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Susceptibility of Aromatic and Non-aromatic Rice to *Sitophilus oryzae* L. and their Influence on the Insect and Infestation Rate under Sub-Himalayan Plains of West Bengal

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Authors' contributions

This work was carried out in collaboration among all authors. Author TKH designed the study. Author SB wrote original draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Relative susceptibility of local aromatic and non-aromatic rice grains to rice weevil, *Sitophilus oryzae* L. (Curculionidae, Coleoptera) was studied under laboratory conditions in the sub-Himalayan plains of West Bengal in two seasons (viz. winter and spring-summer) during 2020-

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2021. Results revealed that after 9 weeks of storage, the highest mean grain weight loss due to *S. oryzae* varied from 14.30% to 20.89% in the two types of rice grains in two seasons. The corresponding highest mean grain damage % ranged from 36.89 % to 41.56%. The grain weight loss and grain infestation % were always higher in the aromatic rice (Uttar Sugandhi) compared to non-aromatic rice (Jaldhepa) and also in the spring-summer season than the winter months. Carbohydrate and protein content of grains were reduced to the extent of 9.08% to 15.28% and 18.62% to 32.58% in aromatic and non-aromatic rice during winter and spring-summer seasons respectively as a result of infestation of *S. oryzae*. During winter and spring-summer seasons, from 5 pairs of adult weevils, a total of 188.60 and 142.20 and 264 and 237 number of adults were produced in aromatic and non-aromatic rice cultivars respectively at 9 weeks after their release. The adult population was always female biased.

Keywords: Sitophilus oryzae; aromatic rice; grain loss; carbohydrate and protein content.

1. INTRODUCTION

Cereal grains are the major sources of proteins and carbohydrates of human diet [1]. Among cereals, rice is the staple food of Indian population and also half of the world's population (Oko et al., 2012). Apart from protein and carbohydrates, it also contains calcium, iron, zinc, fibre, magnesium, manganese, selenium, B vitamins and other nutrients [2]. Rice weevil has got economic importance. It is the most destructive insect pest originated from India and now it has a cosmopolitan [3]. In developing countries, rice supplies food equivalent to 715 kcal/capita/day, 27% dietary energy, 20% dietary protein and 3% of dietary fat [4]. Rice is stored for an extended period and grain losses in stores are the severe problems in the world [5]. Due to substantial post-harvest loss of grains inflicted by stored grain pests, long duration storage of cereals and other products is often not possible [6]. During post-harvest period grain losses vary from 12-16 million metric tons every year in India [7]. Loss of grains due to stored insect pests in storages vary from 9-20% in the developed and developing countries in the world (Gad et al., 2022) [8]. The damage to stored grains and products is about 20-30 % in the tropical region whereas it is 5-10 % in the temperate areas of the world [9,10]. In India, about 6.5% of the total grains stored are consumed by pests (Raju, 1984). Among stored grain pests, coleopteran insects are the predominant ones and among storage grain beetles, rice weevil (*Sitophilus oryzae* L.) (Curculionidae, Coleoptera) is one of the most significant and economic insect pests of stored grains and their products [11]. It is especially destructive to numerous cereal grains namely wheat, rice, maize, barley and cereal-based products causing substantial losses, both quantitatively and qualitatively and the insect though abounds in warm and tropical areas of the world, it thrives well in the cooler region [12-14].

In India, though basmati rice is predominantly cultivated in Himachal Pradesh (60%) followed by Uttar Pradesh (17.1%) and Punjab (16.1%), hundreds of indigenous short grain aromatic cultivars and landraces are cultivated in localized areas of different states and almost every state has its own collection of aromatic rice that perform well in their native areas [15,16,17]. West Bengal also has a long tradition of growing non-basmati rice in some pockets and the state was rewarded for two aromatic rice cultivars viz. Badshah Bhog and Radhunipagal (localized in Malda and Nadia district respectively) [2]. In the sub-Himalayan plains of West Bengal *e.g.* the terai zone, many local aromatic rice landraces are grown besides the usual non-aromatic types and farmers store the harvested rice for a considerable period for their domestic use as well as commercial purposes [18,19]. The warm humid climate of this region is suitable for the infestation of stored grain pests, especially the rice weevil (*S. oryzae).* However, there is lack of information on the extent of loss due to rice weevil to the local aromatic and non-aromatic rice. Hence, the study was undertaken to see the seasonal variation in infestation in stored rice, deterioration in their quality parameters and the rate of development of insects.

