46 (25.45)	22.50 (28.32)	12.06 (20.32)
2.	Tulsi leaf powder 5%	4.32 (12.00)	11.64 (19.95)	20.93 (27.23)	27.22 (31.45)	31.79 (34.32)	37.19 (37.58)	22.18 (28.10)
3.	Custard apple leaf powder 5%	2.28 (8.69)	6.37 (14.62)	12.04 (20.30)	18.68 (25.61)	21.67 (27.74)	28.08 (32.00)	14.85 (22.67)
4.	Karanj leaf powder 5%	3.90 (11.38)	8.92 (17.38)	16.45 (23.93)	22.30 (28.18)	27.75 (31.79)	31.03 (33.85)	18.39 (25.39)
5.	Neem seed kernel powder 5%	0.00 (0.00)	0.00 (0.00)	1.17 (6.21)	2.56 (9.21)	3.72 (11.12)	5.16 (13.13)	2.10 (8.33)
6.	Karanj seed powder 5%	1.35 (6.66)	4.18 (11.80)	6.77 (15.08)	10.21 (18.63)	13.92 (21.91)	16.19 (23.73)	8.77 (17.23)
7.	Turmeric powder 5%	4.90 (12.79)	12.06 (20.32)	21.83 (27.85)	29.96 (33.19)	32.84 (34.96)	38.60 (38.41)	23.37 (28.91)
8.	Sweet flag powder 5%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
9.	Untreated check	6.03 (14.21)	14.68 (22.53)	26.60 (31.05)	35.79 (36.74)	41.63 (40.18)	50.05 (45.03)	29.13 (32.66)
S.E. (m) ±		0.38	0.46	0.46	0.44	0.41	0.38	0.20
C.D. at 5%		1.14	1.39	1.38	1.31	1.23	1.43	0.61
C.V. (%)		8.17	6.05	4.21	3.31	2.80	2.36	1.73

Figures in parentheses are arcsine transformed values,
DAS- Days after storage

Table 4: Germination of sorghum seeds as influenced by different botanicals used for the management of rice weevil

Sr. No.	Treatments	Germination (%)						
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	Mean
1.	Neem leaf powder 5%	83.33 (65.91)	80.67 (63.92)	76.67 (61.12)	71.67 (57.84)	64.33 (53.33)	60.67 (51.16)	72.89 (58.62)
2.	Tulsi leaf powder 5%	77.33 (61.57)	72.33 (58.27)	69.00 (56.17)	61.67 (51.75)	55.67 (48.26)	48.33 (44.04)	64.06 (53.17)
3.	Custard apple leaf powder 5%	81.00 (64.16)	79.33 (62.96)	73.67 (59.13)	68.00 (55.55)	62.67 (52.34)	58.00 (49.60)	70.45 (57.07)
4.	Karanj leaf powder 5%	79.67 (63.20)	77.33 (61.57)	71.33 (57.63)	65.33 (53.93)	60.33 (60.33)	55.67 (48.26)	68.28 (55.72)
5.	Neem seed kernel powder 5%	86.67 (68.58)	84.33 (66.68)	81.33 (64.40)	78.67 (62.49)	76.33 (60.89)	74.33 (59.56)	80.28 (63.63)
6.	Karanj seed powder 5%	83.33 (65.91)	80.67 (63.92)	78.33 (62.26)	75.33 (60.22)	70.33 (57.00)	67.33 (55.14)	75.89 (60.59)
7.	Turmeric powder 5%	79.00 (62.73)	71.67 (57.84)	67.33 (55.14)	61.67 (51.75)	53.33 (46.91)	44.67 (41.94)	62.95 (52.50)
8.	Sweet flag powder 5%	91.67 (73.22)	88.67 (70.33)	88.33 (70.03)	86.33 (68.30)	86.00 (68.03)	85.67 (67.75)	87.78 (69.54)
9.	Untreated check	71.33 (57.63)	66.67 (54.74)	60.67 (51.16)	56.00 (48.45)	47.67 (43.66)	38.33 (38.25)	56.78 (48.90)
S.E. (m) ±		0.65	0.88	0.73	0.90	0.66	0.71	0.41
C.D. at 5%		1.94	2.63	2.18	2.68	1.97	2.11	1.24
C.V. (%)		1.94	2.44	2.11	2.73	2.13	2.41	1.24

