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SOME QUANTITATIVE OBSERVATIONS ON PODS AND SEEDS OF *VACHELLIA NILOTICA* (L.) P.J. HURTER & MABB.

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Abstract

The pods and seeds collected from two mature trees of *Vachellia nilotica* (L.) P.J. Hurter & Mabb. from Karachi were studied for their quantitative characteristics such as their sizes, variation in their weights, inter-seed distances, pericarp and seed yields per pod, brood size and mean single seed weight per pod, pattern of within-pod seed size distribution, mother tree – and pod-related variation of individual seed weight, seed packaging cost and seed number – seed size trade off. The results have been discussed in the context of available ecological literature.

Introduction

Angiospermic fruits typically consist of pericarp and seed (s), which collectively function to maximize plant reproductive success. Seeds are responsible for plant population regeneration in the form of seedling emergence on germination whereas the pericarp provides seed protection and aids in dispersal at times (Primack, 1987; Leishman *et al.*, 2010). The pericarp not only occupies a significant proportion of fruit biomass (e.g., Willson *et al*., 1990), it also determines the immediate physical and chemical environment of the seeds (Primack, 1987). Determining within-fruit reproductive allocation is, therefore, of importance to the understanding of seed size evolution and plant life history strategies (Chen *et al.,* 2010). Within-fruit reproductive allocation has been scarcely examined across a wide range of fruit types and taxa although it is critical to the understanding of the evolution of fruit size and seed size (Chen *et al*., 2011). Identifying reproductive allocation patterns is one of the major tasks in population biology of plants (Harper, 1977). Several studies have quantified reproductive allocation at both the fruit and seed levels (Obeso, 2004; Lord and Westoby, 2006; Martinez *et al*., 2007). Fruit size has been frequently suggested to be related to within-fruit biomass allocation between seeds and pericarp (e.g., Herrera, 1987; Willson *et al.*, 1990; Lee *et al.*, 1991; Mehlman, 1993; Celis-Diez *et al.*, 2004; Martinez *et al.*, 2007) and pattern of seed packaging costs may significantly vary among broadly ecological similar species and within species (Willson *et al.,* 1990; Chen *et al.*, 2010; Khan and Zaki, 2012).

Fig. 1. The pods of *V. nilotica*.

Table 1. Morphometric data of two V. *nilotica* mother plants

Parameter	Mother Plant A	Mother plant B
H (m)	9.14	7.62
CH (m)	5	4
CD (m) a	14.5	13
CD (m) b	12	11
SD (cm) *	63.7	47.8
BA (dm^2) **	31.85	17.94

*, Multistemic tree; H, height; CH, Canopy height; CD, Canopy Diameter ; SD, Stem diameter;
BA, Basal area; a and b, Horizontal canopy diameters at right angles.
**, Cummulative BA.

Table 2. Some edaphic properties associated with the *V. nilotica* mother plants in the campus of University of Karachi.

Mother Plants	ECe ($dS.m^{-1}$) *		pH *		Soil Texture (0-30 cm)
	Surface	Sub-surface	Surface	Subsurface	
V. nilotica (plant A)	1.10	1.85	8.89	8.65	Loam
V. nilotica (plant B)	0.96	1.60	9.0	8.60	Loamy clay

*, saturated Extract. Surface (0-15 cm); Subsurface, 15-30 cm.

Fig. 2. The seeds of *V. nilotica*. A, Normal seeds B, insect-eaten seeds. Enclosed inside the circle are the seed-boring insects - the beetle (Bruchidus sp.).

Vachellia nilotica (L.) P.J. Hurter & Mabb. is an important tropical tree species of arid regions. It is exceedingly variable species (Ali (1973). Since within-fruit reproductive allocation in our local flora has not yet been published under local environment except a publication of Khan and Zaki (2012) in a single tree fruit crop of *Cassia fistula*. The objectives of the present investigation are to study pod and seed characteristics of *Vachellia nilotica* (L.) P.J. Hurter & Mabb. with reference to the pod and seed sizes and their variation. Besides investigations on brood size, effects of within-pod position of seeds on seed size and the seed packaging cost are also undertaken. Allometric relations between the pod components and the seed number-seed size trade offs are also studied.

Materials and Methods

Climatic Peculiarities of the area: The climate of Karachi is of BWh type and bio-climate type as determined by Holdridge’s system falls in the category of Tropical Bush Formation (Qadir *et al*., 1966). The rainfall is irregular and averages below 200mm, mostly received in summer (Khan *et al*., 2006). Annual evapo-transpiration is 1750 mm (Zubenok, 1977). Summer (May-October) and winter (November-April), are two climatic extremes. Solar radiation is maximum in summer months of May and June and substantially lower in winter months (Ahmad *et. al.*, 1991).

Selection of trees and their Morphometry: Two plants of *V. nilotica* were selected in Karachi University Campus for the collection of pods. Their morphometric parameters such as height, stem diameter, canopy height, canopy diameter, etc. were recorded.

Collection of soil samples and soil analysis: The soil samples from underneath of each tree were taken from two horizons, (0-15 cm and 15-30 cm). Soil samples were analyzed for their texture, salinity status, and pH as per standard methods of USDA (1956).

Collection of pods: One hundred pods of current year growth were collected from each individual plant in February 2012. The sampling of pods was random – selecting them from all four sides of the canopy and only apparently undamaged pods were sampled. The pods were air dried in the laboratory for around sixty days.

Measurements of pods and seeds: The shape of each pod was drawn on the graph paper and seeds positions were located in each pod on graphs so that the inter-seed linear distance may be measured accurately. The seeds were weighed individually according to their position from proximal to distal portion of pod and noted on the graph besides the pod's shape diagram on the graph. An electrical balance with an accuracy of 0.1mg was used to weigh the seeds. After recovery of seeds, residual pod mass (Pericarp) was also weighed.

The healthy pods, in terms of normal seeds, from each mother plant were employed to study effect of position of seed on the seed size, seed packaging cost, seed weight variation with pods and the mother plants, mean seed availability from each pods and seed number- seed weight trade off. The pattern of distribution of seed size within pods was determined in 30 normal pods of each mother tree with the criterion that none of the pods had deformed shriveled, fungal infected or insect-eaten seeds. Mother plant-A had 56% of such pods and mother plant-B 75%. From the available healthy pods, thirty representative sample pods were selected randomly and studied for such parameters as distribution of seed-size in pods, mean seed weight of individual seed for a pod, inter-seed distance in pods, seed weight variation in normal pods, the brood size and the seed packaging cost on individual pod basis.

Seed classification: Besides separation of deformed, abortive, fungus-infected and insect-eaten seeds, the seeds were classified into various sizes as per criterion given below. The deformed and shriveled seeds or those damaged by fungi or eaten by the insects were pooled as waste seeds. Small seeds - ≤ 59.9 mg; Medium seeds – 60.0-110.9 mg; large seeds: 111—160.mg and Very large seeds - ≥ 160 mg.

Within-pod-position of seed and seed size: To investigate the seed size relations with the position of the seed within normal healthy pods, four approaches were employed. In the first approach, a pod was divided into two parts- above and below the middle seed (s) and the middle seed weight was compared with the mean weight of the seeds falling above the middle seed (s) or below the middle seed (s). In the second approach, the weight of the first proximal seed was compared with the mean of the rest seeds falling below the proximal seed until the last distal seed. The third approach was converse to the second one. The weight of the most distal seed was compared with the mean of the seeds present above the distal seeds until the most proximal seed. In the fourth approach, average weight of i^{th} seed starting from the first (proximal) seed to the ultimate (distal) seed was determined in healthy pods (usually 30) of each mother plant. To detect a pattern of the seed size distribution within pods, average weight of seeds (sequentially numbered from proximal to distal end) were plotted against the seed number for each mother plant.

Estimation of seed packaging cost: To underpin the within-pod biomass allocation, the ratio of the mass of the pericarp to the seeds was calculated. The two parameters, pericarp mass.seed^{-1} and pericarp mass.g^{-1} seeds, were considered to represent the seeds packaging cost (Mehlman, 1993; Chen *et al.*, 2010, Khan and Sahito, 2013a and b) in the healthy pods of the two mother plants.

Seed size-Seed number trade off: Allometric relations amongst the pod components and the seed size-seed number trade-off was determined by correlation and regression analysis

Statistical analysis: The location and dispersion parameters of data, wherever necessary were calculated and the frequency distributions were characterized with skewness (g1) and kurtosis (g2). Kolmogorov-Smirnov z test (KS-z test) was performed to detect normal distribution, if necessary (Sokal and Rholf, 1995). KS-z test assesses whether the observations could reasonably have come from the normal distribution. The ANOVA analysis was performed to distinguish main and interactive effects within and between the factors and compare the means. The data was analyzed on canned statistical packages such as costat, mstat and SPSS version 10 and 12.

Results and Observation

The morphometric data of the trees whose pods and seeds have been studied are given in the Table 1. Both of the trees were mature (7-9m high) with basal area ranging between 17.94 – 31.85 dm² with luxuriantly growing canopies. Texturally, the associated soil was loam to loamy clay – non- saline in nature (Table 2). One hundred pods collected from each of the tree were preserved in glass vessel and studied for various quantitative parameters. Pods were regularly constricted between the seeds with grayish pubescence (Fig. 1). They were indehiscent (schizocarpic) straight or curved and velvety. They break into mericarps without releasing seeds. The pericarp of mature pods had moisture c 58.76 ± 2.24 % and total soluble sugars c 75.45 ± 20.69 $mg.g^{-1}$ pericarp.