2. MATERIALS AND METHODS

The experiment was conducted in two seasons viz. winter (November, 2020- January, 2021) and summer season (March, 2021- April, 2021).

2.1 Maintenance of Pure Culture of Rice Weevil, *Sitophilus oryzae* L.

Original pure culture of *S. oryzae* maintained at the Department of Entomology was used for the study. Ten pairs of adults (5 days old) were released (male and female ratio 1 :1) in 500 g of fresh, disinfested rice grains kept in the plastic containers (2 litre capacity) which were covered with muslin cloth and maintained at room temperature under dark environment for egg laying. Released adults were removed from the containers after 48 hours to avoid the overlapping generation. Five similar sets were made for obtaining good no. of adults. Weevils used for the experiment were those emerged from this fresh culture. Fresh rice grains were supplied in the container at regular intervals for proper development of the adults. For releasing same age -weevils in pairs, the male and female adults were sexed following the taxonomic keys as per Rees (2004) and Halstead (1963).

For the study, 25 g of fresh, bold and un-infested rice grains of each type viz. local aromatic- Uttar Sugandhi (KNS-3-1 developed from Kalonunia, a local aromatic rice landrace) and local non-aromatic rice– Joldhepa (a local landrace) were taken in a plastic container (250 g capacity). The rice grains were sterilized in a UV chamber for 30 minutes to kill/ eliminate any inhabiting insect stages or pathogen. Five pairs (male: female - 1:1) of newly emerged adults (5 days old) of *S. oryzae* were released in each of the containers covered with a piece of muslin cloth and tied with a rubber band for proper aeration and were kept under black curtain to create a dark environment for normal activity and proper development of the insects. The containers were maintained in the laboratory (under normal room temperature and humidity with 14: 10 h (light: dark) photoperiod) throughout the course of the study which was extended for nearly two months. The experiment was laid out in a CRD design with five replications. Each container was examined periodically and the record of losses of weight of grains and number of damaged grains were taken at weekly intervals. Total no. of adults emerged from each of the containers (i.e. replication) were counted and sexed at 9 weeks after release of the adults.

Various physical parameters of the rice grains viz. length, breadth, moisture content (%), 100 grain weight were estimated before the initiation of the experiment. Similarly biochemical parameters namely initial and final protein (%) and carbohydrate content (%) of the grains were estimated.

2.2 Estimation of Loss of Grain Due to Infestation of *Sitophilus oryzae*

Weight loss %: Weight loss of grains was estimated at weekly intervals for consecutive 9 months.

Weight loss of grains was worked out following the formula of Adams and Schulton (1978):

$$\textbf{Weight loss (\%)} = \frac{(UND) - (DNU)}{U\,(ND + NU)} \times 100$$

where,
U - Weight of un-infested grains (g), NU - Number of un-infested grains, D - Weight of infested grains (g) and ND - Number of infested grains

Grain damage%: It was estimated as per the following method:

$$\textbf{Pe Grain damage (\%)} = \frac{\text{Number of damaged grains}}{\text{Total number of grains}} \times 100$$

Moisture percentage (%) of grain: The moisture percentage (%) of grains was determined by using High Constant Temperature Oven method. The procedures followed are mentioned below.

$$\text{Grain moisture \%} = \frac{M2-M3}{M2-M1} \times 100$$

where,
M1= Weight of the weighing container with cover in gm.
M2=Weight of the weighing container with cover and rice grains before drying.
M3=Weight of the weighing container with cover and rice grains after drying.

Length and breadth of rice grains: The length and breadth of ten randomly collected grains were measured in mm with the help of a digital Vernier- caliper and the average length and breadth of rice grains were worked out. For length, two terminal tips of the grains were considered while the middle part of the grain was taken into account for the breadth.

