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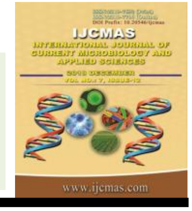

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Review on Morpho–physiological Attributes of Groundnut at Various Growth Stages

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A B S T R A C T

The crop phenology, growth and productivity are strongly influenced by changing the cropping season. The *kharif* (June-Oct.) is the major groundnut- growing season. The CGR is higher in *kharif* crop than *rabi* season crop, but the average per day dry matter production is similar in both the seasons. Flowering and fruiting, in groundnut, are of an indeterminate type, which generally has an effect on yield and quality. Ideal type of groundnut would be one that sets all its young fruits within 4-5 days and spends the rest of the growing season filling them. The apparent photosynthesis AP of well- developed canopies may reach values of 6 to 8 $gCO^2\ m^{-2}h^{-1}$. The CO2 enrichment from 400 to 800 µ mol mol^{-1} had positive effects on growth and yield, but not above 800 µmol mol^{-1}. The rate of translocation is positively correlated with net photosynthetic rate and the yield improvement in groundnut, is mainly due to partitioning of assimilates between vegetative and reproductive parts, length of grain-filling period and rate of fruit development. As the light interception is about 95% complete at an LAI of 3, the extinction coefficient for visible radiation was about 1. CGR, RGR and NAR between 60-90 DAS were significantly correlated with pod yield. NAR was negatively correlated with LAI, specific leaf area and the distribution of DM to the pod and was positively correlated with leaf N content Water stress delayed pod initiation, and the major cause of variability in pod yield and harvest index was the delay between peg initiation and onset of rapid pod growth. Under water stress there is poor pod filling that reduced kernel size, shelling percentage, SMK % and lipid content of kernel. Depending upon the stage, moisture stress causes 22-47 % yield reductions.

Introduction

Groundnut is an important oilseed and food legume in tropical and subtropical areas in different agro climatic regions between latitude 40^oS and 40^oN. In India it is mostly grown as a rainfed crop in well drained sandy soils in low 750mm a normal and medium rainfall.

Groundnut is not only a major oilseed crop but also an important food crop in India. India groundnut occupies an area of 40.68 lakh ha with production of 66.15 lakh tonnes and productivity of 1626 kg ha^{-1} in *Kharif* season (2017-18). In *rabi-summer*, it is being grown in 8.39 lakh ha with production of 16 lakh tonnes with productivity of 1909 kg ha^{-1} (2017-18). In Andhra Pradesh, in *Kharif* season, it is cultivated in an area of 6.48 lakh ha with production of 8 lakh tonnes and productivity of 1238 kg ha^{-1}. In *rabi* season, it is cultivated in 0.90 lakh ha with production of 2.07 lakh tonnes and productivity of 2300 kg ha^{-1} (AICRP on Groundnut, Annual Report, 2017).

Our productivity in the state as well as in our country is still low in both irrigated and rainfed conditions in comparison with USA (3540 kg ha^{-1}) and China (2624 kg ha^{-1}) whereas the average productivity was 938 kg ha^{-1} in India during the last decade.

Rainfall is the most significant climatic factor affecting groundnut production, as 70% of the crop area is under semi-arid tropics characterized by low and erratic rainfall. Low rainfall and prolonged dry spells during the crop growth period were reported to be main reasons for low average yields in India especially in Andhra Pradesh.

Morphology and botanical types of groundnut cultivation

The *Arachis hypogaea* was first described as a species by Linnaeus in 1753 and till 1839 only one species of *Arachis*, *A. hypogaea* Linn. (The cultivated groundnut) was described (Ramnath Rao, 1988). The cultivated *A. hypogaea* was initially divided into two large botanical groups, Virginia and Spanish-Valencia on the basis of branching pattern. In Virginia group, the main stem does not have reproductive axes and alternate pairs of vegetative and reproductive axes (inflorescences) are borne on the cotyledonary lateral and other n+1 branches (alternate branching). In the Spanish-Valencia group, reproductive branches are borne in a continuous series on successive nodes of the cotyledonary and other lateral branches, on which the first branch is always reproductive (sequential branching pattern). Spanish cultivars produce n+2 vegetative branches irregularly, while Valencia cultivars do not. However, Gibbon *et al.,* (1972) described the subspecies and botanical varieties in details as follows,

Subspecies *hypogaea*: procumbent, decumbent or erect growth habit, alternate branching, inflorescence never borne directly on main axis, first branch on the cotyledonary lateral always vegetative, 2-4 seeded pod, testa colour commonly tan, seed dormancy usually present, foliage dark green.

var. *hypogaea* (Virginia bunch): procumbent to erect growth habit, main axis in procumbent form, short and not exceeding 40-50 cm, 2-seeded pod, medium late maturing.

var. *hirsute* (Virginia runner): procumbent growth habit and main axis may exceeds 1 m, pod strongly beaked and with 2-4 seeds, very late maturing.

