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AXIAL DIMENSIONS OF PODS AND SEEDS AND WITHIN-POD-ALLOCATION OF PHYTOMASS AND SEED PACKAGING COST IN *ERYTHRINA SUBEROSA* ROXB. (PAPILIONACEAE)

D. Khan[1], Zulfiqar Ali Sahito[1]*, M Javed Zaki[1] and S. Shahid Shaukat[2]

[1]*Department of Botany, University of Karachi, Karachi -75270, Pakistan.*
[2]*Institute of Environmental Studies, University of Karachi, Karachi-75270, Pakistan.*

ABSTRACT

Biomass investment in pods, seeds and seed packaging was studied in *Erythrina suberosa* Roxb. from the campus of the University of Karachi, Pakistan. The pods were tardily dehiscent or indehiscent for long period of time. The seeds were placed in the pod lengthwise. On an average, the pod was 21.96 ± 0.78 cm long, 2.12 ± 0.43 cm broad and 1.49± 0.29cm thick at the mid of the middle seed chamber. The mean seed was 13.31 ± 0.9mm long, 8.77 ± 0.104 mm broad and 7.78 ± 0.50mm thick. The mean sphericity of seed was 72.11 ± 0.41%. On an average pod weighed 4.140 ± 0.1478g, ranging from 1.475 to 10.5431g (CV: 30.27). The pod weight was distributed asymmetrically; skewed positively and leptokurtic [Kolmogorov-Smirnov z (KS-z) = 1.352; $p < 0.052$]. The brood size (*sensu* Uma Shaanker *et al.*, 1998) averaged to 3.62 ± 0.125 per pod varying from 1 to 9 (CV: 37.07%). Brood size distributed asymmetrically with significant degree of positive skewness (PSD) and leptokurtosis. There were two types of seeds *E. suberosa* produced a) light brown seeds b) dark reddish brown seeds. The seed mass averaged to 2.4594 ± 0.0929 g per pod and varied by a quantum of 40.5%. The distribution of mean single seed weight for a pod (MSSW) was asymmetrical (negatively skewed (NSD) and leptokurtic) among the pods. It averaged to 0.6825 ± 0.0109g and varied from 0.0634 to 0.9324g The pericarp mass per pod varied from 1.3560 to 6.5653g (CV: 56.41%) and averaged to 1.6809 ± 0.0884g. There was no trade-off between fruit size and allocation of resources to seeds. The distribution of pericarp mass showed PSD and leptokurtosis. Some 40.17 ± 1.09 % of the pod biomass was allocated to pericarp (seed protection) and 59.83 ± 1.09 % to the seeds (reproductive function). In a linear model, seed weight per pod (SWPP) coupled with TNS (brood size) as independent variables influenced MSSW significantly ($r = 0.754$ $p < 0.0001$). In this model, brood size influenced MSSW negatively. The weight of individual seed for a sample of 412 seeds averaged to 686.49 ± 7.287 mg varying from 51.0 to 987.6 mg (19.36-fold variation). Seed packaging cost (SPC) in *E. suberosa* was 0.7480 ± 0.4202 $g.g^{-1}$.seeds and 0.4959 ± 0.0245 $g.seed^{-1}$. The seed packaging cost ($SPC_2 = g.g^{-1}$.seeds) related with brood size in accordance with a negative power model (exp. = -0.561863) i.e. the investment of biomass in pericarp had a negative trade-off with brood size.

Key Words: *Erythrina suberosa* Roxb, Axial dimensions of pods and seeds, Brood size, Pericarp and Seed weight, Within-pod biomass allocation, Seed packaging cost

INTRODUCTION

Seeds are the delivery system of genetic materials from one generation to the next. The life cycle involves seed formation, maturation, dissemination and germination – a complex chain of events, many of which are poorly understood or documented (Bonner and Kaarfalt, 2008), Determining within-fruit-reproductive-allocation is important for the understanding of reproductive bionomics and seed size significance in plant life strategy (Chen *et al.*, 2010). The quantification of reproductive allocation of biomass at fruit and seed levels has been made in several ecological studies (Willson *et al.*, 1990; Lee *et al.*, 1991; Lord and Westoby, 2006; Martinez *et al.*, 2007; Chen *et al.*, 2010, Khan and Zaki, 2012; Khan and Sahito, 2013 a, b and b; Khan *et al.*, 2013). Such studies are important and interesting (Mehlman, 1993) since pattern of seed-packaging varies significantly among broadly ecologically similar species and within species (Willson *et al.*, 1990; Chen *et al.*, 2010) and even among fruits within an individual (Khan and Zaki, 2012; Khan and Sahito, 2013a,b; Khan *et al.*, 2013). In this paper, variation in reproductive allocation of biomass within pods and variation of seed size and seed packaging cost in an individual tree of *Erythrina suberosa* Roxb. (Vernacular name: Gul-e-Nishtar, corky coral tree), a pantropical ornamental multipurpose legume, is studied. It is mostly cultivated. It grows fast and bursts into bloom in summer when it produces scarlet mass of flowers. Its pods and seeds are potentially useful in many ways; therefore, axial dimensions of pods and seeds are also described for their engineering significance.

MATERIALS AND METHODS

One hundred and fifteen mature dark brown pods from a large tree (Height c 10m and stem diameter c 60 cm) of *Erythrina suberosa* Roxb. in the campus of University of Karachi were collected in 2012. These pods were air-dried for around 60 days in laboratory. Measurements were made on pods and seeds to determine biomass investment in seed and seed packaging for following parameters after Mehlman (1993) and Chen *et al.* (2010). 1.

*, Present Address: University of Chinese Academy of Sciences, Beijing 100039, PR China & The State Key Laboratory of Plant Cell & Chromosome Engineering, Centre of Agricultural Resource Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang, Hebei, PR China.

Pod weight (PW) of air-dried pods, 2. Total seed weight per pod (SWPP), 3. Number of seeds per pod (TNS, the brood size), 4. Pericarp weight per pod (PWP), 5. Mean single seed weight (MSSW) in a pod, 6. *Per cent* proportion of pericarp weight to fruit (pod) weight (PPFR), 7. *Per cent* proportion of seed weight to fruit (pod) weight (PSFR), 8. Pod weight per seed (PWS = PW / TNS), 9. Seed packaging cost per seed (SPC_1 = PWP / TNS and 10. Seed packaging cost per g seeds (SPC_2 = PWP / SWPP). The weight of each seed recovered from the pods was recorded pod-wise.

The location and distribution parameters were calculated for the pod and seed characteristics. The frequency distributions were characterized with skewness (g1) and kurtosis (g2) (Zar, 2010). Kolmogorov-Smirnov (KS-z and KS-d) and Shapiro-Wilks tests were performed to detect normal distribution. In allometric analysis, the slope of the fitted regression line was compared with the slope of the null line using following t-test formula ($t = b - H / SE_b$; df = n -2, where n is the number of samples, t, the t-statistics, b, slope of the fitted line, SE_b is the SE of b and H is the slope of null line) (Underwood, 1997).

The linear measurements of pods were expressed in cm and in case of seeds in mm. The axial dimensions (Length (L.), breadth (B) and thickness (T) of seeds measured with a precision of 0.1 mm. A 3-dimensional expression of the axial dimension defines the shape of the solid object and when it is in relation to a sphere it is called sphericity which may be defined as " the ratio of the surface area of a sphere with the same volume as the seed to the surface area of the seed" (Mohsenin, 1986). Sphericity of seeds was measured according to the methods of Mohsenin (1986). The seed volume and surface area were measured according to the formula of Jain and Ball (1997).

