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PODS AND SEEDS CHARACTERISTICS WITHIN A POD CROP OF AN AMALTAS TREE (*CASSIA FISTULA* L. – CAESALPINIACEAE): I. INSECT INFESTATION, NUMBER OF SEEDS PER POD AND THE PACKAGING COST

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ABSTRACT

The total pod crop of 166 pods was collected from a solitary tree of *Cassia fistula* L. Excluding unripe pods, 101 mature fruits were air-dried for around 100 days in laboratory and studied for their insect infestation, size dimension, seed content, pod shape deformation, seed weight variation and seed packaging cost. Besides a leaf-stitcher (*Piesmopoda obliquifasciata* Hamps), two more insects associated with the pod - a seed borer moth, *Trachylepidia fructicasseilla* Ragonot and *Oxyrhachis rufescens.*). The mean number of infestation (number of cocoons of *T. fructicasseilla* per pod) was 0.5743 ± 0.1804 – maximally reaching to 12 in one pod only. The distribution of cocoons amongst pods was highly positively skewed.

The *C. fistula* pods were slightly lesser than 40 cm in length on an average – ranging from 16.6 to 51.0 cm and around 1.08 to 2.20 cm in diameter (mean = 1.80 ± 0.18). The pod weighed from 12.7 to 91.0 g in mass and 23.7 to 189.9 cm^3 in volume (mean = 100.5 ± 3.5 cm^3). The part of pod admeasuring ≤ 1 cm in diameter was devoid of any seeds or contained highly shriveled seeds. The number of locules in pods distributed asymmetrically (negatively skewed) and averaged to 93.92 ± 2.73 – varying from 38 to 127 per pod. The yield of healthy seeds fluctuated greatly from none to 110 seeds / pod averaging around 55.78 ± 2.29 seeds. The number of shriveled seeds per pod averaged to 4.41 ± 0.6845 per pod and exhibited highly positively skewed distribution with long tail with maximum number of shriveled seeds from a pod to be 49. There was a great degree of multi-colinearity among the structural and reproductive parameters. The distribution of seed weight of 100 randomly-selected and individually-weighed seeds was leptokurtic and negatively skewed. The seed weight of individual seed averaged to 109.5 ± 3.10 mg and varied around 28.2 % i.e., around 3.23- folds. Clearly, the mean seed weight was a direct function of the pod weight but varied negatively with the total number of seeds developing in a pod. The data indicated a degree of trade-off between seed weight and seed number. The packaging cost calculated in terms of residual pericarp biomass (g) per g seeds in healthy pods averaged to 6.9613 ± 0.4609 g and varied with the pods from 3.69 to 14.16g per g seeds (3.84-folds variation).

Key Words: *Cassia fistula* L, *Trachylepidia fructicasseilla*, *Oxyrhachis rufescens*, *Piesmopoda obliquifasciata*, Seed weight distribution, seed weight -seed number trade off, Packaging cost of seeds.

INTRODUCTION

There are few studies which have quantified reproductive allocation at both fruit and seed levels (Lord and Westoby, 2006; Martinez *et al.,* 2007; Chen *et al.,* 2011). Angiospermic seeds developing from ovules are enveloped in Pericarp. Seeds give rise to seedlings and pericarp provide protection to seeds and at times dispersal. Pericarp occupies significant proportion of the fruit biomass. Determining within fruit reproductive allocation is, therefore, important for the understanding of seed size significance in plant life strategy (Chen *et al.,* 2010). Many ecologists are now interested in examining the scaling relationship between the seed packaging, and the individual seed mass. Such studies are likely to be important and interesting since seed-packaging patterns should vary significantly among broadly ecologically similar species and within species (Wilson *et al.,* 1990). In this paper, characteristics of pod and seeds for a major part of pod crop of an individual of a Golden Shower tree, Amaltas, (*Cassia fistula* L.; Caesalpiniaceae) is described with emphasis on seed weight and seed packaging cost. *C. fistula* and some of its related species are greatly affected with a number of insects (Ahmad and Salar Khan, 1986; Bhatta and Bhatnagar, 1986; Bajwa and Gul, 1995; Yousuf and Gaur, 1998; Gaur *et al.,* 1999; Nair, 2001; Armando Briceno and Fraternidad Hernandez, 2006)), in present studies, beside fecundity related observations, insect infestation of pods has also been investigated.

MATERIALS AND METHODS

A total crop of 166 pods was collected from a solitary tree of *Cassia* fistula (nearly 30 cm in stem diameter and 10 m in height) which was felled in the campus of Government National College, Karachi for space clearing in 2007. Excluding green unripe pods, 101 brown-black mature fruits were selected for study. These pods were air-dried for around 100 days in laboratory and studied for their size dimension, seed content, pod shape deformation, seed weight variation and seed packaging cost. The pods of *C. fistula* are often deformed variously due to narrowing at proximal, distal or in the mid region of the pod (Fig. 1). Besides, usual length and width measurements, the deformed pods were also measured for the length and diameter of their narrower part. The volume of pods was estimated from formula PV = πr^2.PL, where r is the radius of the cylindrical pod, PL is the length of the pod and PV is the volume of the pod. The deformed pods were adjusted for their length and volume appropriately through subtraction of length or volume of the narrowed part of the pod from the raw magnitude of length or volume. It was considered necessary in view of the fact that narrower part of the pod, if lesser than one cm in diameter, was devoid of any seed or had highly shriveled seeds. Each pod was weighed and then opened carefully. The number of healthy and shriveled seeds was recorded from each pod and seeds were stored in dry bottles for further study. The number of locules was also counted in pods. Some of the pods contained larvae, cocoons and / or dead pupae or their exoskeleton of an insect which were recorded. Likely, some pods yielded no seeds but the remains of the insects besides their excreta only. The numbers of cocoon from the pods were recorded along with the number of seeds eaten. After recovery of seeds, residual pod mass (Pericarp) was weighed. The two parameters - residual pod mass.seed^{-1} and residual pod mass.g^{-1} seed, were employed to determine the packaging cost (Mehlman, 1993; Chen *et al.,* 2010). To follow a general pattern of seed weight distribution 100 randomly selected seeds were weighed individually. The location and dispersion parameters of data were calculated and the frequency distributions were characterized with skewness and kurtosis and Kolmogorov-Smirnov z test was performed to detect normal distribution (Sokal and Rholf, 1995).

To elucidate the identity of the insect, 20 infested pods collected from *C. fistula* trees in the campus of the University of Karachi were incubated in a glass vessel provided with thin cotton cloth over its mouth from late December 2011 to the mid of May 2012. The insects reared were studied for their morphology and compared with relevant literature.

RESULTS AND DISCUSSION

The data collected on various quantitative parameters of 101 mature pods of *C. fistula* (c 61 % of the total crop – excluding green immature pods) and their seeds are presented in Table 1 and have been averaged in Table 2. Only a small fraction of flowers set fruit in *C. fistula*. Pods are green and photosynthetic when immature and stay for quite longer period of time on tree turning glossy blackish brown in colour at maturity. They are indehiscent and cylindrical but seldom deformed in shape due to narrowing in proximal, distal or in the mid region of the pod presumably owing to the variation in growth rate during their development (Fig. 1). Such a deformation affects the fecundity of the pod in the sense that the part of pod admeasuring ≤ 1 cm in diameter is devoid of any seeds or contains highly shriveled seeds. The deformation in shape was observed in 15 pods (14.85% of the pods studied). Some 85% of the pods were free from such deformation. Amongst the deformed pods, the narrow infertile part averaged to be 24.98 ± 3.36 % (varying from 4.8 to 42.6 %) on the basis of length (Table 3) influencing the volume of the pod by a quantum of 0.8 to 15.7 % (mean = 7.4 ± 1.16 %).

INSECT INFESTATION

In all, 19 pods (18.8%) were found to be infested with an insect and 82 pods (81.2 % of the pods studied) had no infestation. Seventy six pods contained a mixture of healthy, shriveled or insect-damaged seeds. Only 25 pods were perfectly healthy in the sense that they contained healthy seeds and no infestation and no shriveled seeds. In four pods all the seeds have been eaten up by the larvae.

The rearing of the insect in the laboratory provided 22 insects out of 20 infested pods in a period from late December 2011 to March 2012. Major spurt of moth emergence was, however, noticed from late March to mid of May 2012. Up till this time some 83 adult insects have emerged, *in toto* - some of them have been shown in Fig.2. The length of the insect so reared in the laboratory averaged to 1.07 ± 0.02 cm varying around 16.2 %, from 0.7 to 1.50 cm. The insect size tended to distribute normally as the Kolmogorov-Smirnov z was insignificant (1.228, $p < 0.098$) (Fig. 3). The pest individuals of 0.9 to 1.2 cm in length occupied around 71% of the population and those from 1.0 to 1.1 c, were nearly 43.4% of the population. The insects emerging during April to mid of May 2012 were generally larger in size than those emerging from late December 2011 to March 2012. These insects, on morphological study and comparison from the literature, were identified as a moth, the seed borer pyralid, *Trachylepidia fructicassiella* Ragonot (Fig. 2 and 4-7). The mean number of infestation (number of cocoons per pod) was 0.5743 ± 0.1804 – maximally reaching to 12 in one pod only. The distribution of cocoons amongst pods was highly positively skewed (Fig. 8).

