Int. J. Biol. Res., 2(1): 13-22, 2014.

AXIAL DIMENSIONS OF SEEDS, WITHIN-REGMA ALLOCATION OF PHYTOMASS AND SEED PACKAGING COST IN A WILD CASTOR BEAN, *RICINUS COMMUNIS* L. (EUPHORBIACEAE)

D. Khan, Zulfiqar Ali Sahito and M. Javed Zaki

Department of Botany, University of Karachi, Karachi-75270, Pakistan
[*]Corresponding author e-mail: yousufzai_ khan_doctor@yahoo.com

ABSTRACT

The axial dimensions of seeds, within-fruit allocation of biomass and seed packaging cost were determined in a wild castor bean plant from village Khuhra, Tehsil gambit, district Khairpur Mirs, Sindh. The dry fruit (regma) weight averaged to 1.6643 ± 0.0215g and varied by 18.53% (0.9493–2.4466g). The castor fruit produced 2 to 4 seeds but generally 3 seeds per regma in 91% of the cases. Eight percent of the fruits had 2 seeds and only 1% produced 4 seeds. The length, breadth and thickness of seeds averaged to 13.85 ± 0.15, 8.45 ± 0.069 and 5.63 ± 0.062 mm, respectively with as low variation as 6.89, 5.13 and 6.92%, respectively. The lowest variation was seen in sphericity (3.91%). The sphericity averaged to 62.78%. Seed weight per regma (SWPR) averaged to 0.9751 ± 0.0137g varying from 0.3466 to 1.3888g (CV: 19.90%). Mean single seed weight in a regma (MSSW) varied by 17.08% among the fruits and averaged to 0.3327 ± 0.0040g (0.1490–0.4629g). It deviated marginally from normal distribution (negatively skewed; KS-z = 1.297, p<0.069). Mean single seed weight (MSSW) related with the magnitude of variation (CV) in seed weights among the seeds of a regma in an inverse fashion. The variation amongst the seed weight (CV) in fruit was largely the direct function of the weight of the smallest seed in the fruits (r = 0.930; F = 1268.16 (p<0.0001) and not the heaviest seed of the regma (r = 0.024, NS). It was observed that MSSW when two seeds developed in a regma was not significantly different from the regular state of three seeds in regma (F = 0.556, p<0.457 and t = 1.873, p<0.10, NS). The very occurrence of four seeds in only two fruits (1%) of the regma didn't allow the comparison of MSSW of 4-seeded state to 3-seeded or 2-seeded state. These results led us to conclude that there was no competition among seeds developing in the same fruit. Excluding seeds of small category (≤ 100 mg), the individual seed for a sample of N = 552, averaged to 349.307 ± 1.854 mg and distributed normally (KS-z: 1.224, p<0.100). It varied only by 12.47% - nearly half to the variation in case of all sizes of seeds inclusive (24.63%). Seed packaging cost per seed (SPC_1) and per g. seeds (SPC_2) averaged to 0.2297 ± 0.0038 and 0.7029 ± 0.0127g, respectively and varied by a quantum of 23.41 and 14.14%, respectively. There was no trade-off between fruit size and allocation of resources to seeds.

KEYWORDS: *Ricinus communis*, Regma, Within-regma biomass allocation, seed Packaging cost.

INTRODUCTION

Pericarp and seeds occupy significantly varying proportion of the fruit biomass in angiosperms and 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; Khan and Sahito, 2013a and b; Khan *et al.,* 2013). 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). These workers have examined the relationship between the seed weight and the seed packaging cost. 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 plant (Khan and Zaki, 2012; Khan and Sahito, 2013; Khan *et al.,* 2013, 2014). In this paper, within-fruit allocation of biomass in a wild *Ricinus communis* L. (vernacular- Palma Christi, Castor oil plant) is studied.

R. communis is a widely planted species up to c 1300m for its seeds containing oil. It may be self-sown around villages (Stewart, 1972). There are hundreds of natural forms and cultivated varieties of the species including annual and perennial types (Francis, 2014). Annual forms are c 1.2m in height and perennial forms size up to small tree. Castor has been cultivated in Africa, Asia from ancient times. A single large plant (8m canopy diameter) was found to produce 0.15 million seeds and small plant (c 1m canopy diameter) produced 1500 seeds (*http://www.issg.org/database*). Physical properties of seeds of a cultivated form of castor in Iran (Gharibzahedi *et al.,* 2011), six varieties of castor of different origin (Brazil, USDA /ARS and Texas and one introduced in Brazil from India (Severino and Auld, 2013) and two forms of castor bean from Nigeria (Akande *et al.*, 2012) and wild castor from Sokoto (Aisha *et al.*, 2013) have recently been published. There exists large divergence of seed size in castor. The seeds and pollens characters of Egyptian provenances were found to be important for the formal recognition of intraspecific taxa in this species (Shaheen, 2002). Therefore, in this paper we have also reported on the physical characteristics of seeds of a self sown castor plant from a country side of Sindh. This is pertinent in view of the fact that castor seeds are of great economic value and have a number of applications in several industries and other economic uses (CSIR, 1972; Labalette *et al.*, 2008; Salihu *et al.,* 2012; Imasuen *et al.,* 2014)) which necessitate the knowledge of their physical and chemical properties for its usefulness in engineering designs for varying types of processing.

MATERIALS AND METHODS

Two hundred mature fruits (regma) from a plant of *Ricinus communis* L. growing in the village Khuhra, Tehsil gambit, district Khairpur Mirs, Sindh were collected in 2012. These fruits were air-dried for around 60 days in laboratory. Fruits and seeds were weighed on electronic weigh meter with a least count of 0.0001g. To determine biomass investment in seed and seed packaging following parameters were determined after Mehlman (1993) and Chen *et al*. (2010). 1. Regma weight (RW) of air-dried regmas, 2. Total seed weight per regma (SWPR), 3. Number of seeds per regma (TNS, the brood size), 4. Pericarp weight per regma (PWR), 5. Mean single seed weight (MSSW) in a regma, 6. *Per cent* proportion of pericarp weight to fruit weight (PPPF), 7. *Per cent* proportion of seed weight to fruit weight (PPSF), 8. Regma weight per seed (RWS = RW / TNS), 9. Seed packaging cost per seed (SPC_1 = PWR / TNS and 10. Seed packaging cost per g seeds (SPC_2 = PWR / SWPR). The weight of each seed recovered from the fruits was recorded.

