Plant and Soil **160**: 113–118, 1994.
© 1994 *Kluwer Academic Publishers. Printed in the Netherlands.* PLSO 3104

The influence of plant growth habit on calcium nutrition of groundnut (*Arachis hypogaea* L.) pods*

U. HARTMOND[1], J.H. WILLIAMS[2] and F. LENZ[1]
[1]*Institut für Obst- und Gemüsebau der Rheinischen-Friedrich-Wilhelms Universität Bonn, Auf dem Hügel 6, D-5300 Bonn 1, Germany* and [2]*International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Sahelien Center, B.P. 12404, Niamey, Niger*

Received 10 March 1993. Accepted in revised form 2 October 1993

Key words: *Arachis hypogaea*, calcium availability, calcium contents, groundnut, nutrition, growth habit, pod distribution, shelling percentage

Abstract

In field experiments in India and Niger runner and bunch groundnut cultivars were compared for their pod distribution pattern and its relevance to the calcium (Ca) supply for pod development. Bunch cultivars produced sixty to eighty percent of their pods within 5 cm of the tap root. Runner cultivars explored a radius of up to 30 cm for pod production and exploited the soil area in a more homogeneous manner than bunch types. The available soil volume per pod was 19 to 27 cm^3 for bunch types and 43 to 46 cm^3 for runner types, varying the potential for Ca competition between pods. Computation of the soil Ca content needed to satisfy pod Ca requirements showed that much higher concentrations were needed for the bunch cultivars than for the runners. No significant differences in Ca content of pods existed between bunch and runner cultivars. However, in the runner cultivars, the Ca content of the more widely dispersed pods in outer zones was greater than that of the more densely populated inner pod zones. Regression analysis of shelling percentage across a range of environments showed that the shelling percentage of runners declined less rapidly than did the shelling percent of bunch types, indicating that runners were more efficient in exploiting Ca at lower soil Ca availability than the bunch types.

Introduction

Calcium nutrition of groundnut pods is a major limiting factor to production in many regions of the world. Ca requirements vary with stage of pod development, are greatest at the start of gynophore swelling (Bledsoe et al., 1949). Deficiencies at this stage result in failure to expand into a pod. Deficiencies in later stages result in the failure to fill the pod with seed, resulting in the phenomena known as 'pops'. In Ca-deficient soils the number of empty pods increases and the quality of seeds is reduced (Wiersum, 1951). Gypsum application generally increases yields (Slack and Morrill, 1972), but the Ca-fertilizer uptake efficiency of the fruit is as low as 2 to 3% (Keisling et al., 1982). While application of fertilizers can rectify deficiencies, a better understanding of the factors influencing Ca availability to the pods is needed. Knowledge of the basis of genetic variations for pod filling will allow these to be exploited in a systematic manner to solve the problems of pod filling.

The cultivated groundnut has a wide range of

---

* Approved as ICRISAT Journal Article No. 1372.

morphological attributes (Gibbons et al., 1972), including pod shapes and sizes, branching patterns, and growth habit. The most widely recognised attribute influencing the Ca nutrition of pods is pod size, which determines the Ca uptake-surface: volume ratio of the fruit (Kvien et al., 1988). Shell thickness and internal resistances also may be important to the supply of Ca to the seeds (Kvien et al., 1988). Walker et al. (1976) reported higher yields of a runner when compared to bunch cultivars at low soil Ca level suggesting plant habit may influence Ca nutrition.

This study was conducted to evaluate the impact of dispersion of pods in the soil by plant growth habit on the Ca availability to pods.