Subspecies *fastigiata*: erect to decumbent growth habit, sequential branching; flowers always present on main axis; first branch on cotyledonary lateral reproductive, seed dormancy usually absent, foliage usually lighter in colour than hypogaea.

var. *fastigiata* (Valencia): vegetative branches on primaries absent or regularly placed at distal nodes, inflorescence simple, pods with 2-4 seed (rarely 5), pods beak absent or slight, testa colour tan, red, white, yellow, purple or variegated.

var. *vulgaris* (Spanish): vegetative branches occasional and regularly placed; inflorescence compound, pod usually with 2 seeds, beak present or absent, testa colour tan, red, white or purple.

Phenology

Phenology is the study of developmental timing in relation to the calendar. In groundnut, both perennial and annual species occur, but the perennial or indeterminate growth habit is most common. Harvesting of groundnut *(Arachis hypogaea L)* crops is rarely determined by physiological maturity.

Phenological studies have been more concerned with the timing of developmental processes i.e. the start, the duration and the end rather than with the rate of development. The rate of developmental process such as leaf production is usually expressed as number per day, whereas events which occur once in life cycle are generally expressed as the duration (D). There are several physiological processes occurring right from seed germination to harvest and systematic study of these is essential for the success of any crop in a given area.

However, Williams *et al.,* (1978) divided the groundnut crop's life time into ten phases:

1-germination and emergence;
2-vegetative growth only;
3-vegetative growth and first flowers;
4-active flowering with first pods being produced;
5-flowering, peg production, pod production and the start of significant kernel growth;
6-vegetative growth ceasing and rapid kernel growth commencing;
7-pod initiation ceasing and rapid kernel growth continuing, defoliation usually starts;
8-first mature pods present;
9-30 to 40% of the pods mature;
10-50 to70% of the pod mature, defoliation rapid and crop lifted at the end of this phase.

However morpho physiological attributes are discussed with more details under the separate headings as vegetative and reproductive growth and seed development.

Vegetative growth

Germination and seedling growth

The groundnut seed consists of two cotyledons, upper stem axis and young leaf primordia (epicotyl), and lower stem axis (hypocotyl) and primary root. The epicotyl consists of 3 buds-1 terminal with 4 leaf primordia and 2 cotyledonary laterals with 1-2 leaf primordia. Thus, the embryo contains all the leaves and above ground part that appears during the first 2 weeks of growth. The active growth of quiescent seed is resumed after water uptake imbibitions. The metabolism in groundnut seed is very low at seed moisture levels below 10% but increases rapidly during water absorption and hydration of cell walls and protoplast. Generally groundnut seed requires more than 35% seed moisture for germination. Besides water, the external substances required for seed germination are oxygen and suitable temperature. During germination of groundnut seeds, C_2H_4 production rises prior to any visible signs of growth and reaches to peak twice, at emergence of the hypocotyl-radical and when radical emerges from the hypocotyl (Morgan *et al.*, 1970).

The minimum and maximum temperature requirements of groundnut are not well established but it germinates more quickly within range of 20-35^{o}c with optimum temperature between 30-33^{o}C for most rapid germination and seedling development. In moist soil, the primary roots emerge in 24-36 h and root grows 0.5 to 4.0 cm in 4 days. During the first few hours of germination the radical consists of about half hypocotyls and half primary roots, depending upon the depth of sowing. The hypocotyl is the portion of stem, which lies between the primary root, and cotyledons and it can elongate enough to bring the cotyledons to the soil surface. The field emergence of groundnut is neither epigeal nor hypogeal, but intermediate. However, Dwivedi and Saha (1985) found epigeal germination behaviour in groundnut where the hypocotyl carries cotyledons to the soil surface and remains there. The germination completes in 7-10 days after seed is sown.