The Pods

Pod length: Within a crop of 100 pods the average pod length (PL) of *V. nilotica* mother plants A, and B were 12.3 ± 0.2369 and 11.72 ± 0.2663 cm, respectively (Table 3). The mean pod length of pooled sample was 12.04 ± 0.1788 cm and some 55% of the pods in composite sample had length of 10-15 cm. PL tended to be some what negatively skewed in both of the mother plants and the composite sample as well. The modal class was represented with pods of 14 cm in length (22%) in mother plant A and by pods of 13 cm length (19%) in mother plant B. The pod length in the two mother plants was thus comparable.

Pod width: The mean width of pods of mother plants A and B were 1.58 cm ± 0.0235 and 1.523 ± 0.0246 cm, respectively. The pod width ranged from 1.10 to 2.20 cm in the pooled sample (Table 3).

Pod weight: The weight of the air-dried pods of *plant* A ranged from 1.22 to 5.16g and plant B from 1.26 to 5.02g. The mean pod weight in mother plant A amounted to 3.43g ± 0.09067 and plant B 3.27 ± 0.0905g. The distribution of pod weight in both plants was negatively skewed. The frequency curve of pooled sample was platykurtic (Table 3) and negatively skewed. The pod weight varied around 28%.

Pod-size comparison: The pods collected from the two mother plants were similar in their linear dimensions and weight as the comparison of pod size parameters by the paired t-test indicated no significant difference in pod size amongst the mother plants (Table 4).

Relationship of pod weight with pod length and pod width: The three parameters of pod viz. the pod length, pod width and the pod weight related significantly with each other linearly positively. The pod weight related with pod length and width equally in significant fashion (Table 5). The predictive multiple regression equation pertaining to pod weight relationship with pod length and width is given in Fig. 3. The explanatory power of this multiple regression equation was, however, some what low (Fig. 3). The quadratic surface plot in Fig. 3 and zero order and partial correlations associated with multiple regression equation indicated that pod weight was more controlled by the pod length as compared to the pod width.

The Seeds

The seeds of *V. nilotica* are blackish brown in color, smooth, sub-circular, and compressed (Fig.2). They are attacked by bruchids.

Seed Classification: Fig. 4 depicts the seed size grading and the proportion of waste seeds of *V. nilotica* mother plants A and B. From the crop of 100 pods of mother plant-A, some 1060 seeds were recovered of which the predominating class was composed of large seeds (51%). From mother plant-B 100 pods yielded 1003 seeds in which large seeds occupied a proportion of 62%. The percentage of waste seeds was around 12 % in mother tree -A and 6% in mother tree-B. Pod based inter-tree similarity as per Czekanowski (1913) index was 93.06% between the two mother trees. In composite sample of 2063 seeds, there were 9% waste seeds, 9% small seeds, 24% medium-sized seeds and 56% large-sized seeds (Fig.5).

Seed / mericarp ratio: The seed / mericarp ratio for normal seeds recovered, as calculated in the composite sample of pods (N=200), was 0.91 i.e. 91 % of the mericarps (seed chambers) in pods had developed seeds.

Brood size (all-types of pods inclusive): Following Uma Shaanker *et al.* (1988), brood size was here represented as the number of healthy seeds recovered from a pod. The mean brood size in *V. nilotica* averaged to 9.39 ± 0.22 seeds per pod varying around 32.48% (Fig. 6). Brood size distribution tended to be negatively skewed.

Seed weight distribution in all pods studied: Seed weight distribution of normal seeds recovered from 100 pods of each mother plants of *V. nilotica* and their composite sample is depicted in Table 3 for 936, 942 and 1878 seeds, respectively. The seed weight averaged to 112.71 ±1.217 mg in plant A with maximum / minimum variation around 51-folds and 111.89 ± 1.389 mg in plant B with 40-fold variation in mass. In both plants, the distribution was negatively skewed and varied 33.5 and 31.24%, respectively. The pooled sample also distributed asymmetrically with mean weight of individual seed to be 112.30 ± 0.833 mg and varying 32.14% (ranging from 4.70 to 240 mg; 51 – fold variation).

Variation of mean seed weight (MSW) in a pod around the grand mean value of seed weight: The average mass of a seed in healthy pods of two *Vachellia* mother plants around the grand mean is presented in Fig. 7, The distribution of mean seed mass was asymmetric (positively skewed) around the grand mean of 0.123 ± 0.0019 and 0.125 ± 0.0015 g, respectively.

Brood- and seed- size in healthy pods: Within a crop of sixty healthy pods of *V. nilotica*, the brood size (Mean: 11.233 ± 0.2953) was larger than that in all pods studied (N = 200) – brood size: 9.39 ± 0.22 ($t = 5.01$, $p < 0.0001$). Brood size healthy pods varied symmetrically around the mean (CV: 20.36%) (Table 3).

The seed weight of seeds recovered from healthy pods of *Vachellia* (composite sample) distributed asymmetrically (negatively skewed with mean of 123.58 ± 1.189 mg. The magnitude of mean seed weight was higher in healthy pods than that of the all type inclusive pods of *Vachellia* (Table 3). The mean weight of individual seed in normal healthy pods was higher (123.54 ± 1.189 mg) than the mean weight of individual seed for all types of pods (112.301 ± 0.834 mg) ($t = 7.78$, $p < 0.001$).

Inter-seed distances: The frequency distribution of inter-seed distances as measured in healthy pods of the species is represented in Fig. 10. For 636 observations, the inter-seed distance averaged to 1.054 ± 0.0095 cm ranging from 0.30 to 2.30 cm (CV: 22.68%). The distribution was asymmetrical and highly leptokurtic (kurtosis = 3.284; KS-z = 4.908, $p < 0.0001$). It appears that inter-seed distance was quite consistent in this species. In nearly 400 instances (62.89%) the inter-seed distance ranged from 0.9 to 1.10 cm. The 7.67-fold variation in inter-seed distance may be due to complex of reasons including environmental perturbations during the pod development.

Distribution pattern of seed size within pods (positional effect): To investigate within-pod positional effect on the seed size, four approaches were employed

1) Comparison of weight of the first proximal seed with the mean weight of the rest of the seeds in the pod.

2) Comparison of the weight of the last (distal seed) with the mean weight of the seeds lying above the distal seeds.

3) Comparison of the weight of middle seed (s) of the pod with the mean weights of seeds lying proximally or distally.

4) The mean seed weight of each seed in healthy pods was determined sequentially from proximal to distal seed.

It is interesting to note that in composite samples of healthy pods the frequency of proximal seed was lesser in weight than the mean weight of the rest seeds was significantly higher as compared to the frequency of proximal seed weight to be higher than the mean of the seeds towards distal end (Table 6).

The comparison of weight of distal seed with the mean weight of seeds above the distal seeds presented no clear cut picture at least in the composite samples, although there were considerable events of occurring larger distal seed at least in some pods of mother plant –A.

As regards to the third approach, no clear cut pattern emerged except that the middle seed was significantly heavier than mean weight of the upper seeds as indicated by pair comparison t-test analysis in case of mother plant-A ($t = 3.155$, $p < 0.004$) (Table 6*).* In mother plant-B, mean weight of the upper seeds was significantly larger than the mean weight of the seeds below the middle seeds ($t = 2.28$, $p < 0.030$). Other pairs for comparison were insignificant (Table 7).

Table 3. Location and dispersion parameters of dimensions of pod and their brood size and seed weight of Vachellia *nilotica* subsp. *indica*.