Materials and methods

Field experiments were conducted between 1988 and 1990 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) near Hyderabad, India, and at the ICRISAT Sahelian Center in Niger. The soils of the experiment station in India are medium deep Alfisols (Udic Rhodulstalfs), with a sandy topsoil (67–80% sand, 15–25% clay) and loamy subsoil (38–59% clay). The pH ranges from 6.0 to 7.2 and cation exchange capacity between 4.8 and 14.8 cmol [+] kg^{-1} soil with usually high Ca contents (800–1200 mg kg^{-1}; El-Swaify et al., 1987). In India, two experiments examined the pod dispersal of groundnut genotypes representative of the major morphological groups, and the role played by Ca fertilizer on the distribution of pods. During the rainy season 1988, in Experiment 1, two bunch varieties (ICGS(E) 21 and ICG(FDRS) 42) and two runner varieties (Kadiri 71-1 and M 13) were compared under 4 levels of gypsum application (0, 200, 400, 600 kg ha^{-1}). Experiment 2 was conducted in the post rainy season (November to April, 1988-89) under irrigation. This experiment was a modification of *Experiment 1* in that two spreading bunch types (Robut 33-1 and ICGS(HYQ) 50), were added and gypsum application rates increased (0, 400, 800, 1200 and 1600 kg gypsum ha^{-1}). Both experiments were sown at 30 × 10 cm spacing on 1.2 × 9m plots arranged in randomized block designs with 3 replications. Gypsum was applied at pegging (40–50 days after sowing). The pod distribution was assessed on 20 plants per plot. At maturity, plants were harvested manually and their fruits picked from concentric zones, according to distance from the tap root. Four zones were defined using 2.5 cm intervals. Observation showed that no pods were below 5 cm in the soil, so the volume of each zone (V_i), and the volume of soil available to each pod (V_p) were estimated using equations 1 and 2 (below): –

$$V_i = 5 \times (\Pi r_0^2 - \Pi r_i^2)[\mathrm{cm}^3] \qquad (1)$$

where V_i = soil volume of pod zone i; r_0 = radius to the outer limit of the zone; and r_i = radius to the inner limit of the zone. And

$$V_p = V_i / n[\mathrm{cm}^3.\mathrm{pod}^{-1}] \qquad (2)$$

where n = number of pods in the zone i.
This assumed an even distribution of pods within the zone, and no interference from neighbouring plants. Pods were then air-dried, weighed and shelled to obtain the percentage sound mature kernels.

The Sahelian Center of ICRISAT is located near Niamey, on sandy Alfisols (Psammentic Paleustalfs of the Labucheri Series) with 94% sand and only 3% clay in the top soil. These soils have a very low exchange capacity (<3 cmol [+] kg^{-1} soil) with a pH of 5.0 to 5.2 and a Ca-content of 80 to 100 mg kg^{-1} (West et al., 1984). In Niger, three experiments were sown at 50 × 20 cm spacing on 4 × 5 m plots. Twelve kg ha^{-1} nitrogen and 30 kg ha^{-1} phosphate as diamonium-phosphate was applied before sowing, and plots were treated with 20 kg ha^{-1} a.i. carbofuran to help control micro variability (ICRISAT, 1988).

During the rainy season of 1989, *Experiment 3* compared the pod and pop distribution on a bunch (28-206) and a runner variety (47-16) without manipulation of Ca level. In the dry season of 1989 (*Experiment 4*) four cultivars (28-206 and ICG(MS) 550; bunch types; and 47-16 and M13 runners) were grown with two levels of irrigation (100% and 33% of evapotranspiration) and two levels of Ca application (0 and 240 kg ha^{-1} Ca) in factorial treatment combinations. The final experiment (*Experiment 5*) examined the Ca nutrition of 9 bunch, and 3 runner cultivars at three levels (0, 120, or 240 kg ha^{-1}) of Ca applied as gypsum.

For the experiments in Niger, pods with a single locule and two locules were separated, and the number of filled ovules assessed for each class. After ashing (AOAC, 1975), seed and shell samples were analyzed for Ca content by EDTA titration with Patton/Reeder indicator (Bassett et al., 1981).

All experiments were analyzed using conventional analysis of variance techniques for the primary analyses. The trials in Niger were used for a combined analysis with each combination of experiment, Ca level and irrigation defined as an individual environment for pod filling purposes. Stability analysis (Finley and Wilkinson, 1963) was used to compare the effects of habit on pod filling (shelling percentage) across these environments. This approach overcame the difficulties in characterizing the Ca supply environment, which changed during the season due to leaching, and Ca transport differences resulting from different levels of soil water content.

Results and discussion

Pod density as influenced by growth habit

No quantitative data is available on pod distribution of different morphological types and the manner in which environmental factors may influence this. The pods of bunch types were concentrated around the main stem. Up to eighty percent of their pods were within a radius of 2.5 cm of the tap root, often touching each other. Few pods were produced farther than 7.5 cm from the main stem. In strong contrast, runner cultivars exploited a radius of up to 30 cm. Only 30 to 40% of the pods were within the inner 5 cm radius, and the remainder were more evenly distributed over the rest of the pod zone (Fig. 1). Thus, the runners exploited the potential podding area in a more homogeneous manner than bunch types.

