MATERNAL INVESTMENT OF BIOMASS IN PODS, SEEDS AND SEED PACKAGING IN *DELONIX REGIA* (BOJER) RAFIN (CAESALPINIACEAE)

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ABSTRACT

Biomass investment in pods, seeds and seed packaging has been studied in a tree of *Delonix regia* (Bojer) Rafin from the campus of the University of Karachi, Pakistan. The pods are woody and tardily dehiscent or indehiscent for long period of time and seeds are mottled and transversely placed in the pod. The weight of air-dried pods (PW) varied from 19.40 to 98.36 g (CV = 34.23%) and averaged to 61.6797 ± 2.5238g. The pod weight distributed normally [Kolmogorov-Smirnov z (KS-z) = 0.792; p<0.557]. The brood size (TNS, number of normal seeds per pod (*sensu* Uma Shaanker *et al.,* 1998) averaged to 13.43 ± 0.668 (CV: 41.63%). As the value of KS-z, 0.764, was insignificant (p<0.603) the brood size tended to be normally distributed. The seed mass per pod (SWPP) averaged to 5.3435 ± 0.2995 g per pod and varied by a quantum of 48.64%. The distribution of mean single seed weight for a pod (MSSW) was symmetrical among the pods. It averaged to 0.3951 ± 0.0117g and varied from 0.1414 to 0.5573g. The pericarp mass per pod varied from 18.15 to 89.31g (CV: 33.79%) and averaged to 56.291 ± 2.271g. The pericarp mass tended to be normally distributed. Some 91.45 ± 0.302 % of the pod biomass was allocated to pericarp (seed protection) and 8.52 ± 0.302 % to the seeds (reproductive function). The three parameters of pod (PW, SWPP and TNS) collectively interacted in a model to significantly influence the MSSW ($R^2 = 0.899$). In split sub models, PW coupled with TNS and SWPP coupled with TNS as independent variables influenced MSSW significantly (p<0.0001) and in both cases TNS (brood size) associated with MSSW negatively. The weight of individual seed for a sample of 946 seeds averaged to 397.40 ± 3.936mg varying from 55.81 to 638.10 mg (11.52-fold variation). Seed packaging cost (SPC) in *D. regia* was 11.912 ± 0.5272 g.g^{-1}.seeds and 4.5493 ± 0.1882 g.seed^{-1} - quite higher than several pod-dehiscent-legumes. The seed packaging cost (SPC$_2$ = g.g^{-1}.seeds) related with brood size in accordance with a negative power model (exp. = -0.54841) i.e. the investment of biomass in pericarp had a negative trade-off with brood size.

KEYWORDS: *Delonix regia*, Brood size, Seed weight, Within-pod biomass allocation, Seed packaging cost

INTRODUCTION

Angiospermic seeds developing from ovules are enveloped in Pericarp. Seeds give rise to seedlings and pericarp provide protection and nutrition to seeds and at times dispersal. Pericarp occupies significantly varying proportion of the fruit biomass. 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 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; Khan *et al.,* 2013). Some ecologists have been interested in examining the scaling relationship between the seed packaging and the individual seed mass. Such studies are likely to be 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, 2013; Khan *et al.,* 2013).

In this paper, variation in pod-, and seed-size and seed packaging cost within an individual tree of *Delonix regia* (Bojer) Rafin (vernacular- Royal Poinciana, Flamboyant, Gul Mohr), a most beautiful ornamental multipurpose legume, is studied. It is native of Madagascar and an endangered species in wild. This spectacular tree bursts into bloom on the onset of summer with scarlet mass of flowers on flat spreading canopy. Its pods and seeds may be used in multiple ways.

MATERIALS AND METHODS

Seventy mature dark brown pods from a tree of *Delonix regia* growing 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. 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). Kolmogorov-Smirnov z (KS-z) test was performed to detect normal distribution (Sokal and Rholf, 1995). In allometric analysis, the slope of the fitted regression line was compared with the slope of the null line using 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).

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RESULTS AND DISCUSSION

Pod size: Pods of *D. regia* are 30-60 cm long, 3-5 cm wide and 0.6-0.8 cm in thickness. Pods are tardily dehiscent or even indehiscent even when fallen on the ground. They are green flaccid when young and turn dark brown and woody on maturity. Young pods are edible (Du Puy *et al.,* 1995). They are firm, compressed, parallel-edged, straight, pendent, many-seeded, filled between the seeds with wood and shortly beaked at the tip. The weight of air-dried pods varied from 19.40 to 98.36 g (CV = 34.23%) and averaged to 61.6797 ± 2.5238 g (Table 1). The pod weight distributed normally (KS-z = 0.792; p<0.557) and mostly (74.3% of the pods) concentrated in the region of 50.1 to 98.36g and 25.7% were below 50g in weight. Pods < 20g in weight were only 1.4% of the total pods studied. Only 4 pods (5.71% of the total pods) had one seed each smaller than 100mg.