The linear measurements of seeds were expressed 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 $K = \sqrt{(BT)}$

The location and distribution parameters were calculated for the fruit and seed characteristics. The frequency distributions were characterized with skewness (g1) and kurtosis (g2) (Zar, 2010). Kolmogorov-Smirnov (KS-z) test was 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).

RESULTS AND DISCUSSION

Regma and the brood size: The regma of castor is generally a trilobate, globose schizocarp densely covered with curved cylinderic projections (c 0.7-0.90 cm) with bristle like tip on outer surface of the fruit to facilitate dispersal of fruit (Fig. 1). The stock (pedicel) of the regma measures 1.105 ± 0.0744 cm (CV: 30.14%) and fresh regma diameter inclusive prickles averaged to 2.38 ± 0.065 (CV: 12.33%). The castor fruit in our studies appeared to produce 2 to 4 seeds but generally 3 seeds per regma in 91% of the cases. Eight percent of the fruits had 2 seeds and only 1% produced 4 seeds (Fig. 2B). Weis (1991) reported 3-4 seeds per castor regma whereas Severino and Auld (2013) have reported that 0.8% of the castor regma produced 4 seeds, 1.8% only one seed, 14.3% 2 seeds and most of the fruits (83.1%) produced three seeds each. In our studies none of the fruit produced one or none seed. In 8% of the fruits abortion of seed resulted in two seeds per regma. According to Severino and Auld (2013) the abortion was more frequent in cultivar Al-Guarany in which 3.1% of the fruits aborted two seeds and 20% of the fruits aborted one seed as compared to the cultivar 'BRS Energia' where two-seed abortion was found in only 0.4% of the fruits and one seed aborted in 7.4 % of the fruits. It is obvious that there was more abortion in CV. 'Al-Guarany' and 'BRS Energia' as compared to the local provenance of Sindh.

The dry fruit weight of our local plant averaged to 1.6643 ± 0.02154g and varied by 18.53% (0.9493–2.4466g) (Table 2; Fig. 2A). The regma weight varied significantly with the brood size (F: 24.86, $p<0.0001$). Two types of varieties of wild castor are reported by Akande *et al*. (2012) from Nigeria. The fruit of Large Seed variety (LSV) weighed 1.290 ± 0.12g) and that of in small seed variety (SSV) 0.238 ± 0.01g (Akande *et al*., 2012).

The seeds: The seeds of *R. communis* are oval shiny beige coloured with darker streak. Seeds are, however, reported to widely vary in colour - red, white, grey, faint chocolate and purple (*www.ikisan.com/crop/).* They resembled to engorged ticks of dog. Storage at ambient temperature is reported to bring losses of the viability by around 75% in initial three months. Seeds of castor are caruncluate and endospermic. According to seed classification system of Martin (1946) and later revised by Baskin and Baskin (2007), the castor seeds are kept in the category of foliate axile seed type (FA_1 type i.e. embryo spatulate axile erect; cotyledon thin to thick and slightly expanded to broad). Seeds are rich in triglyceride 'ricinolin' (c 85%, Alam *et al*., 2010). They are poisonous and contain Ricin (www.billcasselman. com/cwod_archive/beaver_castor_two.htm), a water soluble protein. Even a small amount of masticated seeds may be lethal. Fatal doses are 2.5–6 seeds for humans. The broken seeds may cause irritation (CSIR, 1972). Forty to sixty percent oil content in castor seeds, make them very valuable put to some 700 uses. In Eastern part of Nigeria, the castor seeds are, however, used to prepare a fermented food condiment called 'OGIRI' (NCRI, 2013). Fermented castor seed meal may be included in chicken starter diets @ 50g/kg (Oso *et al.,* 2011).

Fig. 1. Green fresh regma (A), mature regma (B) and seeds (C) of *Ricinus communis*.

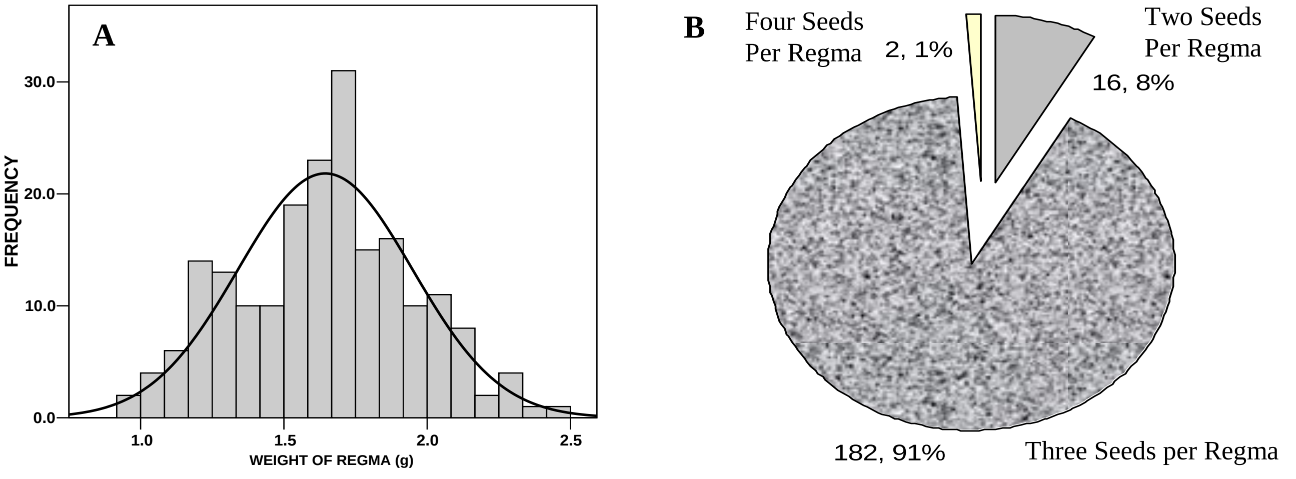


Fig. 2. Distribution of regma weight (A) and brood size (B) in *R. communis*.

The caruncle (elaiosome) associated with seed is involved in seed dispersal by ants (myrmechory). Caruncle initially contains starch but at maturity much of its reserve is lipids. It has no cuticle unlike rest of seeds. It facilitates seeds to absorb water and germinate (Bianchini and Pacini, 1996).