Arithmetic diameter (mm) = $L + B + T / 3$

Geometric diameter (mm) = $(L * B * T)^{1/3}$

Sphericity (Ø) = $(L * B * T)^{1/3} / L$

Seed Volume (V, mm^3) = $0.25 [(\pi / 6) L (B + T)^2$

Seed surface area (S. mm^2) = $\pi KL^2 / (2L - K)$ …. Where $K = \sqrt{(BT)}$

RESULTS AND DISCUSSION

THE PODS:

The pods of *E. suberosa* are stipitate, torulose, falcate, dark brown in colour distinctly veined and narrowed sometimes very deeply between the seed chambers (Fig.1 A and B). The outer wall is leathery and brittle on drying. The inner wall is whitish cream in colour continuous along the pods and enclosing seeds (Fig. 1C). It is also brittle on drying. The seeds are arranged length-wise in pods.

Axial dimensions of pods

The pod length ranged from 12 to 29 cm (mean: 21.96 ± 0.778 (Table 2). Some 62.5 % of the pods fall between 20 and slightly larger than 25 cm. Pod breadth averaged to 2.1 ± 0.043 cm. In 85% of the cases pod breadth varied between 1.4 and 2.2 cm. The pod thickness at the middle of the seed chamber was 1.485 ± 0.294 cm. The pod breadth and thickness varied by 12-13% only whereas pod length with comparatively higher quantum, 22.39%. There was maximum variation in the number of seed chambers in pods (38%). The axial parameters and the number of seed chambers per pod tended to follow normal distribution (Table 1). The number of seed chamber in pods (SC) varied from 1-9 and related highly significantly with pod length ($r = 0.896$, $p < 0.01$, 2-tailed) and relatively lesser significantly with pod breadth ($r = 0.386$, $p < 0.05$, 2 tailed test). There was no correlation between pod thickness and number of chambers in pods ($r = 0.231$, NS). Pod breadth was more closely related with pod thickness ($r = 0.716$) than pod length ($r = 0.496$) (Table 2).

Number of seed chambers in a pod (SC) = - 2.2771 + 0.3603 Pod length (cm) ± 0.889
t = - 4.17 t = 12.45
$p < 0.002$ $p < 0.0001$; F = 154.97, r = 0.896, $r^2 = 0.803$, Adj. $r^2 = 0.7998$

THE SEEDS

There are two types of seeds *E. suberosa* produces a) light brown seeds b) dark reddish brown seeds (Fig, 1D). The seeds were ellipsoid – reniform, smooth and shining presumably due to lipid exudation from seed surface (Fig. 3B). This colour dimorphism of seeds may not only be seen within an individual plant but also within a pod. This colour differentiation of seed coat may presumably be under genetic control i.e. due to two or more allelic forms of the gene controlling testa colour. The seeds are used in items as necklaces, rosaries and good-luck charms. The seeds contain a number of organic acids, alkaloids and steroids. It was for the first time that erysotrine was found to occur naturally in this species (Singh and Chawla, 1970; Bisby, 1994). Its alkaloids show curare-like activity. Seeds show promising activity against certain muscular rigidity (Khare, 2007). It has anti-diabetic properties (Soumyanath, 2005). The economic significance of seeds led us to determine also the axial dimensions and related parameters of the seeds to record this data for future agro-engineering use of the seeds.

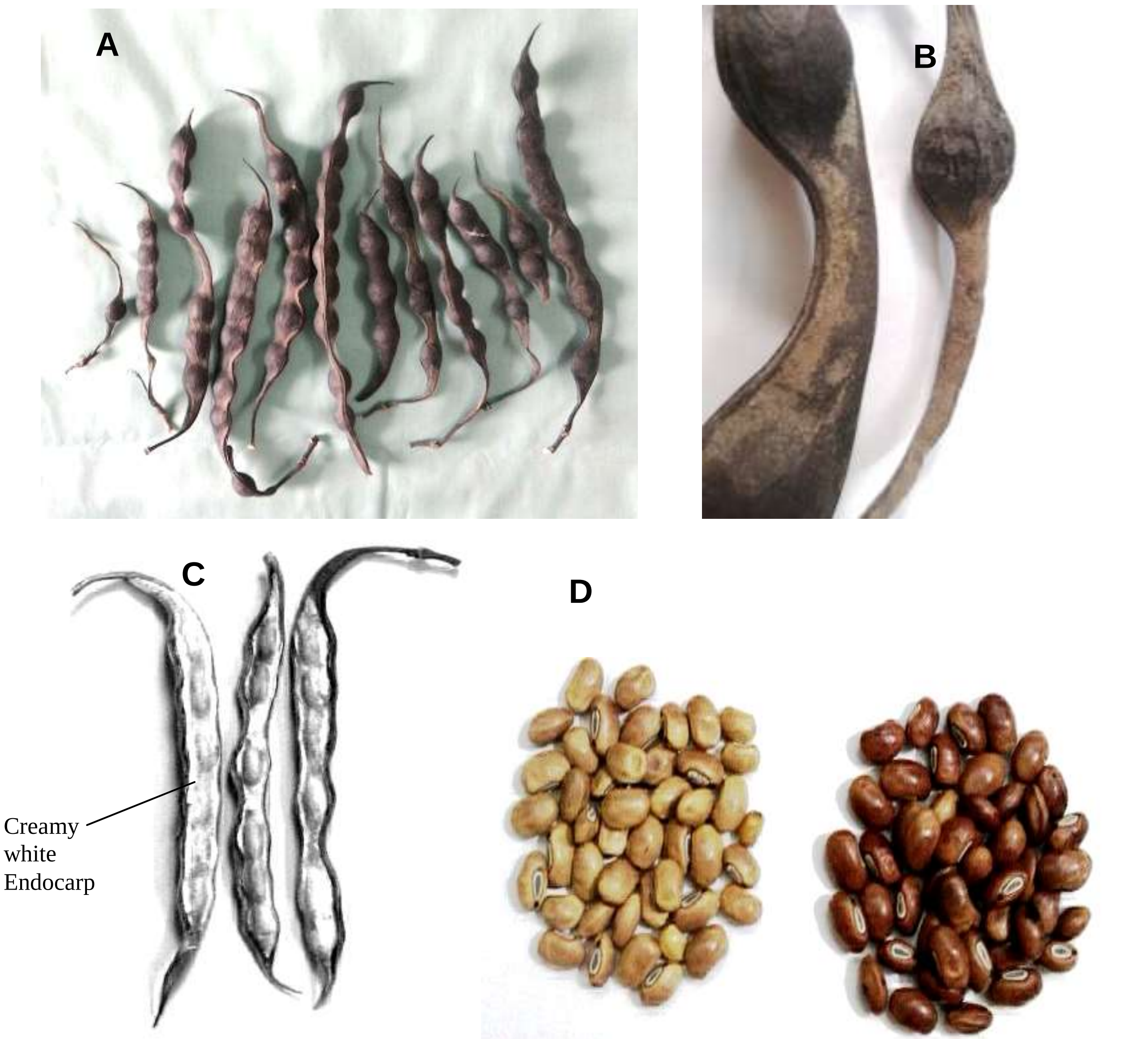


Fig. 1. Pods and seeds of *Erythrina suberosa*. A, Pods – 1-9 seed chambered; B, close up view of pod surface – light brown rementa visible; C, Pods (upper layer removed) showing creamy white inner layer enclosing several seeds; the seeds are arranged length–wise in the pod; D, seed colour dimorphism – light brown and dark reddish brown seeds.