Table 1. Location and dispersion statistics of pods and seeds of *D. regia*.

Parameter	N	Min.	Max.	Mean	SE	CV (%)	G1	G2	KS-z	p	Curve (KS-z based)
PL (cm)	55	19.0	51.0	31.879	1.0449	24.31	0.271	-0.579	0.680	0.745	Symmetrical
TNS	70	4	28	13.43	0.668	41.63	0.421	-0.280	0.764	0.603	Symmetrical
PW (g)	70	19.400	98.361	61.6797	2.5238	34.23	-0.273	-0.744	0.792	0.557	Symmetrical
SWPP (g)	70	0.8483	9.9730	5.3435	0.29953	41.28	0.069	-1.085	0.663	0.771	Symmetrical
PERI (g)	70	18.15	89.31	56.291	2.271	33.79	-0.276	-0.742	0.739	0.646	Symmetrical
MSSW (g)	70	0.1414	0.5573	0.3951	0.0117	24.70	-0.073	-0.920	0.969	0.305	Symmetrical
PWPS (g)	70	2.3081	10.0014	4.9443	0.19306	32.67	0.657	0.079	0.872	0.433	Symmetrical
PPFR	70	83.38	96.20	91.4840	0.3019	2.76	-0.615	1.607	0.670	0.761	Symmetrical
PSFR	70	3.8006	16.6189	8.5163	0.3019	29.66	0.615	1.607	0.670	0.761	Symmetrical
SPC_1 (g.seed^{-1})	70	1.9245	9.5770	4.5493	0.18816	31.80	0.717	0.247	0.824	0.505	Symmetrical
SPC_2 (g.g^{-1} seeds)	70	5.0172	25.3117	11.912	0.5272	37.03	1.369	1.636	1.323	0.060	+ Skewed & Leptokurtic

g1, skewness; g2, kurtosis. sg1 (N: 70) = 0.287; sg2 (N: 70), 0.566. sg1 (N: 55) = 0.322; sg2 (N: 55), 0.634.
Key to the acronyms: PL, pod length (cm); TNS, Seeds per pod; PW, pod weight (g); SWPP, Seed yield per pod; PERI, pericarp MSSW, mean single seed weight in a pod; PWPS, pod weight per seed; SPC_1, seed packaging cost (g per seed); SPC_2. Seed packaging cost (g per g seeds); PPFR, per cent proportion of pericarp mass to fruit mass; PSFR, per cen*t* proportion of seed mass to fruit mass

Brood size: The brood size (number of normal seeds per pod (*sensu* Uma Shaanker *et al.,* 1998) in *D. regia* averaged to 13.43 ± 0.668 (CV: 41.63%) and had insignificant positive skewness). Some 50% of the pods had 10 to 20 seeds and 71.4% of the pods had 5 to 20 seeds per pod. None of the pod was, however, completely devoid of seeds. The brood size in *D. regia*, in present studies, appeared to be lesser than that (20-40) reported by Ali (1973). 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).

The insignificant value of KS-z (0.764; p<0.603) indicated that the brood size tended to be normally distributed (Table 1; Fig. 1). Uma Shaanker *et al.,* (1988) have also reported the brood size to be normally distributed in *Bauhinia recemosa, B. ungulata, and Cassia fistula*. Distribution of brood size in *C. fistula* is also reported to be normal by Khan and Zaki (2012). The distribution of brood size has, however, been reported to significantly vary from the normal in several plants. This trait may be positively skewed (PSD) or negatively skewed (NSD). The pattern of brood may probably come up due to differences in the developmental history specific to the individual pods in the environmental context. 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). In *Leucaena*, for example 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). NSD of seeds in pods is said to be a common feature of majority of multi-ovulate species (Lee and Bazzaz, 1982).

Seed mass per pod: The seed mass per pod averaged to 5.3435 ± 0.2995 g per pod and varied by a quantum of 41.28%. As the number of seeds per pod varied greatly and in consequence the seed yield ranged from 0.8483g per pod to 9.9730g in case of pods containing several seeds (Table 1). The seed mass per pod tended to follow normal distribution (KS-z = 0.663, p<0.771).

Mean single seed weight in pod (MSSW): The distribution of MSSW was symmetrical among the pods. It averaged to 0.3951 ± 0.0117g and varied from 0.1414 to 0.5573g (Table 1).