The breakdown of seed storage reserves, transport of reserve material to embryonic axis and synthesis of new materials from the breakdown products are the three main chemical changes occurring in rehydrated imbibed seeds. In groundnuts as the metabolic reserves are largely lipids (40-54%) and proteins (20-30%), the lipids breakdown takes place through glyoxylate cycle and enzymes malate synthatase and isocitric lyase are essential during conversion of fats to carbohydrates. The abscisic acid (ABA) inhibits germination and synthesis of isocitric lyase and ethylene reverse the inhibitory effects of ABA on germination (Ketring, 1975). The gibberellic acid and ethylene promotes the germination and isocitric lyase enzymes control the balance between fat and carbohydrate. The protein degradation occurs 4 to 9th days of germination. The chemical compound after breakdown are translocated to the growing points of the embryonic axis and utilized for seedling growth. During germination the dry weight of developing seedlings decreases (cotyledons dry wt. decreases by 60% and protein depleted by 70%). Misra *et al.,* (1992) however, reported that sucrose, indigenously present in cotyledons, is translocated to the growing axis for first three days, subsequently catabolism of oil began the proteolysis begins soon after imbibitions and free amino acids increased, but the rapid degradation of protein was observed after 4th day of imbibition.

Canopy development, leaf area, leaf area index, leaf area duration and specific leaf weight

The groundnut leaves are tetra foliate, peripinnate with two pairs of opposite subsessile, obovate leaflets with entire ciliate margin, are born spirally in 2/5 phyllotaxy and arrangement is distichous. Stipules are prominent, linear and adenate to some length and become free at the pulvinus. In general, the sub species *hypogaea* has dark green foliage with small leaflets and sub sp. *fastigiata* has light green and larger leaflets. The leaflets have hairs mainly on the abaxial surface and on the margins which is related to resistance to leaf hoppers. The leaf size ranges from 4 cm^2 in the first seedling stage up to 80 cm^2 in upper leaves of fully developed stand. The specific leaf weight ranges from 4.1 to 6.7 mg cm^{-2} in young fully expanded leaves.

The leaf is the photosynthetic unit and in groundnut it exhibits nyctiotropic movements daily where the adaxial surfaces of leaflets come together and petiole bends downwards. Stomata appear on both sides of the leaf. The groundnut leaves show exponential increase in their number from 20 to 90 days after sowing, but the leaf production during this period differs with botanical types and is higher in the Virginia-runner followed by semi-Virginia bunch and erect Spanish types.

The groundnut plant has a distinct main stem and varying number of lateral branches and carriage of laterals is an important character determining the growth habit. The bunch types have thicker stem than runners. The internodes are short and highly condensed at the base but are longer at the higher nodes. Spreading (runner, trailing, procumbent and prostrate) and erect (upright, erect bunch and bunch) are two distinct growth habits in groundnut. However, 6 types of growth habit (procumbent 1 and 2; decumbent 1, 2, and 3 and erect) have been described for groundnut (IBPGR-ICRISAT, 1985).

The groundnut stems develop anthocyanin pigments in their epidermal cells, the colour of which may be purple (violet), pink, dark red, light red or green. The stem contains long shoot and glandular hairs with bulbous base. The leaves of the erect types are larger than of spreading. Varietal differences in the pattern and coverage of canopy in different plant types under non-competitive conditions are observed. The leaf area and dry matter regularly increased from 3rd leaf stage up to peg formation. With plant age, the leaf number increased most for spreading varieties and leaf weight increased most for semi-spreading varieties (Velu and Gopalakrishnan, 1987).

The quick coverage of canopy is related to the length of cotyledonary laterals and maintenance of high leaf area index (LAI) is advantageous. It could also be manipulated by plant density and to achieve maximum yield, the LAI, leaf dry matter and total dry matter at 14^{th} leaf stage should be more than 4.0, 175 g m^{-2} and 500 g m^{-2}, respectively (Forestier, 1973).

A high seedling vigour during early stages of crop growth up to the pod filling stage, maintenance of high leaf area duration from the pod filling stage to maturity and efficient translocation of photosynthates (high harvest index) were the major physiological parameters responsible for high yields from early sowings. The canopy development at crop maturity was not always related to kernel yield, however, canopy development at peak flowering had a strong positive association with kernel yield and higher levels of stability for kernel yield could be achieved through correction of canopy development towards compaction in Virginia runners and more pronounced in case of Spanish genotypes (Prasad, 1993).