Table 1. Morphometric parameters of pods, number of seeds per pod and pods and seeds weights in *Cassia fistula.*

S. No.	PL (cm)	PD (cm) *	PV (cm^3)	NSH	PW (g)	SW (g)	Remarks
1	39	1.8	99.2	55	42.5	4.9	+ 12 shriveled, 8 eaten, 8 Cocoon
2	41	1.75	98.6	49	59.0	4.9	+ 9 shriveled seeds
3	44	2	138.2	62	55.2	6.5	-
4	37.5	2	117.8	48	53.2	6.3	+ 2 shriveled seeds
5	47.8	1.9	135.5	34	78.2	4.7	+ 27 shriveled seeds
6	44.2	1.15	45.9	60	65.8	6..9	+ 12 shriveled seeds
7	50	2.2	189.9	56	91.0	6.8	+ 23 shriveled seeds
8	48.2	2	151.3	02	74.4	0.86	+ 30 damaged seeds (eaten by insect) , pod fully infested
9	47	1.7	106.6	76	58.7	7.2	+ 2 shriveled
10	44.5	1.9	126.1	66	66.5	8.4	+ 1 shriveled
11	43	2	135	57	57.3	6.95	+3 shriveled, 2 small
12	51	1.95	152.2	54	67.9	7.0	+8 damaged, 2 shriveled, 10 eaten, 7 Cocoon with live pupae
13**	22 (14) ***	1.7	34.9 (21.8)***	24	17.7	2.0	+ 3 shriveled, 1 Cocoon
14	42.8	1.8	108.9	77	52.4	8.9	+ 4 shriveled, 1 small
15	41.2	1.65	88.1	80	49.1	8.25	+ 2 shriveled, 6 small seeds
16	40	2	125.6	-	54.5	1.55	+ 49 shriveled
17	44.5	2	139.7	52	67.1	6.7	+ 1 shriveled
18	47.5	1.7	107.8	69	64.0	8.35	+ 11 shriveled
19	42	1.9	119	88	53.9	9.10	+ 12 small seeds
20**	29.5 (28)	1.8	76.8 (71.2)	51	36.6	5.9	+ 3 shriveled seed
21**	29.5 (25)	1.9	73.1 (63.6)	52	33.9	5.5	-
22	48.5	1.8	123.4	60	65.2	6.8	+ 8 shriveled
23	48.8	1.9	138.3	58	73.1	7.2	+ 1 small, 3 damaged seeds, 3 Cocoon
24	48.2	1.95	143.9	72	74.7	8.3	+ 8 shriveled, 1 smaller
25	45	1.9	127.5	55	74.5	7.0	-
26	48.5	1.92	140.4	90	74.2	10.7	+ 3 shriveled seed
27**	40 (24)	1.7	60.6 (54.5)	40	29.5	4.4	+ 1 shriveled seed
28**	36.6 (22.2)	1.9	63.7 (56.5)	46	26.3	4.1	+ 1 shriveled seed
29	43	1.8	109.4	64	61.9	7.85	-
30	40.6	1.8	103.3	61	61.2	6.9	-
31	36.5	2	114.6	47	52.8	5.0	+11 shriveled, 1 small seed
32	38	1.9	107.7	-	49.3	0.8	+ 31 shriveled, 10 eaten, 6 Cocoons
33	49.5	2.1	171.4	55	80.8	7.6	+ 6 shriveled, 7 small seeds
34	22.5	1.7	51	29	29.9	3.05	-
35	21.5	2.05	70.9	29	36.8	3.5	-
36	17.5	2.1	60.6	22	26.4	2.0	+ 1 shriveled
37	21	1.2	23.7	-	12.7	0.2	+ 4 shriveled, 3 small
38	26.1	1.65	55.8	40	28.7	3.7	+ 1 shriveled seed
39	42	2	131.9	65	67.6	7.0	-
40	43	1.8	109.4	77	56.6	9.4	+ 10 small seeds
41	42.5	1.8	108.1	87	55.6	9.2	-
42	42.2	1.8	107.3	92	56.1	9.7	+ 6 shriveled
43	45.6	1.8	115.9	77	54.0	8.2	+ 3 shriveled
44	47.5	1.8	120.8	90	53.2	9.0	+ 9 shriveled
45	16.6	1.7	37.7	28	17.1	2.5	+ 3 shriveled, 2 small seed
46	42.8	1.82	111.3	54	55.0	6.5	+ 2 damaged, 2 Cocoons
47	46.5	1.9	131.8	73	63.9	9.5	+ 1 shriveled, 2 damaged, 1 Cocoon
48	41.5	2	130.3	54	64.7	3.2	+ 6 small seeds

S. No.	PL (cm)	PD (cm) *	PV (cm^3)	NSH	PW (g)	SW (g)	Remarks
49	39	1.75	93.8	72	49.9	8.2	+ 1 shriveled seed
50	45	1.90	127.5	54	72.9	7.05	+ 4 shriveled seeds
51	21	1.8	53.4	32	21.0	2.8	-
52	41	1.8	104.3	52	48.5	6.1	+ 3 shriveled, 1 damaged, 1 Cocoon
53	37	1.81	95.2	58	43.6	6.2	+ 10 shriveled, a small seeds
54	41.4	1.70	93.2	59	48.1	6.2	+ 8 shriveled seeds
55	50.2	2.1	173.8	67	83.2	9.2	+ 8 shriveled
56	47.80	2	150.1	59	73.6	7.75	-
57	42.5	1.7	96.4	86	50.8	8.95	+ 6 shriveled seeds
58	38	1.8	96.6	64	55.1	3.35	-
59	43	1.9	121.8	69	58.9	3.15	+ 2 small seeds
60	41.8	1.8	106.3	85	50.9	9.45	-
61	17.4	1.7	39.4	31	20.6	2.95	+ 1 eaten seed, 1 Cocoon
62	22	1.4	33.9	11	18.1	1.20	+ 2 small, 3 eaten/damaged; 2 Cocoons
63	21	1.45	34.7	60	21.2	5.0	+ 1 Shriveled seed
64**	34 (19.5)	1.6	46.5 (39.4)	34	28.3	3.3	+ 1 shriveled seed
65	45.5	2	142.9	59	71.5	8.7	+ 3 shriveled seeds
66	39	1.6	78.4	56	41.8	5.7	+ 1 shriveled seed
67	26.3	1.65	56.2	40	32.1	4.8	-
68	42.5	1.85	114.2	53	67.4	6.8	+ 5 shriveled seeds
69	35.2	1.8	89.5	57	40.4	5.95	+ 7 shriveled, 2 eaten seeds, Cocoons
70	37.5	1.75	90.2	38	49.3	3.65	+ 9 shriveled
71	45	2	141.3	58	64.9	6.0	+ 7 shriveled, 2 Cocoons
72	45.5	1.85	122.2	77	52.5	7.8	+ 3 shriveled
73	31.5	1.8	80.1	53	36.8	5.78	-
74	41.8	1.7	94.8	83	48.3	8.1	+ 5 shriveled seeds
75	39.2	1.6	78.8	45	49.9	5.6	-
76	48.1	1.8	122.3	93	60.8	10.2	-
77	31	1.7	70.3	48	31.7	5.45	-
78	24	1.7	54.4	37	34.5	4.03	+ 4 eaten, 1 very small, 1 Cocoon
79	48	1.8	122.1	74	60.6	8.4	+ 1 shriveled, 1 eaten, 1 Cocoon
80	31	1.6	62.3	40	39.7	4.65	-
81**	41 (39.0)	1.8	96.5 (95.8)	41	49.7	4.2	+ 16 shriveled, 6 damaged, 6 Cocoons
82	27.5	1.7	62.4	27	25.3	3.35	+ 5 eaten seed , 1 Cocoon
83	36	1.6	72.3	41	39.8	4.3	+ 7 shriveled seeds
84	40	1.8	101.7	56	60.3	6.1	-
85**	39.5 (30.2)	1.7	87.7 (79.2)	55	42.5	5.9	+ 1 shriveled, 1 very small seed
86**	42 (33)	1.9	89.3 (82.3)	58	40.9	5.9	-
87**	41(37)	1.75	89.1(87.6)	62	40.6	5.35	+3 shriveled, 3 damaged, 1 Cocoon
88**	37 (21)	2.0	61.9 (56.4)	37	29.8	3.7	+ 1 shriveled
89**	34 (26.5)	1.9	81.2 (74.1)	25	27.6	2.8	+ 7 shriveled, 6 damaged, 2 Cocoons
90**	41(36.5)	1.65	99.8 (74.1)	92	49.4	9.3	+ 2 shriveled, 1 small
91**	41 (27.5)	1.7	70.5 (60.3)	91	39.2	6.1	-
92	51	1.9	152.1	108	73.6	11.8	-
93	40	2.0	125.6	110	72.8	12.0	-
94	43	1.8	109.5	86	46.4	9.9	-
95	42	1.7	95.3	72	49.9	8.1	+ 1 shriveled seed
96	30	1.7	80.1	48	44.5	5.2	+ 1 shriveled seed
97	50.4	2.0	158.2	72	64.6	9.0	+ 5 shriveled seeds
98	38	1.7	101.4	38	30.0	4.2	+ 4 shriveled seeds
99	41	1.9	116.2	25	23.9	2.73	+ 1 small seeds
100	48.2	2.0	151.4	75	73.5	10.3	+ 16 shriveled seeds
101**	23 (21.5)	1.3	29.2 (28.5)	25	18.1	2.73	+ 1 small seed

*, at the widest part of the pod; **, Deformed pods; ***, effective pod length and pod volume in parenthesis – Calculated by excluding the part of pod less than 1 cm in diameter and bearing no seeds. PL (Pod length); PD, Pod diameter; PV, Pod Volume, NSH, number of healthy seeds, PW, Pod weight; SW, Seeds weight.