Pericarp mass: The pericarp mass per pod varied from 18.15 to 89.31g (CV: 33.79%) and averaged to 56.291 ± 2.271g. The distribution of pericarp mass tended to be normally distributed as the magnitude of KS-z was low (0.739) and insignificant (p<0.648) (Table 1).
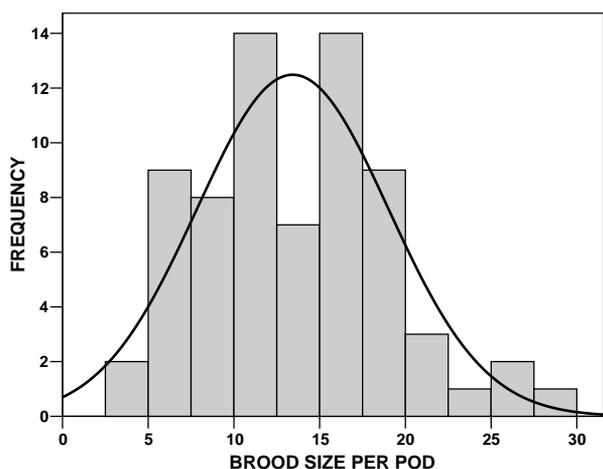
N = 70, Mean = 13.43, SE = 0.668, Median = 13.00, SD = 5.591, CV (%) = 41.63, G1 = 0.421, Sg1 = 0.287, G2 = -0.280, Sg2 = 0.566, Minimum = 4, Maximum = 28, KS-z = 0.764, p<0.603
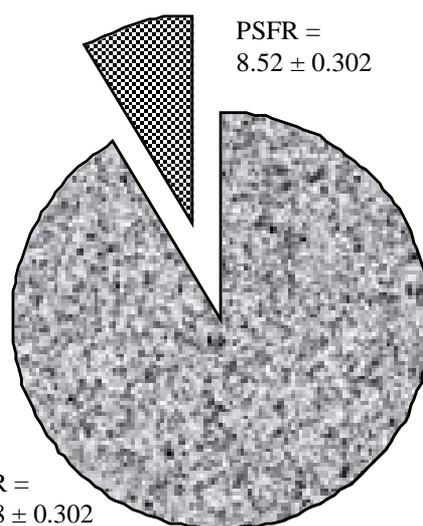
Fig. 1. Distribution of brood size.

Fig. 2. Percent proportion of Pericarp mass to fruit mass (PPFR) and seed mass proportion to fruit mass (PSFR).

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 *D. regia,* 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 *D. regia* pods studied (N = 70), 91.45 ± 0.302 % of the pod biomass was allocated to pericarp (seed protective function) and 8.52 ± 0.302 % to the seeds (reproductive function) (Fig. 2).

Individual seed weight: The weight of individual seed for a sample of 946 seeds averaged to 397.3925 ± 3.936mg varying from 55.81 to 638.10 mg (11.52-fold variation) (Fig. 3). Seed weight of *D. regia* is variously reported. About 4500 seeds from Puerto Rican sources weighed around 1kg i.e. on an average a seed weighed 222.2 mg (Marrero, 1949) and around 2000 – 3000 Columbian seeds weighed around 1kg i.e. single seed on an average weighed to 333.3 to 500 mg (Navarette, undated). CAB International (2000) reported 1600-3700 *D. regia* seeds to weigh 1kg i.e. single seed weighs 270.3 to 625 mg.

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 distribution of seed weight in *D. regia* was negatively skewed and leptokurtic (KS-z = 1.808; p<0.003) (Fig. 3) i.e., *D. regia* produced more smaller seeds than expected from normal distribution of seed weight as also reported in *Purshia tridentata* (Krannitz, 1997). Seed weight in *Cassia fistula* was also found to be leptokurtic and negatively skewed by Khan and Zaki (2012). 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 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 *D. regia* was observed to be lesser (CV: 30.46%) than that of the brood size (CV: 41.63%). It is in agreement with Harper's (1961) contention that there is lesser variation in seed size than the seed number. It has strongly been supported by Smith and Fretwell's (1974) model of resource optimization.
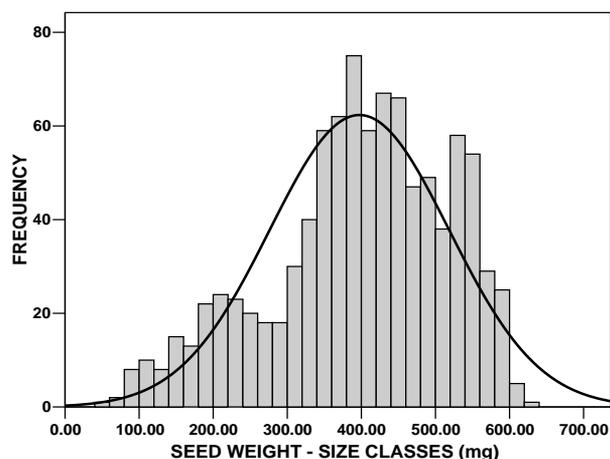
N = 946, Mean = 397.3925, SE = 3.9361, Median = 408.3350, SD = 121.06259, CV (%) = 30.46, G1 = -0.539, Sg1 = 0.080, G2 = -0.279, Sg2 = 0.159, Minimum = 55.81, Maximum = 638.10, KS-z = 1.808, p<0.003