CGR, NAR and RGR

Though growth is a genotypic character, largely influenced by seasonal and environmental conditions, the dry matter accumulation in groundnut crop follows the growth pattern characterized by (i) a lag phase in early growth, (ii) exponential increases in weight from vegetative to flowering stage, (iii) a linear and maximum growth rate during late vegetative to early pod filling, and (iv) levelling of weight during late pod filling stage. The early growth is due to stem elongation and leaf production, simultaneously the lateral branches accounts for the bulk of later growth. The leaf and stem dry weight increases in sigmoidal fashion upto maximum value, which occur 90 to 100 days after planting. During this period leaves and stems accumulate weight at similar rates, after that the leaf weight declines but stem weight either remains constant or decreases. The roots accounts for 5 to 7 % of the total dry matter, at one month after planting and only 1 to 2%, at harvest.

The growth rate is faster in the erect varieties and they attain high dry matter earlier than in the spreading ones, but in spreading the growth continue for a longer period and hence accumulate more dry matter (Singh and Joshi, 1993). However, the genotypes did not differ markedly in their relative growth rate (RGR) between 25-40 days. The mean net assimilation rate (NAR) of an average crop ranged in between 13.1-15.0 g m^{-2} $week^{-1}$, the runner and bunch did not differ much in NAR, but it was higher in runner during pod initiation (Enyi, 1977). The NAR was low during flowering initiation (25-40 days), pod initiation and pod development (40-70 days) stages but higher during pod filling stage.

There is a relationship between CGR, LAI and both to grain yield and the environmental factor of the surrounding. In Rhodesia, the maximum CGR were 88, 120 and 194 g m^{-2} $week^{-1}$ at 17.9, 20.1 and 23.3^{o}C temperature, respectively (Williams *et al.*, 1975a) and at mean daily temperature 23.3^{o}C, the CGR was highest, but maximum seed yield was obtained at the 20.1^{o}C (Williams *et al.*, 1975b). The average crop growth rate of groundnut in USA is reported to be 191 kg

ha^{-1} day^{-1} (Duncan *et al.,* 1978). While calculating the crop growth rate during pod filling stage the pod weights because of their high energy contents are adjusted by multiplying with a factor coefficient of 1.65 (Duncan *et al.*, 1978) for a well irrigated crop. However this is inappropriate for stressed crop because of lower ratio of kernel to pod weight. Using the shelling percentage of well irrigated crop a conversion coefficient of 2.4 therefore was calculated for kernel tissue weights alone for stressed crop and was used by Matthews *et al.,* (1988b) in their experimentation.

Plant height had a positive relationship with leaf area index, crop growth rate, harvest index and leaf nitrogen content, whereas it had negative relationship with number of branches, net assimilation rate and nitrogenase activity. Leaf area index was positively correlated with crop growth rate and negatively correlated with NAR. Further the pod yield had positive correlation with total dry matter at 60 DAE, leaf area index, net assimilation rate, nitrogenise and leaf nitrogen, however, total dry matter at harvest had negative relationship with harvest index. CGR, RGR and NAR between 60-90 DAS were significantly correlated with pod yield. In Japan, NAR was negatively correlated with LAI, specific leaf area and the distribution of DM to the pod and was positively correlated with leaf N content, Ono (1982).

Assimilation and translocation of dry matter

The carbon fixation comprises a major part of the dry matter, the net CO_2 assimilation is the principle factor determining the productivity. The improvement in the photosynthetic efficiency to obtain high biomass and yield is one of the recent areas of research for crop physiologist. The groundnut is a C_3 plant and assimilates CO_2 by reductive pentose phosphate pathway with CO_2 compensation point near 50 ppm. However, the photosynthetic efficiency of groundnut is almost equal to C_4 plants (Dwivedi *et al.*, 1984). The groundnut leaf is amphistomatus as the stomatal frequency is similar on abaxial and adaxial surfaces with the total for both ranging from 300-400 per mm^2 (Bhagsari and Brown, 1976). But the adaxial surface show high rate of CO_2 diffusion and $2/3^{rd}$ of net photosynthesis. The average photosynthetic rate of groundnut has been reported to be 24 to 41 mg CO_2 dm^{-2} h^{-1} with an apparent photosynthetic (AP) rate of 0.7-1.0 mg CO_2 dm^{-2} s^{-1}) in USA (Bhagsari and Brown, 1976), 20-25 mg CO_2 dm^{-2} h^{-1} in India (Nautiyal *et al.*, 1999b), however photosynthetic rate of as high as 77 mg CO_2 dm^{-2} h^{-1} has been also reported (Trachtemberg and Mc Cloud, 1976). The percentage nitrogen, chlorophyll and specific weights are positively correlated with photosynthetic rate, but the stomatal frequency and photosynthesis are negatively correlated.