The seeds were fairly consistent in size and shape (Table 1). The length, breadth and thickness of seeds averaged to 13.85 ± 0.1504, 8.449 ± 0.0686 and 5.63 ± 0.0616 mm, respectively with as low variation 6.89, 5.13 and 6.92%, respectively. Arithmetic and geometric diameters varied by 9.3 and 8.69%, respectively. The lowest variation was seen in sphericity (3.91%) which averaged to 62.78%. For the parameters studied, the maximum variation was exhibited by the surface area (10.6%) and the volume (11.85%) of the seeds. Akande *et al*. (2012) have reported length, breadth and thickness of Large Seed variety (LSV) seeds of Nigeria to be 13-20.5, 10 -15 and 5-9.5 mm, respectively and the Small Seed variety (SSV) had seeds ranging from 6 to 9.5 mm in length, 3.3 to 5.2 mm in breadth and 3 to 4.5 mm in thickness). The wild castor bean of Sokoto State of Africa is reported to be 8.3 mm long and 4.2 mm wide (Aisha *et al.*, 2013). The seeds in case of common cultivated plants are reported to measure 11.19x7.79mm to 13.54 x 9.80mm *(www. Ikisan.com/crop/)*. The seeds of in hand castor plant from Sindh were, therefore, smaller than LSV seeds but substantially larger than the SSV seeds of Nigeria. Das *et al*. (2000) have reported castor seed to maximally reach 20mm in length. There is, therefore, large variation in seed size in castor due to varietal reasons. The seed length of some Egyptian provenances of castor bean was lesser than 1.2 cm and greater than 1.2 cm in others (Shaheen, 2002).

Table 1. Physical properties of *R. communis* seeds.

Parameter	Min	Max	Mean	SE	CV (%)	g1	g2
Length (mm)	12.0	16.00	13.8463	0.15040	6.89	-.234	-.213
Breadth (mm)	7.40	9.15	8.449	0.06860	5.13	-.729	.193
Thickness (mm)	5.0	6.40	5.6318	0.06157	6.92	-.097	-1.260
Arithmetic diameter (mm)	8.133	10.20	9.309	0.07913	5.37	-.803	.599
Geometric diameter (mm)	7.613	9.3823	8.6773	0.07182	5.23	-.774	.398
Sphericity (%)	57.66	66.95	62.776	0.388	3.91	-.322	-.504
Volume $(mm)^3$	241.40	451.03	361.536	8.45229	11.85	-.590	.246
Surface area (mm^2)	133.33	208.07	177.129	2.96977	10.60	-.730	.559

N – 40; g1, skewness; g2, kurtosis; Sg1 = 0.344, Sg2 = 0.733

Seed weight per regma (SWPR): SWPR averaged to 0.9751 ± 0.01372g varying from 003466 to 1.388g (CV: 19.90%) and distributed asymmetrically (negatively skewed and leptokurtic) with significant KS-z value (1.483, $p<0.025$) (Table 2). It varied significantly with brood size ($F = 34.39$, $p<0.0001$).

Pericarp weight per regma (PWR): Pericarp weight of regma varied by 23.18% among the regmas studied and averaged to 0.6692 ± 0.01097g per regma. On an average percent proportion of pericarp to regma (PPPR) was 40.705 ± 0.4060 and percent proportion of seeds to regma (PPSR) was 59.395 ± 0.4060 (Table 2). Both of these parameters were highly asymmetrical in distribution and varied with brood size significantly (F: 6.451, $p<0.002$).

Mean single seed weight in a regma (MSSW): MSSW varied by 17.08% among the fruits and averaged to 0.3327 ± 0.00402g (0.1490–0.4629g). It deviated marginally from normal distribution (KS-z = 1.297, $p<0.069$). It didn't vary with brood size significantly ($F = 0.812$, $p<0.446$) (Table 2; Fig. 3).

Table 2. Location and dispersion of fruit and seed characteristics of *R. communis*. Acronyms of parameters as given in Materials and Methods.

Parameter	N	Min.	Max.	Mean	SE	CV (%)	g1	g2	KS-z	p
RW (g)	200	0.9493	2.4466	1.6443	0.021543	18.53	0.019	-.370	0.775	0.669
TNS	200	2	4	2.93	0.0210	9.96	-2.102	7.287	7.477	0.0001
SWPR (g)	200	0.3446	1.3888	0.97512	0.013718	19.90	-0.554	-0.245	1.483	0.025
MSSW (g)	200	0.1490	0.4629	0.332679	0.004017	17.08	-0.595	0.048	1.297	0.069
PWR (g)	200	0.0551	1.3751	0.669212	0.010968	23.18	0.380	2.867	1.137	0.150
RWS (g)	200	0.3164	0.8155	0.562363	0.006577	16.54	0.134	-0.101	0.589	0.879
SPC_1 *	200	0.0184	0.4989	0.229683	0.003806	23.41	0.835	5.106	1.389	0.042
SPC_2 **	200	0.0481	1.9408	0.702927	0.012725	14.14	2.506	15.801	2.202	0.0001
PPPF	200	4.5932	65.9957	40.70479	0.406024	14.11	-0.775	11.414	1.598	0.012
PPSF	200	34.0043	95.4068	59.29529	0.406024	9.68	0.775	11.414	1.598	0.012

Sg1 = St. Error of skewness = 0.172; Sg2 = St. Error of kurtosis = 0.342.