Figures in parentheses are arcsine transformed values,
DAS- Days after storage

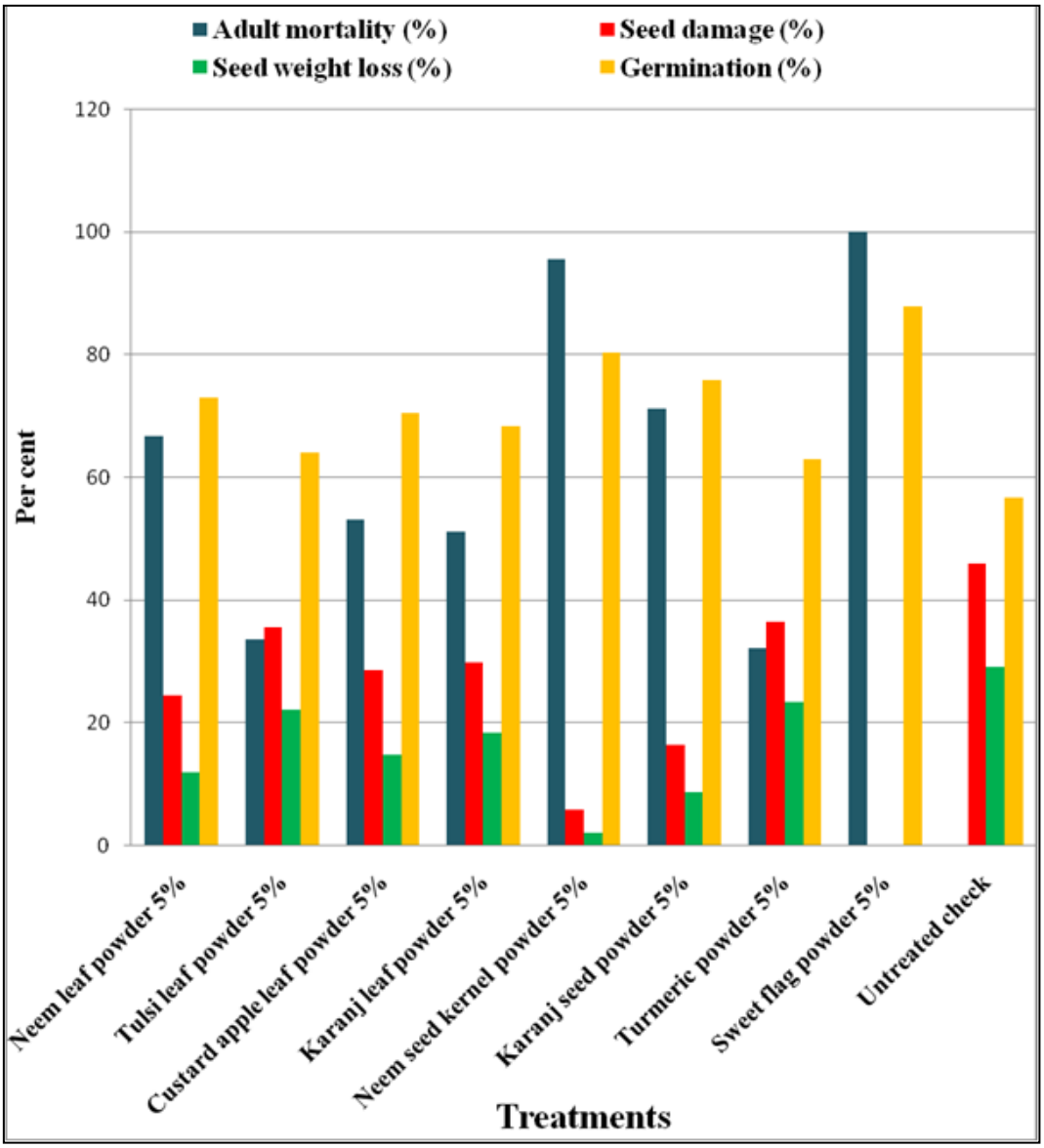

Fig 1: Adult mortality, Seed damage, weight loss and germination of sorghum seeds as influenced by different botanicals used for the management of rice weevil

a) Adult mortality

Among the tested botanicals, sorghum seed treated with sweet flag rhizome powder @ 5% was found significantly superior in reducing 100 per cent adult population at monthly interval upto 180 days. The next best botanical was neem seed kernel powder @ 5% caused 100 per cent mortality of adult insects up to 60 days and thereafter it was reduced by 98.33 to 85.00 per cent up to 180 days.