Fig. 3. Frequency distribution of single seed weight of *Delonix regia*.
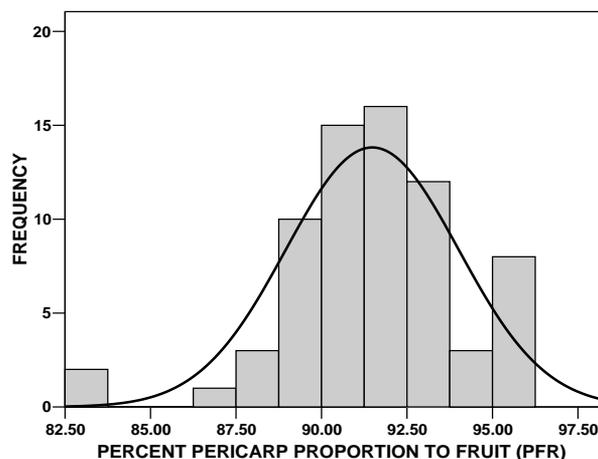
N = 70, Mean = 91.4837, SE = 0.30187, Median = 91.6104, CV = 2.76%, g1 = -0.615, Sg1 = 0.287, g2 = 1.607, Sg2 = 0.566, Minimum = 83.38, Maximum = 96.20, KS-z = 0.670, p<0.761

Fig, 4. Distribution pattern of percent proportion of pericarp to fruit mass (PPFR).

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. High degree of seed weight variation within an individual of *D. regia* (CV: 30.46%) appears to highly environmental and may be thought to have important ecological implications in its life history diversification (Braza *et al.*, 2010).

Variation in per cent proportion of pericarp to fruit mass: The PPFR (% pericarp to fruit mass proportion) varied among the pods from 83.38 to 96.20 (mean = 91.484 ± 0.3019g. PPFR appeared to be negatively skewed (g1 = - 0.615) and leptokurtic (g2 = 1.607) but tended to be distributed normally on the basis of Kolmogorov-Smirnov test (KS-z = 0.670, p<0.761) (Table 1; Fig. 4). It varied only 2.76%. 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 – the lowest for *Nothapodytes pittosporoidea* (0.152) and the 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). Converse to it, higher proportion of biomass may be favoured to seeds when the principal cause of mortality is the limitation in some critical resource (Baker, 1972).

Seed packaging: The investment in seed packaging in *D. regia was* much higher than that in several leguminous species (Table 2). Seed packaging cost in *D. regia* was 11.912 ± 0.5272g.g^{-1}.seeds and 4.5493 ± 0.1882 g.seed^{-1}. 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 *A. 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. Moreover, the seed packaging cost is quite higher in indehiscent pods as compared to the dehiscent ones.

Table 2. Seed packaging costs in some leguminous species.

Species	SPC (g.g^{-1}. seeds)	SPC (g. seed^{-1})	Dehiscence	Reference
Acacia nilotica				
Mother plant A	1.7398 ± 0.1722	0.2011	Schizocarpic	Afsar Uddin (2012)
Mother plant B	1.7107 ± 0.1721	0.2081	Schizocarpic	
A. stenophylla				
	2.3732 ± 0.1160	0.2495 ± 0.01076	Schizocarpic	Khan & Sahito (2013)
Albizia lebback				
Mother plant A	2.2940 ± 0.1488	0.2647 ± 0.1235		Afsar Uddin (2012)
Mother plant B	2.4145 ± 0.0149	0.2965 ± 0.0103	Tardily dehiscent	
Mother plant C	2.8150 ± 0.0302	0.2923 ± 0.0234		
Cassia fasciculate	-	0.0765 ± 0.00189	-	Willson *et al.*, (2010)
Cassia fistula	6.961 ± 0.4610	0.7672 ± 0.0514	Indehiscent	Khan and Zaki (2012)
Leucaena leucocephala				
Mother plant A	0.7497 ± 0.0458	0.0305	Dehiscent	Afsar Uddin (2012)
Mother plant B	0.9798 ± 0.0027	0.0350	Dehiscent	
Mother plant C	0.7799 ± 0.0357	0.0306	Dehiscent	
Acacia coriacea ssp. *pendens*	3.640 ± 0.220	0.4277 ± 0.0231	Dehiscent	Khan *et al.*, (2013)
Delonix regia	11.912 ± 0.5272	4.5493 ± 0.1882	tardily dehiscent to indehiscent	Present study

Relationships between pod, seed and seed packaging parameters: Multiple trends of association were indicated between the pod and seed characteristics of *D. regia* (Table 3) through the analysis for Spearman Rank Correlation (rho). Higher was the pod weight, larger was the number of seeds, total seed yield per pod (SWPP) and the pericarp weight. The parameters of seed packaging cost (SPC$_1$ and SPC$_2$) related with seed yield per pod negatively but such a relationship was much closer in case of SPC$_2$ i.e. packaging cost expressed as g.pericarp.g^{-1}.seeds. SPC$_1$ and MSSW associated negatively significantly. The relationship of SPC$_2$ with MSSW was relatively weak.