The method used to find the available soil volume based on pod distribution gave consistent distribution patterns for cultivars from various morphological groups across environments. Since the depth of the fruiting zone did not vary greatly between the cultivars investigated, the soil volume per pod was a function of the numbers of pods produced and the habit of each variety. This differed for habit groups, being between 19 and 27 cm^3 for bunch types, and 43 to 46 cm^3 for runner types in experiment 2 (Table 1). Thus, at low soil fertility competition for Ca is potentially less for the pods of runner cultivars than for bunch types.

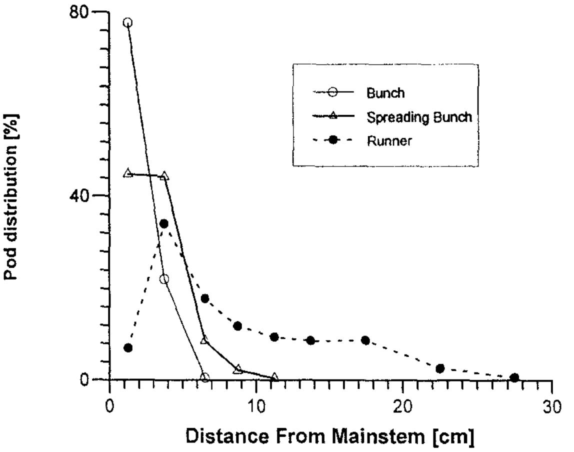

Fig. 1. Distribution of runner, spreading bunch, and bunch groundnut type as the percentage of the total pods per plant (Experiment 1).

The effect of soil Ca on pod distribution

Since pod initiation is influenced by Ca (Bledsoe et al. 1949), the pod distribution is potentially sensitive to competition for soil Ca. Gypsum application effected the pod distribution of some varieties (ICGS(E) 21 in experiments 1 and 2, Kadiri 71-1 in Expt 1 and Robut 33-1 in Expt 2). In these cases, increasing gypsum rates tended to reduce the soil volume per pod as soil CA concentrations increased (Table 2). Other cultivars did not show any clear tendencies. Although this effect was not visible in all cultivars, this is most probably due to greater success in development of the first pegs that form pods under fertile conditions. At inadequate soil Ca-contents some pegs near the tap root may not develop or fill properly. In such a case assimi-

Table 1. Mean volume of soil (cm^3) available to single pods of two bunch, two spreading bunch and two runner groundnut cultivars at 5 levels of gypsum application (kg ha^{-1}) (Experiment 2)

Gypsum (kg ha^{-1})	Bunch		Spreading Bunch		Runner	
	ICGS(E) 21	ICG(FDRS) 42	Robut 33-1	ICGS(HYQ) 50	Kadiri 71-1	M13
0	28.4	20.4	26.2	35.8	26.6	45.2
400	18.2	30.8	21.4	27.8	67.8	35.0
800	20.2	31.2	21.4	33.2	39.2	46.4
1200	14.6	25.0	22.0	32.0	44.6	49.6
1600	14.6	29.0	20.2	27.0	37.2	53.2
Mean	19.2	27.3	22.2	31.2	43.1	45.9
SE Genotype				±1.20		
SE Genotype*Gypsum				±2.68		
CV%				26.4		

Table 2. Ca-contents (g kg^{-1}) of shells from pods growing 0–5 cm, or from 5–10 cm from the tap root of two runner groundnut cultivars (Experiment 4)

Genotype	Distance from the tap root	
	0–5 cm	5–10 cm
47-16	1.43	1.72
M13	1.93	2.27
SE	0.7	
CV%	20.5	

lates are available for the plants to develop pods at higher nodes to compensate for failure at the first nodes. These later pegs enter the soil farther away from the stem, consequently enlarging the area used for pod production. Apparently this feed-back mechanism increased the soil volume exploited as a compensation for inadequate Ca concentrations in the zone close to the stem.

Calcium content and shelling percentage

Varieties differed significantly in the Ca content of both shell and seed,and in the total Ca present in the fruit (data not presented), but only in experiment 5 was the shelling percentage and the proportion of filled locules significantly correlated with the Ca content of the shells and kernels (Table 3). This shows that the other factors, such as transport resistance (Kvien et al., 1988) and threshold levels for deficiency also may be important considerations in determining pod filling.