The least effective botanicals were tulsi leaf powder @ 5% and turmeric rhizome powder @ 5% which were reduced

population from 36.67 to 30.00 and 36.67 to 26.67 per cent respectively. Rest of the botanical treatments *viz*., karanj seed powder @ 5%, neem leaf powder @ 5%, custard apple leaf powder @ 5% and karanj leaf powder @ 5% were corded adult mortality by 76.67 to 61.67, 76.67 to 51.33, 61.67 to 43.33 and 58.33 to 40.00 per cent at monthly interval up to 180 days of storage, respectively. No adult mortality was recorded in untreated check.

As regard of mean adult mortality, the significantly best treatment was sweet flag rhizome powder @ 5% which was retained its residual toxicity and caused significantly maximum adult mortality (100.00%). However the effectiveness of rest of the botanicals in descending order was neem seed kernel powder @ 5% (95.56%) > karanj seed powder @ 5% (71.11%) > neem leaf powder 5% (66.67%) > custard apple leaf powder 5% (53.06%) > karanj leaf powder 5% (51.11%) > turmeric rhizome powder @% (32.22%) > untreated check (0.00%).

The present findings are in line with Kudachi and Balikai (2009) [10], they showed that sweet flag rhizome powder had 100 per cent mortality of *S. oryzae* and lowest mortality rate observed in turmeric rhizome powder 5% (38.22%). Jadhav (2006) [7], also reported that sweet flag storage caused cent per cent mortality of *S. oryzae* in pop sorghum upto 180 days after. Further, Biradar (2000) [3] reported that sweet flag rhizome extract 5 per cent v/v at 30 days after storage offered 100 per cent mortality of rice weevil. Arve *et al.* (2013) [2] revealed that neem seed @ 5g/100g (91.86%) have highest per cent mortality and lowest mortality recorded in control with 6.67 per cent followed by tulsi @ 1 g/100g (19.06%) and turmeric @ 1 g/100g (21.10%).

b) Seed damage

The seed treated with sweet flag rhizome powder @ 5% was noticed no infestation of the pests upto 180 days storage. The next significantly best treatment was neem seed kernel powder @ 5% which was recorded seed damage of 1.67 to 13.00 per cent at monthly interval up to 180 days. The maximum seed damage was recorded in turmeric rhizome powder @ 5% (9.67 and 18.00%) and tulsi leaf powder @ 5% (11.33 and 19.33%) at 30 and 60 days, respectively and thereafter tulsi leaf powder @ 5% and turmeric rhizome powder @ 5% recorded damage by 29.67 to 64.33% and 30.33 to 67.33% after 90 to 180 days, respectively. The treatments *viz*., karanj seed powder @ 5% (5.33 to 28.67%), neem leaf powder @ 5% (7.00 to 42.00%). custard apple leaf powder @ 5% (8.33 to 51.33%), karanj leaf powder @ 5% (8.67 to 54.00%) was found effective in reducing the seed damage caused by the *S. oryzae* from 30 day an interval up to 180 days. Significantly maximum damage was noticed in untreated check (17.33 to 83.67%, respectively).

As regards mean per cent seed damage, sweet flag rhizome powder @ 5% protected seeds from *S. oryzae* with 100 per cent protection followed by neem seed kernel powder @ 5% (5.95%) showing best results. The treatments *viz*., karanj seed powder @ 5%, neem leaf powder @ 5%, custard apple leaf powder @ 5% and karanj leaf powder 5%, damage was 16.44, 24.50, 28.61 and 29.94 per cent, respectively. While maximum damage was noticed in untreated check (45.95%) followed by turmeric rhizome powder @ 5% (36.44%) and tulsi leaf powder @ 5% (35.61%).

These results are in conformity with the results of Jadhav (2006) [7] who reported that no seed damage was reported after six month of treatment when treated with sweet flag rhizome powder @ 1% while neem seed powder @ 5% recorded significantly less percentage of damaged seeds. Sunilkumar *et al.* (2005) [18] reported that, sweet flag rhizome powder and custard apple seed powder recorded significantly minimum damage to seeds with 17.20 and 20.00 per cent, respectively followed by neem seed powder @ 1% (21.00%) against *S. oryzae* in sorghum at 180 days after storage. Kudachi and Balikai (2009) [10] also reported that, sweet flag rhizome powder 1% showed zero per cent seed damage and neem seed powder @ 5% (3.33%) and highest damage recorded in tulsi leaf powder @ 5% (36.69%) and turmeric powder @ 5% (34.78%) against *S. oryzae* in sorghum at 180 days after storage. Also Bhanderi *et al*. (2015) [4] reported that, the plant products *viz*., sweet flag powder, custard apple seed powder and neem seed powder were the most effective and kharanja leaf powder, adsali leaf powder, tulsi leaf powder and turmeric powder were found to be least effective.