Parameter	N	Mean	SE	Median	CV (%)	g1	Sg1	g2	Sg2	Min.	Max.	KS-z	Curve
Pod Length (cm)													
PL A (cm)	100	12.31	0.237	12.75	19.35	-0.529	0.241	0.132	0.478	6.0	18.00	1.154 (p < 0.140)	S
PL B	100	11.77	0.266	12.20	22.72	-0.342	0.241	-0.229	0.478	5.0	18.60	0.976 (p< 0.296)	S
PL (pooled)	200	12.04	0.179	12.50	20.99	-0.448	0.172	-0.084	0.342	5.0	18.60	1.529 (p< 0.019)	AS
Pod width (cm)													
PWD A	100	1.576	0.0235	1.60	14.93	0.067	0.241	-0.384	0.478	1.10	2.20	1.306 (p < 0.066)	S
PWD B	100	1.523	0.0246	1.50	17.14	0.748	0.241	-0.154	0.478	1.10	2.20	2.072 (p < 0.0001)	AS
PWD (pooled)	200	1.548	0.0171	1.50	15.64	0.172	0.172	-0.045	0.342	1.10	2.20	1.910 (p < 0.0001)	AS
Pod weight (g)													
PW A	100	3.425	0.0969	3.538	21.31	-0.306	0.241	-0.709	0.478	1.215	5.159	0.923 (p< 0.388)	S
PW B	100	3.266	0.0904	32.34	27.74	-0.280	0.241	-0.521	0.478	1.262	5.0216	0.637 (p< 0.812)	S
PW (pooled)	200	3.345	0.0664	3.473	28.06	-0.272	0.172	-0.636	0.342	1.215	5.159	0.841 (p< 0.478)	S
Brood (BR) size (all pods studied)													
BR A	100	9.28	0.313	10.0	33.87	-0.799	0.241	0.512	0.478	Zero	15	1.461 (p < 0.028)	AS
BR B	100	9.36	0.321	9.0	34.48	-0.443	0.241	-0.109	0.478	1	15	1.012 (p< 0.257)	S
BR (pooled)	200	9.39	0.220	10.0	32.48	-0.614	0.172	0.102	0.342	zero	15	1.546 (p < 0.017)	AS
Brood size (BRH) healthy pods													
BRH A	30	10.43	0.403	10.0	21.46	0.064	0.427	-0.521	0.833	6	15	0.786 (p < 0.568)	S
BRH B	30	12.03	0.379	12.6	17.25	-0.816	0.427	0.159	0.833	7	15	0.980 (p < 0.290)	S
BRH (pooled)	60	11.23	0.295	11.5	20.36	-0.332	0.309	-0.715	0.608	6	15	1.017(p < 0.25)	S
Single seed weight – All pods studied (mg)													
SSW A	936	112.71	1.217	120.70	33.05	-0.589	0.080	-1.400	0.160	4.70	240.0	2.648 (p< 0.0001)	AS
SSW B	942	111.90	1.139	121.25	31.24	-0.979	0.080	0.405	0.159	6.80	188.7	4.142(p< 0.0001)	AS
SSW (pooled)	1878	112.36	0.831	121.10	32.07	-0.758	0.056	0.099	0.113	4.70	240.0	4.626 (p< 0.0001)	AS
Single seed weight – 30 Healthy pods (mg)													
SSWH A	313	122.49	0.192	130.0	27.70	-1.173	0.138	1.311	0.275	8.1	180.4	2.015 (p< 0.001)	AS
SSWH B	361	124.53	0.147	128.7	22.45	-1.258	0.128	2.457	0.256	11.4	188.7	2.387 (p< 0.0001)	AS
SSWH (pooled)	674	123.58	1.189	129.7	24.98	-1.238	0.094	1.900	0.188	8.10	188.70	3.145 (p< 0.0001)	AS
Pericarp weight per pod (g) – Healthy pods													
Pericarp A	30	2.124	0.182	2.301	46.82	-0.489	0.427	-0.653	0.833	0.1756	3.6989	0.687 (p< 0.733)	S
Pericarp B	30	2.416	0.106	2.301	23.93	-1.704	0.727	4.272	0.833	0.3803	3.3321	0.887 (p< 0.411)	S
pericarp pooled	60	2.270	0.106	2.514	36.12	-0.920	0.309	0.516	0.608	0.1756	3.6989	1.088 (p < 0.187)	S
Seed weight per pod (g) – Healthy pods													
SW / pod A	30	1.3493	0.0699	1.276	28.40	0.250	0.427	-0.586	0.833	0.6291	2.0761	0.586 (p< 0.882)	S
SW / pod B	30	1.5018	0.0641	1.568	23.39	-0.195	0.727	-0.849	0.833	0.7830	2.1179	0.678 (p< 0.748)	S
SW /pod pooled	60	1.4256	0.0480	1.375	26.13	0.002	0.309	-0.840	0.608	0.6291	2.1179	0.552 (p< 0.921)	S

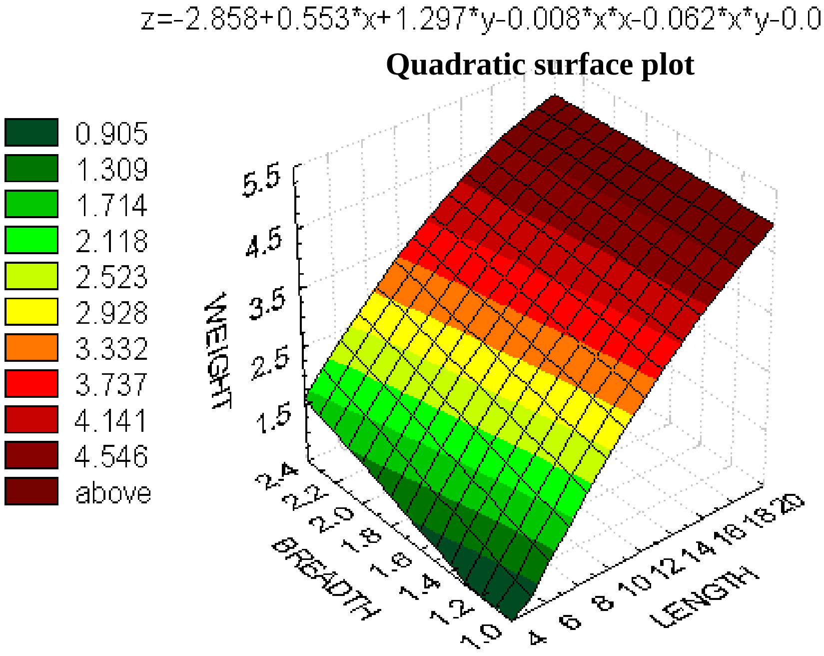
A, mother plant A and **B**, mother plant B. **PL**, pod length (cm); **PWD** pod width (cm); **PW**, pod weight (g); **BR**, Brood (total pods); **BRH**, Brood size healthy pods; **SSW**, single seed weight (mg); **SSWH**, Single seed weight Healthy pods (mg); **SW**, total seed weight per pod; g1, skewness; g2: kurtosis; **, as per Kolmogorov-Smirnov–z test (KS-z). St. Error for skewness (Sg_1) =$\sqrt{}$ 6N (N-1) / (N-2) (N+1) (N+3); St. Error for kurtosis (Sg_2) = $\sqrt{}$ 24N (N-1)2 / (N-3) (N-2) (N+3) (N+5); **S**, symmetrical; **AS**, asymmetrical.

Table 4. Paired samples Test (pod dimensions compared in plants between mother plants of *V. nilotica*.

Pairs of Characters (Mother plant A –Mother plant B)	Paired Differences					t	df	p Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pod Length (cm)	0.5330	3.5101	0.3510	-0.1635	1.2295	1.518	99	0.132
Pod Width (cm)	0.0530	0.3135	0.03135	-0.0092	0.1152	1.691	99	0.094
Pod Weight (g)	0.159485	1.30085	0.130085	-0.0986	0.4176	1.226	99	0.223

Table 5. Simple linear correlation coefficients (r) amongst three pod characteristics [PL(pod length), PWD(pod width), and PW (pod weight)] in the pooled samples.

Species	PL vs. PWD	PW vs. PL	PW vs. PWD
Vachellia nilotica (N = 200)	0.395	0.620	0.633

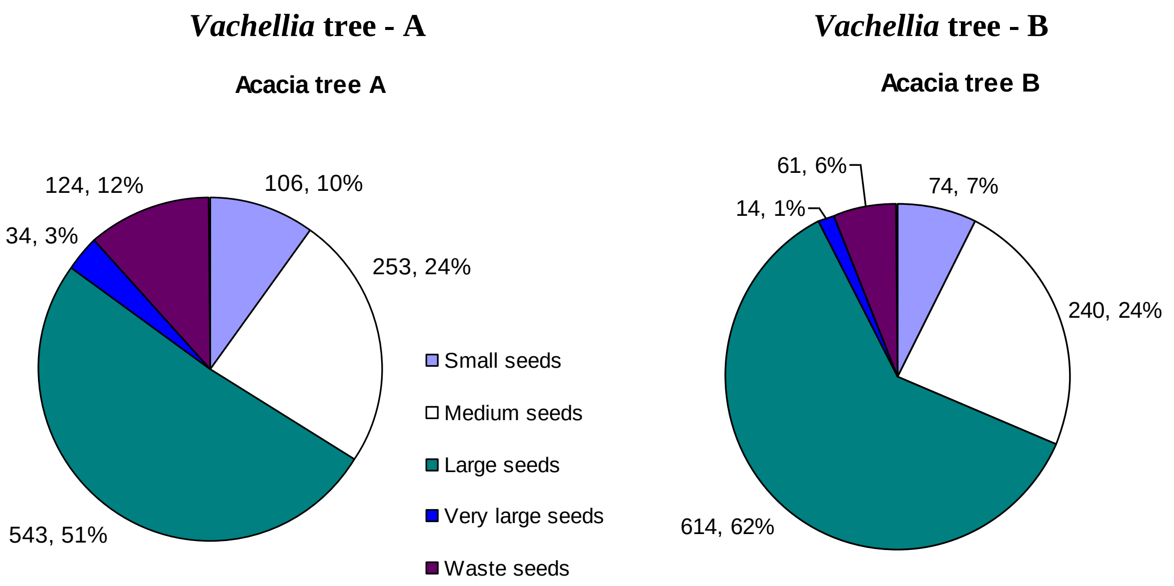


Multiple linear regression equation:

PW = -0.595 + 0.0268 PL + 0.459 PWD ± 01.624
t = -1.8 t = 15.2 t = 2.5
$p < 0.075$ $p < 0.0001$ $p < 0.014$
R = 0.7503, R^2 = 0.563, adj. R^2= 0.558,
F = 126.66 ($p < 0.0001$)

	PL	PWD
Zero order Correlation:	0.741	0.230
Partial Correlation:	0.734	0.117

Fig. 3. *Vachellia nilotica*: Quadratic surface plot of pod weight (g) with pod length (cm) and pod width (cm). N = 200.



POD-BASED INTER-TREE SIMILARITY: 93.06%

Fig. 4. The magnitude and percentage proportion of the seed types recovered from 100 pods each of two *Vachellia nilotica* plants (A and B). Key to the seed classification: Small seeds, 0 - ≤ 60 mg; Medium seeds, > 60 mg - ≤ 110 mg; large seeds, > 110 - ≤ 160 mg and very large seeds, > 160 mg.