100 grain weight (g): Hundred (100) grains were taken from the seed lot and weighed (g) by an electronic weighing balance (METTLER TOLEDO, ME 104)

2.3 Estimation of the Biochemical Parameters of Rice Grains

Total carbohydrate: The total carbohydrate content was estimated following the Anthrone method (Sadasivam,1996) using glucose as a standard.

Total protein: The protein content from the grain powder was determined following the method of Bradford (1976).

Agro climatic condition of the Experimental area: The agro-climatic condition of this zone is characterized by high rainfall and high relative humidity with moderate temperature. The minimum and maximum temperature varied from 24℃ to 33℃. The average rainfall of this zone 3000mm. Maximum and minimum relative humidity is varied from 70-88% and 39-62% respectively.

3. RESULTS AND DISCUSSION

3.1 Grain Weight Loss (%)

The results presented in Table – 1 and Table-2 revealed that the highest % weight loss of grains due to *S. oryzae* in aromatic (Uttar Sugandhi) and non-aromatic (Jaldhepa) cultivars was 14.99% and 13.61% during winter months whereas the corresponding loss was 21.48 % and 20.31 % during - Spring-summer seasons, respectively. Thus, grain weight loss % was significantly greater in aromatic rice than non-aromatic type and it was also more in spring – summer season compared to winter months. It was observed that grain weight loss (%) increased at each interval of weeks. During winter season grain weight loss % was below 5% upto 5 WAS (weeks after storage) (3.07% and 3.05 % in aromatic and non-aromatic rice respectively). However, with successive increase at each interval of weeks, the weight loss figures rose to 14.99 % and 13.61% respectively after 9 WAS i.e. after two months. In spring-summer season, the weight loss was more than 5% at 5 WAS (8.16 % and 7.70%) in Uttar Sugandhi and Jaldhepa respectively and the grain weight loss was maximum at 9 WAS (21.48% and 20.31% respectively).

3.2 Grain Damage %

Grain damage due to rice weevil was in greater proportion compared to weight loss of grain (Tables 2 and 3). In winter, grain infestation was greater than 5% after 1 WAS in both the cultivars (5.41 % and 5.30% in Uttar Sugandhi and Jaldhepa respectively) and it went on increasing at each interval of weeks. After 5 WAS, the corresponding % loss of grain was 10.35 % and 9.55 % respectively. The grain damage % increased to 38.26% and 35.53% in Uttar Sugandhi and Jaldhepa respectively at 9 WAS. Similarly, compared with winter season, grain infestation was higher in both the cultivars in spring- summer season. Within 1st week of exposure of the grains to the weevils the % infested grain was 7.46 % and 10.13 % in aromatic and non- aromatic rice cultivars respectively and there was also an increase in infestation at each subsequent week. At 5 WAS the infestation % was 23.00 % and 22.92% respectively and finally at 9 WAS the corresponding figures were 42.29% and 40.84% respectively. Thus, grain infestation was always higher in aromatic rice than non-aromatic one. The results are in conformity with Khan and Halder [20] who observed that with increase in storage period of rice there was a gradual increase in infestation % of rice grains. Mondal and Chakraborty [21] and Okram [5] also reported that rice grain weight loss (%) and damage (%) increased as the storage duration was prolonged and the loss reached the maximum after 60 days and 90 days respectively.

There are numerous reports on the % weight loss of grains due to *S. oryzae* and the reports vary in the extent of loss/ damage. Bhuiyan et al. [22] observed that after 120 days of storage, *S. oryzae* caused 11-16% weight loss in husked rice. Mondal and Chakraborty [21] observed 5.1-21.16% and 12.6- 35. 8% weight loss in non-basmati and basmati rice varieties respectively as a result of infestation by rice weevil for a storage time of 60 days. Okram [5] also found that after 90 days of storage, weight loss % of grains were 21.11% in winter and 29.16% in summer. Mehta et al. [23] obtained 2.66 ± 0.53 % to 14.82 ± 0.38 % and 9.92 ± 4.85 % to 27.16 ± 10.31 % weight loss and grain damage respectively in wheat seeds due to rice weevil after 30 days of storage. Thus, our results are in conformity with the above. The difference in the extent of loss/ damage may be due to difference in the variety of the crop, season of study and moisture content of the seeds.