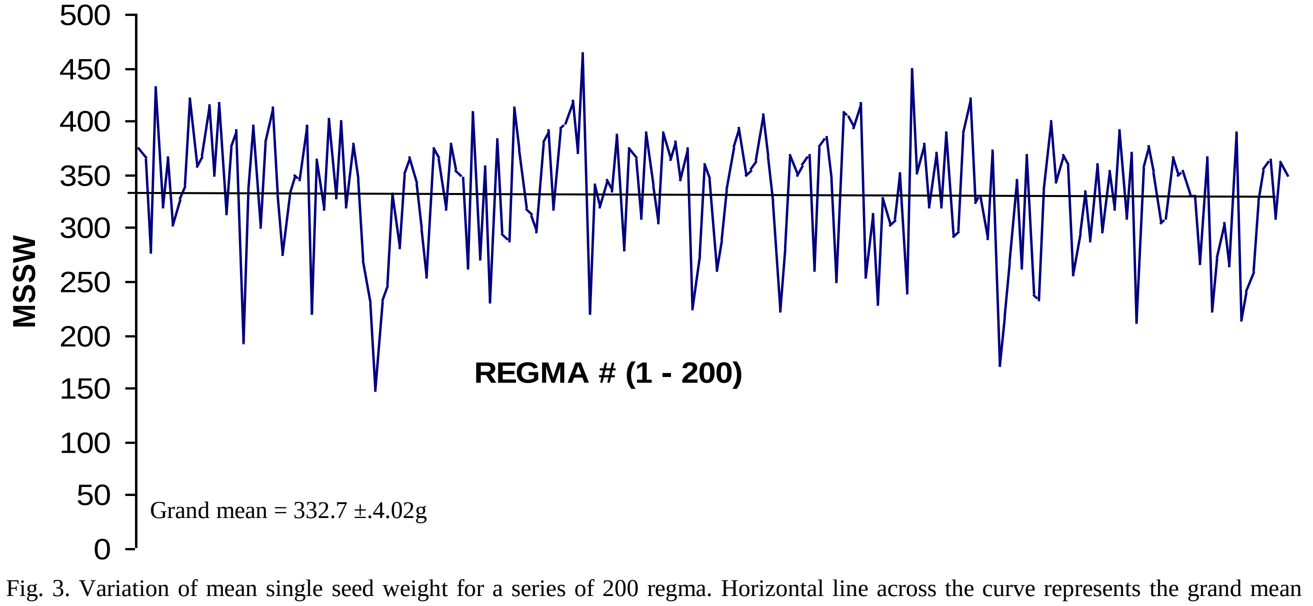
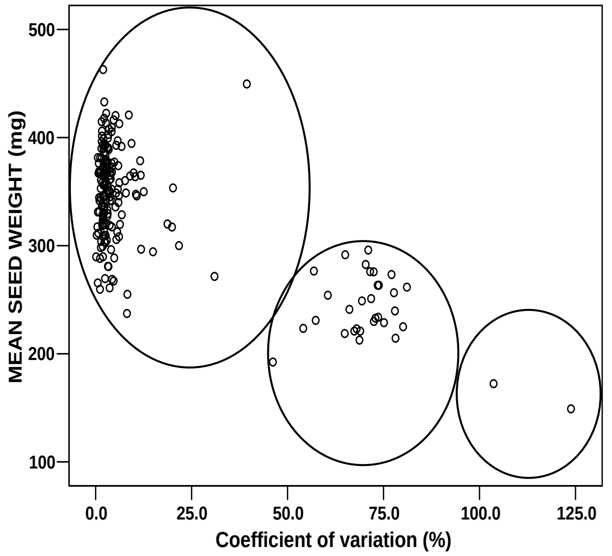


Fig. 3. Variation of mean single seed weight for a series of 200 regma. Horizontal line across the curve represents the grand mean value (0.3327 g).

Mean single seed weight (MSSW) related with the magnitude of coefficient of variation (CV) in seed weights among the seeds of a regma in an inverse fashion (Fig. 4). Larger was the magnitude of CV, lesser was the magnitude of MSSW. Furthermore, the variation amongst the seed weight (CV) in fruit was largely the direct function of the weight of the smallest seed in the fruits ($r = 0.930$; $F = 1268.16$ ($p<0.00001$) and not the heaviest seed of the regma ($r = 0.024$, NS). The weight of smaller seeds in regma studied accounted for 86.49% of the variance in CV.

It may be hypothesized that if competition existed between seeds in a regma, the seeds would be expected to grow heavier and large when regma had lesser number of seeds. In our studies (Fig. 5), it was seen that MSSW when two seeds developed in a regma was not significantly different from the regular state of three seeds in regma ($F = 0.556$, $p<0.457$ and $t = 1.873$, $p<0.10$, NS). The very occurrence of four seeds in two fruits only (1%) of the regma didn't allow the comparison of MSSW in 4-seeded state to 3-seeded or 2-seeded state. The above statistical results led us to conclude that there was no competition among seeds developing in the same fruit and presumably each seed had its independent source of nutrients. Our results are in confirmation to the results of Severino and Auld (2013) who concluded that "*Castor seeds growing in the same capsule did not appear to compete for limited assimilates*".



MSSW (mg) = 356.2652 – 1.54532 CV (%) ± 40.4993
t = 107.28 t = +-14.03
p<0.00001 p<0.00001
r = 0.7061; r^2 =0.4986; Adj r^2 = 0.4961;
F = 196.92 (p<0.00001)

Fig. 4. Relationship of MSSW with variation of seed weight in fruit (N = 200).

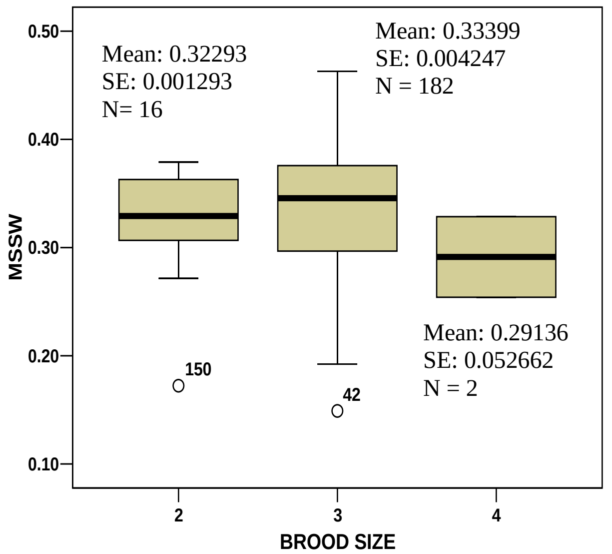
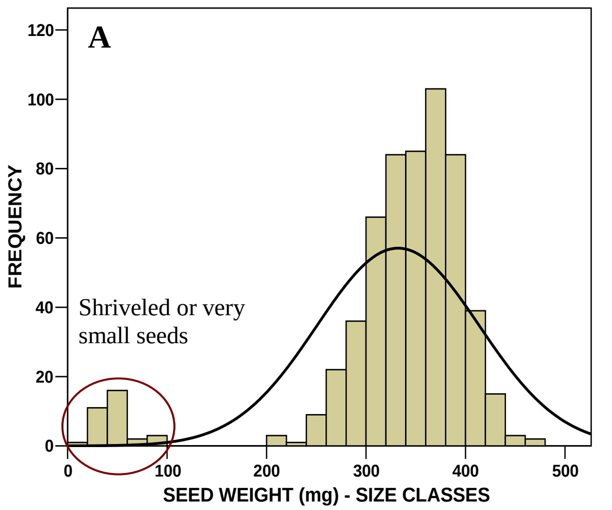
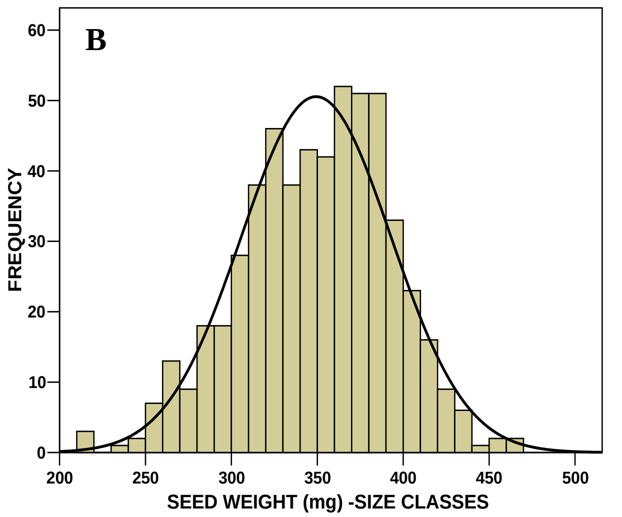


Fig. 5. Box plot representation of relationship of MSSW (g) with the brood size.