Axial dimensions of seeds

The data on axial dimensions of seeds are outlined in Table 3. The seed length averaged to 13.31 ± 0.1899mm and generally concentrated (50.9%) in a class of 11 - 15 mm. Some 33 % of the seeds were, however, longer than 15 mm. The seed breadth was 8.766 ± 0.1038 mm, substantially (56.9%) falling within a class, 8.1 to 10 mm. The seed thickness ranged between 4.02 to 11.1 mm and averaged to 7.48 ± 0.502 mm and generally belonging to size category of 7.26 to 10 mm. The arithmetic and geometric diameters of seeds averaged to 24.57 ±0.31 and 9.515 ± 0.114 mm, respectively. The seeds were found to have sphericity of 72.11 ± 0.411 % which was larger than *Ricinus communis* seeds (67.62-67.84; Gharibzahedi *et al.,* 2011). The seeds were quite variable in volume (40.42 %) and around 41.3 % of the seeds belonged to a class of 500.1 – 700 mm^3 (mean volume of seed: 489.298 ± 15.40 mm^3). The surface area of a mean seed amounted to 248.55 ± 5.465 mm^2. The surface area varied from 78,625 to 451.625 mm^2. In 49.7 % of the seeds, the surface area varied from 200.1 to 300 mm^2. The sphericity of seeds showed the lowest variation (CV: 7.32%) and the volume showed the maximum variation (CV: 40.42%) (Table 3). The other measurements exhibited variation below 18%. Surface area showed moderate degree of variation (CV: 28.24%). None of the basic axial and derived parameters except seed thickness and volume distributed normally (Table 3). Physical and engineering properties of seeds of different species have been reported by various workers (details in Mohsenin, 1986; Gharibzahedi *et al.*, 2011). Such data as reported here for *E. suberosa* could be useful for designing machines for any kind of processing of its seeds for its economic utilization.

Table 1. Location and dispersion parameters of pods axial dimensions.

Parameters	Pod Length * (cm)	Pod Breadth** (cm)	Pod Thickness *** (cm)	Seed Chambers
N	40	40	40	40
Mean	21.96	2.008	1.485	5.20
SE	0.7775	0.0427	0.294	0.313
Median	22.65	2.050	1.50	5.50
CV (%)	22.39	13.46	12.53	38.02
Skewness	-0.363	-0.010	-0.649	-0.293
Kurtosis	-0.937	-0.027	0.315	-0.534
Minimum	12	1.4	1.0	1
Maximum	29.0	2.6	1.8	9
Test for Normal Distribution				
KS-z	0.680	0.847	0.994	0.994
p	0.744	0.470	0.277	0.272

*, including mucro and stalk; **, between the widest points; ***, at the mid of the middle seed chamber. SE for skewness: 0.374 & SE for Kurtosis: 0.733.

Fig.2. Selected healthier seeds – showing adorned Hilum with white oval border enclosing gray central area. Micropyle is black. Hilum side is concave and side opposite to Hilum is convex.

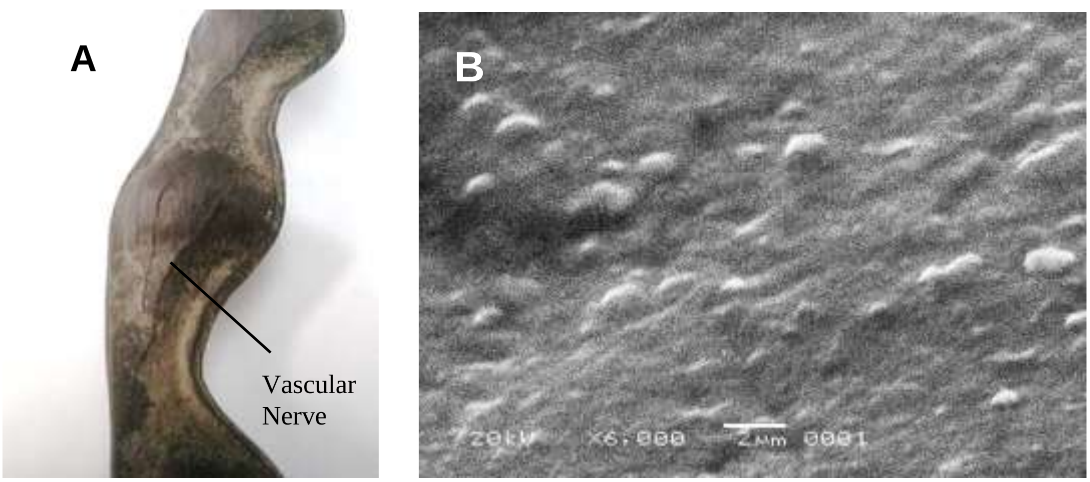


Fig.3. A, Pod surface with vascular nerves; B, SEM of seed surface of *Erythrina suberosa (*Magnification 6000 X*)*. Surface is smooth, glabrous. White spots are 1-2 μm presumably the lipid globules excreted out from the seed surface.

Table 2. Inter-relationships amongst pod dimensions (correlation 'r'). PL, Pod length; PB, pod breadth; PT, Pod thickness; SC, Seed chambers in a pod.

PL	PL			
PB	0.496**	PB		
PT	0.354*	0.716**	PT	
SC	0.896**	0.386*	0.231 NS	SC

Significance: *, $p < 0.05$; **, $P < 0.01$ (Two-tailed test.).

On an average a pod weighed 4.140 ± 0.1478g, ranging from 1.475 to 10.5431g (CV: 30.27%). The pod weight is distributed asymmetrically (skewed positively and leptokurtic (Table 3).

Table 3. Physical properties of seeds of *Erythrina suberosa* (N= 165).

Parameter	Length (mm)	Breadth (mm)	Thickness (mm)	Arithmetic Diameter (mm)	Geometric Diameter (mm)	Sphericity (%)	Volume (mm^3)	Surface Area (mm^2)
Mean	13.310	8.7664	7.4822	24.5706	9.5154	72.1067	489.2981	248.550
SE	0.1899	0.1038	0.09175	0.3091	0.1135	0.41108	15.398	5.4648
Median	14.150	9.1500	7.530	25.9933	9.9356	71.1281	516.85	263.104
CV (%)	18.33	15.21	15.75	16.16	15.32	7.32	40.42	28.24
g1	-0.688	-0.604	-.363	-0.655	-0.610	2.027	-0.020	-0.293
Sg1	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189
g2	-0.636	-0.265	0.141	-0.600	-0.399	8.420	-0.416	-0.472
Sg2	0.376	0.376	0.376	0.376	0.376	0.376	0.376	0.376
Minimum	7.00	5.020	4.020	14.390	5.443	61.886	85.856	78.628
Maximum	17.00	11.500	11.100	32.20	12.914	103.202	1136.02	451.625
KS-z	2.054	1.718	1.209	1.910	1.722	1.434	1.028	1.392
p	0.001	0.005	0.108	0.001	0.005	0.033	0.241	0.041

Table 4. Location and dispersion statistics of pods and seeds parameters of *E. suberosa*.

Parameter	N	Min.	Max.	Mean	SE	CV (%)	G1	G2
TNS	115	1	9	3.62	0.1250	37.07	1.020	2.108
PW	115	1.475	10.5431	4.1403	0.1478	30.27	1.591	3.841
SWPP	115	0.7396	6.2522	2.4594	0.0929	40.50	1.212	2.399
MSSW	115	0.0634	0.9324	0.6825	0.0109	17.17	-1.249	5.715
PWPS	115	0.6963	2.6511	1.1788	0.0264	24.41	1.940	6.685
SPC_1	115	0.0194	2.1179	0.4959	0.0245	53.07	2.668	13.289
SPC_2	115	0.0279	3.792	0.7480	0.4202	60.24	3.675	23.070
PERI	115	1.3560	6.5653	1.6809	0.0884	56.41	2.524	10.276
PPFR	115	2.7111	79.8873	40.1718	1.0879	29.05	-0.214	1.771
PSFR	115	20.113	97.289	59.5282	1.0879	19.64	0.214	1.771

Parameter	KS-z	p	KS-d	p	Lilliefors p	Shapiro-Wilks (W)	p
TNS	2.135	0.0001	0.199	< 0.01	< 0.01	0.902	0.0001
PW	1.352	0.052	0.126	< 0.10	< 0.01	0.883	0.0001
SWPP	1.285	0.074	0.120	< 0.10	< 0.01	0.926	0.0001
MSSW	0.699	0.0713	0.065	> 0.20	> 0.20	0.928	0.0001
PWPS	1.399	0.055	0.124	< 0.10	< 0.01	0.859	0.0001
SPC_1	1.965	0.001	0.183	< 0.01	< 0.01	0.783	0.0001
SPC_2	2.259	0.0001	0.211	< 0.01	> 0.01	0.714	0.0001
PERI	1.625	0.010	0.155	< 0.05	< 0.01	0.800	0.0001
PPFR	1.586	0.013	0.148	< 0.05	< 0.01	0.948	0.0001
PSFR	1.586	0.013	0.148	< 0.05	< 0.01	0.948	0.0002

Legend (Table 4)

g1, skewness;
g2, kurtosis.