During winter biological activities of the insects are slowed down due to low temperature which reflects in the lower % grain infestation while the

Table 1. Grain weight loss (%) due to *S. oryzae* in aromatic and non-aromatic rice cultivars during winter, 2020 – 21

Cultivars	Grain weight loss (%) at weekly intervals								
Month / week	**November**	**December**				**January**			
	IV	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
WAS*	1	2	3	4	5	6	7	8	9
Uttar Sugandhi	0.40	0.87	1.35	1.96	3.07	5.36	8.17	11.18	14.99
Joldhepa	0.44	0.71	1.54	2.16	3.05	5.27	7.66	10.83	13.61
Mean differences	-0.05	0.16	-0.19	-0.19	0.02	0.09	0.50	0.35	1.37
Mean cultivars	0.42	0.79	1.44	2.06	3.06	5.32	7.92	11.01	14.3
t- value	-0.236	0.591	-0.745	-0.431	0.057	0.091	0.403	0.180	1.031
Prob.	0.818	0.570	0.477	0.677	0.955	0.929	0.697	0.861	0.332

WAS = weeks after storage Prob.= Probability*Mean of 5 replications*

Table 2. Grain weight loss (%) due to *S. oryzae* in aromatic and non-aromatic rice cultivars during spring-summer, 2021

Cultivars	Grain weight loss % at weekly intervals								
Month/week	**March**				**April**				**May**
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**
WAS*	1	2	3	4	5	6	7	8	9
Uttar Sugandhi	0.55	2.07	3.14	5.07	8.16	11.25	14.41	17.82	21.48
Joldhepa	0.42	1.83	2.94	4.33	7.70	10.63	13.75	16.91	20.31
Mean differences	0.12	0.24	0.20	0.74	0.46	0.62	0.66	0.91	1.16
Mean cultivars	0.48	1.95	3.04	4.70	7.93	10.94	14.08	17.37	20.89
t- value	0.972	0.480	0.294	1.145	0.457	0.409	0.387	0.427	0.403
Prob.	0.450	0.643	0.775	0.285	0.659	0.692	0.708	0.680	0.696

WAS= weeks after storage Prob.= Probability*Mean of 5 replications*

reverse occurs during summer season due to prevalence of higher temperature and humidity. Our results are in agreement with Sinha (1973), Khare and Agarwal [24], Malgorzata (2011) who reported that temperature and humidity are the two important factors determining the development of population, reproduction and survival of the insect which ultimately reflects in the infestation and they observed greater % infestation of grains during summer months. The present findings also lend support from Okram [5] who obtained higher weight loss of grain % and infested grain % during summer months compared with winter. During winter months the temperature and RH% were 7 to 25℃ and 47 -74%. whereas the same during spring-summer months were 19℃-35℃ and 64-88 %respectively. Thus our results are inconformity with the above. Temperature is a critical environmental factor that affects the development of *S. oryzae*, which is directly linked to grain quality and the occurrence and progression of pest infestations [25].

3.3 Physical and Biochemical Parameters of Rice Grains

The length and breadth of the Uttar Sugandhi were 6.44 mm and 2.20 mm and 6.34 mm and 2.23 mm respectively in winter and spring-summer respectively while in case of Joldhepa (Table- 5 and 6) the corresponding values were 5.54 mm and 2.10mm and 5.55 mm and 2.12 mm respectively. During winter and spring – summer season the moisture % of the grains were 11.06% and 11.16% respectively for Uttar Sugandhi while the figures for Joldhepa were 10.64% and 10.76 % respectively. Thus,

Table 3. Damaged grains (%) due to *S. oryzae* in aromatic and non-aromatic rice cultivars during winter, 2020- 21