   Few associations were important with respect to the allocation of resource investment in pods and its components and were studied through regression analyses. There was a linear relationship between logarithms of seed yield per pod and mass of the pod (r = 0.8695). The slope of the line b = 1.226 (SE$_b$ = 0.08449) was significantly different from the b for the null line (1) (t = 2.67, p<0.05) (Fig. 5). It implied that fruit size influenced the amount of resources that are proportionally allocated to seed production. While large fruit produce larger mass of seeds than small fruits, the approximate slope value of 1.266 of the regression line indicated that proportionately small fruit invested the smaller resources to seed production and large fruits invested larger resources to seeds. There was, therefore, a positive trade-off between fruit size and allocation of resources to seeds.

Table 3. Spearman Rank correlation coefficients amongst various pods and seeds characteristics. (N = 70).

TNS	TNS								**Spearman rho matrix**
PW	0.658**	PW							
SWPP	0.882**	0.835**	SWPP						
MSSW	0.194	0.644**	0.603**	MSSW					
PWS	-0.491**	0.260*	-0.172	0.489**	PWS				
SPC$_1$	-0.529**	0.219	-0.226*	0.425**	0.994**	SPC$_1$			
SPC$_2$	-0.735**	-0.291*	-0.721**	-0.270*	0.650**	0.698**	SPC$_2$		
PERI	0.596**	0.997**	0.772**	0.660**	0.290*	0.257*	-0.251*	PERI	
PPFR	-0.745**	-0.277*	-0.754**	-0.304*	0.648**	0.684**	0.907**	0.295*	PPFR
PSFR	0.735**	0.291*	0.718**	0.232	-0.650**	-0.698**	-0.999**	-0.208	-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
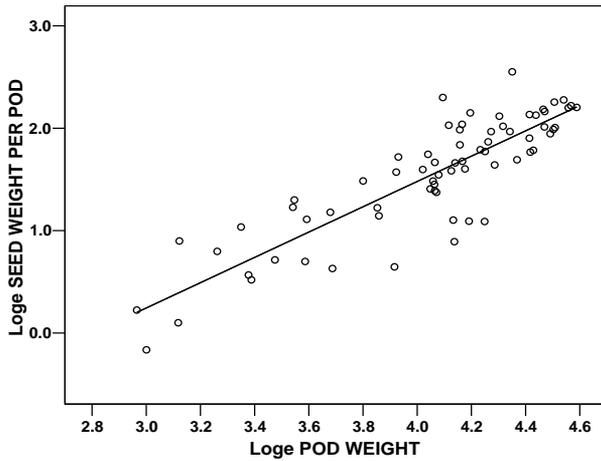
$Y = -3.4306 + 1.2265\ X \pm 0.28832$
$\quad\quad t = -9.97 \quad\quad t = 14.52$
$\quad\quad p<0.0001 \quad p<0.0001$
$\quad\quad F = 210.72,\ r = 0.8695,\ r^2 = 0.7560,\ N = 70,\ SE_b = 0.0849$

Fig. 5. Relationship between logarithms of seed yield per pod and pod weight.
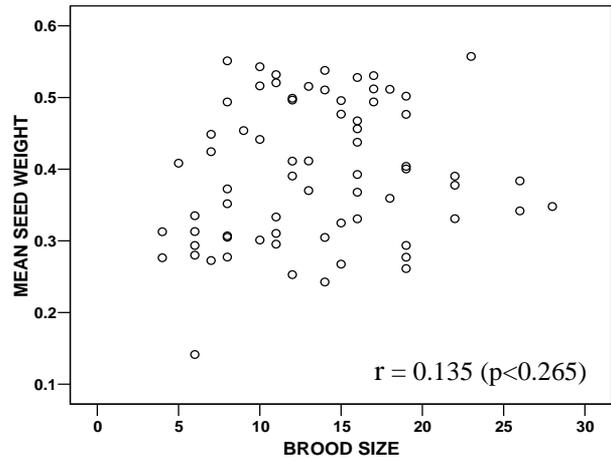
Fig. 6. Relationship of Mean single seed weight (MSSW) in a pod and the brood size.

No correlation was detected between mean single seed weight in pod and the brood size (Zero order r = 0.135; p<0.265; Fig. 6) as single independent parameter. However, the three characteristics of pod (PW, SWPP and TNS (Brood size) related with MSSW through following significant multiple regression equation which accounted for 89.9% variance in MSSW.