SE of Skewness (Sg1) (N: 115) =0.226; SE of kurtosis (Sg2) (N: 115) = 0.447.

KS-z, Kolmogorov-Smirnov z.
KS-d, Kolmogorov-Smirnov d.

Key to the acronyms: PL, pod length (cm); TNS, Seeds per pod; PW, pod weight (g); SWPP, Seed weight per pod; MSSW, mean single seed weight in a pod; PWPS, pod weight per seed; SPC_1, seed packaging cost (g. pericarp per seed); SPC_2. Seed packaging cost (g pericarp per g seeds); PERI, Pericarp; PPFR, Percent proportion of pericarp wt. to fruit wt; PSFR, % proportion of seed wt. to fruit wt.

Brood Size

Brood size (*sensu* Uma Shaanker *et al.*, 1998) averaged to 3.62 ± 0.125 per pod varying from 1 to 9 (CV: 37.07%). Brood size distributed asymmetrically with significant degree of positive skewness and leptokurtosis (Table 4; Fig. 4). The brood size per pod predominantly belonged to the category of 2-5 seeds (90.5%) which is practically in agreement with Ali (1977). In our data pods containing one seed only were two in number (1.7% of the total pods). Pods with 6-8 seeds were 6.8% of the total pods and only one pod (0.9%) had 9 seeds. None of the pod was, however, completely devoid of seeds. The brood size of some caesalpiniacean species has been reported by Uma Shaanker *et al*. (1988) - *Bauhinia purpurea* (9.9 ± 2.92), *Bauhinia recemosa* (10.86 ± 6.52), *B. ungulata* (13.0 ± 10.14), *Tamarindus indica* (4.59 ± 2.72) and *Cassia fistula* (78). Based on the study of 101 pods, the brood size in *Cassia fistula* has been reported to be 55.78 ± 2.29 (ranging from 0 to 110) by Khan and Zaki (2012). *In Delonix regia*, the brood size was 13.43 ± 0.668 ranging from 4 to 28 (Khan and Sahito, 2013b). Brood size of acacias is comparatively higher than *E. suberosa* (Afsar uddin, 2012; Khan and Sahito, 2013a; Khan *et al.,* 2013). The significant value of KS-z (2.135, p < 0.0001) indicated that the brood size didn't distribute normally. (Table 4; Fig. 4). Brood size has been reported to be normally distributed in *Bauhinia recemosa, B. ungulata, and Cassia fistula* (Uma Shaanker *et al.* (1988; Khan and Zaki (2012). The distribution of brood size has, however, also been reported to significantly vary from the normal in several plants. This trait may be positively skewed (PSD) or negatively skewed (NSD) also. The pattern of brood may probably come up due to differences in the developmental history specific to the individual pods in the environmental context (Khan and Sahito, 2013b). PSD in brood size is induced when a minority of ovules develops into mature seeds in most fruits and seed-to-ovule ratio is low i.e. < 50 % and as a result fruits are one to few-seeded (Uma Shaanker *et al.,* 1988). Furthermore, the coefficient of variation for brood size remains quite high. There are, however, examples of some species that accomplish brood size NSD through a maternally regulated pre-fertilization inhibition of pollen grains germination by the stigma. (Ganeshaiah *et al.,* 1986, 1988). NSD of seeds in pods is said to be a common feature of majority of multi-ovulate species (Lee and Bazzaz, 1982). In *Leucaena*, the germination of pollen grains is inhibited by the stigma unless a minimum threshold number of pollens are deposited. This leads to NSD of fertilized ovules (Ganeshaiah *et al.,* 1986). A similar mechanism has also been reported in *Tammarind* (Thimmaraju *et al.,* 1989; Usha, 1986), and *Moringa* (Uma Shaanker and Ganeshaiah, 1987).

Number of seed chambers per pod

The number of seed chambers per pod were as many as the number of seeds per pod and varied from 1 to 9 (mean = 3.62 ± 0.125). Irrespective of the number of seed chambers in a pod, no seed chamber in 115 pods was found to be devoid of seed. However in three pods, one seed each was observed to be smaller (< 320 mg) and seven pods had one ill-filled seed each (≤ 160 mg). Excluding these seeds seed weight distribution tended to be normally distributed (N: 402; KS-z: 0.577, p < 0.894). All pods contained seeds of variable weight. The intra-fruit patterns of seed development are generally interpreted to the consequences of resource and fertilization gradients. Some patterns could also be due to neighbour effects. Positive neighbour effects leading to higher frequency of contiguous positions of seeds in pod have been reported by Joshi *et al.* (1993) in *E. suberosa* on the basis of presence / absence data of developing seeds in fresh pods. Since no seed chamber was found empty in mature pods, in our case, we couldn't test out such a hypothesis.

Seed weight per pod (SWPP)

The seed mass per pod averaged to 2.4594 ± 0.0929 g per pod and varied by a quantum of 40.5%. As the number of seeds per pod varied greatly and in consequence the seed yield ranged from 0.7396 g per pod to 6.2522g in case of pods containing several seeds (Table 4). The pod mass per pod tended to be positively skewed and leptokurtic.

Mean single seed weight in pod (MSSW)

The distribution of MSSW was asymmetrical (negatively skewed (g_1 = -1.249, Sg_1 = 0.226,) and leptokurtic (g_2 = 5.715, Sg_2 = 0.447) among the pods. It averaged to 0.6825 ± 0.0109g and varied from 0.0634 to 0.9324g (Table 4; Fig. 9). The seeds ≤ 500 mg were 2.6%, those from 501-800 mg were 85% and those > 800 mg were 12.2% only.

Pericarp Mass

The pericarp mass per pod varied from 1.3560 to 6.5653g (CV: 56.41%) and averaged to 1.6809 ± 0.0884g. The distribution of pericarp mass showed PSD and leptokurtosis as the magnitude of g1 and g2 was highly significant (2.524 and 10.276, respectively). KS-z and other normality tests were also highly significant (Table 4).

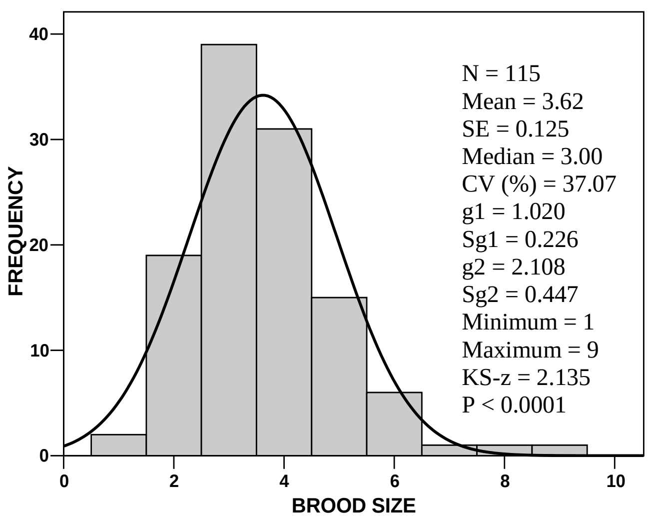
Functional allocation of biomass in pods

In Angiosperms, a fruit may be considered to serve three basic functions in the life history– reproductive, protective and dispersal. In *E. suberosa,* there is no special structure for dispersal of seed after release from the pod;

there were only two functional categories – protective due to pericarp and reproductive in form of seeds. In pods studied (N = 115), 40.17 ± 1.09 % of the pod biomass was allocated to pericarp (seed protective function) and 59.83 ± 1.09 % to the Seeds (reproductive function) (Fig. 5). Both of these parameters were asymmetrically distributed (Fig. 7 and 8). PPFR is known to vary in plants (Herrera, 1987; Lee *et al.*, 1991). Chen *et al*. (2010) has reported data on average pericarp mass to fruit mass ratio in 62 broad-leaved woody tropical species – lowest for *Nothapodytes pittosporoidea* (0.152) and largest for *Liquidamber formosana* (0.972). The higher proportion of biomass investment in pericarp is suggested to be favoured when offspring mortality is density-dependent (Janzen, 1970; Ganeshaiah and Uma Shaanker, 1991). Higher proportion of biomass allotted to seeds in *E. suberosa* may be indicative to the principal cause of offspring mortality in this species presumably due to the limitation in some critical resource (cf. Baker, 1972) in the field. The nature of seedling mortality in this species needs to be investigated.