Cultivars	Damaged grains (%) at weekly intervals								
Month / week	November	December				January			
	IV	I	II	III	IV	I	II	III	IV
WAS*	1	2	3	4	5	6	7	8	9
Uttar Sugandhi	5.41	8.01	10.35	13.45	17.83	22.18	26.90	31.90	38.26
Joldhepa	5.30	7.84	9.55	12.17	14.80	20.55	25.07	29.72	35.53
Mean differences	0.11	0.17	0.79	1.29	3.04	1.63	1.82	2.18	2.73
Mean cultivars	5.35	7.92	9.95	12.81	16.31	21.37	25.98	30.81	36.89
t- value	0.196	0.193	0.769	0.764	1.406	0.737	0.625	0.632	0.960
Prob.	0.848	0.851	0.463	0.466	0.197	0.481	0.549	0.544	0.364

WAS= weeks after storage Prob.= Probability*Mean of 5 replications*

Table 4. Damaged grains (%) due to *S. oryzae* in aromatic and non-aromatic rice cultivars during spring – summer season, 2021

Cultivars	Damaged grains (%) at weekly intervals								
Month / week	March				April				May
	I	II	III	IV	I	II	III	IV	I
WAS*	1	2	3	4	5	6	7	8	9
Uttar Sugandhi	7.46	11.73	15.82	19.11	23.00	27.72	32.08	37.13	42.29
Joldhepa	10.13	10.16	13.74	17.96	22.92	27.41	31.40	36.25	40.84
Mean differences	-2.67	1.57	2.08	1.15	0.08	0.31	0.69	0.88	1.45
Mean Cultivars	8.79	10.64	14.78	18.53	22.96	27.57	31.74	36.69	41.56
t- value	-5.87	1.807	1.082	0.790	0.056	0.142	0.331	0.338	0.455
Prob.	0.573	0.108	0.310	0.452	0.956	0.889	0.748	0.743	0.659

WAS= weeks after storage Prob.= Probability*Mean of 5 replications*

aromatic rice grains were more slender and wider in size and had greater moisture content than the non-aromatic type. Weight of 100 seeds in case of Uttar Sugandhi was 1.66 gm and 1.69 gm in winter and spring-summer respectively whereas in case of Joldhepa it was 1.53 gm and 1.57 gm respectively (Table 5 and 6) reflecting that the aromatic grains greater seed mass than the non-aromatic grains.

These results are in agreement with Arnason et al. [26] who reported that weight loss and adult population was more with high moisture %. Okram [5] also reported that short bold aromatic rice (SBA) had greater loss of weight of grains and number of infested grains due to higher moisture %, breadth, length, 100 grain weight. It is evident from the data furnished in Table 5 and 6 that in aromatic rice, carbohydrate % was more and protein% was less compared with the non-aromatic rice. During both the seasons, there was a reduction in the carbohydrate% and protein% of grains due to infestation of the rice weevil. In winter, the % reduction of carbohydrate and protein in Uttar Sugandhi was 10.72% and 21.05% respectively whereas it was 9.08% and 18.63% in summer. The % reduction of carbohydrate and protein in Joldhepa was 10.13% and 22.43% during winter whereas it was 15.28% and 32.58% in spring-summer season respectively. Thus % loss of protein was more than that of carbohydrate.

3.4 Adult Weevil Population

Results of the number of adult weevils produced after 60 days of storage (Table 7) show that there was significant variation in the adult population built-up of rice weevil between the cultivars and also between the seasons. The adult population was more in aromatic rice Uttar Sugandhi during both winter and spring-summer seasons (188.60 and 264.00 respectively) than non- aromatic Joldhepa (142.00 and 237.00 respectively). The results also reveal that much higher no. of adults were produced during spring-summer season than winter months in both the cultivars. Khan and Haldar [20] observed that adult rice weevil population on rice increased gradually with increase in storage period. Bhanderi et al. [27] also noticed that adult *S. oryzae* population in different sorghum varieties

Table 5. Physical and biochemical parameters of aromatic and non-aromatic rice grains during winter, 2020-21