c) Weight loss

There was no weight loss recorded in seeds treated with sweet flag rhizome powder @ 5% and neem seed kernel powder @ 5% upto 60 days of storage. Thereafter, sweet flag rhizome powder @ 5% was also found free from weight loss of seed and neem seed kernel powder @ 5% was recorded less weight loss i.e. 1.17 to 5.16 per cent upto 180 days. Other botanicals *viz*., karanj seed powder @ 5%, neem leaf powder @ 5%, custard apple leaf powder @ 5%, karanj leaf powder @ 5%, tulsi leaf powder @ 5% and turmeric rhizome @ 5% were significantly reduced weight loss by 1.35 to 16.19, 1.50 to 22.50, 2.28 to 28.08, 3.90 to 31.03, 4.32 to 37.19 and 4.90 to 38.60 per cent as against untreated check (6.03 to 50.05%), respectively upto 180 days of storage of sorghum seed .The average weight loss caused by *S. oryzae* in descending order of their efficacy was sweet flag rhizome powder @ 5% (0.00%) > neem seed kernel powder @ 5% (2.10%) > karanj seed powder @ 5% (8.77%) > neem leaf powder @ 5% (12.06%) > custard apple leaf powder @ 5% (14.85%) > karanj leaf powder @ 5% (18.39%) > tulsi leaf powder @ 5% (22.18%) > turmeric rhizome powder @ 5% (23.37%) > untreated check (29.13%).

The results of the present investigation was in agreement with the finding of Jadhav (2006) [7] who revealed that sweet flag @ 1% resulted no loss in seed weight followed by minimum weight loss of sorghum seeds when treated with neem seed powder @ 5% followed by karanj seed powder @ 5%. As per the report of Kalasagond (1998) [8], sweet flag in addition to being toxic to the adult weevils, also provides repellent action against F1 progeny and hence no weight loss observed in seeds. Bhanderi *et al.* (2015) [4] who recorded no weight loss of sorghum seeds when treated with sweet flag powder @ 5% and highest weight loss in untreated check (50.9%) and turmeric rhizome powder @ 5% (45.11%) and tulsi leaf powder @ 5% (46.46%).

d) Seed germination

All the treatments were recorded germination above Indian Minimum Seed Certification Standard (IMSCS) i.e.75 per cent in the range of 91.67 to 77.33 per cent except untreated check (71.33%) at 30 days of storage of sorghum seed. The treatment sweet flag rhizome powder @ 5% was recorded highest germination (88.67 to 85.67%) above IMSCS i.e.75 per cent upto 180 days followed by neem seed kernel powder @ 5% (84.33 to 74.33%). Next best treatment i.e. neem seed kernel powder @ 5% (80.67 to 76.67%) and karanj seed

powder @ 5% (80.67 to 67.33%) which was recorded seed germination above IMSCS i.e.75 per cent at 90 and 120 days of storage and thereafter it was reduced up to 97.33 and 60.67 per cent up to 180 days, respectively and least germination was recorded in untreated check (38.33%).

Over 180 days of storage of sorghum seeds, in order of merit of germination was sweet flag rhizome powder @% (87.78%) > neem seeds kernel powder @ 5% (80.28%) > karanj seed powder powder @ 5% (75.89%) > neem leaf powder @ 5% (72.89%) > custard apple leaf powder @ 5% (70.45%) > karanj leaf powder @ 5% (68.28%) > tulsi leaf powder @ 5% (64.06%) > turmeric rhizome powder @ 5% (62.96%) > untreated seed (56.78%).

The present results are in accordance with the finding reported by Sunilkumar *et al*. (2005) [18], who recorded maximum germination in sorghum seeds treated by sweet flag rhizome powder @ 1% (82.00%). Jadhav (2006) [7] also recorded highest germination percentage of sorghum seeds which was treated with sweet flag powder @ 5% (89.25%) and lowest in turmeric rhizome powder 5% (60.23%) and tulsi leaves powder @ 5% (45.15%). Similar results was reported by Kudachi and Balikai (2009) [10] showing sorghum seeds had highest viability treated with sweet flag 1% (85.9%) had highest germination percentage followed by neem seed kernel powder 5% (81.40%) and minimum in turmeric rhizome and tulsi leaves powder 5% (58.3% to 66.9%). Padmasri *et al*. (2016) [15] revealed that seeds treated with *Acorus calamus* rhizome powder @ 10 g/kg seed had recorded highest germination percentage (85.67). The maximum germination in these treatments may be due to minimum damage to seeds when treated with these botanicals.

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