Individual seed mass

Individual seed weight based on total sample of 412 seeds recovered from the pods averaged to 686.49 ± 7.287 mg. The seed weight data was asymmetric (negatively skewed, g1 = -1.256) and leptokurtic (g2 = 3.405) (Table 4; Fig. 6). The seeds below 500 mg were 7.8%. Most of the seed size data concentrated around the mean value. The category of seed weight ranging from 500.1 - 800 mg was occupying some 71.8 % of the area under the curve. Seeds > 800 mg in weight were 20.4% of the total seed. The individual seed weight varied 19.36-fold. Excluding smaller or ill-filled seeds the seed weight distribution tended to be normally distributed (N: 402; KS-z: 0.577, p < 0.894).



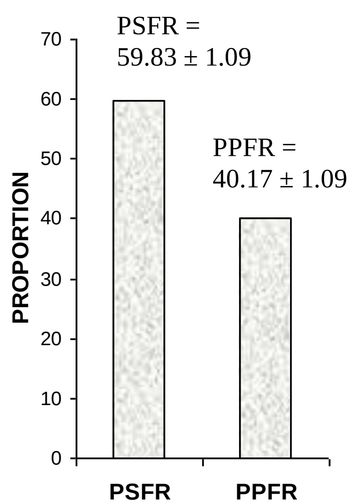


Fig. 5. Proportion of pericarp and seeds.

Fig. 4 Frequency distribution of brood size in *Erythrina suberosa*.

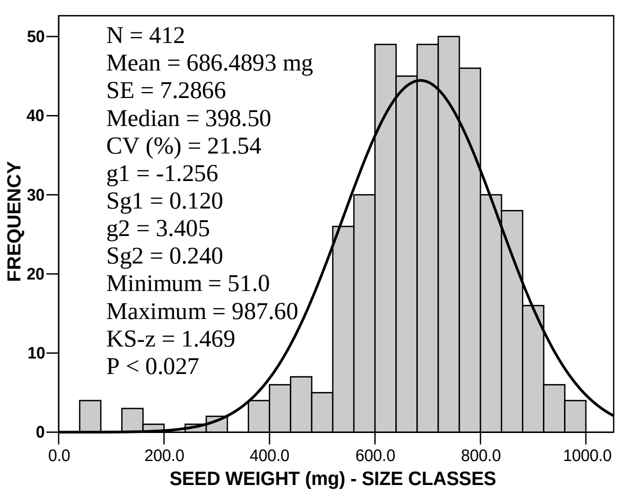


Fig. 6 Distribution of individual seed weight.

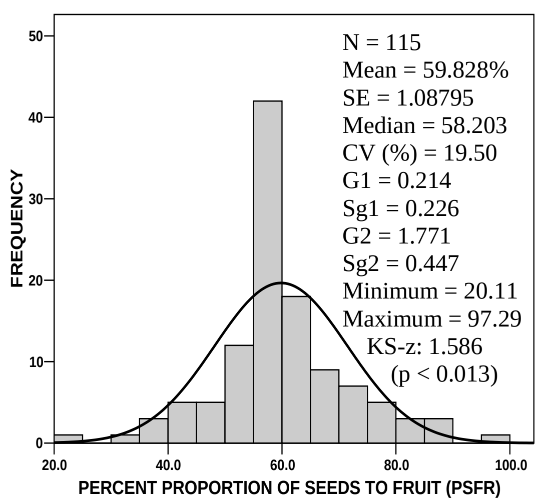
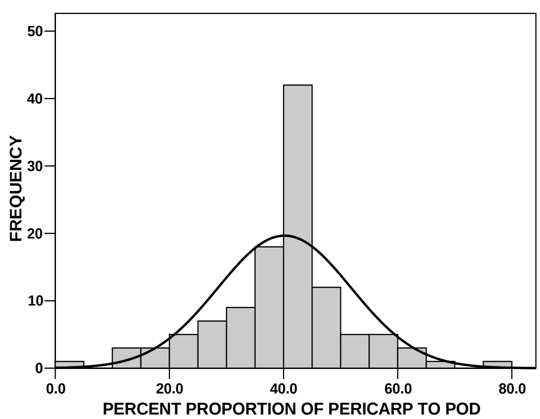


Fig. 7. Distribution of PSFR.

Kumar *et al.* 2010) reported the seed weight in *Erythrina variegata* to vary between 200 to 689.7 mg per seed. Our data on *E. suberosa* appears to be quite close to *E. variegata*. The seeds of *E. suberosa* are larger than that of several legumes such as *Acacia stenophylla*, *Acacia coriacea*, *Albizia lebback*, *Leucaena leucocephala*, *Vachellia nilotica ssp. indica*, *Cassia fistula* and *Delonix regia* (all growing in Karachi) (Afsar uddin, 2012; Khan and Zaki, 2012; Khan and Sahito, 2013 a and b; Khan *et al.*, 2013).



N = 115, Mean = 40.17, SE = 1.088, Median = 41.497,
CV (%) = 29.04, g1 = -0.204, Sg1 = 0.226, g2 = 1.771
Sg2 = 0.447, Minimum = 2.711, Maximum = 79.887
KS-z = 1.585, p < 0.013.

Fig. 8. Frequency distribution of PPFR.

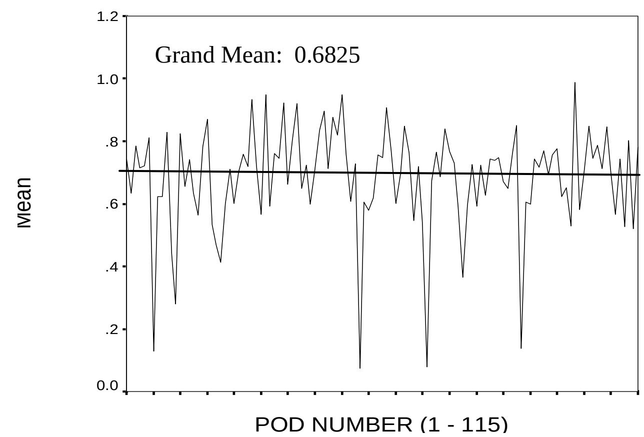


Fig.9. Mean individual seed weight per pod in 115 pods of *Erythrina suberosa*.

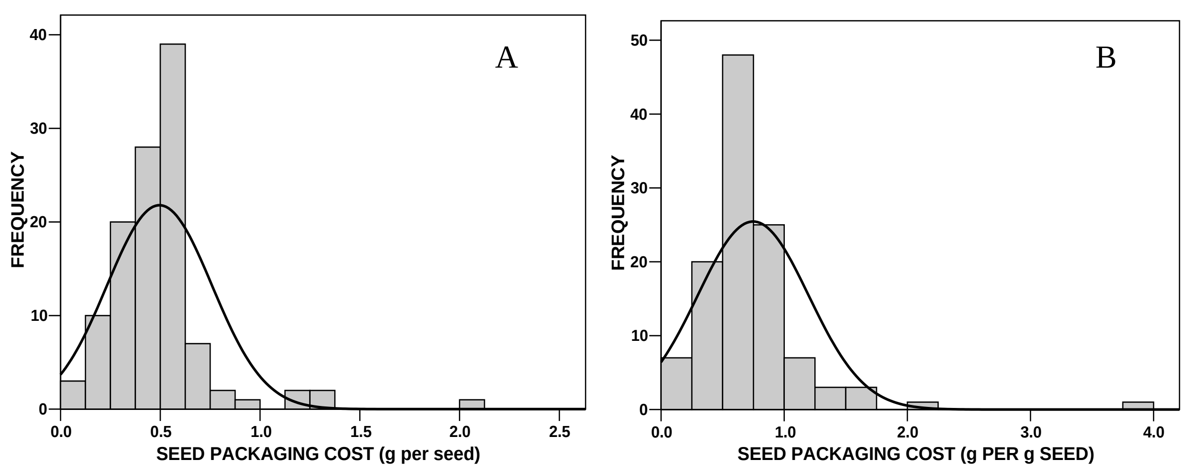


Fig. 10. Distribution of SPC_1 (A) and SPC_2 (B).