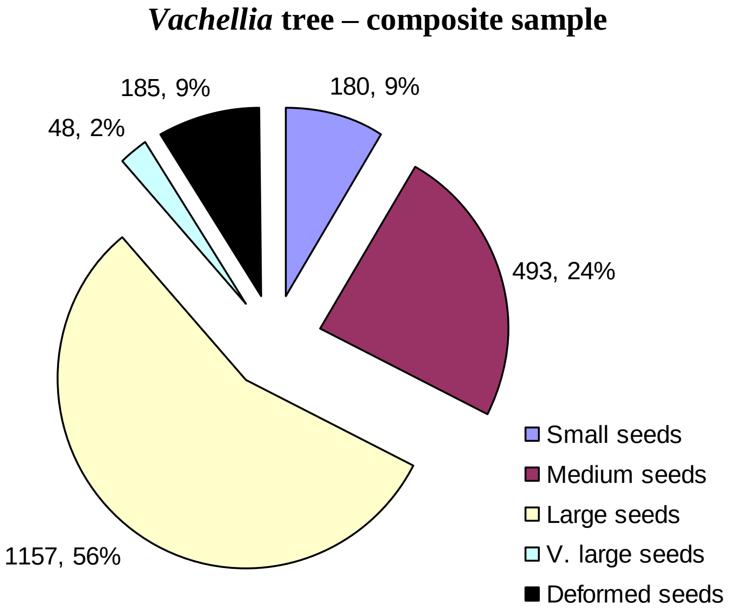


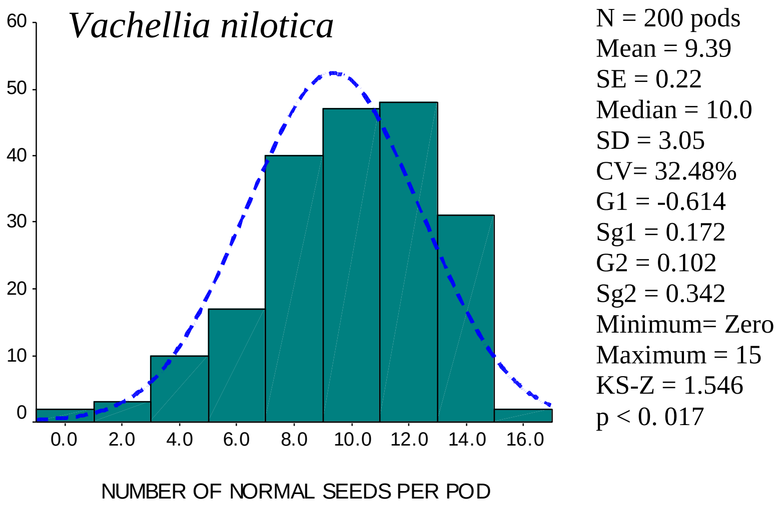
Fig. 5. Seed classification in composite sample of 200 pods of *V. nilotica* collected from two plants.

The maximum number of seeds in any healthy pods was 15. The fourth approach to investigate the pattern of within-pod seed size distribution indicated that the weight of the first seed (proximal seed) was quite lesser in magnitude than that of the subsequent seeds. The proximal seed weighed 115.94 ± 0.00422 mg which was substantially lower than that of any subsequent seeds (number II to XV) by a quantum of c 10mg. All seeds (I to XV) varied in weight in moderate magnitude (12.4 to 28.3 %) (Fig. 11).

Variation in pod and seed characteristics between and within mother plants: The pod characteristics such a pod length, pod width, pod weight, pericarp weight, seed yield per pod and brood size (number of seeds per pod) and mean weight of individual seed in a pod in *V. nilotica* were found to vary insignificantly between the mother trees but highly significantly within the mother plants (between tree component variance explained amounted to 1.42 to 12.44 % and within tree component variance explained was from 87.56 to 99.91 %) as indicated by one-way ANOVA (Table 8).

Variation in seed weight influenced by mother plants and pod: Two-way ANOVA for seed weight data (Table 9) indicated that effects of both the mother trees and the pods were significant on the variation in weight of individual seeds. The mother tree and the pod interacted significantly ($p < 0.0001$). The results highlighted the role and significance of genetics and the ecological history of the mother tree as well as the developmental and the environmental history of the pods.

Seed packaging costs: The seed packaging costs in the pods, in the present studies, were evaluated as SPC_1 = pericarp mass.g^{-1}seed or SPC_2 = pericarp mass.seed^{-1}. SPC_1, averaged to 1.7398 ± 0.1722 in mother plant –A and 1.7107 ± 0.1721 in mother plant B. It distributed normally in both trees but varied quite substantially (54.2 and 36.3 %, respectively in the two mother plants. SPC_2 was 0.2011 and 0.2081g in the two trees, respectively (Fig.12).



N = 200 pods
Mean = 9.39
SE = 0.22
Median = 10.0
SD = 3.05
CV= 32.48%
G1 = -0.614
Sg1 = 0.172
G2 = 0.102
Sg2 = 0.342
Minimum= Zero
Maximum = 15
KS-Z = 1.546
p < 0. 017

Fig. 6. Distribution of number of normal seeds per pod amongst the pods (N = 200) of *V. nilotica*.

Table 6. The comparison of first (proximal) seed mass with the average mass of the rest (lower) seeds in the pods.

Parameter	*V. nilotica*			
	Proximal to lower		*Distal to upper*	
	Plant A N = 30	Plant B N =30	Plant A N = 30	Plant B N =30
NE (%)	3.33	3.33	2.67	16.66
H (%)	36.66	46.66	5333	40.00
L (%)	60	50	40.0	43.33
Composite Sample N = 60				
NE (%)	3.33 ± 0.0		11.67 ± 5.0 a	
H (%)	41.67 ± 5.0		46.67 ± 6.67 b	
L (%)	55.0 ± 5.0		41.67 ± 1.67 b	

Key to the acronyms (Proximal to lower): NE, the first (proximal) seed is near equal in mass to the mean mass of the rest seeds in the pod. **H**, the first proximal seed's mass is higher in magnitude than the mean mass of the rest seeds. **L**, The first proximal seed mass is lesser in magnitude than the mean mass of the rest of the seeds. Dissimilar letter following figure indicates the significant difference at $p < 0.05$ as given by t-test. **Key to the acronyms (Distal to upper): NE**, the last (distal) seed is near equal in mass to the mean mass of the rest (upper) seeds in the pod. **H**, the last (distal) seed's mass is higher in magnitude than the mean mass of the rest (upper) seeds. **L**, The mass of the last seed is lesser in magnitude than the mean mass of the rest of the seeds. Dissimilar letter following figure indicates the significant difference at $p < 0.05$ as given by t-test.

Variation in seed packaging costs between and within mother plants: One-way ANOVA of The SPC data, however, indicated that SPC expressed as g.pericarp.g^{-1} seed or g pericarp.seed^{-1} didn't vary significantly between the mother trees (Table 10). The component variance explained between trees for was very low (0.081 and 0.129%) in this species and within tree component variance explained for was very high around 99% (Table11).

Seed size–seed number trade off: Seed size-seed number trade off was evaluated in healthy pods as the relationship between mean weight of individual seed for a pod (MSW) and the number of seeds per pod (NS, brood size). There was significant ($p < 0.0001$) trade off in pods of *V. nilotica* which was defined curvilinearly (Fig. 13). The given regression equation had an explanatory power of 30%.