Table 3. Correlation matrix of shelling percentage (S%), percentage filled locules (%FL) and relative calcium content in kernels and shells from Experiment 5

	S%	%FL
Ca_{Kernel}	0.405	0.375
Ca_{Shell}	0.291	0.200
%FL	0.762	
	r* = 0.195	r** = 0.254

*α = 0.05; **α = 0.01

Within individual experiments the effect of pod competition on Ca content could only be established for pods of the runner varieties in experiment 3. Although differences in Ca content were small, the effect of a better distribution of the pods and the larger soil volume available to them was apparent in the higher Ca-content of the shells of pods from the outer zone relative to the more densely populated zone closest to the stem (Table 2).

Soil calcium requirements as influenced by pod dispersal

The total amounts of Ca extracted from the soil by the pods are generally small and are correlated to the pod size (Kvien et al., 1988) simply because of the higher total amounts of Ca larger pods contain (Keisling et al., 1982). The soil volume available to individual pods in different cylindrical zones around the plant, and the total Ca-content of pods for 47-16 and 28-206 (1.53 and 2.85 mg pod^{-1} respectively in Experiment 3), were used to estimate the soil Ca-concen-

Table 4. Necessary soil Ca-contents (mg kg^{-1}) to equal the Ca-demand by the pods of a runner and a bunch groundnut cultivar (assuming 100% uptake efficiency) in four sectors around the plant (cm) based on the data from Experiment 3. The hypothetical variety has the pod density of the runner with the pod Ca requirement of the bunch

Genotype	Distance from the tap root			
	0–2.5	2.5–5	5–7.5	7.5–10
47-16 (Runner)	32	23	7	4
Hypothetical	60	43	13	7
28-206 (Bunch)	188	45	10	8

trations needed to meet the pod requirements (Table 4). Although Keisling et al. (1982) reported that the Ca uptake efficiency is as low as 2%, these values were calculated assuming 100% uptake efficiency. This high level of efficiency was utilized because of the uncertainty about the volumes of soil used in the computation of the efficiency by Keisling et al. (1982). However, even though the values may not be absolutely correct, they do provide comparative differences which show the nature of the soil concentrations needed for different types. For these two varieties, the effect of pod dispersal is amplified by the higher total Ca content of the pods of the bunch type. To overcome this, a hypothetical variety was created with the same pod Ca requirement of the bunch type but with the pod, distribution of the runner. Clearly, the high pod densities close to the tap root of a bunch type require much higher Ca concentration than do the lower densities of a runner type with better pod distribution. However, where gypsum is applied to the pod zone at the pegging stage, there is a possibility of a strong interaction of cultivars with differing gypsum application practices. Agronomists and breeders should be aware of this possibility. A broadcast application may be less effective than banding the Ca-fertilizer close to bunch type plants. Even if limited quantities are banded to create locally high concentrations, the bunch types may respond strongly to this treatment. In contrast, the data suggest that the runner types will be able to tolerate lower Ca levels than bunch types when other factors are equal.

Table 5. Proportion of filled pods (%) within concentric rings around the tap root of a runner and a bunch groundnut cultivar (47-16 and 28-206) (Experiment 3)

Genotype	Distance from tap root		
	0–5 cm	5–10 cm	>10 cm
47-16	13.0	16.7	21.2
28-206	27.7	19.9	–
SE Geno*Distance		4.5	
CV%		24.5	

Shelling percentage

The most readily available index of Ca deficiency is provided by the shelling percentage. Comparisons between cultivars for their shelling percentage are, to some extent, confounded by differences in their potential shelling percentage (i.e. without Ca deficiency). However, the differences between the shelling percentage of runners and bunch types were small in the environments which provided the best overall shelling percentage so their effect is small. The value of shelling percentage as an index of Ca deficiency was confirmed by the correlation between the percentage of locules that filled (%FL) and shelling percentage (for example, Table 3) for those experiments for which both parameters were measured. In experiments 1 and 2, there was no evidence of Ca deficiency limiting shelling percentage, but in experiments 3 to 5 there was evidence of Ca deficiency.

Regression analysis (using stability analysis techniques) of the shelling percentage using the combined data for the runner and bunch varieties over all the various combinations of Ca and environment clearly showed the advantage of the runner types in environments in which shelling was less than normal. When the environmental mean shelling percentage was normal (circa 70%), there was little difference between the bunch and runner types. However, when shelling percentage was less than normal, the bunch types had lower shelling percentages than the runners (Fig. 2). This provides strong evidence for benefits to Ca nutrition of pods through pod dispersal effects associated with morphology.