All types of seeds
N = 585, Mean = 332.237, SE = 3.3827
Median = 348.90, CV (%) = 24.63, g1 = -2.305, Sg1 = 0.101, g2 = 5.896, Sg2 = 5.941, Min, = 16.9, Max = 468.3, KS-z = 4.112 p<0.0001



Seeds excluding shriveled and very small seeds:
N = 552, Mean: 349.307, SE: 1.8540,
Median = 352.15, CV (%) = 12.47, g1: -0.274, Sg1: 0.104, g2: -0.084, Sg2: 0.208, Min: 211.9, Max: 468.3, KSD-z: 1.224 (p=0.100)

Fig. 6. Frequency distribution of individual seed weight (including caruncle) of *Ricinus communis*. A, all types of seeds and B, seeds excluding shriveled and very small seeds.

Individual seed weight: Individual seed weight for a sample of all recovered seeds (N= 585) averaged to 332.24 ± 3.383 mg and significantly deviated from normal distribution (negatively skewed, g1: -2.305 & KS-z: 4.112, p<0.0001) (Fig. 6A). Excluding seeds of small category (≤ 100 mg), the individual seed for a sample of N = 552, increased to 349.307 ± 1.854 mg and distributed normally (KS-z: 1.224, p<0.100) (Fig. 6B). It varied only by 12.47% - nearly half to the variation in case of all sizes of seeds inclusive (24.63%). Akande *et al*. (2012) have reported on the seed size of castor varieties. Large seed variety weighed a seed 680 ± 10.0 mg (400-900 mg) and Small seed variety weighed a seed 116 ± 2.0 mg (80-150 mg). Kadambi and Dabral (1955) have reported that variation in castor seed weight from 383.14 to 859.11 mg. Seed weight was reported to exceed 1g per individual seed in provenances collected from El-Kubbania / Aswan, Assuit, barrages, El-Mounfia, new Dermitta and North Sinai (Shaheen, 2002). Seeds were heavier for those provenances which had denser capsule prickles. According to Salihu *et al*. (2012) individual seed weight varies not only from cultivar to cultivar (90-1000mg) but also varies within different racemes. The seed weight, according to Salihu *et al*. (2012) increases as the total number of seeds produced per plant decreases.

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 Castor bean was negatively skewed (Fig. 6) i.e. castor produced relatively 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 (Khan and Zaki (2012). 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 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 number of seeds per regma equalled to 9.96% which was lower than the seed weight variation. This is contrary to the contention of Harper (1961) and Harper *et al*. (1970) which states that seed weight is less variable than seed number. It may, however, be mentioned that several species are known to exhibit less variation in seed weight than seed number (brood size) for example *Acacia coriacea* subsp. *pendens* (Khan *et al.,* 2013), *A. stenophylla* (Khan and Sahito, 2013 a), *Delonix regia* (Khan and Sahito, 2013 b) and *Thespesia populnea* (Gohar *et al.,* 2012). Less variation in brood size than seed weight in *R. communis* may be related to very high frequency of three-seeded regmas (91%).

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. Seed weight variation within an individual of castor bean (CV: 24.63%) appears to be environmentally-induced and may have important ecological implications in its life history diversification (Braza *et al*., 2010).

Variation of seed weight around an 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 Shaanker *et al*., 1988; Ganeshaiah and Uma Shaanker, 1988; Ganeshaiah and Uma Shaanker, 2003). Since Smith-Fretwell (1974) 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 among fruits and total seed mass in fruits 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).

Table 3 A and B. Relationship of three parameters of seed packaging cost (RWS, SPC_1 and SPC_2) with brood sizes (3A) and one-way ANOVA for three parameters of seed packaging cost (SPC_1 , SPC_2 and RWS) for the three brood sizes (B).

A

Brood size	Statistics	RWS	SPC_1	SPC_2
2	Mean *	0.59595 a	0.273019 a	0.882860 a
	N	16	16	16
	SE	0.021556	0.018356	0.090599
3	Mean	0.56019 a	0.226196 b	0.687320 b
	N	182	182	182
	SE	0.006905	0.003733	0.010894
4	Mean	0.49173 a	0.20036 b	0.683625 b
	N	2	2	2
	SE	0.071925	0.034688	0.031682
Total	Mean	0.562363 a	0.229683 b	0.70293 b
	N	200	200	200
	SE	0.006577	0.003805	0.012725

B

Seed packaging costs	Brood groups	SS	df	MS	F	P
SPC_1	Between groups	0.034	2	0.017	6.171	0.003
	Within groups	0.542	197	0.003		
	Total	0.576	199	-		
SPC_2	Between groups	0.563	2	0.282	9.431	0.0001
	Within groups	5.881	197	0.030		
	Total	6.444	199	-		
RWS	Between groups	0.029	2	0.014	1.681	0.189
	Within groups	1.693	197	0.009		
	Total	1.722	199	-		

*, Multiple comparisons are based on LSD mean significant difference at p<0.05- the means followed by the same letter are not significantly different.

Table 4. Pair comparisons of means - RWS, SPC_1 and SPC_2 for the three brood sizes.