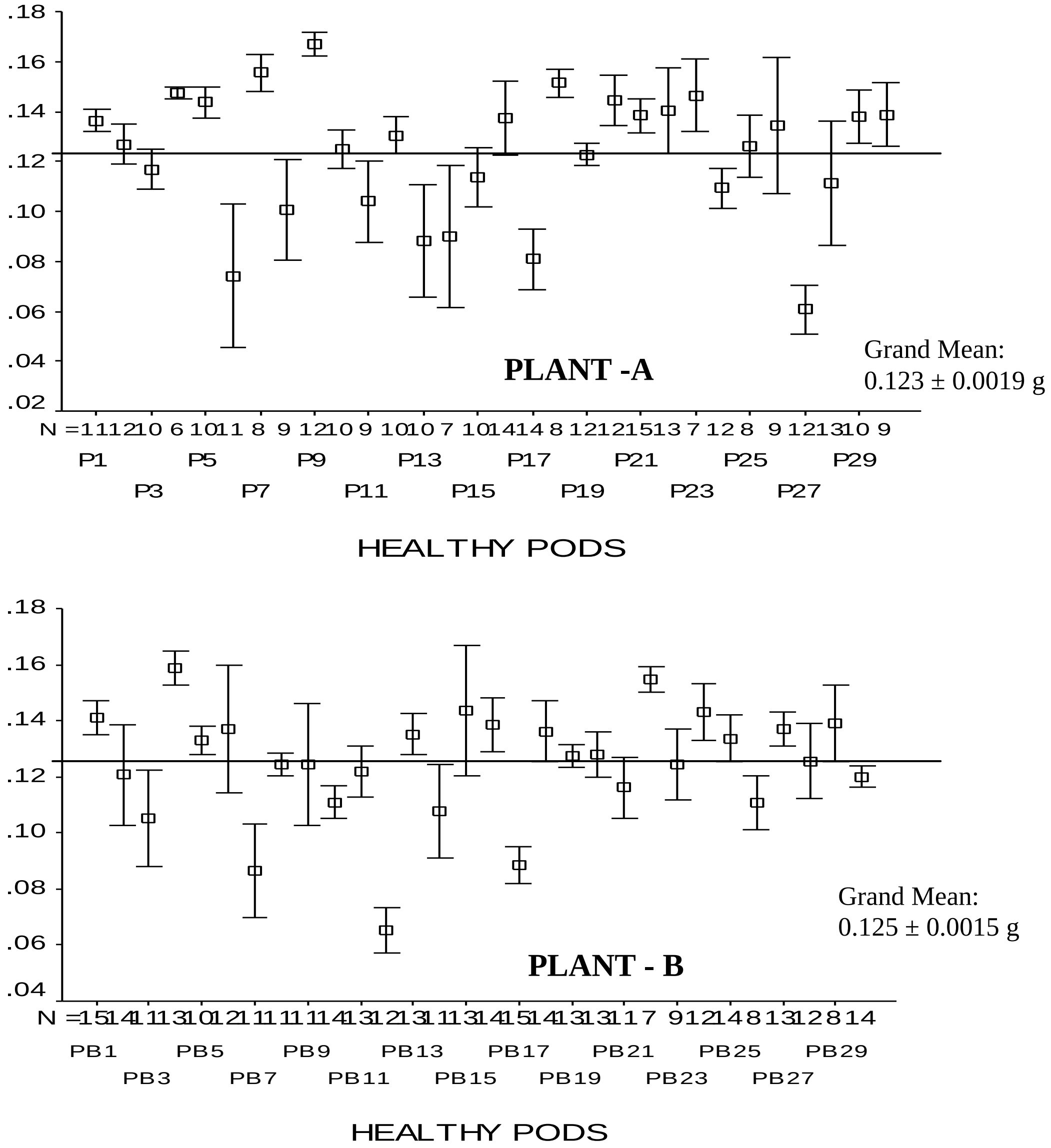


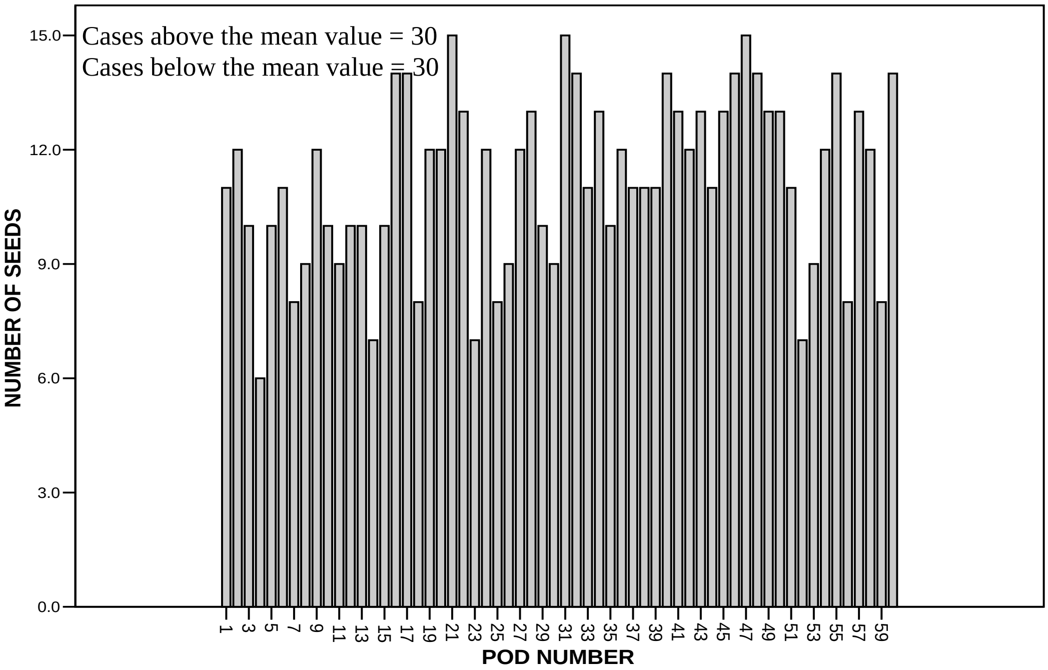
Fig. 7. Variation in mean weight of seed for pod in 30 healthy pods of *V. nilotica* plants A and B. P, pods of plant A (1-30) and PB, pods of plant B (1-30). Solid line represents the grand mean.

Discussion

Our studies indicated that the pod characteristics (pod length, pod width, pod weight, pericarp weight, seed yield per pod, brood size and mean weight of individual seed in a pod) varied insignificantly between the mother trees but highly significantly within the mother plants (between tree component variance explained for these traits was 1.42 to 12.44 % and within tree component variance explained for from 87.56 to 99.91 %) as indicated by one-way ANOVA. The Two-way ANOVA for seed weight data indicated that effects of both the mother trees and the individual pods on individual seed weight were significant. The results highlighted the significant role of genetics and the ecological history of the mother trees as well as the differential variation of developmental and the environmental history of the pods.

Table 7. Comparison of mean weights of middle seed (s), seeds above middle seeds and the seeds below the middle seeds in pods of the *V. nilotica* through paired sample t-test.

Pairs for Comparison		Paired Differences			Significance		
		Mean	Std. Deviation	Std. Error	t	df	p
Mother plant (A)	Upper –middle	-.0079067	.0137278	.0025063	-3.155	29	.004
	Middle-lower	.0053833	.0300556	.0054874	.981	29	.335
	Upper-lower	-.0025233	.0272588	.0049768	-.507	29	.616
Mother plant (B)	Upper-Middle	-.0051613	.0149152	.0027231	-1.895	29	.068
	Middle-lower	.0068403	.0301736	.0055089	1.242	29	.224
	Upper - lower	.0120017	.0288676	.0052705	2.277	29	.030



Mean: 11.236 ± 0.2953; Median: 11.50; CV(%): 20.36; g1: -0.332; Sg1: 0.309; g2: -0.715; Sg2: 0.608; Min: 6; Max: 15, KS-z: 1.017 (p < 0.00001).

Fig. 8. Number of seeds per pod in 60 healthy pods of *Vachellia nilotica*.

Table 8. One way ANOVA for pods and seeds characteristics in healthy pods of *V. nilotica* (30 pods each for the two mother plants).

Characteristics	MS (Trees)	F	p	Variance Explained (%)	
				Between	Within
PL	9.0171267	2.5511	0.1157 (NS)	4.21	95.79
PWD	0.0426666	0.8329	0.3652 INS)	1.42	98.58
PW	2.868106	4.0045	0.0502 (NS)	6.45	93.55
Pericarp	1.078057	1.5586	0.2169 (NS)	2.62	97.38
SW(per pod)	0.2691163	1.9643	0.1664 (NS)	3.28	96.72
SN	38.40000	8.2387	0.0057 (**)	12.44	87.56
MSW	0.0371309	1.3986	0.2418 (NS)	2.36	97.45

Acronyms: PL, Pod Length,; PWD, Pod width; PW, pod weight; pericarp, Pericarp weight per pod; SW, Seed weight per pod; SN, Number of seeds per pod; MSW, Mean weight of individual seed in a pod.

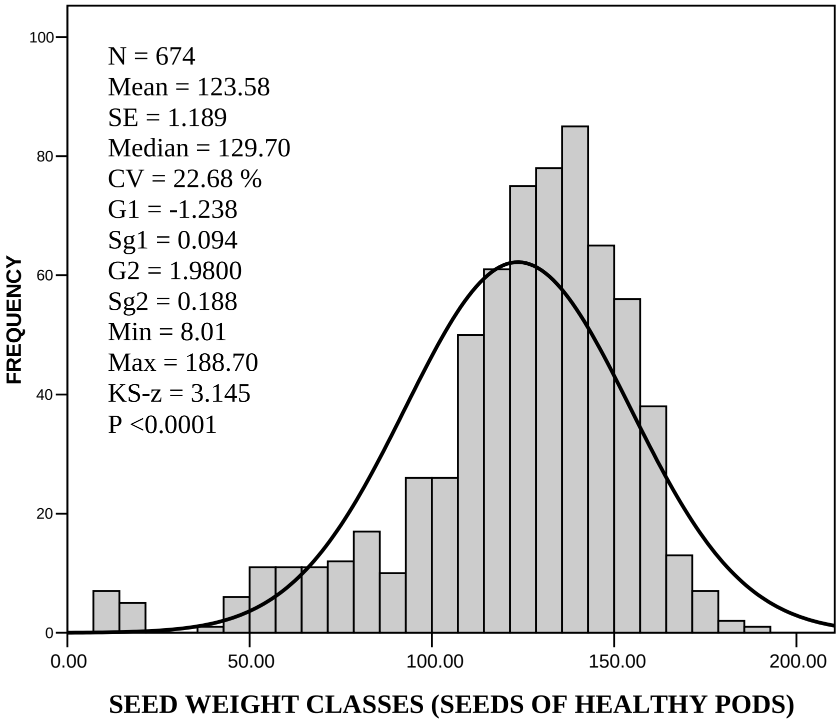


Fig. 9. Seed weight (mg) distribution of seeds recovered from 60 healthy pods collected from sample mother plant A and B of *Vachellia nilotica*.