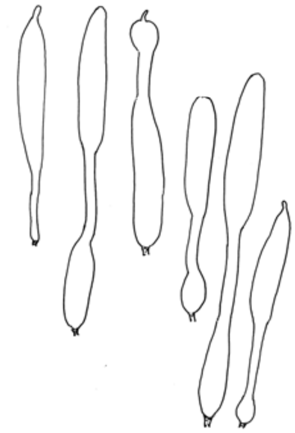


Fig. 1. The shape of a few deformed pods of *C. fistula* due to constriction in proximal, distal or in the mid region of the pod presumably due to variation in growth rate during pod development.

Fig.2. Some individuals of *T. fructicasseilla* reared from the infested pods of *Cassia fistula*. Each major division of the graph paper admeasure 1x 1 cm.

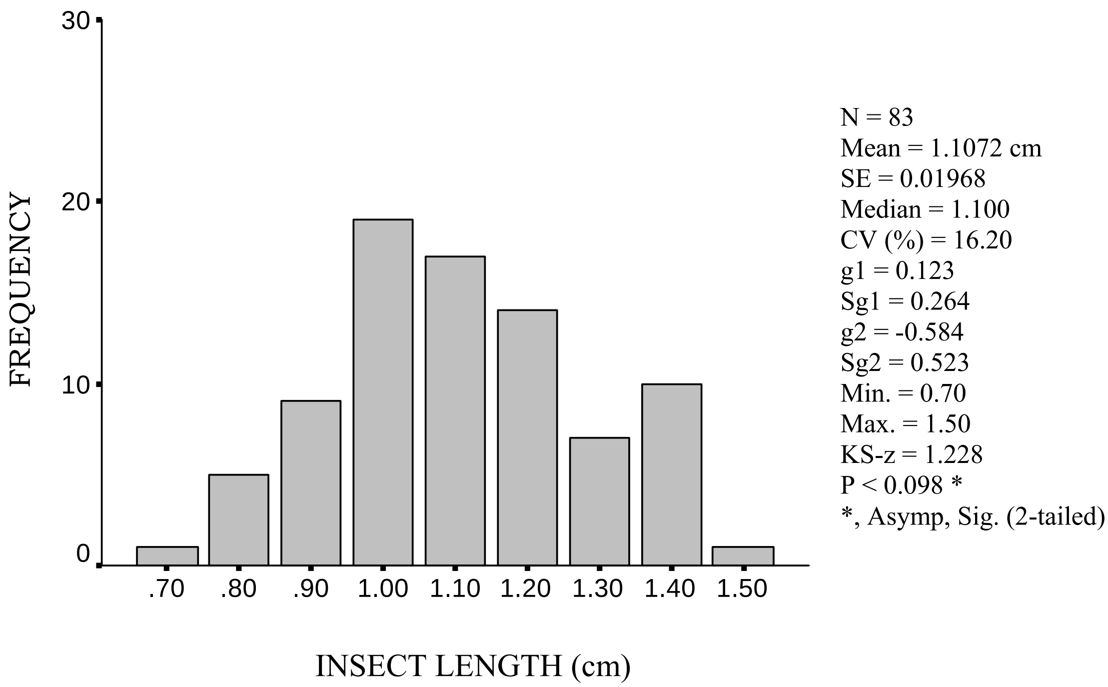


Fig. 3. Distribution of length (head to the extreme posteriority of hind wing, cm) of 83 individuals of *T. fructicasseilla* reared from the pods of *C. fistula* in a period from mid-December to mid May.

Swinhoe and Cotes (1889) enlisted *Trachylepidia fructicassiella* Ragonot (1887) in their catalogue of the moths of India (Punjab) under the family Galleridae. Mathew (2006) has included this species in the pyralid inventory of India under Galleriinae. Hampson (1896) described the above species with reference to its external superficial characters under the family Pyralidae, in his fauna of Lepidoptera from British India. Dyar (1921) described another species *T. indecora* from Trinidad which was synonymised under *T. fructicassiella* as a junior subjective synonym by Whalley in 1964.

The biology and systematics of *T. fructicassiella* has been described by Mukhtar Ahmad Khan *et al.* (1985). Bhatta and Bhatnagar (1986) reported this gilleriine moth to damage *C. fistula* seeds in Madhaya Preadesh, India. Nine adults of this species were found to appear from two *C. fistula* pods imported from India in UK (Martin Honey, Natural History Museum, UK, *http://goweras.blogspot.com/2009/10/alien-import.html*). It has been reported during Hainan Entry-Exit Inspection quarantine from *C. fistula* pods imported from Kuala Lumpur, Malaysia to China. *C. fistula* is widely distributed in China but not the pest (Li *et al.,* 2006). It is distributed in Venezuela on *Cassia gigantea* (Armando Briceño and Hernández, 2006) and Florida (USA) (Heppner, 2002). It has also been reported from South East Asia (Kendrick, 2007). The taxonomy and the structure of the genital complex are in press elsewhere (Younus *et al.,* 2012).

When green, *C. fistula* pods are soft and fleshy and they may be observed to host *Oxyrhachis rufescens* (Membracidae: Oxyrhachinae). We observed many green pods bearing clusters of eggs of this insect on the surface (Fig. 8A) besides larvae and hopping adults. The insect completes its life cycle externally before the fruit is mature and hard and no sap is available to the insect. This species has been recorded from several local tree species mostly leguminous – *Albizzia labback, Prosopis juliflora, Acacia nilotica,* etc. (Ahmad and Perveen, 1983).Yousuf and Gaur (1998) have reported *O. tarrandus* Fabricius to associate with *C. fistula* in Rajasthan, India.

C. fistula is a host to several insect species. One more insect which was observed associating with the plant was *Piesmopoda obliquifasciata* Hampson, commonly known as Leaf-stitcher (Fig. 8 B, C, and D) as it joins the leaf-lets together to form its nest. It feeds on the green photosynthetic part of lamina between the veins producing necrosis of the leaf in quite substantial magnitude. It turns up the plant ugly by browning the part of the leaf infested. Its biology has been studied by Bajwa *et al.* (1998). Foliar damage around 32.6% due to *P. obliquifasceilla* has been estimated by Bajwa and Gul (1995) on trees ranging from 2 to 4.5 m in height in Peshawar.

POD SIZE

The *C. fistula* pods were slightly lesser than 40 cm in length on an average – ranging from 16.6 to 51.0 cm and around 1.08 to 2.20 cm in diameter (mean = 1.80 ± 0.18) (Table 2). The pod weighed from 12.7 to 91.0 g in mass and 23.7 to 189.9 cm^3 in volume (mean = 100.5 ± 3.5 cm^3). Ali (1973) had reported *C. fistula* pods around 60 cm in length.

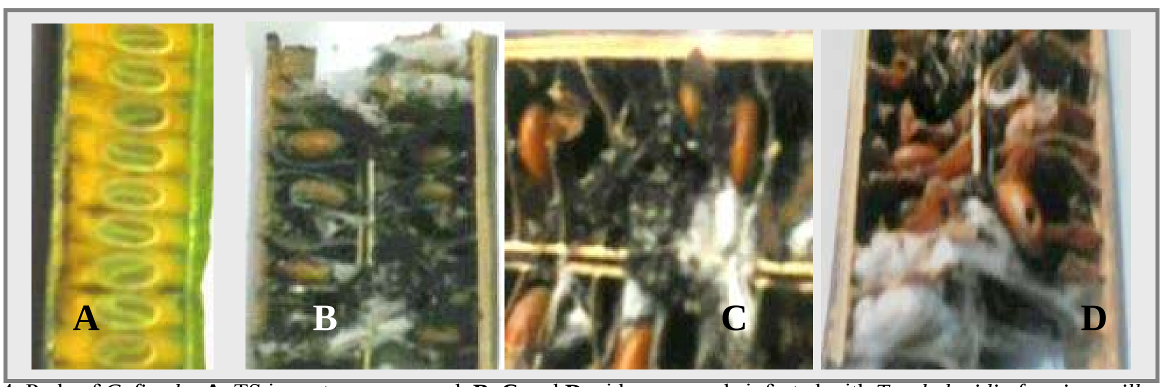


Fig. 4. Pods of *C. fistula*. **A**. TS immature green pod. **B, C** and **D** wide open pods infested with *Trachylepidia fructicasseilla* Ragonot. **B**, general view – black dry pulp adhering to septa; **C**, Cocoon and excreta of the insect; **D**, The eaten seed with a bore made by the insect larva.