MSSW (g) = 0.334 + 0.001 PW (g) + 0.066 (SWPP, g) – 0.025 Brood size ± 0.031113
$\quad\quad\quad\quad t = 24.2 \quad\quad\quad t = 2.13 \quad\quad\quad t = 14.18 \quad\quad\quad t = -17.22$
$\quad\quad\quad\quad p<0.0001 \quad\quad p<0.0001 \quad\quad P<0.0001 \quad\quad p<0.0001$
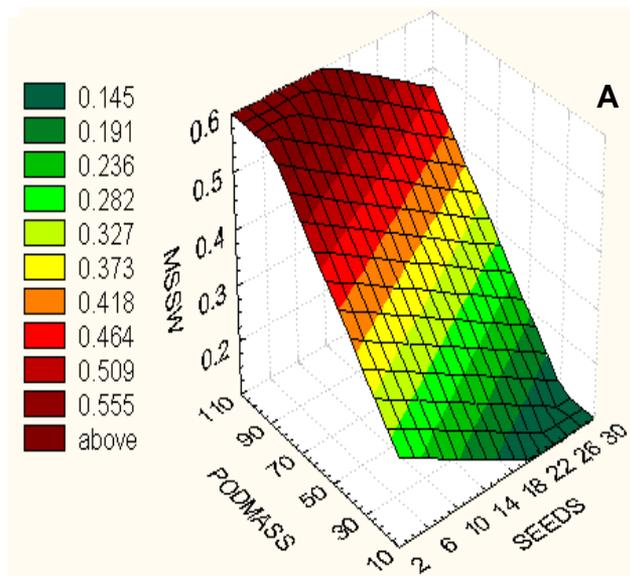$\quad\quad\quad\quad F = 194.95, \quad R = 0.948, \quad R^2 = 0.899, \quad Adj\ R^2 = 0.894$
$\quad$ Zero- Order Correlation = PW, 0.665; SWPP, 0.575; Brood Size, 0.135
$\quad$ Partial Correlation = PW, 0.254; SWPP, 0.868; Brood size, -0.904

This interactive model may be broken into three sub models (Fig. 7 A, B and C). The interaction of seed mass (SWPP) produced in a pod and the brood size appeared to explain variation in MSSW highly significantly (R^2 = 0.892) (Fig. B) with significant partial correlations for both SWPP ($r_{partial} = 0.943$) and Brood size ($r_{partial} = -0.916$). In other model (Fig. 7A) the pod mass and number of seeds per pod explained the variance in MSSW not more than 78.8% (partial correlations for both independent variables were also significant. In the third model (Fig. 7C), the positive interaction of seed mass (SWPP) with pod weight explained variance in MSSW poorly (44.3%) and suffered from insignificant partial correlation ($r_{partial} = 0.036$) for SWPP. Brood size in the above two models (Fig. 7 A and B) significantly influenced the MSSW but negatively i.e. the mean seed weight for a pod was at least in part influenced by the brood size of the pod adversely.

The pod weight per seed decreased in relation to brood size in a statistically significant fashion (Fig. 8). The number of seeds in a pod accounted for the variation in pod weight per seed around 26.52%. The parameter of pod weight per seed (a parameter of seed packaging sensu Mehlman (1993), therefore, had a significant degree of trade-off with the number of seeds per pod (Fig. 8) as also reported in *Arum italicum* by Méndez (1997) and in *Baptisia lanceolata* by Mehlman (1993). The proportion of pericarp mass to fruit mass (PPFR) gradually declined with the increase in seed number per pod i.e., the investment of biomass in pericarp had a trade-off with number of seeds (Fig. 9). The proportion of Pericarp mass to fruit mass is also reported to have a trade-off with brood size in a legume, *Baptisia lanceolata* (Mehlman, 1993). The investment in seed mass (PSFR) increased substantially (r = 0.7450) with the increase of brood size of a pod (Fig. 10). This is also in agreement with Mehlman (1993). Furthermore, the seed packaging cost (SPC_2) related with brood size in accordance with a significantly negative power (exp. = -0.54841) model (r = - 0.7424; Fig.11) i.e. the investment of biomass in pericarp had a negative trade-off with number of seeds.

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. No trade-off was detected between mean single seed weight (MSSE) and brood size (as alone independent variable) in *D. regia*. A significant trade-off between MSSW and the brood size has been reported by Afsar uddin (2012) in *A. nilotica*. 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 by Lokesha *et al.*, *(*1992) that, to an extent, plants can escape the seed-size-seed number trade-off by modifying the chemical composition of their seeds. Trade-off may assume different patterns of sexual and asexual reproduction in *Sagittaria pygmaea* under different nutrient levels (Liu *et al.,* 2009). 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). In *D. regia*, the three parameters of pods (PW, SWPP and TNS) interacted collectively significantly with MSSW – TNS acting negatively. In both split sub models (PW coupled with TNS or SW coupled with TNS as independent variables) interacted with MSSW significantly (p<0.0001) and in both cases TNS (brood size) interacted negatively with MSSW highly significantly i.e. brood size influenced the MSSW adversely. 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.