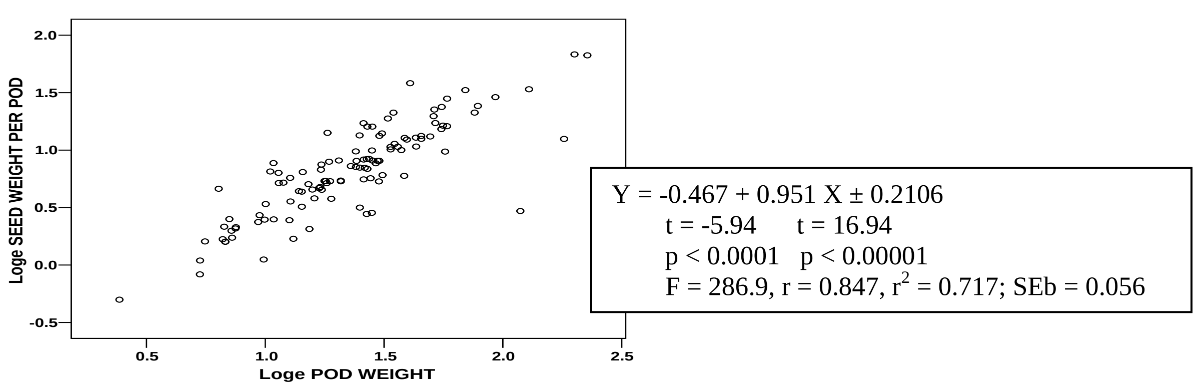


Fig.11. Relationship of logarithms of seed yield per pod and pod weight.

Table 5. Spearman Rank correlation coefficients amongst various pods and seeds characteristics. (N = 115).

	TNS	PW	SWPP	MSSW	PWS	SPC_1	SPC_2	PERI	PPFR
TNS									
PW	0.817**								
SWPP	0.884**	0.847**							
MSSW	0.051	0.169 **	0.355**						
PWS	-0.387**	0.151*	-0.142	0.435**					
SPC_1	-0.417 **	0.059	-0.351 *	0.083**	0.868 **				
SPC_2	-0.394**	-0.084	-0.538**	-0.345 *	0.551 **	0.851**			
PERI	0.385**	0.747**	0.347**	- 0.020**	0.507*	0.582*	-0.504*		
PPFR	-0.394**	-0.084*	-0.538**	-0.345**	0.551**	0.851**	0.999**	0.504	
PSFR	0.394**	0.084*	0.538**	0.345**	-0.551**	-0.850**	-0.999**	-0.504	-0.999**

*, $p < 0.05$; **, $p < 0.01$ (two-tailed). Key to the acronyms: TNS, Number of seeds per pod; PW, Pod Weight; SWPP, Seed weight per pod; MSSW, mean single seed weight in a pod; PWS, Pod weight per seed; Peri, pericarp weight; SPC_1, seed packaging cost (g. pericarp per seed; SPC_2, seed packaging cost (g pericarp per g seeds); PPFR, *per cent* proportion of pericarp mass to fruit mass; PSFR, *per cent* proportion of seed mass to fruit mass.

Intraspecific variation in seed mass is common in tropical species (Janzen, 1977; Foster and Janson, 1985; Khan *et al.*, 1984; Murali, 1997; Marshall, 1986; Upadhaya *et al.*, 2007) and it 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*. *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 *Senna occidentalis* was 18.35% (Saeed and Shaukat, 2000). Seed weight variation in *Thespesia populnea* was around 27% (Gohar *et al.*, 2012)). Sixteen-fold variation in seed mass is reported in *Lamatium salmoniflorum* (Thompson and Pellmyr, 1989). According to Tíscar Oliver and Borja (2010) most 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. Variation in seed mass is even reported within fruits (Stanton, 1984; Mendez, 1997).

The seed weight in *E. suberosa* was asymmetric (negatively skewed and leptokurtic like that in *Delonix regia* (Khan and Sahito, 2013b) i.e. *E. suberosa* also produced smaller seeds in relatively larger number than expected from normal distribution of seed weight. Similar results were reported also in *Purshia tridentata* (Krannitz, 1997). Seed weight in *Cassia fistula* was also found to be leptokurtic and negatively skewed by Khan and Zaki (2012). In *Erythrina* seeds below 100mg were 1.2%, those between 100.1 to 300 mg were 18% of the total seeds. Majority of seeds (79.8%) fall in the category of 400 to 600 mg. Seeds > 600mg in weight were few (0.6%). Halpern (2005) reported normal distribution of seed mass in *Lupinus perennis*. Sachaal (1980) found seed weight to be leptokurtic and positively skewed in *Lupinus texensis*. Seed weight distribution has, however, been reported to be normal in six cultivars of sunflower and skewed in three cultivars (Khan *et al.*, 2011). Seed mass normally distributed in *Blutapason portulacoides* and *Panicum recemosum* but not in case of *Spartina ciliata* (Cardazzo, 2002). 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 may vary within a species with site quality and temporally – varying from symmetry to skewness, from leptokurtosis to platykurtosis (Busso and Perryman, 2005). The variation in weight of seeds of *E. suberosa* was observed to be lesser (CV: 21.54%) than that of the brood size (CV: 37.07%). It is in agreement with Harper's (1961) contention that there is lesser variation in seed size than the seed number. Similar results have been exhibited in *D. regia* (Khan and Sahito, 2013b). It supports by Smith and Fretwell's (1974) model of resource optimization.

The variation in seed size may be the result of many factors (Fenner, 1985; Wulff, 1986). 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). Seed weight is also reported to decline with age in walnut (*Juglans major*) in terrace habitat of central Arizona (Stromberg and Patten (1990). It has also been reported to be the function of plant height in a population of *Ranunculus acris* (Totland and Birks, 1996). 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). 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. It has been suggested that producing seeds of different sizes can be an evolutionary stable strategy in spatially or temporally heterogeneous habitats (Geritz, 1995). 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. The seed weight variation within an individual of *E. suberosa* (CV: 21.54%) appears to highly environmental and may be thought to have important ecological implications in its life history diversification (Braza *et al*., 2010).

Pod weight per seed (PWS)

Pod weight per seed which is considered to be a parameter estimating packaging cost (Mehlman, 1993) averaged to 1.1788 ± 0.0264 g per seed in *E. suberosa* and varied by 24.41% (0.6963 to 2.6511g per seed) (Table 4) which is quite lower than that reported in *Delonix regia* (4.9443 ± 0.1931 g per seed (Khan and Sahito, 2013b). In *Acacia stenophylla* grown in Karachi, PWS varied from 0.25 (in multiple-seeded pods) to 1.05g per seed (in single-seeds pods) (Khan and Sahito, 2013a). Such a range in *Acacia coriacea* ssp. *pendens* was from 0.5g to 2.02 g per seed (Khan *et al.,* 2013).