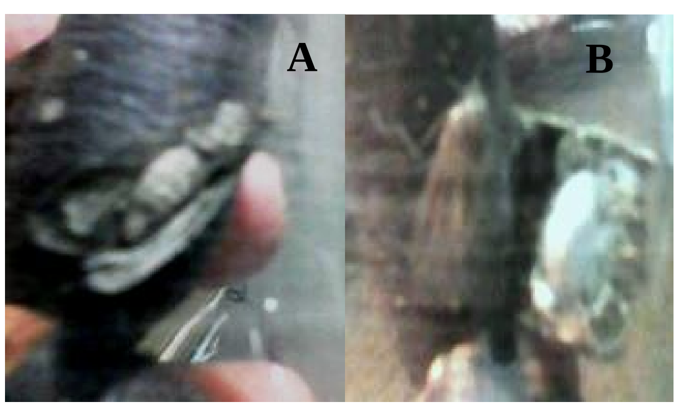


Fig. 5. A, Underside view of mature *Trachylepidia fructicasseilla* Ragnot reared from the pod. B, Dorsal view of two-day old female *T. fructicasseilla* sitting on the pod (mimicry is apparent). A cocoon is also visible containing developing insect.

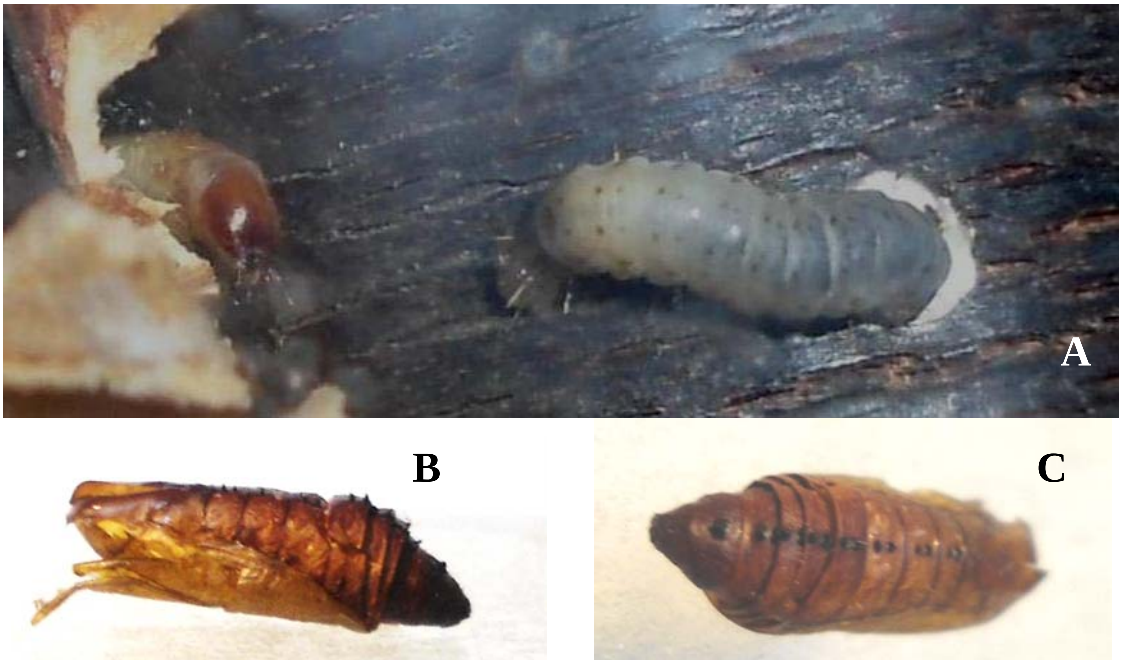


Fig.6. **A**, On breaking of the pod of *Cassia fistula*, larvae of *T. fructicasseilla* came out of the pod- one of them is entering the pod again through an orifice. **B** and **C** are the exovy (exoskeleton) left in the cocoon after the adult moth had escaped.

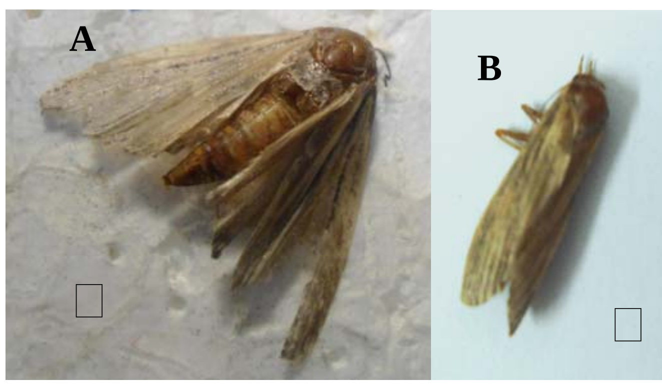


Fig.7. Adult *T. fructicasseilla.* **A,** Female surviving for around five days after its emergence without apparently any food. On the morning of the 6^{th} day, she became restless and its Papilla anales began coming out of its anus as it died. **B,** a male individual.

Fig. 8. **A**. Cluster of empty eggs lay by *Oxyrhachis rufescens* (Membracidae: Oxyrhachinae) on the surface of immature pod of *Cassia fistula*. **B,** The nest formed by *Piesmopoda obliquifasceilla Hamps.* by joining two leaflets of *cassia fistula* leaf; **C**; Excreta of the insect (black material) and other remnants of the insects in a wide open nest **D,** Necrosis of leaf in form of small white dots due to light penetrating through the lamina in brown part of the leaf-lets.

Table 2. Location and dispersion parameters of pod and seed Characteristics of *Cassia fistula* pods (N = 101, 97 and 25). (See text for explanation).

Statistics	PL (cm)	PD (cm)	PV (cm^3)	PW (g)	NSH	TS *	SW (g)	Adj. PL	Adj. PV
Mean	a) 38.99 b) 39.08 c) 37.91	1.802 1.803 1.808	100.59 100.52 97.53	50.198 60.800 50.284	55.78 58.06 60.88	61.31 62.45 60.88	6.103 6.340 6.713	37.74 37.78 36.99	99.44 99.33 96.46
SE	0.864 0.875 1.715	.0189 0.0184 0.0288	3.519 3.528 6.050	1.7496 1.762 3.1414	2.289 2.080 4.612	2.137 2.125 4.612	0.2582 0.2450 0.5160	0.966 0.985 1.790	3.622 3.639 6.233
Minimum	16.60 16.60 21.00	1.06 1.06 1.50	23.7 27.20 51.0	12.70 17.10 21.00	0 11 29	7 15 29	0.200 1.20 2.50	14.0 14.0 21.0	21.80 21.80 51.0
Maximum	51.0 51.0 51.0	2.20 2.20 2.05	189.9 189.9 152.1	91.0 91.0 74.50	110 110 110	110 110 110	12.00 12.00 12.00	51.0 51.0 51.0	189.9 189.9 152.10
CV (%)	22.16 22.05 22.62	9.76 10.07 7.96	34.99 34.56 31.32	34.03 34.50 6.25	40.87 35.28 7.50	34.86 33.52 7.50	42.21 38.07 7.68	26.3 25.7 24.9	36.0 36.1 32.3

Acronyms as in Table 1. *, including healthy, damaged and shriveled seeds. a) 101 pods; b) 97 pods and c) 25 pods. **a**, based on data of all (101) pods studied; **b**, based on data of 97 pods i.e., excluding four pods (# 8, 16, 32, and 37), the seeds of which were more or less completely eaten by the larvae and yielded no or very few (02 seeds in one case) healthy seeds; **c,** data set (N = 25) for healthy pods without shriveled or damaged (eaten) seeds.

Table 3. Proportion of narrow part of pod to the deformed pods size. The part of pod ≤ 1 cm in diameter was always devoid of seeds.

Pod No.*	Proportion (%) Length Based	Proportion (%) Volume Based
13	36.6	8.8
20	28.2	7.2
21	15.3	3.10
27	40.0	10.2
28	39.3	11.4
64	42.6	15.7
81	4.8	0.8
85	22.8	8.1
86	22.9	7.8
87	9.8	1.7
88	43.2	7.3
89	22.1	8.8
90	10.9	3.5
91	25.4	14.4
101	10.9	2.42
Mean CV (%)	24.98 ± 3.36 52.02	7.41± 1.16 60.45

*, as in Table 1.

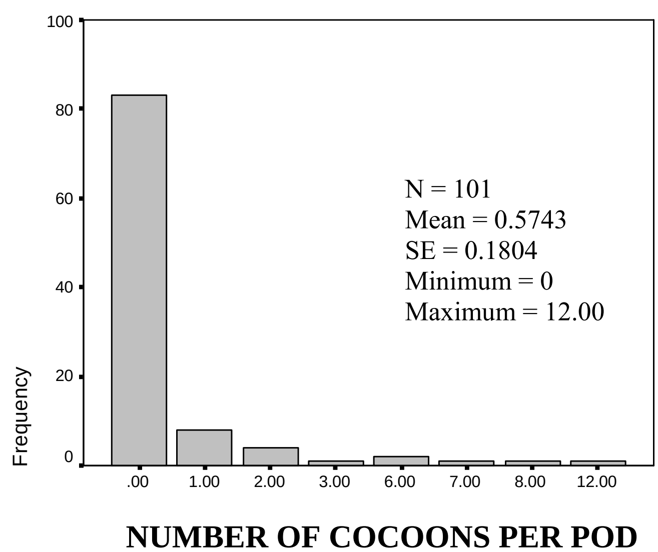


Fig. 9. Distribution of insect pupae/ cocoon among the pods.