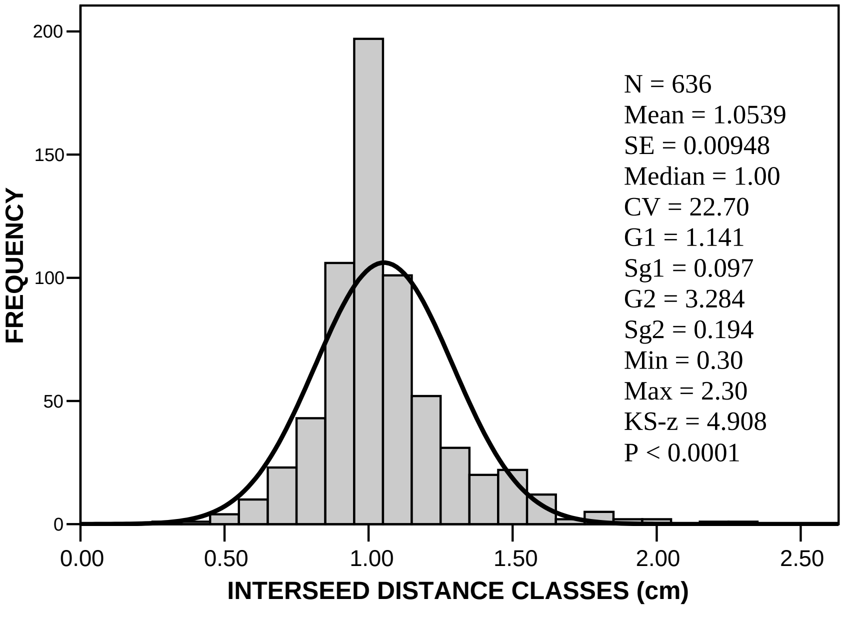


Fig. 10. *V. nilotica*. Distribution of inter-seed distances in pooled sample of 60 normal pods from two mother plants.

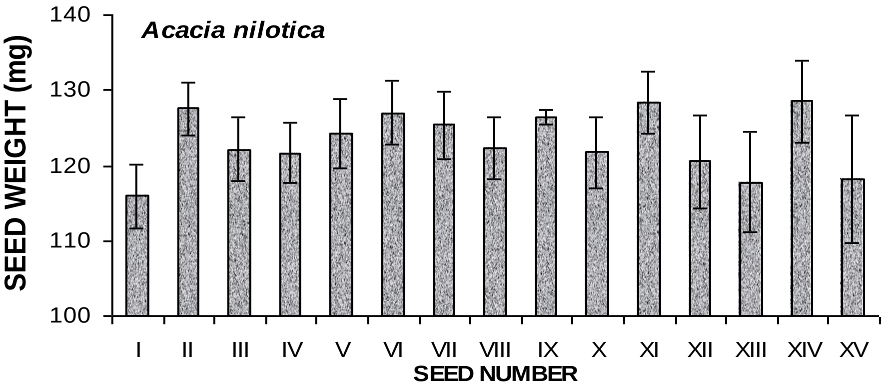


Figure 11. Mean weight for individual seeds for specific position in pod sequentially from proximal to distal end in healthy pods of *V. nilotica*.

Table 9. Two- way analysis of variance of mass data of seeds recovered from 30 healthy pods from two mother plants of *V. nilotica*.

Source	SS	df	MS	F	p
Main effects					
Mother plant	0.04662307	1	0.04662307	14.662	0.00001
Pods	0.24077779	29	0.00830268	2.6110	0.00001
Interaction					
Mother plant x pods	0.2778789	29	0.00958203	3.8335	0.00001
Error	2.6710783	840	0.00317986		
Total	3.2363581	899			

Table 10. Comparison through the Paired Samples Test of seed packaging costs (SPC) in *V. nilotica*.

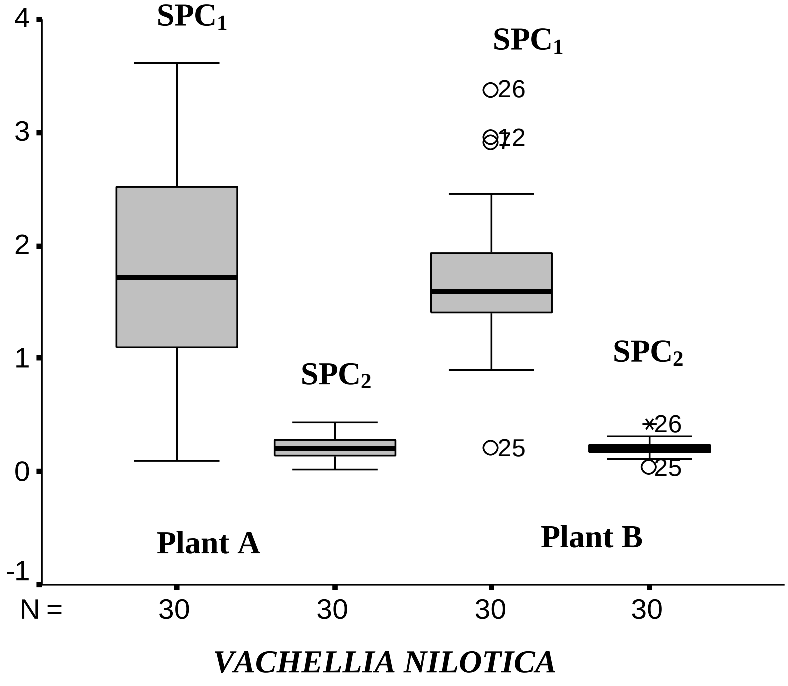
Pairs of Parameters (Mother plant A – Mother plant B)	Paired Differences			t	df	Sig. (2-tailed)
	Mean	SD	SE Mean			
$SPC_1A – SPC_1B$	.029078	1.06359	0.19418	.150	29	0.882 (NS)
SPC_2A - SPC_2 B	-.002903	.105943	0.01934	-.150	29	0.882 (NS)

Acronyms: SPC_1, seed packaging cost expressed as g per g seed; SPC_2, as g per seed.

The pods *V. nilotica* are attacked by fungi and insects. In a composite sample of 2063 seeds of *Vachellia*, there were 9% waste seeds, 9% small seeds, 24% medium-sized seeds and 56% large-sized seeds. It follows from the data that substantial number of seeds are wasted due to various random reasons.

The weight of the individual seed inclusive all seed types averaged to 112.71 ± 1.22 mg in mother plant A with maximum / minimum variation around 51-fold and 111.89 ± 1.39 mg in mother plant B with 40-fold variation in mass. In both plants, the distribution was negatively skewed and varied 33.5 and 31.24%, respectively. The pooled sample also distributed asymmetrically with mean weight of individual seed 112.30 ± 0.833 mg and varying 32.14% (ranging from 4.70 to 240 mg). Shaukat *et al* (1999) have reported individual seed weight for a lot of only 200 seeds of A. nilotica subsp. indica (*V. nilotica subsp. indica*) from Gharo (district Thatta, Sindh), to be 0.1774 ± 0.002g.

Earlier, the seed mass was considered to be the least plastic character (Harper, 1970). There are, however, reports of seed weight variation in several tropical species (Janzen, 1977; Foster and Janson, 1985; Khan *et al.*, 1984; Khan *et al.* 1999, 2002; Khan and Umashanjkar, 2001; Murali, 1997; Marshall, 1986; Upadhaya *et al.*, 2007, Khan *et al.*, 2011). Seed weight variations within a species and an individual (Halpern, 2005) and even within a fruit of an individual as recorded in this study are common. Seed weight variation in plants may be many-fold in magnitude (Zhang and Maun, 1990). Schaal (1980) found 5.6 fold variation among 659 seeds collected from a population of *Lupinus texensis*. The seeds of *Prosopis juliflora* varied in weight by 16.83% (Khan *et al.* (1984) and that of *Opuntia ficus-indica* c. 18.2% (Khan, 2006). Michaels *et al.* (1988) have examined 39 species (46 populations) of plants in eastern-central Illinois and reported variability (in terms of coefficient of variation) of seed mass commonly exceeding 20% - significant variation being among the conspecific plants in most species sampled. Seed weight variation in sage brush is reported to lie between 26.31 and 31.75% amongst the sites and years of study, respectively (Busso and Perryman (2005). Seed weight is highly variable in *Alliaria petiolata* (8-fold among populations, 2.5 – 7.5-folds within population, two-three folds within individuals and 1.4 – 1.8 folds within fruits (Susko and Lovett-Doust, 2000). Halpern (2005) reported seed mass in 5839 seeds of 59 maternal plants of *Lupinus perennis* to be highly variable (5-fold variation). Seed weight variation in *Thespesia populnea* is reported to be around 27% (Gohar *et al.,* 2012). Sixteen-fold variation in seed mass is reported in *Lamatium salmoniflorum* (Thompson and Pellmyr, 1989).



MOTHER PLANT A		MOTHER PLANT B	
SPC_1	SPC_2	SPC_1	SPC_2
Mean = 1.7398	Mean = 0.2011	Mean = 1.7107	Mean= 0.2081
SE= 0.17219	SE=0. 01961	SE=0.17219	SE=0.12215
Q2= 1.722	Q2= 0.20837	Q2 = 1.5862	Q2= 0.20098
SD= 0.943114	SD= 0. 10411	SD = 0.62102	SD= 0. 10411
CV = 54.21%	CV = 51.77%	CV = 36.30	CV = 50.02%
G1= -0.009	G1= -0.388	G1= 0.681	G1=0.497
Sg1 = 0.427	Sg1 = 0.427	Sg1 = 0.427	Sg1 = 0.427
G2= -0.779	G2= 0.453	G2= 1.868	G2= 3.676
Sg2 = 0.833	Sg2 = 0.833	Sg2 = 0.833	Sg2 = 0.833
.Min. = 0.0912	Min.= 0.0176	Min = 0.2033	Min. = 0.0272
Max. = 3.6202	Max. = 0.4283	Max. = 3.3743	Max. = 0.4165
KS-z = 0.416	KS-z = 0.469	KS-z= 0.943	KS-Z= 0.866
P < 0.995	P < 0.980	P < 0.337	P < 0.441

Fig. 12. Distribution of seed Packaging costs in *Vachellia nilotica* mother plants A and B. SPC_1 and SPC_2, seed packaging costs expressed as g per g seed and as g per seed, respectively.