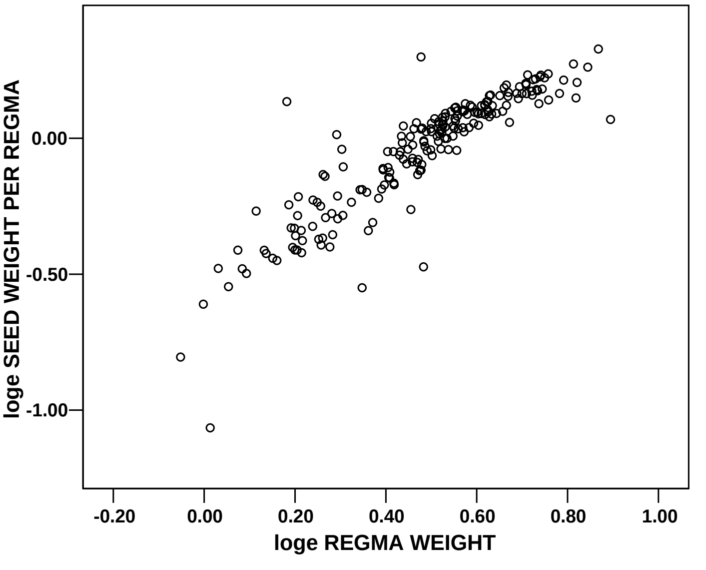
Dependent variable	Brood size (I) TNS	Brood size (J) TNS	Mean difference	SE	p
RWS	2	3	0.035761	0.0241706	0.141
	2	4	0.104222	0.0695202	0.135
	3	4	0.068461	0.0659034	0.300
SPC_1	2	3	0.046823 (*)	0.0136820	0.001
	2	4	0.072656	0.0393527	0.066
	3	4	0.025833	0.0373054	0.489
SPC_2	2	3	0.019554 (*)	0.0450545	0.0001
	2	4	0.0199235	0.1295873	0.126
	3	4	0.003695	0.1228455	0.976

*, The mean difference is significant at p<0.05 as given by LSD

Seed packaging cost: The three parameters of seed packaging cost-regma weight per seed (RWS) (after Mehlman, 1993), pericarp weight per seed (SPC_1) and pericarp weight per g seeds (SPC_2) are described in Table 2. RWS, SPC_1 and SPC_2 averaged to 0.5624 ± 0.0066, 0.2297 ± 0.0038 and 0.7029 ± 0.0127g, respectively and varied by a quantum of 16.54, 23.41 and 14.14%, respectively. Of the three parameters of seed packaging cost, SPC_1 and SPC_2 didn't follow normal distribution (KS-z: 1.389 and 2.202 (p<0.0001). RWS, however, followed normal distribution (KS-z: 0.589, p<0.879). RWS didn't vary with the brood size (Table 3A and B and 4). SPC_1 and SPC_2 varied significantly with the brood size (F= 6.171 and 9.431, respectively; p<0.003 and 0.0001, respectively (Table 3 A and B). The pair comparison of the means of the three parameters against brood size, however, indicated significant decrease in SPC_1 and SPC_2 only in three-seeded as compared to 2-seeded regma (Table 4). Other pair comparisons indicated no statistically significant differences. Abortion of seed, obviously, accentuated the packaging cost.

The investment in seed packaging in an individual plant of castor bean varied significantly by 23.41% as pericarp mass per seed (SPC_1) and 14.14% as pericarp mass per g. seeds (SPC_2). 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 fruits at individual level.

Phytomass allocation to seeds: There was a direct linear relationship (Fig. 6) between logarithms of seed weight per regma and weight of the regma (r = 0.897, p<0.00001). The slope of the line b = 1.039 (SE_b=0.036) was not significantly different from b for the null line (1) (t = 1.083, NS). This is similar to the fruit-seed relationship in *Warburgia salustris* where it was found that larger is the fruit, larger is the seed mass per fruit (Daws *et al.,* 2002). It implied that fruit size had no effect on the amount of resources that are allocated to seed production. The approximate value of 1 of the regression line indicated that proportionately small fruit invested the same resources to the seed production as the larger fruit invested proportionately. There was no trade-off between fruit size and allocation of resources to seeds. Similar results have been reported by Khan and Sahito (2013a) in *Acacia stenophylla*.



Ln SWPR = -0.546 + 1.039 ln (RW) ± 0.098343
t = -29.14 t = 28.63
p<0.0001 p<0.0001
F = 819.73, r = 0.897, r^2 = 0.805, Adj. r^2 = 0.804, SE (a) = 0.019; SE (b) = 0.036

Fig. 6. Relationship of $\log_e$ seed weight per fruit with $\log_e$ regma weight.

REFERENCES

Afsar uddin (2012). *Some quantitative observations on pods and seeds of three Mimosacean species: pods-, seeds – and brood-size variability, packaging cost and seed size-seed number trade off*. M.Sc. Thesis, Dept. Bot., University of Karachi. 139 pp.

Aisha, U., B.L. Aleiro, K. Shehu, B. Hanwa, B.I. Sumayya, M. Shuaibu and M.B. Abubakar. (2013). Seed characteristics and proximate analysis of wild castor plant from Sokoto state. *IOSR J. Environmental Sci., toxicology and Food Tech.* (IOSR-JESTFT) 3(4): 59-63.

Akande, T.O., A.A. Odunsi, O.S. Olabode and T.K. Ojediran. (2012). Physical and nutrient characterization of raw and processed castor (*Ricinus communis* L.) seeds in Nigeria. *World J. Agric. Sciences*, 8(1): 89-95.

Alam, I., S.A. Sharmin, S.C. Mondal, M.J. Alam, M. Khalekuzzaman and M.F. Alam (2010). *In vitro* micropropagation through cotyledonary node culture of castor bean (*Ricinus communis* L.). *Aust. J. Crop. Sci*., 4(2): 81-84.

Alonso-Blanco, C., H.B. Vries, C.J. Hauhart and M. Koornneef. (1999). Natural allelic variation at seed size loci in relation to other life history traits of *Arabidopsis thaliana*. *Proc. Natl. Acad. Sci. USA*, 96: 4710-4717.

Baskin, C.C. and J.M. Baskin. (2007). A revision of martin's seed classification system with particular reference to his dwarf seed type. *Seed Sci. Res*., 17(1): 11-30.

Bianchini, M. and B. Pacini (1996). The caruncle of *Ricinus communis* L. (castor bean): its development and role in seed dehydration, rehydration and germination. *Int. J. Plant Sci.* 157(1): 40-48.

Braza, R., J. Arroyo and M.B. García. (2010). Natural variation of fecundity components in a widespread plant with dimorphic seeds. *Acta Oecologia*, 36: 471-476.

Busso, C.A. and B.L. Perryman. (2005). Seed weight variation of Wyoming sagebrush in Northern Nevada. *Biocell*., 29 (3): 279-285.

Cardazzo, C.V. (2002). Effect of seed mass on germination and growth in three dominant species in southern Brazilian coastal dunes. *Braz. J. Biol*., 62(3): (doi: 10.1590/S1519-69842002000300005)

Chen, H., S. Felker and S. Sun. (2010). Allometry of within-fruit reproductive allocation in subtropical dicot woody species. *Am. J. Bot*., 97: 611-619.