Seed packaging cost (SPC)

The seed packaging cost calculated as g pericarp per seed (SPC_1) and g pericarp per g seeds (SPC_2) are depicted in Table 4 and Fig. 10. SPC_1 and SPC_2 averaged to 0.49599 ± 0.0245 and 0.74798 ± 0.04015 g, respectively. The modal class of SPC`1 (0.5-0.625g per seed) occupied a 32.2 % of the total cases and the modal class of SPC2 (0.5-0.725g per g seed) occupied some 40% of the cases. The distribution in each case was positively skewed and had great degree of leptokurtosis (Fig. 10 and Table 4). There was slightly more variation in SPC_2 (60.25%) than SPC_1 (53.07%).

Table 6. Seed packaging cost in some leguminous species.

Species	SPC (g.g^{-1} seeds)	SPC (g.seed^{-1})	Dehiscence	References
1. *Vachellia (Acacia) nilotica*				Afsar uddin (2012)
Mother plant A	1.7398 ± 0.1722	0.2011	Schizocarpic	
Mother plant B	1.7107 ± 0.1721	0.2081	Schizocarpic	
2. *A. stenophylla*				
	2.3732 ± 0.1160	0.2495 ± 0.01076	Schizocarpic	Khan & Sahito (2013a)
3. *Albizia lebback*				Afsar uddin (2012)
Mother plant A	2.2940 ± 0.1488	0.2647 ± 0.1235	Tardily dehiscent	
Mother plant B	2.4145 ± 0.0149	0.2965 ± 0.0103		
Mother plant C	2.8150 ± 0.0302	0.2923 ± 0.0234		
4. *Cassia fasciculata*	-	0.0765 ± 0.0019	-	Willson *et al.* (2010)
5. *Cassia fistula*	6.961 ± 0.4610	0.7672 ± 0.0514	Indehiscent	Khan and Zaki (2012)
6. *Leucaena leucocephala*				Afsar uddin (2012)
Mother plant A	0.7497 ± 0.0458	0.0305	Dehiscent	
Mother plant B	0.9798 ± 0.0027	0.0350	Dehiscent	
Mother plant C	0.7799 ± 0.0357	0.0306	Dehiscent	
7. *Acacia coriacea* subsp. *pendens*	3.640 ± 0.220	0.4277 ± 0.0231	Dehiscent	Khan *et al.* (2013)
8. *Delonix regia*	11.912 ± 0.5272	4.5493 ± 0.1882	Tardily dehiscent to indehiscent	Khan & Sahito (2013b)
9. *Erythrina suberosa*	0.7479 ± 0.04202	0.4959 ± 0.0245	Tardily Dehiscent to indehiscent	Present study

The investment in seed packaging in some legumes is compared in Table 6. There appeared large variation of SPC amongst legumes. Moreover, the seed packaging appeared quite costlier in indehiscent pods (*C. fistula and D. regia*) as compared to the dehiscent ones. This investment in *E. Suberosa*, on the basis of per g seeds was comparable to *L. leucocephala* but on the basis of per seed it was comparable to *A. coriacea* subsp. *pendens*. Willson *et al.* (1990) had also noted a marked variation in average seed packaging investment amongst 28 species surveyed. *Cassia fasciculata* included in their study showed SPC per seed to be 76.47 ± 1.89 mg per seed. Mehlman (1993) also reported SPC to vary significantly in pods of *Baptisia lanceolata.* Khan and Zaki (2012) have reported packaging cost in indehiscent type of pods of *C. fistula* to vary from pod to pod – (mean SPC: 767.2 ± 51.4 mg per seed to 6961.3 ± 461.0 mg per g seeds). Seed packaging investment across 62 species of 35 families from China (No legume included) is also shown to vary among species (Chen *et al.*, 2010). The lowest cost was 0.065 mg per seed in *Dicroa febrifuga* (Family Saxifragaceae) and highest 1124.897 mg / seed for *Vernicia fordi* (Family Euphorbiaceae). Highest packaging investment is, however, presented by Willson *et al.* (1990) in case of *Asimina triloba* to be 13,101 mg per seed. Afsar uddin (2012) has reported the packaging investments in dehiscent type of pods of *A. lebbeck* (2327.0 mg per g seeds and 281 mg per seed) and *L. leucocephala* (826.0 mg per g seeds and 32 mg per seed) and in schizocarpic pods of *Vachellia (Acacia) nilotica* (1725 mg per g seeds and 205 mg per seed). SPC is not only species specific but also varies with fruit to fruit even in case of a single individual of a species. It signifies the importance of the environmental history of the pods at individual level.

Relationships amongst Pod, Seed and Seed Packaging parameters

Multiple trends of association were indicated between the pod and seed characteristics of *E. suberosa* (Table 5) through the analysis for Spearman Rank Correlation (rho). Higher was the pod weight (PW), larger was the number of seeds per pod (Brood size, TNS), and total seed yield per pod (SWPP). PW related highly significantly with pericarp mass also. The parameters of seed packaging cost (SPC_1 and SPC_2) related with seed yield per pod negatively. SPC_2 was more closely related with SWPP than SPC1 which was more closely related with PWS than SPC_2. SPC_1 and SPC_2 were significantly associated with each other. SPC_2 related with MSSW but relatively weakly.

With respect to the allocation of biomass in pods and its components some correlations were important as studied through regression analysis. There was linear correlation between logarithms of pod weight and seed weight per pod (r = 0.847) (Fig. 11). The slope of the regression line b = 0.951 (SE_b: 0.056) was not significantly different from b for the null line (1) (t = 0.875, NS). It implied that fruit size didn't influence the amount of resources that are proportionately allotted to seed production. Larger fruits produced larger mass of seeds and small fruits allotted small biomass to seeds. There was no trade off between fruit size and allocation of resources to seeds. This is similar to the fruit-seed relationship in *Warburgia salustris* (Daws *et al.,* 2002), *Acacia stenophylla* (Khan and Sahito, 2013 a) and *Acacia coriacea* subsp. *pendens* (Khan *et al.,* 2013) but not the pod-seed relationship in *Delonix regia* (Khan and Sahito, 2013 b). There was, therefore no trade off existed between fruit size and allocation of resources to seeds in *E. suberosa* and acacias mentioned above. Legumes, therefore, vary in their fruit-seed biomass allocation pattern.

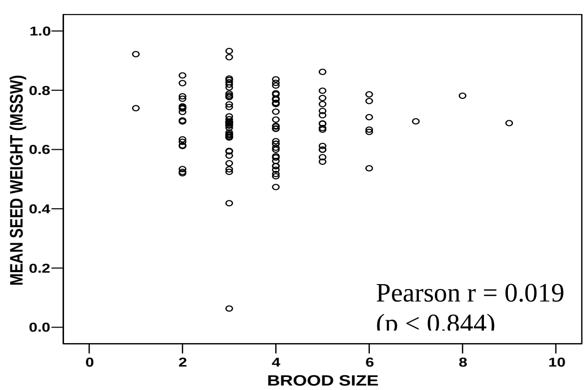
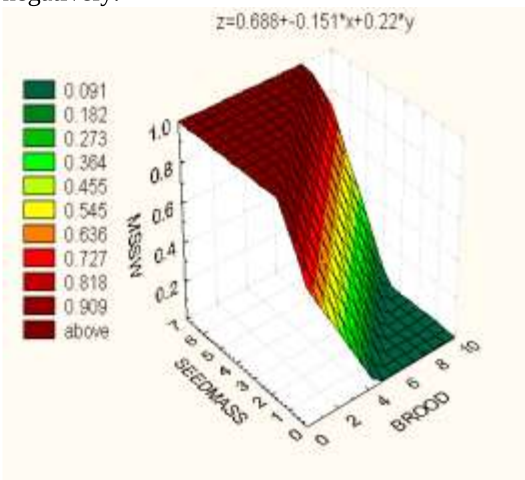


Fig. 12. Relationship of MSSW with brood size.