Seed size variation may be the result of many factors (Fenner, 1985; Wulff, 1986; Mendez, 1997). Winn (1991) has suggested that plants may not have the capability of producing a completely uniform seed weight simply as a result of variation 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 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 (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). Seed weight has also been reported to be the function of plant height in a population of *Ranunculus acris* (Totland and Birks, 1996). Different shrubs of *Purshia tridentata* (Rosaceae) are reported to produce seeds of different mean weights as did different sites (Krannitz, 1997). Most of the variation in seed weight was attributable to variation within individual shrubs (63.2%) where different shrubs accounted for variation by 29% (Krannitz (1997). Howe and Richter (1982), however, demonstrated variation in seed size among plants to be more than the variation within plants in case of *Virola surinamensis*. Variation of seeds in a tropical plant, *Pithecellobium pedicellare*, was almost similar to that in *Virola* (Kang *et. al.,* 1992). In contrast *to P. pedicellare* and *V. surinamensis,* the studies conducted intemperate zone had shown variation in seed size within plants to be greater than among plants (Schaal, 1980; Thompson, 1984; Mazer *et al.,* 1986; Mc Ginley *et. al.,* 1990). O'Malle and Bawa (1987) found variation in seed size within and among plants to be more or less in equal magnitude. It is therefore likely that variation in seed weight is affected by maternal genetics and environmental effects both. Of course, it is difficult to weigh the relative importance of the two groups of factors. The plasticity in seed weight may be regulated by internal and external environment of mother plants (Krannitz, 1997). Obviously the seeds collected from the plants might be a mixture of half sibs and full sibs instead of strict half sibs. Seed weight variation in plants thus appears universal which may be due to trade-off of resource allocation between seed size and number (Venable, 1992) or environmental heterogeneity (Janzen, 1977) or the genetic reasons. Alonso-Blanco *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. Low magnitude of between-trees-component of variance and high within trees component variance in seed size indicate strong canalization of this character in *V. nilotica*. Each tree has, however, registered the environmental variation within trees pod crops of *V. nilotica*.

Table 11. One way ANOVA for seed packaging costs.

Characteristics	MS (Mother Trees)	F	p	Variance Explained (%)	
				Between	Within
SPC_1	0.0003119	0.00047	0.9828 (NS)	0.081	99.81
SPC_2	0.0000536	0.00750	0.9313 (NS)	0.129	99.98

Seed weight distribution in *V. nilotica* was found to be asymmetrical (negatively skewed). All types of seed weight distributions (negatively skewed, positively skewed and normal distribution) have been reported in literature. Seed weight distribution was found to be normal in six sunflower cultivars viz. S-278, local, Hysun 39, Hysun 33, Aussie gold 61 and Aussie gold 04 and Non-normal in NK Armoni, Hybrid 1, Aussie gold 61 and the pooled sample of all cultivars (Khan *et al.,* 2011). Seed mass was also reported to be normally distributed in *Blutapason portulacoides* and *Panicum recemosum* but not in case of *Spartina ciliata* (Cardazzo, 2002). Halpern (2005) reported normal distribution of seed mass in *Lupinus perennis*. Zhang (1998) has reported seed mass variation in *Aeschynomene americana* by weighing 150 seeds from each of its 72 populations to be normally distributed in 9, positively skewed significantly ($p < 0.05$) in 14 and negatively skewed in 49 populations. The mass of mature seeds had a normal distribution in two natural populations of *Arum italicum* (Mendez (1997). Seed weight is reported to vary within a species with site quality and year of study – varying from symmetry to skewness, from leptokurtic to platykurtic (Busso and Perryman, 2005). Seed weight distribution was reported to be skewed in *Phlox drummondii* (Leverich and Levin, 1979). It is certain that high degree of variation in seed mass may be thought to have important ecological implications forming basis of qualitative and quantitative female reproductive fitness so crucial in life history diversification (Braza *et al.* , 2010).

Seed size variation has been shown to have several important ecological implications. Seed mass is associated with seed germination (Baskin and Baskin, 1998; Navarro and Guitan, 2003), seedling vigour and survival, with both across species and within species (Arya *et al.,* 1992; Manga and Sen, 1996; Shaukat *et al.,* 1999; Walters and Reich, 2000; Samreen and Shaukat, 2000; Vaughan and Ramsey, 2001; Halpern, 2005) presumably reflecting the amount of reserves available for early seedling growth (Castro *et al.,* 2006). Heavier seeds produce heavy seedling with rapid pre-photosynthetic growth (Unival *et. al.,* 2008). Contrary to it, in some plants, larger seeds are not reported to give higher germination rate. In *Glycine max*, the higher rate of germination was found to be related to smaller seeds (Tiwari *et al.,* 1982). Espahbodi *et al.* (2007) has reported no significant correlation between seed weight and germination percentage in *Sorbus tormanalis*. Close and Wilson (2002) also found no correlation in seed weight and germination rate in *Eucalyptus delgatensis*. For some species carry over effects of seed size have been reported e.g., Ahmed and Zuberi (1973) reported in *Brassica compestris* L. var. *toria* that plants originating from smaller seeds produced smaller seeds than those originating from larger seeds. Seed size not only affects seedling success but also subsequent generation in *Desmodium paniculatum* (Wulff, 1986b). Larger seeds of *Telfaria occidentalis* are reported to be better adapted to cotyledon damage (Iortsuun *et al.,* 2008). In short, seed size variation produces variation in seedling fitness and thus the survival (Shaukat *et al.,* 1999) in variable environment. Since seedling survivorship of A. nilotica subsp. indica (*V. nilotica* subsp. *indica*) is reported to be the direct function of the seed size (Shaukat *et al.*, 1999), in spite of considerable wastage of seeds (9%), the larger proportion of large- (56%) and medium-sized (24%) seeds may guarantee the perpetuation of *V. nilotica* in variable arid environment.

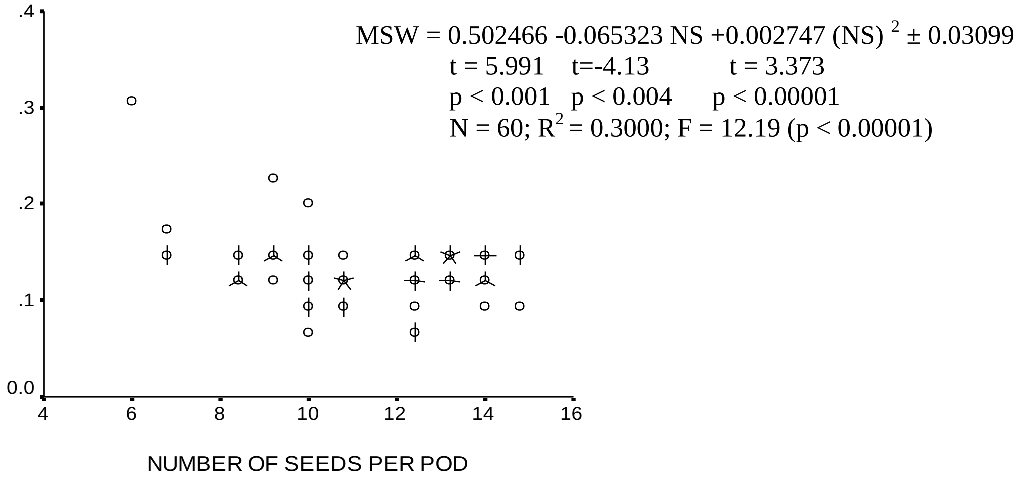


Fig. 13. Relationship of mean seed weight (MSW) with number of seeds (NS) developing per pod (N = 60 healthy pods). The sunflower radii denote the number of overlapping observations.

In both mother plants of *V. nilotica* the distribution of mean seed for a pod was asymmetric (positively skewed) around the grand mean of 0.123 ± 0.0019 and 0.125 ± 0.0015g in the two plants, respectively. Under controlled environmental conditions, Thompson (1984) has reported the distribution of mean seed weight in *Lamatium grayi* (Umbelliferae) around the grand mean of seed to be non-skewed and significantly leptokurtic. Busso and Perryman (2005) have reported frequency distribution of seed weight to vary from symmetry to skewed to right and from leptokurtic to platykurtic for sites and years of study in the Wyoming sagebrush (*Artemisia tridentata* ssp. *wyomingensis* in N. Nevada. Differences in mean seed weight in different fruits of individual plants has been suggested due to differences in environmental conditions e.g., nutrients, light, water or salinity level to which individual mother plants could have been subject during recent period of floral development and growth and seed development and maturation (cf. Gutterman, 1992). Drought during pod filling significantly affects seed weight in Acacia species (Gaol and Fox, 2002). In brief, resource availability commonly limits fecundity (Fenner and Thompson, 2005). Our results on variation of seed weight are some what similar to those reported by Turnbill *et al.* (2006) in *Ceratonia siliqua* where the one-third of the seed mass variation occurred between trees and two-third among the trees. 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.