CSIR (1972). *The Wealth of India*. Raw materials. Vol. 9. Publ. & Inform. Directorate, Council for Sci. Indust. Res. N. Delhi. 472 pp.

Das, S.C., C.O. Isichei, F.K. Okwnasaba and V.E. Uguru. (2000). Chemical, pathological, and toxicological studies of the effects RICOM-1013, J. Ricinus companies var Mirror on women volunteers on rodents. *Phytother Res*., 14(1): 15-19.

Doganlar, S., A. Frary and S.D. Tanksley. (2000). The genetic basis of seed weight variation: tomato as a model system. *Theor. Appl. Genet*., 100: 4267-1273.

Fenner, M. (1985). *Seed Ecology*. Chapman and Hall., NY. 151 pp.

Foster, S.A. and S.A. Jansen. (1985). The relationship between seed size and establishment conditions in tropical woody plants. *Ecology*, 66: 773-780.

Francis, J.K. (2014). Int. Inst. Tropical Forestry- (www.fs.fed/us/global/iitf/pdf/shrubs/Ricinus%20communis.pdf) -visited 4-4-2014.

Ganeshaiah, K.N. and R. Uma Shaanker. (1988). Seed abortion in wind-dispersed pods of *Dalbergia sissoo*: maternal regulation of sibling rivalry. *Oecologia,* 77: 135-139.

Ganeshaiah, K.N. and R. Uma Shaanker. (2003). Sociobiology of plants (pp. 64 -76). In: *Plant resources of Karnataka, A Decade of Diversity*. Univ. Agricultural Sciences. Banglore, India.104 pp.

Gharibzahedi, S.M.T., S.M. Mausavi and M. Ghahderrijani. (2011). A survey on moisture-dependent physical properties of castor seeds (*Ricinus communis* L.). *Aust. J. crop Sci*., 5(1): 1-7.

Geritz, S.A.H. (1995). Evolutionary stable polymorphism and small-scale spatial variation in seedling density, *Am. Nat*., 146: 685-707.

Gohar, Z.N., D. Khan and R. Ahmad. (2012). Plant size-fecundity relations in *Thespesia populnea* (L.) sol. Ex. Corr. growing under arid-saline conditions in Karachi, Pakistan. *Int. J. Biol. & Biotech*., 9(3): 161-190.

Halpern, S.L. (2005). Sources and consequences of seed size variation in *Lupinus perennis* (Fabaceae): adaptive and non-adaptive hypotheses. *Am. J. Bot*., 92(2): 205-213.

Harper, J.L. (1961). Approached to the study of plant competition. In: (Ed.): F.L. Milthorpe. *Mechanism in Biological Competition*. Soc. for Exp. Biology Symposium. 15: 1-39.

Harper, J.L., P.H. Lovell and K.G. Moore. (1970). The shape and sizes of seeds. *Ann. Rev. Ecol. & Syst*., 1: 327-356.

Imasuen, A., F. Inegbedion, C. Erhabor and M. Osuide. (2014). Isolation and characterization of castor seed oil and its utilization potential in the production of polyurethane foam. *Walailak J. Sci. & Tech*., 11 (5): 421-427.

Jain, R.K. and S. Bal (1997). Properties of pearl millet. *J, Agric. Engg, Res*., 66: 85-91.

Janzen, D. (1970). Herbivores and the number of tree species in tropical forests. *Am. Naturalist*, 104: 501-528.

Janzen, D.H. (1977). Variation in seed weight in Costa Rican *Cassia grandis* (Leguminosae). *Tropical Ecology*, 18: 177-186.

Kadambi, K. and S.N. Dabral. (1955). The silviculture of *Ricinus communis* Linn. *Indian Forester*, 81(1): 53-58.

Khan, D. (2006). Some seed and seedling characteristics (tricotyledony) of *Opuntia ficus-indica* (L.) Mill. (Cactaceae*). Int. J. Biol. & Biotech*., 3(4): 795-800.

Khan, D. and M.J. Zaki. (2012). 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. *Int. J. Biol. & Biotech*., 9(1-2): 31-50.

Khan, D. and Z.A. Sahito. (2013a). Variation in pod-and seed sizes and seed packaging cost in *Acacia stenophylla* A. Cunn. Ex. Bentham. – An Australian wattle growing in Karachi, Pakistan. *FUUAST J. Biol*., 3(1): 15-30.

Khan, D. and Z.A. Sahito. (2013 b). Maternal investment of biomass in pods, seeds and seed packaging in *Delonix regia* (Bojer) Rafin (Caesalpiniaceae). *Int. J. Biology Res*., 1(2): 105-114.

Khan, D., M. Anis and M.J. Zaki. (2011). Seed mass variation in seed lots of nine cultivars of sunflower (*Helianthus annuus* L.). *Int. J. Biol. & Biotech*., 8(2): 263-273.

Khan, D., S.S. Shaukat and M. Faheemuddin. (1984). Germination studies of certain desert plants. *Pak. J. Bot*., 16: 231-254.

Khan, D., Z.A. Sahito and M.J. Zaki. (2013). Parental investment of biomass in pod, seed and seed packaging in a tree of wiry wattle (*Acacia coriacea* subsp. *pendens*) growing in Karachi, Pakistan. *Int. J. Biol. & Biotech*., 10(4): 515-536.

Khan, D., Z.A. Sahito, M.J. Zaki and S.S. Shaukat. (2014). Axial dimensions of pods and seeds and within-pod- allocation of phytomass in *Erythrina suberosa* Roxb. (Papilionaceae). *Int. J. Biol. & Biotech*., 11(2-3): 191-206.

Krannitz, P.G. (1997). Seed weight variability of antelope bitterbrush (*Purshia tridentata*: Rosaceae). *Am. Midl. Nat*., 638: 306-321.

Labalette, F.A., A. Estarganat and A. Messean. (1996). Development of castor bean production in France. In: (Ed.): J. Janick. *Progress in New Crops*. Alexandria, ASHS Press.

Lee, T.D. and F.A. Bazzaz. (1982). Regulation of fruit and seed production in annual legume (*Cassia fasciculata*). *Ecology*, 63: 1283-1373.

Lord, J.M. and M. Westoby. (2006). Accessory costs of seed production. *Oecologia*, 150: 310-317.

Marshall, D.L. (1986). Effect of seed size on seedling success in three species of *Sesbania* (Fabaceae). *Am. J. Bot*., 73: 457-464.

Martin, A.C. (1946). The comparative internal morphology of seeds. *Am. Midland Naturalist,* 36(3): 513- 660.