The present series of experiments show that there are substantial differences in the pod distribution of groundnuts from the various habit groups. These differences in pod density indicate

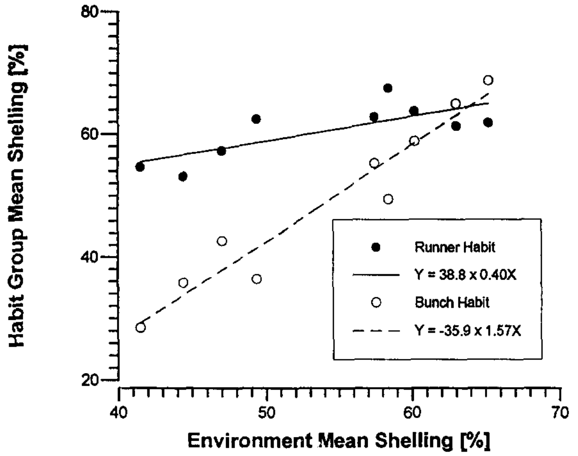

Fig. 2. Variation in shelling percentage of runners and bunch groundnut genotypes across a range of CA availability environments (Combined data).

that the Calcium levels needed on the soil to satisfy the requirements of pods will vary with plant habit. This effect was confirmed by the greater stability of the shelling percentage of runners compared with bunch types in less than optimum pod filling conditions. Breeders can decrease the sensitivity of groundnuts to Ca deficiency by increasing the pod dispersal through choice of morphology.

Acknowledgements

This research was funded as a Special Project by BMZ/GTZ (German Technical Cooperation). Acknowledgements go to the staff of the ICRISAT Groundnut Program for the assistance in conducting the experiments and collecting data.

References

Bledsoe R W, Comar C L and Harris C H 1949 Absorption of radio-active calcium by the peanut fruit. Science 109, 329–330.

EL-Swaify S A, Singh S and Pathak P 1987 Physical and conservation constraints and management component for SAT Alfisols. *In* Alfisols in the Semi Arid Tropics, pp. 33–48. ICRISAT, Patancheru, India.

Finley K W and Wilkinson G N 1963 The Analysis of Adaptation in a Plant-Breeding Program. Aust. J. of Agric. Res. 14, 742–754.

Gibbons R W, Bunting A H and Smartt J 1972 The classification of varieties of groundnuts (*Arachis hypogaea* L.). Euphytica 21, 78–85.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1988 Annual report 1987. Patancheru, A.P. 502324, India: ICRISAT pp 265.

Isaak R A and Johnson W C 1975 Colloborative study of wet and dry ashing techniques for the elemental analysis of plant tissue by atomic absorption spectrophotometry. J. Assoc. Off. Anal. Chem. (AOAC) 58, 436–440.

Keisling T C, Hammons R O and Walker M E 1982 Peanut seed size and nutritional calcium requirement. J. Plant nutr. 5, 1177–1185.

Kvien C S, Branch W D, Sumner M E and Csinos A S 1988 Pod characteristics influencing calcium concentrations in the seed and hull of peanut. Crop Sci. 28, 666–671.

Slack T E, and Morrill L G 1972 A comparison of a large-seeded (NC2) and a small-seeded (Starr) peanut (*Arachis hypogaea* L.) cultivar as affected by levels of calcium added to the fruit zone. Soil Sci. Soc. Am. Proc. 36, 87–90.

Vogel A I 1978 A Textbook of quantitative inorganic analysis including elementary instrumental analysis. 4th ed., revised by J Basset, R C Denney, G H Jeffrey and J Mendham. Longman London, New York. pp 326–329.

Walker M E, Keisling T C and Drexler J S 1976 Responses of three peanut cultivars to gypsum. Agron. J. 68, 527–528.

West L T, Wilding, L P Landeck J K and Calhoun F G 1984 Soil survey of the ICRISAT Sahelian Center, Niger, West Africa. Bulletin of Soil and Crop Sciences Department/ Trop. Soils, Texas A&M University, College Station, Texas.

Wiersum L K 1951 Water transport in the xylem as related to calcium uptake by groundnuts (*Arachis hypogaea* L.). Plant and Soil 3, 160–169.

Section editor: H Lambers