MSSW (g) = 0.232 + 0.004 PW – 0.009 Brood size
             t = 9.82   t = 9.66   t = -4.91
                  p<0.0001 p<0.0001   p<0.0001
                  F = 48.16, R = 0.788, R^2 = 0.598, Adj R^2 = 0.587
Zero Order Correlations = PW, 0.665; Brood size, 0.135
Partial Correlations = PW = 0.763, Brood size = -0.515
SE regression: 0.062111.
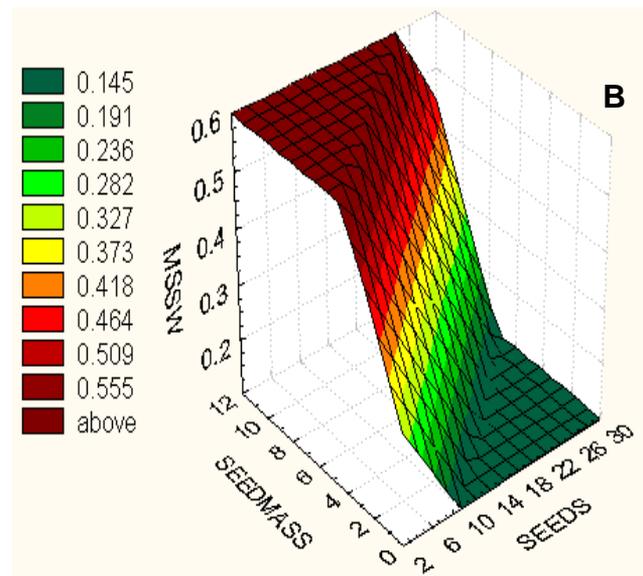
MSSW (g) = 0.355 + 0.073 SWPP – 0.026 Brood size
             t = 9.82   t = 9.66   t = -4.91
                  p<0.0001   p<0.0001   p<0.0001
                  F = 48.16, R = 0.944, R^2 = 0.892, Adj R^2 = 0.888
Zero-Order Correlations = SWPP, 0.575; Brood size. 0.135
Partial Correlations = SWPP, 0.943, Brood size = -0.916
SE regression: 0.0621
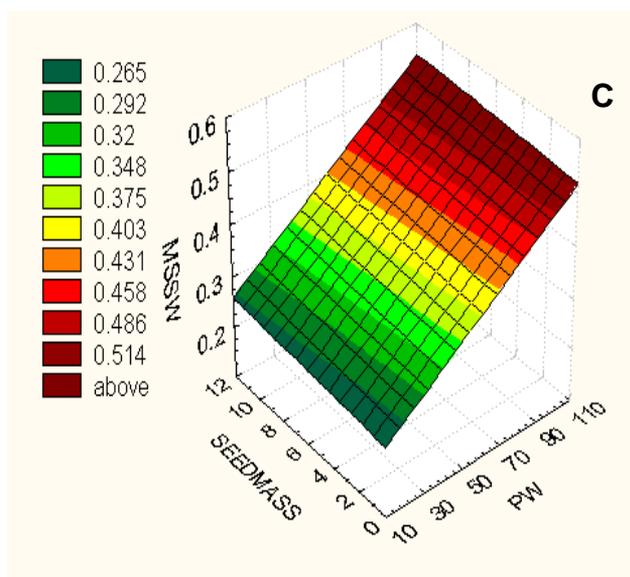
MSSW (g) = 0.209 + 0.003 PW – 0.002 SWPP
             t = 7.61   t = 3.68   t = 0.293
                  p<0.0001 p<0.0001   p<0.770
                  F = 26.62, R = 0.665, R^2 = 0.443, Adj R^2 = 0.426
Zero-Order Correlations = PW, 0.665; SWPP, 0.575
Partial Correlations = PW = 0.410, SWPP = 0.036
SE regression: 0.07239.