The groundnut leaves become less efficient with age after full expansion, the photosynthetic rate increased until the leaf was about 2 weeks old and then decreased as the leaf aged. The AP was highest in leaf-3, the youngest fully-expanded leaf on the branch and lowest in leaf-8, leaf-5 exhibit intermediate (Henning *et al.*, 1979; Sastry *et al.*, 1980). The weekly maximum canopy AP increased from about 1g CO_2 m^{-2} h^{-1} at 3 weeks after emergence to a value of 6.5 at 8 to 9 weeks and thereafter it drops nearly to 1 g CO_2 m^{-2} h^{-1} at 14 to 15 weeks (Ketring *et al.*, 1982). The AP decreased with the plant age, and at 110 and 140 days the average AP decreased 21 and 58% from that of 80 DAE (Trachtemberg and Mc Cloud, 1976). In Growth chamber the AP reached to nearly zero at 40 days after unfolding of leaves, but in field grown crop even the significant AP was observed at 60 days old leaf (Trachtemberg and Mc Cloud, 1976).

The Leaf and stem photosynthesis contribute equally to DM yield till 60 DAS and thereafter stem photosynthesis is more important. Efficiency of reproduction and translocation was highest in Valencia and Spanish. The decrease in photosynthesis (Pn) under stress was associated with a decrease in stomatal conductance (gs) and RWC (Nautiyal *et al.,* 1995).

The translocation of photosynthates involves movement of metabolites from mesophyll cells to phloem tissue, phloem loading, translocation in phloem, unloading and metabolism of photosynthates in the site of utilization. The rate of translocation is positively correlated with net photosynthetic rate; however, environmental factors affect efflux and distribution of photosynthates. During the early stages the partitioning of dry matter is into the leaf and stem but in later stages it accumulates simultaneously in the vegetative parts and fruits as these two phases overlap in groundnut. Thus the quicker cessation of the vegetative growth (dry matter accumulation in stems) makes more photosynthates available for pods and is a desirable character. In USA the yield improvement was due to partitioning of assimilates between vegetative and reproductive parts, length of grain-filling period and rate of fruit development (Duncan *et al.,* 1978).

The auto radiographic study have shown that in vegetative stage, growing leaves exported most of the 14C to the apices, young expanding leaves and to the roots, but soon after the initiation of pegs and pod the developing pod became the major sinks, at pod developmental stage the foliage of each branch was restricted mostly to the pods produced by that branch (Khan and Akosu, 1971). The basal leaf (L-3) of the first branch exported only downwards to the pods attached to it, the fifth leaf exported both acropetally to the apex and basipetally to the pods, and the youngest unfolded leaf exported mostly to apex and only a small portion to the pod attached to the branches (Khan and Akosu, 1971). The metabolic reserves are built up on the fruit and seed coat during early maturation and utilized later during seed development when available translocated photosynthate gets diminished.

Reproductive Growth

The *Arachis* is a perennial or annual legume with 3 or 4 *foliolate*, stipulate leaves, papillionate flowers, a tubular hypanthium and underground fruits (pods). The underground fruiting habit and highly condensed reproductive branches (inflorescence) has led to an inaccurate description of this plant till 1950s. A unique structure `peg' is an expanded intercalary meristem at the base of the basal ovule resulting in a lomentiform carpel of 1-5 segments, each containing single seed with two massive cotyledons and a straight embryo. The bunch and runner groundnut types differ in their duration (110-120 days in sequential and 130-150 in alternate branched) and seed dormancy.