Martin, G.C., K. Uriu and C.N. Nishijuma. (1980). The effect of drastic reduction of water input on mature walnut tree. *Hortic. Sci*., 15: 157-158.

Martinez, I., D. Gupta and J.R. Obeso. (2007). Allometric allocation in fruits and seed packaging conditions the conflict among selective pressures on the seed size. *Evol. Ecology*, 21: 517-533.

McGinley, M.A. (1988). Within and among plant variation in seed mass and papus size in *Tragopogon dubios*. *Can. J. Bot*., 67: 1298-1304.

McGinley, M.A., D.H. Timme and M.A. Geber. (1987). Parental investment in offspring in variable environment: theoretical and empirical considerations. *Am. Nat*., 130: 370-398.

Mehlman, D.W. (1993). Seed size and seed packaging variation in *Baptisia lanceolata* (Fabaceae). *Am. J. Bot*., 80(7): 735-742.

Méndez, M. (1997). Sources of variation in seed mass in *Arum italicum. Int. J. Plant Sci*., 158(3): 298-305.

Michaels, H.J., B. Benner, A.P. Hartgerink, T.D. Lee, S. Rice, M.F. Wilson and S. Rice. (1988). Seed size variation: magnitude, distribution and ecological correlates. *Evol. Ecol*., 2(2): 157-166.

Mohsenin, N.N. (1986). *Physical Properties of Plant and Animal Materials.: Structure, Physical Characteristics and Mechanical Properties* (II revised Edition). Gordon and Breach Science Publishers. N.Y. xvii + 891 pp.

Murali, K.S. (1997). Pattern of seed size, germination and seed viability of tropical tree species in southern India. *Biotropica*, 29: 271-279.

NCRI (2013). Castor breeding. National Cereal Research Institute, Nigeria. *Ann. Res. Rev*., pp. 203-223.

Oso, A.O., W.A. Olayemi, A.M. Bamgbose and O.F. Fowoyo. (2011). Utilization of fermented castor oil seed (*Ricinus communis* L.) meal in diets for cockerel chicks. *Arch, Zootec.*, 60(229): 75-82.

Roach, D.A. and R.D. Wulff. (1987). Maternal effects in plants. *Ann. Rev. Ecol. Syst*., 18: 209-235.

Sachaal, B.A. (1980). Reproduction capacity and seed size in *Lupinus texensis*. *Am. J. Bot*., 67: 703-709.

Saeed, S. and S.S. Shaukat. (2000). Effect of seed size on germination, emergence, growth and seedling survival of *Senna occidentalis* Link. *Pak. J. Biol. Sci*., 3(2): 292-295.

Salihu, B.Z., A.K. Ghana and B.O. Apuyor. (2012). Castor oil plant (*Ricinus communis* L.): Botany, Ecology and Uses. *Int. J. Sci. and Research* (IJSR), 3(5): 1333-1341.

Severino, L.S. and D.L. Auld. (2013). Seed abortion and the individual weight of castor seed (*Ricinus communis* L.). *Industrial Crops and Products*, 49: 890-896.

Shaheen, A.M. (2002). Morphological variation within *Ricinus communis* L. in Egypt: fruit leaf, seed and pollen. *Pak. J. Biol. Sci*., 5(11): 1202-1206.

Smith, C.C. and G.D. Fretwell. (1974). The optional balance between seed size and number of offspring. *The Ann. Naturalist*, 108: 499-506.

Stanton, M.L. (1984). Seed variation in wild radish: effect of seed size on components of seedling and adult fitness. *Ecology*, 65: 1105-1112.

Stewart, R.R. (1972). *The Annotated Catalogue of the Vascular Plants of West Pakistan and Kashmir.* Fakhri Printing Press, Karachi.

Stromberg, J.C. and D.T. Patten. (1990). Variation in seed size of a southwestern riparian tree, Arizona walnut (*Juglans major*). *Am. Midl. Nat*., 124(2): 269-276.

Thompson, J.N. and O. Pellmyr. (1989). Origins of variation in seed number and mass: interaction of sex expression and herbivory in *Lamatium salmoniflorum*. *Oecologia*, 79: 395-402.

Tíscar Oliver, P.A. and M.E. Lucas Borja. (2010). Seed mass variation, germination time and seedling performance in a population of *Pinus niger* subsp. *Salzamannii*. *Forest Systems*, 19(3): 344-353.

Totland, Q. and H.J.B. Birks. (1996). Factors influencing inter-population variation in *Ranunculus acris* seed production in an alpine area of south-western Norway. *Ecography*, 19(3): 269-278. (Doi: 10.1111/j.1600-0587.1996.tb00236.x)

Uma Shaanker, R., K.N. Ganeshaiah and K.S. Bawa. (1988). Parent-offspring conflict, sibling rivalry, and brood size patterns in plants. *Ann. Rev. Ecol. Syst*., 19: 177-205.

Underwood, A.J. (1997). *Experiments in Ecology*. Cambridge University Press, Cambridge, UK.

Upadhaya, K., H.N. Pandey and P.S. Law. (2007). The effect of seed mass on germination, seedling survival and growth in *Prunus jenkinsii* Hook. f. & Thoms. *Turk. J. Bot*., 31: 31-36.

Venable, D.L. (1992). Size-number trade-off and the variation in seed size with plant resource status. *The Am. Naturalist*, 140: 287-304.

Weis, E.A. (1991). *Castor, Sesame and Safflower*. Leonardo Hill Books. Int. Text Books Co. Ltd. London (pp 21-24).

Willson, M.F., H.J. Michaels, R.I. Bertin, B. Benner, S. Rice, T.D. Lee and A.P. Hartgerink. (1990). Intraspecific variation in seed packaging. *Am. Midl. Nat*., 123: 179-185.

Winn, A.A. (1991). Proximate and ultimate sources of within-individual variation in seed mass in *Prunella vulgaris* (Lamiaceae). *Am. J. Bot*., 78: 838-844.

Wulff, R.D. (1986). Seed size variation in *Desmodium paniculatum* I. factors affecting seed size. *J. Ecol*., 74: 87-97.

Zar, J.H. (2010). *Biostatistical Analysis*. 5th Ed. Prentice-Hall, Englewood Cliffs. New Jersey, USA.

Zhang, J. (1998). Variation and allometry of seed weight in *Aeschynomene americana*. *Annals of Botany*, 82: 843-847.

Zhang, J. and M.A. Maun. (1990). Seed size variation and its effects on seedling growth in *Agropyron psammophilum*. *Bot. Gaz*., 151: 106-113.

(Received March 2014; Accepted April 2014)