NUMBER OF LOCULES PER POD AND THE LOCULAR WIDTH

The number of locules in pods distributed asymmetrically (negatively skewed) and averaged to 93.92 ± 2.73 – varying from 38 to 127 per pod (Fig. 10). The number of locules in a pod was the direct function of the pod length (Fig. 11). The locular width averaged to 0.4342 ± 0.0098 cm with asymmetric distribution (from 0.30 to 0.69). The locular width was independent of the pod length ($r = 0.043$, $P < 0.769$). In 84 % of the cases locular width ranged from 0.375 to 0.475cm (Fig. 12).

NUMBER OF SEEDS PER POD

The yield of healthy seeds fluctuated greatly from none to 110 seeds / pod averaging around 55.78 ± 2.29 seeds. The healthy seeds were found to distribute normally among the pods (g1 and g2 and KS-z being insignificant (Fig. 13). The number of shriveled seeds per pod averaged to 4.41 ± 0.6845 per pod and exhibited highly positively skewed distribution with long tail with maximum number of shriveled seeds from a pod to be 49 (Fig. 14). The total number of seeds (healthy, shriveled, smaller and damaged seeds) like healthier seeds distributed normally among the pods (Fig. 15) and averaged to 61.31± 2.22 seeds per pod and ranging from 4 to 110. The normal distribution exhibited by total number of seeds may probably be attributed to lesser number of shriveled, smaller or eaten seeds (less than 10%). In all, 6197 seeds were recovered from 101 pods of which 5634 (0.92%) were healthy seeds and 563 (9.08%) were shriveled, small or damaged seeds. Damaged seeds amounted to 1.404% of the total produce against 476 seeds (7.68%) shrived or smaller seeds. It follows from the results that seeds damaged due to insect (an extrinsic cause) was much lower than the intrinsic reasons producing shriveled or smaller seeds. It may be due to low infestation of pods of a solitary tree in the present case. According to Bhatta and Bhatnagar (1986) the isolated *C. fistula* plants are less prone to the moth attack and the intensity of moth attack increases with the density of the plant. They further reported that larvae of *T. fructicasseilla* damaged up to 62% of the seeds produced by the plant. Larger is the density of the host plant, larger is the intensity of the seed damage. *C. fistula* seeds are reported to be a potential source of dietary proteins ~ 26% and carbohydrates ~ 50% (Akinyede and Amoo, 2009). They asserted that it may be used in human food and food formation if phytic acid may be removed.

The seed weight recoverable from the pods averaged to 6.103 ± 0.258 g per pod varying from 0.2 to 12g per pod and depended upon the infestation of the pod by the moth and also on the proportion of the deformation of their shape due to their critical narrowing. The narrower part if narrower or equal to 1 cm, gave no healthy seeds.

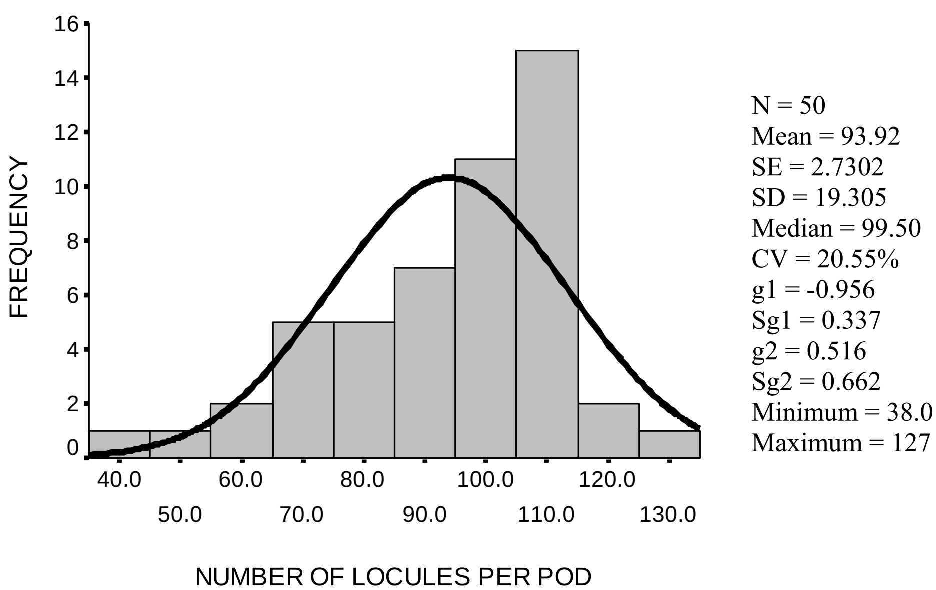


Fig. 10. Distribution of number of locules per pod.

ALLOMETRIC RELATIONS AMONG STRUCTURAL AND REPRODUCTIVE PARAMETERS

The Table 4 represents the allometric relations of structural and reproductive parameters of pods. There was a great degree of multi-colinearity among the parameters. The relationship was substantially invariant as regards to the magnitude of Pearson's r in the three types of pods - the total pods studied; (N =101); the pods excluding those four pods the seeds of which were completely eaten by the insect larvae (N = 97) and the pods yielding healthy seeds with no shriveled, smaller or damaged seeds (N = 25). There were, however, certain interesting relationships which may be described as follows:

Table 4. Correlation matrix of Pearson (r) among structural and reproductive parameters of *Cassia fistula* pods.

	PL	PD	PV	NS	PW	SW	PL(adj)	PV adj	TNS
PL	1.00								
PD	0.400 a 0.354 b 0.384 c	1.00							
PV	0.578 0.850 0.860	0.704 0.679 0.675	1.00						
NS	0.578 0.651 0.697	0.140 0.154 0.326	0.438 0.526 0.618	1.00					
PW	0.851 0.843 0.828	0..518 0.480 0.557	0.895 0.889 0.914	0.495 0.569 0.567	1.00				
SW	0..658 0.714 0.731	0.220 0.232 0.439	0.563 0.639 0.747	0.912 0.894 0.806	0..616 0.680 0.708	1.00			
PL (adj)	0.927 0.926 0.945	0.372 0.331 0.389	0.887 0.884 0.904	0.558 0.641 0.597	0.892 0.887 0.873	0.667 0.734 0.733	1.00		
PV (adj)	0.844 0.837 0.838	0.692 0.668 0.651	0.995 0.995 0.996	0.424 0.511 0.558	0.896 0.890 0.916	0.554 0.631 0.737	0.897 0.894 0.909		
TNS	0.702 0.716 -	0.233 0.193 -	0.580 0.597 -	0.924 0.963 -	0.625 0.640 -	0.874 0.881 -	0.692 0.712 -	0.566 0.584 -	

Key to the acronyms: PL, Pod Length; PD, Pod diameter; PV, pod volume; NSH, Number of healthy seeds per pod; PW, Pod weight; SW, Healthy Seeds Weight per pod; PL (adj.), Adjusted pod length; PV (adj.), Adjusted pod volume; TNS, Total number of seeds / pod (healthy + shriveled + small).

a, based on data of all (101) pods studied; **b**, based on data of 97 pods i.e., excluding four pods (# 8, 16, 32, and 37), the seeds of which were more or less completely eaten by the larvae and yielded no or very few (02 seeds in one case) healthy seeds; **c,** data set (N = 25) for healthy pods without shriveled or damaged (eaten) seeds.

The number of seeds recovered from the pods related with the pod length significantly.

$NS = - 2.04835 + 1.53586 (PL) \pm 15.50$
t = - 0.332 t = 8.37
p < 0.741 p 0.0001
r = 0.6513, N = 97
$R^2 = 0.4242$; Adj. $R^2 = 0.4180$; F = 70.0 ……………………EQ. 1

$\log_e NS = 2.71254 + 0.032668 (PL) \pm 0.28689$
t = 19.96 t = 9.62
p < 0.000 p 0.000
$R^2 = 0.4932$; Adj. $R^2 = 0.4878$; F = 92.46
r = 0.7022, N = 97…………………………………EQ. 2

The following was the best fit equation to define relationship between number of seeds (NS) and length of pod (PL).

$\text{Log}_e NS = 0.108838 + 1.06745 (\text{loge } PL) \pm 0.2860$
$R^2 = 0.4964$, Adj. $R^2 = 0.4910$, r = 0.7044, F = 93.62 ………EQ. 3
N = 97 (Not including the pods with no healthy seeds i.e., sample # 16, 32, and 37 and an outlier sample # 8).