Fig. 7. Relationship of MSSW with pod mass and Brood size (A), relationship of MSSW with Seed mass per pod and the brood size (B) and relationship of MSSW with Seed mass and Pod weight (C).
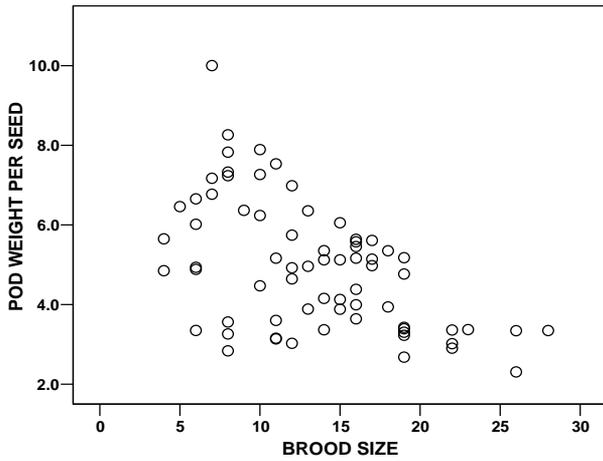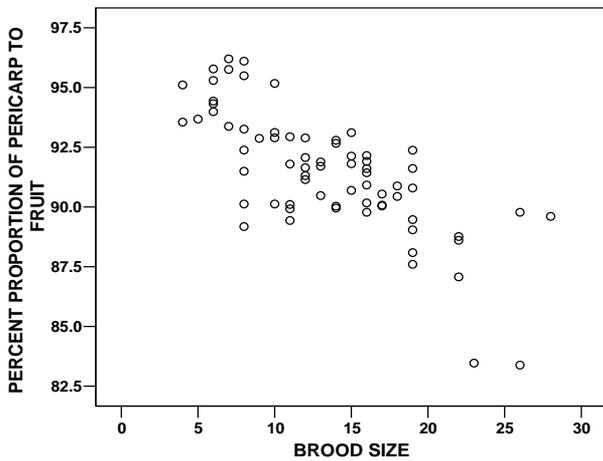
Pod wt. per seed = 6.999095 – 0.153016 Brood size ± 1.3801
            t = 16.21   t = -5.15
            p<0.0001   p<0.0001
      F = 26.52 (p<0.0001), r = - 0.5297, r^2 = 0.2670

Fig. 8. Relationship of pod weight per seed (g) and the brood size.
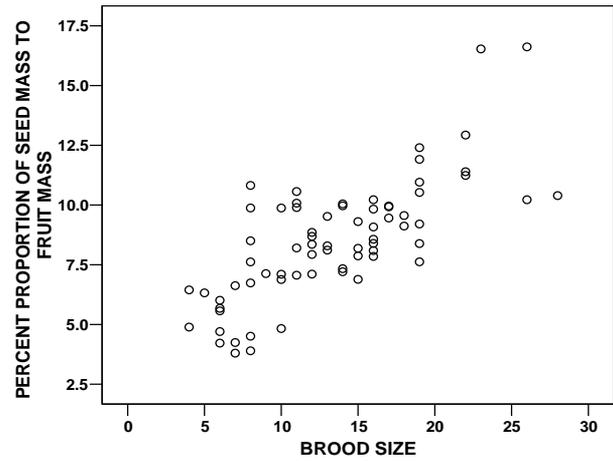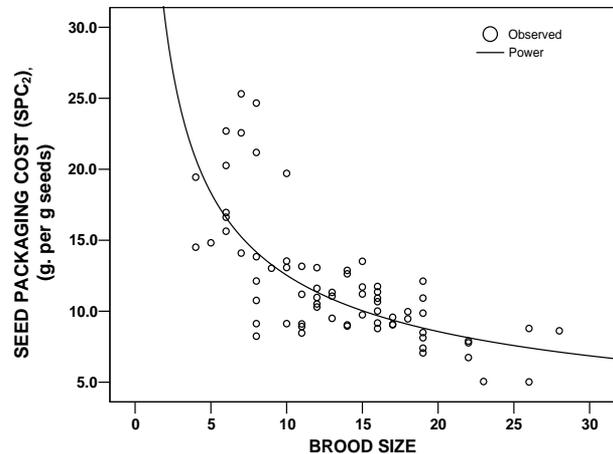

PSFR = 3.9972 + 0.33649 Brood size ± 1.6922
            t = 7.529   t = 9.21
            p<0.0001   p<0.0001
      F = 84.79 (p<0.0001), r = 0.7450, r^2 = 0.5550

Fig. 10. Relationship of PSFR with brood size.

PPFR = 96.0023 – 0.3365 Brood size ± 1.697
            t = 180.8   t = -9.28
            p<0.0001   p<0.0001
     F = 84.79 (p<0.0001), r = -0.7450, r^2 = 0.5550

Fig. 9 Relationship of PPFR with brood size.

$Y = 44.38123 . X^{-0.54841} \pm 0.22748$
            t = 6.55   t = -9.14
            p<0.0001   p<0.0001
     F = 83.50; r = - 0.7424, r^2 = 0.5512, N = 70

Fig. 11. Relationship between seed packaging cost (SPC$_2$) and brood size.

Variation in seed mass against the number of seeds in fruit is generally viewed by ecologists in terms of Smith-Fretwell theory of optimization of allocation of resources where parents maximize their fitness producing seeds with a homogenous optimal size. Variation around the optimal 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, 2013).

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