The branching in groundnut is related with pod yield and there is a good correlation between yield and branching and the length of internodes. It is desirable to initiate early branching, which increase the total flower bearing areas and the chances of pod formation because the flower borne at the basal part of the plant has greater chance to develop into pods. The cultivated groundnuts are classified by assigning main axis, as `n' and the first, second and third branches as n+1, n+2 and n+3. The two main botanical sections of *A. hypogaea* differ in the distribution of vegetative branches and inflorescences on the main axis and the branches. In sequential type (Spanish and

Valencia), inflorescences are borne from the second nodes of the primary branches (n+1) and are usually bunch type. In the Spanish type the n+1 branches grow upwards from the very beginning whereas in the Valencia group, these branches grow outward first and then upward. In the alternate branching type (Virginia), the first two nodes of primary branches bear secondary (vegetative) branches (n+2), the next 2 nodes bear inflorescences and the next 2 again vegetative branches and so on. The same sequence is repeated on the secondary branches, but the inflorescence never develops on the main axis. The runner forms have prostrate n+1 branches (Virginia runner), whereas the spreading forms have more upright branches (Virginia bunch). The flowering, pollination and pegging are the main reproductive growth phases, which are described, separately in the following text.

Flowering, pollination and pegging

The flowering in groundnut commences 20-30 days after emergence (DAE) depending upon genotypes and environment and most of the flowers appear in between 35-70 DAE. There are usually 4 stages of flowering, the pattern of which depends upon cultivar and environment. At first stage only a few flowers are produced followed by a stage of rapid flowering, peak is reached at the third stage and decline in the fourth stage. The groundnut produces much more flowers than it develops pods. Nearly 40% of the flowers fail to develop, while another 40% produce only pegs. The ratio of pod produced to flower is generally 1:7 and removal of flowers result in prolong flowering. The flower bud is only 6-10 mm long a day before anthesis, during the day hypanthium elongates to 10-20 mm, but at night elongation is faster and at the time of anthesis the buds are 50-70 mm long. The buds generally open at the beginning of the light period, but may be delayed due to cold or wet weather. The Anther may dehisce 7-8 h before the opening of flowers. On warm and sunny days, the flowers wither within 5-6 h after flowering leaving ovary and style which remains turgid after the day of anthesis.

As the daily mean temperature rises from 20 to 30^{o}C the number of days required for first flowering is reduced from 38 to 25 days in sub species *hypogaea* (Virginia runner) and from 35 to 24 days in sub species vulgaris (Valencia and Spanish) (Ono, 1979). The number of flowers produced per plant varies among genotypes and between botanical group. Runner produced more flowers per plant and also had a longer duration of flowering than the erect one. The number of flowers produced per plant ranged from 40-250 in Runner and 100-150 in bunch types. The cumulative flower production of `Makalu Red' a spreading type was 240 (Williams *et al.,* 1975a). Flowering gets reduced as pegging and fruiting progress. Flowering stops when the soil moisture drops to wilting point but continuation of fruiting depends on the length of drought. RH had a positive effect on the daily production of flowers. The groundnut is a self-pollinated crop as the stigma is enclosed in the keel, but high frequency of cleistogamy has been reported (Murty *et al.,* 1980). The stigma protrudes above the anthers and is receptive before anthesis. In nature the stigma and anther are exerted in few groundnut causing cross-pollination from less than 1% to 3.9%. Fertilization is completed in about 6 h after pollination (before mid-day) and flower wither. The ovary at the base of the calyx tube becomes mobilised for growth within a week after fertilization and an intercalary meristem below the ovary is activated. The developing ovary pierces through the floral parts by the activity of the meristem to reveal an elongating peg called carpophore (gynophore) which bears fertilized ovules at its tips. The growth of peg is geotropic until it penetrates the soil upto 5-7 cm depth. The tip then becomes diageotropic and ovary starts developing into fruit. The peg begins rapid geotropic elongation and starts to penetrate the soil about 7 to 14 days after fertilization of the flower. Following soil penetration the ovary at the peg tip reinitiates growth and a groundnut fruit is formed. If the pegs fail to contact and enter the soil it usually wither, however, in humid conditions some cultivars belonging to *fastigiata* occasionally form underdeveloped small and green aerial pods. The portion of peg in the soil is white, while the aerial portion of peg normally develops pink to purple colour due to anthocyanin pigments which is cultivar dependent and very much influenced by the environment. The thickness of peg is 1-2 mm, the cultivars of subspecies *fastigiata* have thicker pegs than *hypogaea*. The peg growth is affected by relative humidity and on an average, the daily peg growth is 0.62 cm at 100% RH, and only 0.02 cm at 57% RH. But generally the RH of the air is quite low in many groundnut-growing regions at the start of flowering and at the time of pegs penetrate into the soil.