The recoverable seed weight (SW) from pods was directly dependent upon the pod weight (PW) in the three types of pods. The variation in recoverable seed weight per pod even in healthy pods (N =25) was accounted for only around 50% by the pod weight. In other categories of pods yielding mixture of healthy and shriveled and damaged seeds (N = 101 and N = 97) such a relationship was comparatively weaker which may be due to pod deformation, infestation or some other unknown developmental constraint (s) to the seed (see equations: 4 - 6).

$SW = 1.550 + 0.0911 PW \pm 2.058$
t = 2.49 t =7.78
p < 0.014 p 0.0001 N = 101; $R^2 = 0. 616$; Adj. $R^2 = 0.380$; F = 60.58 ……………EQ. 4

$SW = 1.581 + 0.0941 PW \pm 1.730$
t = 2.84 t = 9.04
p < 0.741 p 0.0001 N = 97; $R^2 = 0.680$; Adj. $R^2 = 0.463$; F = 81.77………………EQ.5

$SW = 0.867 + 0.1160 PW \pm 1.862$
t = 0.681 t = 4.80
p < 0.503 p 0.0001 N = 25; $R^2 = 0.708$; Adj. $R^2 = 0.501$; F = 23.07………………EQ.6

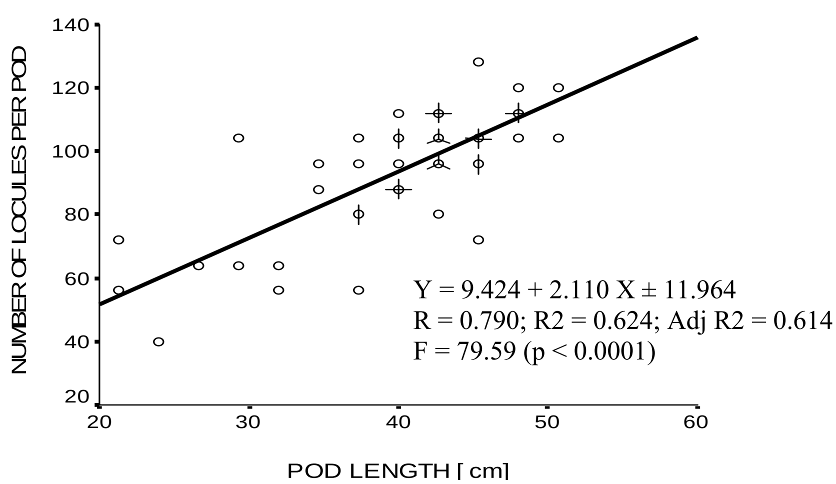
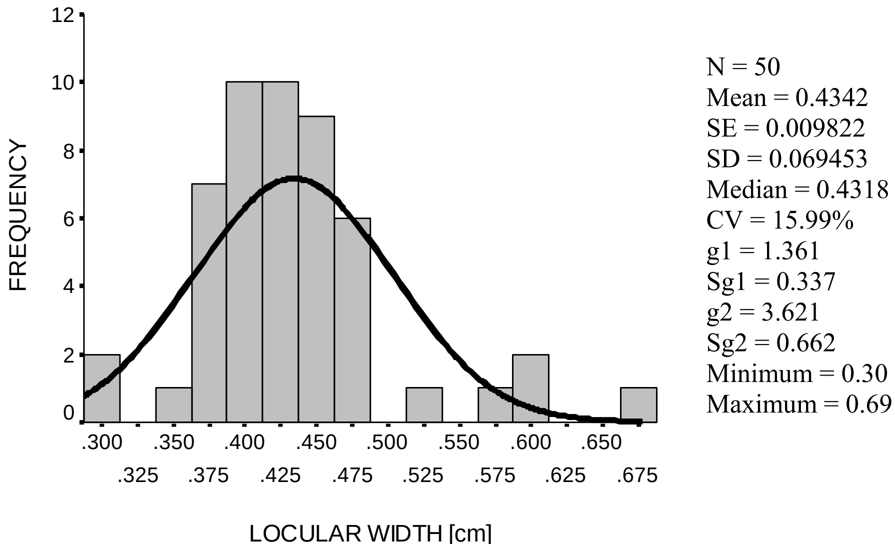


Fig. 11. Relationship of number of locules with the pod length (cm).



]Fig. 12. Distribution of locular width (cm) in pods.

SEED WEIGHT DISTRIBUTION

The distribution of seed weight of 100 randomly-selected and individually-weighed seeds was leptokurtic and negatively skewed. The class B and I, J and K were relatively better represented. The class B of 55 mg seed weight category was around 11.88 % and Classes I, J and K corresponding to 125, 135 and 145 mg seed weight categories collectively occupied a proportion of 55% (Fig. 16). The seed weight of individual seed averaged to 109.5 ± 3.10 mg and varied around 28.2 % i.e., around 3.23- folds.

Seed size variation within species and individuals is common (Halpern, 2005). Wide intraspecific variations in seed mass have been reported in several tropical species (Janzen, 1977; Foster and Janson, 1985; Khan *et al.,* 1984; Khan *et al.* 1999, 2002; Khan and Umashanjkar, 2001; Murali, 1997; Marshall, 1986; Upadhaya *et al.,* 2007). Seed weight distribution was found to be normal in six sunflower cultivars viz. S-278, local, Hysun 39, Hysun 33, Aussie gold 61 and Aussie gold 04 and Non-normal in NK Armoni, Hybrid 1, Aussie gold 61 and the pooled sample of all cultivars (Khan *et al.,* 2011). Seed mass in a seed lot of sunflower cultivar Aussie gold 61 is reported to normal distribution by Anis *et al.* (2011). Seed mass was also reported to be normally distributed in *Blutapason portulacoides* and *Panicum recemosum* but not in case of *Spartina ciliata* (Cardazzo, 2002). Halpern (2005) reported normal distribution of seed mass in *Lupinus perennis*. Zhang (1998) has reported seed mass variation in *Aeschynomene americana* by weighing 150 seeds from each of its 72 populations to be normally distributed in 9, positively skewed significantly ($p < 0.05$) in 14 and negatively skewed in 49 populations. The mass of mature seeds had a normal distribution in two natural populations of *Arum italicum* (Mendez (1997). Seed weight is reported to vary within a species with site quality and year of study – varying from symmetry to skewness, from leptokurtic to platykurtic (Busso and Perryman, 2005). Seed weight distribution was reported to be skewed in *Phlox drummondii* (Leverich and Levin, 1979). Such a high degree of variation in seed mass may be thought to have important ecological implications forming basis of qualitative and quantitative female reproductive fitness so crucial in life history diversification (Braza *et al.* (2010).

Seed weight variation in plants may be many-fold in magnitude (Zhang and Maun, 1990). Sachaal (1980) found 5.6 fold variation among 659 seeds collected from a population of *Lupinus texensis*. Khan *et al.* (1984) have reported seed weight variation in desert herbs to be around 6.82 % in *Achyranthes aspera*, 12.91% in *Peristrophe bicalyculata*, 14 % in *Cassia holosericea* and 16.83% in *Prosopis juliflora,* a tree legume. *Opuntia ficus-indica* exhibited seed weight variation c. 18.2% (Khan, 2006). Michaels *et al.* (1988) have examined 39 species (46 populations) of plants in eastern-central Illinois and reported variability (in terms of coefficient of variation) of seed mass commonly exceeding 20% - significant variation being among the conspecific plants in most species sampled. Seed weight variation in sage brush is reported to lie between 26.31 and 31.75% amongst the sites and years of study, respectively (Busso and Perryman, 2005). Seed weight is highly variable in *Alliaria petiolata* (8-fold among populations, 2.5 – 7.5-folds within population, two-three folds within individuals and 1.4 – 1.8 folds within fruits (Susko and Lovett-Doust, 2000). Halpern (2005) reported seed mass in 5839 seeds of 59 maternal plants of *Lupinus perennis* to highly variable (5-fold variation). Aziz and Shaukat (2010) have shown seed weight variation to be 19.47% in *Ipomoea sindica*, 23.3% in Cleome *viscosa*, and 19.13% in *Digera muricata*. Sixteen-fold variation in seed mass is reported in *Lamatium salmoniflorum* (Thompson and Pellmyr, 1989). According to Tíscar Oliver and Borja (2010) variation occurred in seed mass within trees of *Pinus nigra* subsp. *Salzamannii* (c 61%) rather than between them (c 39%). Four-fold variation in seed mass was found ranging from 8 to 32 (-36) mg. Significant variation in seed size exists in *Jatropha curcas* in various agro-ecological zones of India (Ghosh and Singh, 2011).