Cultivars	Length (mm)	Width (mm)	Moisture %	Seed weight (100) (g)	Carbohydrate %		% Reduction of carbohydrate	Protein %		% Reduction of protein
					B.I.*	A.I.**		B.I.	A.I.	
Uttar Sugandhi	**6.44**	**2.20**	**11.06**	**1.66**	**57.82**	**51.62**	**10.72**	**6.79**	**5.36**	**21.05**
Joldhepa	**5.54**	**2.10**	**10.64**	**1.53**	**47.40**	**42.60**	**10.13**	**9.85**	**7.64**	**22.43**
Mean difference	0.90	0.10	0.42	0.12	10.42	9.02	0.59	-3.05	-2.27	1.38
t- value	5.162	0.922	2.238	0.984	9.232	9.248	.869	-15.711	-7.720	.395
Prob.	0.000	0.383	0.055	0.353	0.000	0.000	.410	0.000	0.000	.703

B.I. = Before infestation A.I.** = After infestation*

Table 6. Physical and biochemical parameters of aromatic and non-aromatic rice grains during spring-summer, 2021

Cultivars	Length (mm)	Width (mm)	Moisture %	Seed weight (100) (g)	Carbohydrate %		Reduction % of carbohydrate	Protein %		Reduction % of protein
					B.I.	A.I.		B.I.	A.I.	
Uttar Sugandhi	**6.34**	**2.23**	**11.16**	**1.69**	**55.95**	**50.87**	**9.08**	**6.32**	**5.14**	**18.63**
Joldhepa	**5.55**	**2.12**	**10.76**	**1.57**	**47.42**	**40.17**	**15.28**	**9.45**	**6.37**	**32.58**
Mean diff.	0.788	0.11	0.406	0.12	8.532	10.7	6.20	-3.13	-1.23	13.95
t- value	5.619	2.001	3.108	1.013	5.295	8.261	-5.252	-64.064	-14.873	-17.257
Prob.	0.000	0.080	0.014	0.340	0.000	0.000	.001	0.000	0.000	.000

Mean of 5 replications B.I. = Before infestation A.I.** = After infestation*

Table 7. Adult population of *S. oryzae* after 9 weeks in aromatic and non-aromatic rice cultivars

Cultivars	Winter season (2020-21)				Spring- summer season (2021)			
	No. of adults			Male: female ratio	No. of adults			Male: female ratio
	Total adults	Male	Female		Total adults	Male	Female	
Uttar Sugandhi	**188.60**	**90.40**	**98.20**	**1:1.08**	**264.00**	**124.40**	**139.60**	**1:1.12**
Joldhepa	**142.20**	**69.00**	**73.20**	**1:1.06**	**237.00**	**104.40**	**130.60**	**1:1.25**
Mean of cultivars	165.4	79.7	85.70		250.50	114.40	135.10	
Mean difference	46.40	21.40	25.00		27.00	20.00	9.00	
t- value	5.382	5.077	4.914		5.421	4.724	2.617	
Prob.	0.0006	0.0009	0.0011		0.0006	0.0014	0.0307	

**Mean of 5 replications.*

Table 8. Correlation of grain damage %, weight loss %, adult population with different physical and bio-chemical parameters of rice cultivars

Parameters		Correlation coefficient (r)					
		Grain length	Grain breadth	Moisture %	Seed weight (100)	Carbo-hydrate %	Protein%
Grain damage %	Uttar Sugandhi	0.705	0.096	0.880*	0.147	0.671	-0.495
	Jaldhepa	0.450	0.518	0.408	0.955*	0.699	-0.717
Weight loss %	Uttar Sugandhi	0.554	0.671	0.537	0.525	0.198	-0.310
	Jaldhepa	0.200	0.668	0.842	0.414	0.704	-0.828
Adult population	Uttar Sugandhi	0.484	0.505	0.338	0.537	0.250	0.483
	Jaldhepa	0.125	0.806	0.767	0.227	0.140	0.069