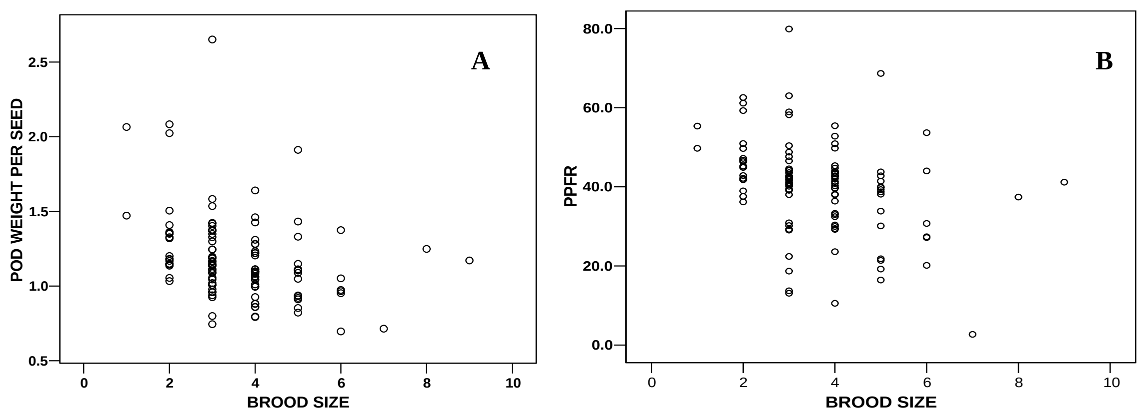
There was no correlation between MSSW and the brood size as alone independent variable (Fig. 12). However, in a linear model, seed mass (SWPP) and brood size collectively related with MSSW significantly (R^2 = 0.568) with highly significant partial correlation for both SWPP and Brood size (Fig. 13). It was apparent that magnitude of

MSSW by this model narrowed in range substantially with the increase of the brood size. It was apparent in this model (Fig. 13) that seed mass produced in a pod related with MSSW positively but the brood size influenced MSSW inversely i.e. the mean seed weight for a pod was at least in part was influenced by the brood size of the pod negatively.



MSSW = 0.688 - 0.151 Brood size + 0.220 SWPP ± 0.078
t = 32.594 t = -11.21 t = 12.12
P < 0.001 p < 0. 0001 p < 0.0001
F = 73.50, R = 0.754, R^2 = 0.568, Adj. R^2 = 0.560
Zero Order: Brood size = - 0.019, SWPP = 0.287
Partial Corr.: Brood size = - 0.707, SWPP = 0.753

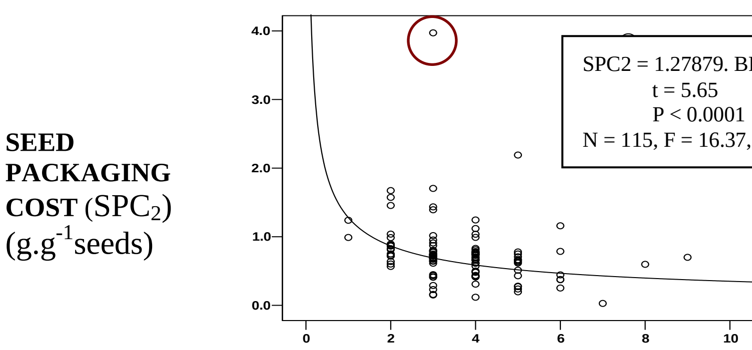
Fig. 13. Relationship of MSSW with Pod mass and the brood size collectively (A), relationship of MSSW with seed mass and the brood size collectively (B) and relationship of MSSW with Pod mass and seed mass collectively (C).



PWS = 1.542694. Brood Size $^{-0.2331}$ ± 0.2015
t = 15.64 t = - 4.65
P < 0.0001 p < 0.0001
F = 21.58, r = 0.4004, r^2 = 0.1604, Adj. r^2 = 0.1529

PPFR = 51.004 - 2.995 Brood Size ± 11.001
t = 17.72 t = - 3.899
P < 0.0001 p < 0.0001
F = 15.20, r = - 0. 344, r^2 = 0.119, Adj. r^2 = 0.111

Fig. 14. Relationship of pod weight per seed (A) and PPFR (B) with brood size.



SPC2 = 1.27879. BROOD SIZE $^{-0.561863}$ ± 0.5579
t = 5.65 t = -4.05
P < 0.0001 p < 0.0001
N = 115, F = 16.37, r = 0.3558, r^2 = 0.1205, Adj. r^2 = 0.1183

N = 114 (Outlier Excluded)
SPC2 = 1.23933. BROOD SIZE $^{-0.548774}$
t = 5.88 t = -4.12
P < 0.0001 p < 0.0001
SE: 0.53512, F = 16.96,
r = 0.3626, r^2 = 0.1315, Adj. r^2 = 0.1238

Fig.15. Relationship of seed packaging cost (SPC_2) with brood size. Point within a circle is an outlier.

The pod weight per seed of *E. suberosa* which is a parameter of seed packaging cost (*sensu* Mehlman, 1993) related inversely with brood size through a negative power model (exp.: -0.2331) but a simple linear negative relationship existed between PPFR and brood size (b = -2.995) (Fig. 14 A and B). Similar to PWS, the parameter of packaging cost, SPC2, declined with brood size in a negative power fashion (exp.: -0.561863) (Fig. 15). Such a significant negative relationship between PWAS and brood size has also been reported by Méndez (1997) in *Arum italicum*. Negative relationship between PPFR and brood size has also been reported in *Baptisia lanceolata* (Mehlman, 1993)) and in *Delonix regia* (Khan and Sahito (2013 c). Significant negative power relation between SPC_2 and brood size has also been reported in *D. regia* by Khan and Sahito (2013b). It is then obvious that like *B. lanceolata* and *D. regia* the investment of biomass in pericarp in *E. suberosa* has a negative trade-off with the brood size.

Much of the ecology is the result of trade-offs (Crawley, 1997). Various types of trade-offs have been reported in literature with reference to life history strategies of plants. Although no trade-off was detected between mean single seed weight (MSSE) and brood size (as alone independent variable) in *E. suberosa* but collectively, brood size and total mass of seeds in a pod presented a significantly interactive regression model with explanatory power of 56.8% to influence MSSW in which brood size interacted negatively with MSSW. A similar relationship is reported in *D. regia* (Khan and Sahito, 2013b). A significant trade-off between MSSW and the brood size has been reported by Afsar uddin (2012) in *Vachellia (Acacia) nilotica*. Like *E. suberosa*, a negative trade-off between mean single seed weight and brood size has also been reported in *Cassia fistula* by Khan and Zaki (2012). Aniszewski *et al.* (2001) has reported seed size-seed number trade-off at intraspecific level in *Lupinus polyphyllus* Lindl. Sõber and Ramula (2013), on the other hand, found no such trade-off in this species when studied from 39 populations of Finland. 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). It has also been suggested that, to an extent, plants can escape the seed-size-seed number trade-off by modifying the chemical composition of their seeds (Lokesha *et al.,* 1992). Variations in available resources due to genotype or the environment may result in negative, neutral and positive relationship between seed number and seed weight in individual plants (Venable, 1992). Besides, plasticity in pericarp allocation in response to the increase in brood size within a pod was obvious. It should be a significant ecological adaptation in the life history phenomenon in this species in arid stressful environment.

The variation around the optimal seed size within an individual or a population could be related to variation in parental size or quality of resources (McGinley, 1988), physiological, developmental or morphological constraints (McGinley *et. al*., 1987), parent offspring conflict and sibling rivalry (Uma Shankar *et al*., 1988; Ganeshaiah and Uma Shankar, 1988; Ganeshaih and Uma Shaanker, 2003). Since Smith-Fretwell model predicts optimum seed size expected in a particular ecological context, different optima for different individuals of a species may be expected. This concept may probably be as well extended to fruits of an individual tree where different optima may occur for different fruits produced on a tree. It may be adjudged from the high degree of variation of mean single seed weight (MSSW) among the pods and total seed mass in pods (SWPP) of an individual tree. A reproductive potential of a fruit obviously should be a function of its developmental history based on both its external and internal environments (Khan and Sahito, 2013a and b).

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