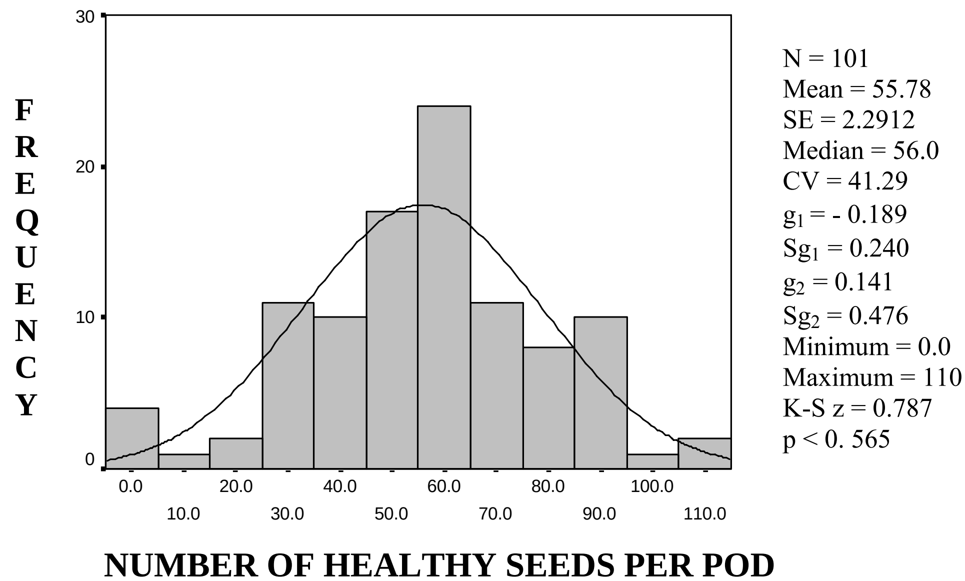


Figure 13. Frequency distribution of recoverable healthy seeds in pods of *C. fistula*.

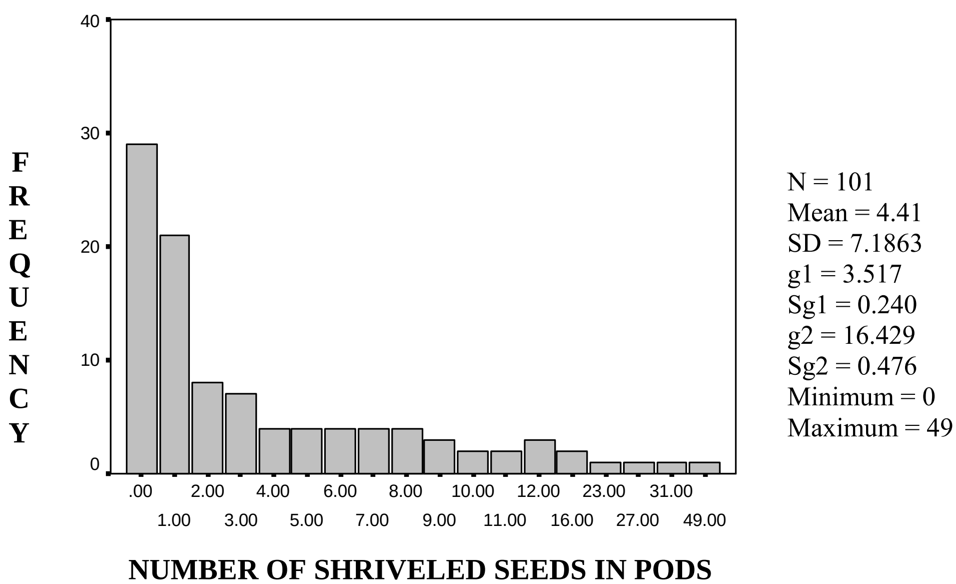


Fig. 14. Distribution of shriveled seeds among the pods.

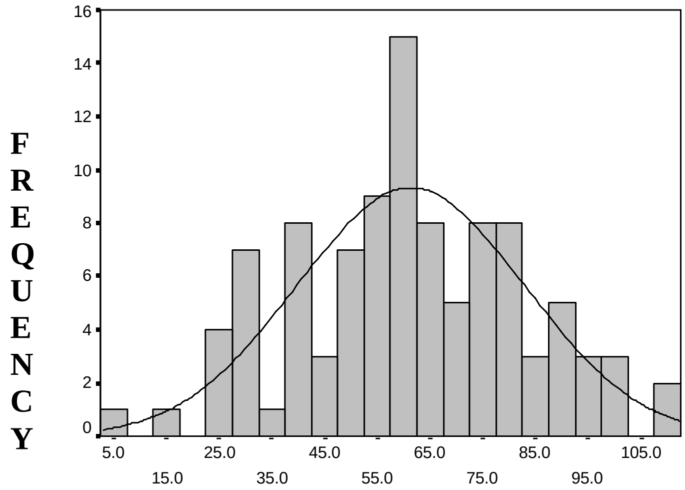


Figure 15. Frequency distribution of total number of seeds per pod in *C. fistula*.

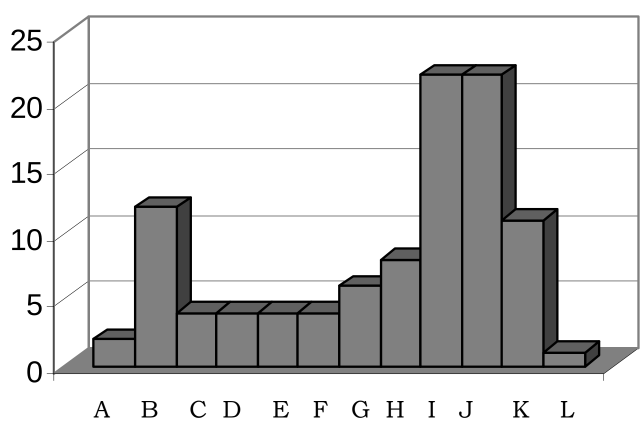


Fig 16. Seed weight distribution in *Cassia fistula*. Key to the class mid points: A. 45 mg; B, 55; C, 65; D, 75; E, 85; F, 95; G, 105; H, 115; I, 125; J, 135; K, 145; L, 155mg. The hypothesis that population is normal may be rejected at $p < 0.05$.

The variation in seed size may be the result of myriad of factors (Fenner, 1985; Wulff, 1986). Earlier impression of seed weight constancy in earlier ecological literature seems to be arising primarily from observations of the relative constancy of mean seed mass in some plant species rather than an analysis of the variability among individual seed masses which have demonstrated considerable variability (Obeid *et al*., 1967). Winn (1991) has suggested that plants may not have the capability of producing a completely uniform seed weight simply as a result of variations in resource availability (e. g., soil moisture during seed development). Seed size is significantly reduced under moisture stress in mature trees of walnut (Martin *et al.,* 1980). Seed weight is said to be the direct function of precipitation (moisture availability) and monthly precipitation is reported to explain around 85% of the total variation in seed weight in Wyoming sage brush, *Artemisia tridentata* (Busso and Perryman, 2005). The large variation of seed mass among plants suggests a potential for but not necessarily the presence of genetic control of seed size. This is because maternal parents may influence seed size via both maternal genetics and the maternal environment effect (Roach and Wulff, 1987; Busso and Perryman, 2005). Obviously the seeds collected from the plants might be a mixture of half sibs and full sibs instead of strict half sibs. Seed weight variation in plants thus appears universal which may be due to trade-off of resource allocation between seed size and number (Venable, 1992) or environmental heterogeneity (Janzen, 1977) or the genetic reasons. Alonso-Balnco et al. (1999) have indeed identified several gene loci responsible for natural genetic variation in seed size in *Arabidopsis thaliana*. Doganlar *et al.* (2000) have presented seed weight variation model in tomato. It may be asserted that within a species, seed mass variation should have both genetic and environmental components. Contrary to it the variation within a plant can only reflect environmental variance due to either development stability or genetically based adaptive variability –very difficult to distinguish (Hickman, 1979).

SEED WEIGHT / SEED NUMBER TRADE-OFF

Fig. 17 represents the relation ship of mean seed weight of recovered seeds as a function of Pod weight and total number of seeds per pod. This relationship was given by the following equation. Clearly, the mean seed weight was a direct function of the pod weight but varied negatively with the total number of seeds developing in a pod. The data indicated a degree of trade-off between seed weight and seed number.

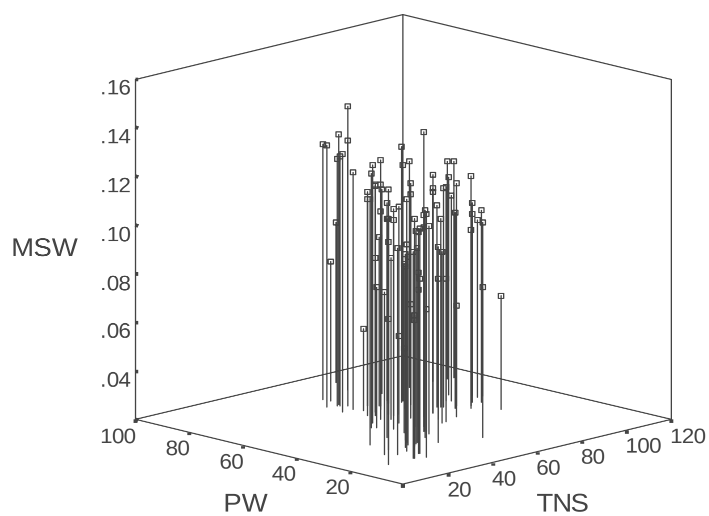


Fig. 17. Relationship of mean seed weight (MSW) for a pod with pod weight and total number of seeds in the pod.