**Correlation is significant at the 0.05 level (2-tailed).*

increased when storage duration was increased. Okram [5] obtained significantly higher no. of adult weevils of *S. oryzae* in different stored rice varieties during summer (295.47±10.84 to 364.67±11.88) than winter months (155.64±14.06 to 255.70±15.40). She also recorded higher adult weevils in aromatic rice cultivars than non-aromatic types. Thus, our results lend support from the above. It was observed that the female population was higher in both the cultivars and also in both the seasons. The male: female ratio was 1:1.08 and 1:1.12 in case of Uttar Sugandhi in winter and spring-summer season respectively whereas it was 1:1.06 and 1:1.25 in case of Jaldhepa respectively. The results are in accordance with Rajasara and Patel [28] who observed that adult female population of *S. oryzae* was more than that of male. Bhanderi [29] found male : female of *S. oryzae* ranged from 1: 1.0.95 to 1: 1.31 when reared on different sorghum varieties. Similar results of adult female biased population were obtained by Khan et al*.* [30], Bhanderi et al. [29], Pradeep and Jagginaver (2015) and Okram [5]. Thus, the results of the present study are in accordance with the above.

3.5 Correlation between Grain Weight Loss%, Grain Damage%, Adult Population and Different Physical and Bio-Chemical Parameters of Aromatic and Non-Aromatic Rice

Results of the correlation studies (Table 8) reveal that % damaged grain, % weight loss and adult population in both aromatic rice and non-aromatic rice had positive association with the length and breadth of rice grains, weight of 100 grains and moisture % of seeds. However, the association was pronounced for grain damage % and weight loss% with moisture % (r= 0.880* and 0.842 for aromatic and non-aromatic rice respectively). The correlation was significant between grain damage % and seed weight (r= 0.955*). Similarly, the correlation between adult population and grain breadth was distinct in case of non-aromatic rice (r= 0.806). The results further demonstrate that the carbohydrate content of the grain had positive association with % grain damage, % weight loss of grain and adult population development. However, the association was distinct in case of both the type of rice for % grain damage (r= 0.671 and 0.699 respectively) whereas in case of non-aromatic rice for % weight loss (r= 0.704). It was observed that grain damage %, weight loss % and adult population had negative association with protein % of grains and the results was pronounced for weight loss % in case of non-aromatic rice (r= - 0.828).

Okram [5] observed that whenever there was an increase in the breadth of the rice grain the weight loss was increased by 0.08% and damaged grain also increases by 0.08%. Thus, our results lend support from the above.

Khan et al*.* (2005) reported that higher the moisture content greater was the grain weight loss and adult population. Similar results were also obtained by Okram (2021). Because increasing moisture percentage in seeds invites the pest attack to a greater extend as the grains becomes soft and loose [31]. The results of the present study are in agreement with the above.

Okram [5] found that % rice grain weight loss and % damaged rice grain due to f S. oryzae were negatively correlated with the protein content (%) of the grains and a positive correlation with carbohydrate content (%) of the grains. She also found a positive correlation in respect of % weight loss and % damaged grain with length and breadth of different rice grains. The above results corroborate our findings in the present study.

It reveals from the results that between the two rice cultivars, the weevils had a greater preference towards the aromatic rice, which is reflected from the higher values of % weight loss of grains, % grain damaged as well as adult population developed in aromatic rice at 60 days after their release in both the seasons studied in the experiment. Size and toughness of grains are important determinants to suit the larval development. Tonggjura [31] studied the relationship between seed size and hardness of seeds and found that smaller seeds were hard, compact and therefore, were more resistant to the insect damage whereas the bigger grains were loose and soft and were more easily attacked by the insects. Russell [32] noticed that larger varieties of seeds of sorghum were most preferred by *S. oryzae* than small sized seeds. Russell [33] further observed that the rice weevils preferred larger size of grains. Tewari and Sharma (2002) observed positive association between seed size and rice weevil infestation. Okram [5] observed that SBA rice (short bold aromatic) experienced the highest % loss of grain (by weight and number) during different seasons as the short bold grains provided greater suitability to the inhabiting larvae. Thus, our results are in line with the above.