For all pods studied (N=200), the mean brood size in *V. nilotica* averaged to 9.39 ± 0.22 seeds per pod varying around 32.48%. The brood size distribution was found to be negatively skewed. On the other hand, within a crop of sixty healthy pods of *V. nilotica*, the brood size (Mean: 11.233 ± 0.2953) was larger than that in all types pods (pods containing normal as well as shriveled seeds, deformed, fungus-infected or insect-eaten seeds) of *Vachellia* studied. Brood size of healthy pods varied symmetrically around the mean (CV: 20.36%). Uma Shaanker *et al.* (1988) have reported brood size in Acacia nilotica (*V. nilotica)* to be 7.44, from India (site and environment not mentioned). The negatively – skewed distribution of brood size per pod as found in species in hand is a common feature of many multi-ovulated species (Lee and Bazzaz, 1982). *Tamarindus indica* L., is, however, reported to exhibit positively –skewed distribution of seeds per pod (Thimaraju *et al.*, 1989) which has been demonstrated to be mainly due to pollen grain differences onto the stigma. Our results follow the pattern of brood as suggested by Uma Shaanker *et al.* (1988) i.e. negatively skewed brood distribution in fruits. *Vachellia* has many-seeded fruits and majority of ovules (> 90%) within the ovary mature into seeds in most fruits as is suggested by very high seed number - mericarp number ratio in this species. There are examples that some species accomplish the negatively skewed brood size through a maternally regulated pre-fertilization inhibition of pollen grains germination by the stigma (Ganashaiah *et al.*, 1986, 1988). In *Leucaena*, for example the germination of pollen grains is inhibited by the stigma unless a minimum threshold number of pollen tubes is deposited. This leads to a negatively skewed distribution of fertilized ovules. A similar mechanism has also been reported in *Tammarind* (Usha, 1986), *Moringa* (Uma Shaanker and Ganashaiah, 1987), *Epilobium* (Snow, 1986), and *Nicotiana* (Cruzan, 1986). This probably ensures the development to maturity of those flowers that receive a single load of pollen grains from a particular parent. Detailed discussion on negatively skewed distribution is given in Uma Shaanker *et al.*, 1988). Further elucidation of brood size patterning in *V. nilotica* needs further investigation.

A fruit of an Angiospermic plant consists of typically pericarp and seeds. Within fruit reproductive allocation among various fruit components has scarcely been examined across the range of fruit types and taxa although it is critical in the evolutionary perspective (Chen *et al*., 2010). In the present studies, seed packaging cost (SPC) was determined on the basis of the quantum of residual biomass (pericarp) of pod per seed or per g seeds. SPC, in terms of g.pericarp.g^{-1}seed averaged to 1.7398 ± 0.1722 in mother plant –A and 1.7107 ± 0.1721 in mother plant B of *Vachellia*. It distributed normally in both trees but varied quite substantially (54.2 and 36.3 %, respectively in the two mother plants. SPC, in terms of g.pericarp.$seed^{-1}$ was comparatively low – 0.2011 and 0.2081g in the two trees, respectively. One-way ANOVA of The SPC data, however, indicated that SPC expressed as g.pericarp.$seed^{-1}$ or g pericarp.$seed^{-1}$ didn't vary significantly among the mother trees of *V. nilotica* (within component variance explained for was very low (0.081 and 0.129%, respectively). *Conversely, w*ithin tree component variance accounted for was very high i.e. > 94%. Seed packaging have been studied by Willson *et al.* (1990)) in twenty eight species and they noted a marked variation in average seed packaging investment in almost all 28 species surveyed. *Cassia fasciculata* included in their study showed SPC per seed to be 76.47 ± 1.89 mg per seed. It has also been demonstrated by Mehlman (1993) to vary significantly in pods of *Baptisia lanceolata.* Seed packaging investment across 62 species of 35 families from China (No legume included) is 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 *Asimina triloba* to be 13,101.0 mg per seed. Khan and Zaki (2012) have reported that packaging cost in *C. fistula* varied from pod to pod even in case of the healthier indehiscent pods - 767.2 ± 51.4 mg per seed and 6961.3 ± 461.0 mg per g seeds.

Seed size-seed number trade off in *V. nilotica* was evaluated in healthy pods as the relationship between mean weight of individual seed for a pod (MSW) and the number of seeds per pod (NS, brood size). There was significant ($p < 0.001$) trade off in *V. nilotica* which was defined curvilinearly. The seed size / seed number trade-off is a common phenomenon in many plants. A negative trade off between MSW and NS has also been demonstrated in *C. fistula* by Khan and Zaki (2012). Aniszewski *et al.* (2001) have reported seed size / seed number trade off even at intraspecific level in *Lupinus polyphyllus* Lindl. Within a plant, average seed weight has been reported to decrease as the number of seeds within a fruit of wild radish increased (Stanton, 1984). Chen *et al.* (2009) has reported that the total fruit mass and total seed mass in tropical woody species were positively correlated with twig size. Seed size was positively associated with fruit size, which was in turn positively correlated with twig diameter but negatively correlated with the ratio of twig length to twig diameter. Seed size was negatively and isometrically correlated with seed number per twig mass in both the ever green and deciduous species demonstrating the existence of trade-off between seed size and number. Smith and Fretwell (1974) developed a theoretical model for understanding relationship between seed number, seed weight and available resources. Plant species are known to show larger variations in seed number than seed weight (Harper *et al.,* 1970). Smith and Fretwell (1974) suggested that seed number is controlled by available resources and specific seed weight. The understanding of trade-off between seed number and weights in plants can be represented with a model in which fixed amount of available resources can be distributed into different combinations of numbers and weights. This model supports the stabilizing selection theory for seed weight which establishes this concept of an optimum seed weight that maximizes parental fitness (Smith and Fretwell, 1974; Sadras, 2007). However, plant to plant 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). Seed weight is more genetically controlled and is less plastic than seed number. Seed weight is highly heritable more than seed number (Sadras, 2007) and thus it plays very important role in modulating seed number (Sadras and Egli, 2008).

Variation in seed mass against the number of seeds in fruit is generally viewed by ecologists in terms of Smith-Fretwell theory (Smith and Fretwell, 1974) or recently proposed game theory (DeJong and Klinkhamer, 2005). Smith-Fretwell Theory (1974) proposed optimization model 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 (e.g. McGinley, 1988), physiological, developmental or morphological constraints (e.g., McGinley *et. al*., 1987), parent offspring conflict and sibling rivalry (Uma Shankar *et al*., 1988; Ganashaiah and Uma Shankar, 1988). 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 extended to fruits of an individual tree where different optima may occur for different fruits produced on a tree over a period of time and internal and external environmental forces may differentially interact with different fruits developing over time. Gambín and Borrás (2010) tested resource distribution and trade off between seed number and seed weight across several crops and asserted that seed number and individual seed weight combinations across species were related and could be explained considering resource availability when plants are adjusting their seed number to the growth environment seeds are adjusting their storage capacity. The available resources around the seed set period are important and are proportionally allocated to produce either many small seeds or few larger seeds depending on the particular species. A considerable investment of maternal parent is on the structural components of the package. The economic aspects of the packaging costs demand larger number of seeds to be packed so that SPC is reduced (Bookman, 1984; Corner, 1957; Ganashaiah *et al.*, 1986, Janzen, 1982). If other things are equal, the maternal parent should be selected to favour a negatively skewed distribution of brood size (Ganashaiah *et al.*, 1986, Lee, 1984).

In the composite samples of healthy pods of *V. nilotica* the frequency of proximal seed to be lesser in weight than the mean of the rest seeds was significantly higher than the frequency of proximal seed weight to be higher than the mean of the seeds towards distal end. The comparison of weight of distal seed with the mean weight of seeds above the distal seeds presented no clear cut picture at least in the composite samples, although there were considerable events of occurring larger distal seed at least in one mother plant of *Vachellia*. As regards to our third approach, no clear cut pattern emerged except that the weight of the middle seed was significantly heavier in pair comparison t-test analysis ($t = 2.277$, $p < 0.03$) in case of mother plant-B. Also the seed weight of middle seed in healthy pods of mother plant-A was heavier than the mean weight of the upper seeds of the pods.

The maximum number of seeds in any healthy pod of *V. nilotica* was 15. The fourth approach to investigate the pattern of within-pod seed size distribution indicated that the weight of the first seed (proximal seed) was quite lesser in magnitude than that of all the subsequent seeds. In pods studied, the proximal seed weighed 115.94 ± 0.00422 mg which was substantially lower than that of any subsequent seeds (number II to XV) by a quantum of c 10mg.

The pattern of seed size variation in pods as seen here may be thought to be related with the disparity of nutrition availability to the seeds in multi-seeded fruits (Mendez, 1997). Within fruit seed mass variation i.e. unequal seed mass partitioning among seeds in a fruit is considered to result from differential parental supply related to the genetic quality of seeds (Temme, 1986). The position effect within a fruit (Lee, 1988), parent-offspring conflict (Lloyd, 1992) or sibling rivalry (Uma Shaanker *et al.*, 1988). It may, at least in part, be due to gravity effects on photosynthates transport in *Vachellia* having an elongated and hanging pod with single vascular supply along the ventral suture. Considering a pipe-line analogy, the photosynthates moving through phloem under gravity tends presumably to be lesser availabe to the proximally developing seeds and more available to the subsequent seeds. Phloem unloading and transport, however, from source (leaves) to sink (developing seeds) may change with assimilate production at the source which may directly effect assimilate availability to the developing seeds by changing the pressure differences that governs photo-assimilate movement (Patrick, 1997). Ganashaiah and Uma Shaanker (1994), using the concept of fluids flow, assumed that probability of any given sink getting the resource molecule should be the function of 1) sink drawing ability and 2) amount of resource molecule already moved to that sink. That is to say that any molecules moving to a sink auto-catalytically increases the probability of the later molecule to move to the sink. In an elongated pod, thus differentially favourable sinks may develop. Ganashaiah and Uma Shaanker (1994) have demonstrated that in such scenarios seed abortion may also take place even under the conditions of resource abundance. It may be mentioned that some nutrition to seeds and pods of *V. nilotica* should have been provided by the green pods themselves.

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