MSW (g) = 0.09056 + 0.0004655 Pod weight (g) – 0.000204 Total number of seeds per pod ± 0.017

t = 15.24	t = 3.55	t = -1.87
p < 0.0001	p < 002	p < 0.064

N = 97, R^2 = 0.12, Adj. R^2 = 0.102, F = 6.43 (p < 0.002)

The seed size / seed number trade-off is a common phenomenon in many plants. Aniszewski *et al.* (2001) has reported seed size / seed number trade off even at intraspecific level in *Lupinus polyphyllus* Lindl. Within a plant, average seed weight has been reported to decrease as the number of seeds within a fruit of wild radish increased (Stanton, 1984). Chen *et al.* (2009) has reported that the total fruit mass and total seed mass in tropical woody species were positively correlated with twig size. Seed size was positively associated with fruit size, which was in turn positively correlated with twig diameter but negatively correlated with the ratio of twig length to twig diameter. Seed size was negatively and isometrically correlated with seed number per twig mass in both the ever green and deciduous species demonstrating the existence of trade-off between seed size and number. Our data suggest that developing embryos within a fruit compete for maternal resources of *C. fistula*. Seed weight variation observed in our present studies could be due to the trade off between seed weight and seed number developing inside the pod. Of course, the environmental heterogeneity and the genetic reasons cannot be ignored. The elucidation of role of these factors in *C. fistula* fecundity requires, no doubt, further studies.

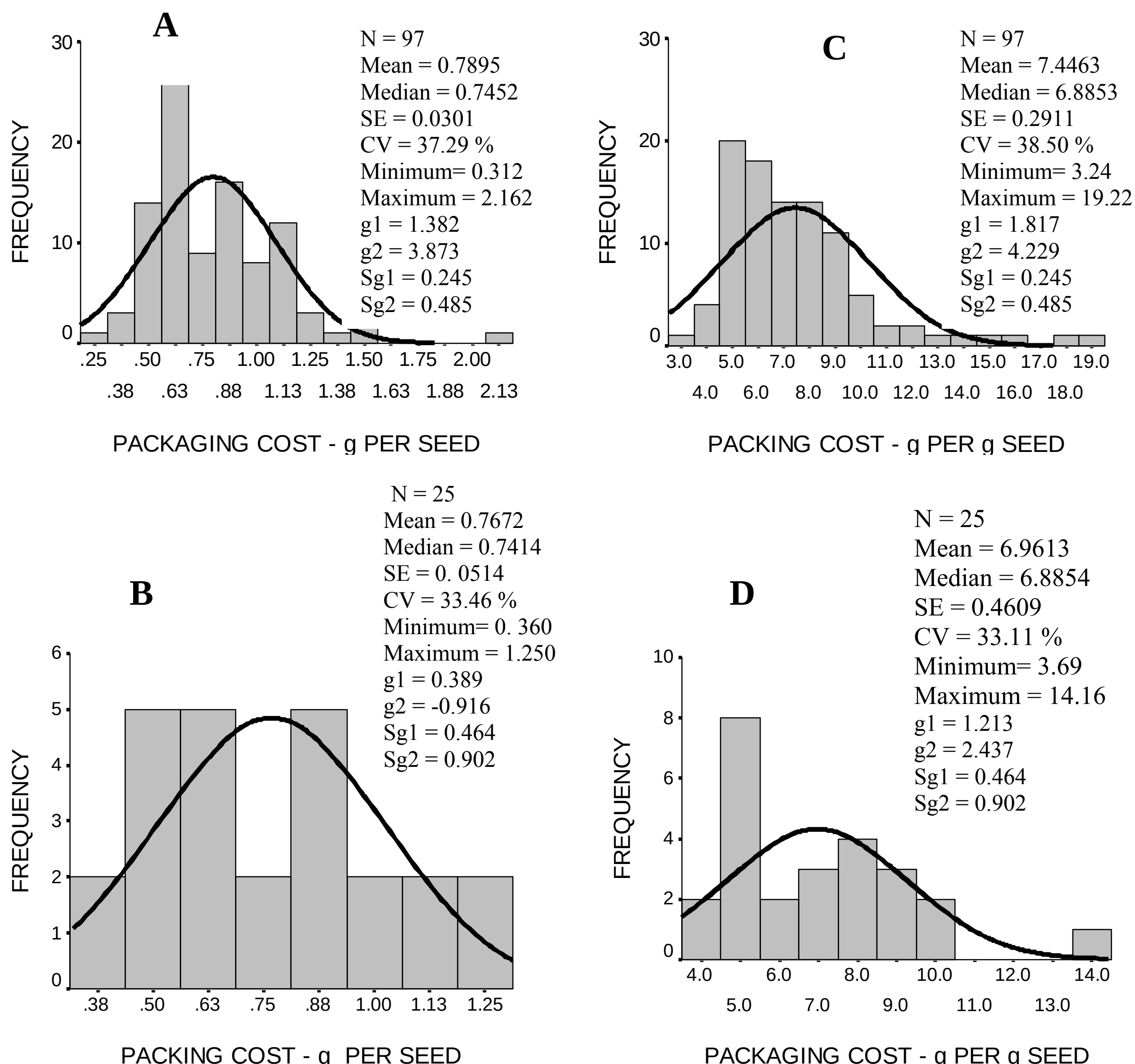


Fig. 18. Packaging costs (g seed $^{-1}$ and g. g $^{-1}$ seeds in *Cassia fistula*. **A and C,** data of 97 pods (excluding four pods i.e., pod # 8, 16, 32, and 37) as their seeds were more or less completely eaten by the larvae and so they yielded no healthy seeds (just 2 seeds in one case only); **B and D**, data set of 25 perfectly healthy pods yielding all healthy seeds and no shriveled or damaged (eaten) seeds.

PACKAGING COST

A fruit of an Angiospermic plant consists of typically pericarp and seeds. Within fruit reproductive allocation among various fruit components has scarcely been examined across the range of fruit types and taxa although it is critical in the evolutionary perspective (Chen *et al*., 2010). In the present studies, packaging cost was determined on the basis of the quantum of residual biomass (pericarp) of pod per seed or per g seeds in the two types of pods – a) all pods studied except four pods yielding no seeds (N = 97) and b) the pods free of infestation (N = 25) and yielding healthy seeds and no shriveled seeds (Fig. 18). The packaging cost per seed in the two types of the pods averaged to 0.7895 ± 0.0301 g (0.312 – 2.162) in the first type of pods and 0.7672 ± 0.0514 g (0.360 – 1.225) per seed in the healthy pods. The two means were not statistically significant (t = 0.3745, NS). The packaging cost calculated in terms of residual biomass (g) per g seeds averaged to 7.4463 ± 0.2911 (3.24 - 19.22) and 6.9613 ± 0.4609 (3.69 - 14.16) in the two types of pods, respectively. These means were also not significantly different from each other (t = 0.97, NS). In each case, the packaging cost was distributed asymmetrically except that packaging cost per seed in healthier pods Showed some tendency to follow normal distribution. Seed packaging have been studied by Wilson *et al.* (1990)) in twenty eight species and they noted a marked variation in average seed packaging investment in almost all 28 species surveyed. It is demonstrated by our data that packaging cost in *C. fistula* varies from pod to pod even in case of the healthier pods. The packaging cost calculated as residual pod biomass per seed or per g seeds correlated significantly with each other (Fig. 19) but the variation accounted for in one parameter by the other was low (adj. $R^2 = 0.5821$). In view of the variation in the seed weight, in our studies, determination of packaging cost on the basis of residual mass per g seed appears to be more reliable than determining the packaging coast on per seed basis.

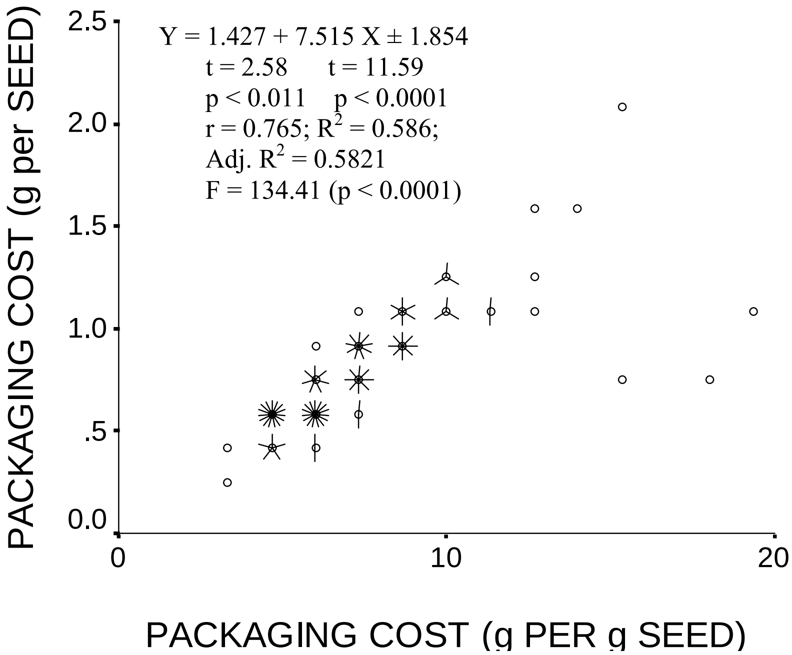


Fig. 19. Relationship between Packaging costs calculated on the basis of per seed and per g seeds.

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