The aromatic rice (Uttar Sugandhi) had higher moisture % (11.6% and 11.17% in winter and spring-summer season respectively), greater length, breadth, weight of 100 grains and higher % of carbohydrates and lower % of protein in grains compared with non-scented rice (Joldhepa). It is a well-known fact that with the increment of moisture % in seeds there will be increased pests attack as the moisture of the grains influences the oviposition, infestation, reproduction and development of the rice weevils. Aromatic rice Uttar Sugandhi contained higher moisture % (11.06% and 11.17% respectively) than non- aromatic cultivar (Joldhepa) (10.64% and 10.76% respectively) during both the seasons. These results are in agreement with the Arnason et al. [26] and Syed et al. (2001) who reported that weight loss and adult population was more with high moisture %. Okram [5] also reported that short bold aromatic rice (SBA) had greater loss of weight of grains and higher number of damaged grains due to higher moisture %, breadth, length, 100 grain weight.

The loss of grain was positively correlated with carbohydrate % and negatively correlated with protein %. Carbohydrate is the main part of the endosperm and rice grains contain 70-80% starch, 7 % protein, 1.5% oils and Vitamin A, B and C (Kochhar, 1986). Various workers found that rice grains having more carbohydrate content suffered more *i.e.* higher the amount of carbohydrate higher would be the infestation which was also found in our studies. The findings lend support from Park et al. (2003) who observed that the weevil larvae fed on the carbohydrate present in the rice grains causing weight loss and product contamination. Okram [5] also observed that slender bold aromatic rice (SBA) grains had highest % of carbohydrate and suffered the most in so far as weight loss and damaged grains were concerned. Interestingly, starch and protein content of the grains were negatively associated and as seeds with higher protein % would serve an indicator of low starch

%, will lower down the pest attack (Hucl, 1996) as the weevil prefer carbohydrates. Similar observations have been suggested earlier by Nawrot et al. [34] who found protein content as a parameter responsible for resistance to some wheat varieties. Amos et al. (1986), Ram and Singh (1996) and Rehaman et al. [35] found a negative correlation between protein content in rice grains and adult weevil infestation suggesting lower infestation and these are in support of the present finding.

Aromatic rice is known to be preferred to insects to non-aromatic types owing to its higher nutritive values and presence of some biochemical constituents which might attract the insects. However, there are contradictory reports on this aspect. Okram [5] based on a study with 50 rice cultivars observed that two aromatic landraces viz. Tulaipanji and Mohanbhog (grown in Uttar Dinajpur and Nadia district respectively) suffered the highest grain weight loss of 34.83% and 33.2% respectively due to *S. oryzae* after 90 days of storage which is supportive of the result of the present studies where Uttar Sugandhi suffered higher weight loss % and grain damage%. However, Khan and Haldar [20] observed that Kalijira, an aromatic rice was least infested by rice weevil. Mondal and Chakraborty [21] found less infestation in aromatic rice and suggested that the phenolic compounds in rice grains imparted significant negative impact on rice weevil infestation; grain protein content exerted little effect while grain lipid and carbohydrate had moderate effect on grain infestation. Further studies on the presence of various other biochemical compounds may throw some light for the preference of the rice weevil to aromatic rice.

4. CONCLUSION

Rice weevil is the most common and destructive pest of stored rice in most parts of the world. Higher intensity of grain loss (% by weight and number) and more number of adult weevils emerged after 60 days of storage in aromatic rice indicate that it supports the physical, biochemical and nutritive requirements of the weevil. Infestation increased with increase in duration of storage period was observed irrespective of the cultivar and season. Magnitude of infestation was higher in spring-summer season than winter months. Sub-Himalayan plains of West Bengal is characterised by warm humid climate, which favours the infestation of stored grain pests. As different aromatic landraces are grown, the degree of infestation due to rice weevil may vary and thus there is a need for further study on this aspect. However, the generated information will help farmers and other stakeholders adopt remediation measures to keep the pest at bay.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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DECLERATION

The authors declare that there is no conflict of interest.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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