In groundnut, the flowering and fruiting are of an indeterminate type, which generally has an effect on pod yield and quality. The ideal type of groundnut would be one that sets all its young fruits within 4-5 days and spends the rest of the growing season filling them. Same times there are two peaks of flowering in normal sown crop many part of India causing higher reproductive efficiency than the late sown crop which has no peak. More numbers of flowers produced upto 45 DAS cause a greater reproductive efficiency and higher pod yield. The continuous removal of flowers increased the daily flower production from 3 to 20. Talwar *et al.,* (2002) found that Vegetative growth was increased by flower removal in groundnuts cv. M 13, pod number increased by removing early phase (0-4 weeks) flowers and decreased by removing middle (5-9 weeks) phase flowers, or middle + late flowers (9 weeks to maturity). Gynophore removal in the late phase increased numbers of mature pods. Removal of pegs for one week from the onset of flowering increased root biomass and aerial pegs but reduced pod yield (Narayanan *et al.*, 1984). The Virginia cultivars compensated better for initial lost pegs than bunch types.

Seed growth and development

For the initiation of pod formation darkness is essential and a mechanical stimulus is needed for the normal thickening and diageotropic orientation of the pods. The peg, after reaching its maximum depth in soil, becomes diageotropic and horizontal and pod development initiate from enlargement of pod at the base. The normal podding zone is 4-7 cm below the surface. The pod expands rapidly in the soil by the development of a large parenchymatous tissue called endocarp lying between the ovules and shell. The endocarp recedes with ovules growth and disappears completely when the seed have matured. In the mean time the inner face of the shell becomes increasingly dark brown due to increase in tannin content and become very dark brown at maturity. It takes about 60 days from the time of fertilization to full maturity. The swelling of ovaries commences two days after, the pod attains its maximum size within 3 weeks. During the pod filling the leaves near the plant periphery contribute most to the pods and the photosynthetic capacity of leaves decreased during this period (Henning *et al.,* 1979).

The optimum soil temperature in the podding zone is 31-33^{o}C (Ono, 1979), at lower temperature of around 23oC the number and weight of pod increases but require longer filling period (Dreyer *et al.,* 1981). The fertilized flowers ranged from 50-60% in runner and 20-70% in bunch types and only about 60-65% of these fertilized flowers elongated as pegs. All the pegs do not grow long enough to reach the soil and to develop into pods, and all the pegs entering into soil do not develop into mature pods. On an average about 40 % of the pegs do not produce pods. Thus finally only 8- 16 % of the flowers turned into pod in bunch types while 12-18 % turned into pod in runner types.

Generally most of the early formed flowers develop into pods, but the flowers that appear 70 DAS form only immature pods at harvest. Also the early formed flowers of an inflorescence inhibit the development of the other flowers into pegs (Bunting and Elston, 1980).

The groundnut fruit that is generally referred to as a pod is a indehiscent and up to 10 cm in length. The mature pod normally contains 2-4 seeds but 5 and 6 seeds per pod have also been recorded occasionally. The fruit consists of two valves, structurally dehiscent but functionally indehiscent and when pressed, splits along the longitudinal suture. The shell consists of an outer spongy layer, a middle fibrous and woody layer and an internal layer that with maturation becomes thin and papery. The mechanical tissues on the pod give it the reticulate pattern. The cultivars differ in fruiting patterns, in bunch type the pods are more near the tap root than in runner type. The pod number and weight can be measured at about 60 to 70 DAE, pod number rises rapidly to a maximum at 100-120 DAS and than remain constant till harvest. The pod weight increases in a linear fashion during pod filling and the linear growth rate continues until near harvest. The rate of pod dry matter accumulation during linear growth phase ranges from 5 to 10 g m^{-2} ground area day^{-1} (Singh, 2003).

The competition between the developing vegetative sinks and the reproductive sinks appears to be one of the limitations in the productivity. Shading at full bloom stage reduces yield. As the assimilate supply is not limiting factor the pods initiated earlier had a higher growth rate than those of later. This is the reason why the earlier pods contained more seeds than later formed, and the basal nodes bear more pod than upper nodes. It is possible to induce the upper nodals gynophores to set pods but that reduces the yield of the basal nodal pods. Moreover, the induction of pods in upper nodal gynophores prolongs the life cycle of plant. Each inflorescence bears only a single fruit even though several fertilized ovaries develop from the latter flowers.

The seeds size, weight and seed coat colours are the important economic and distinguishing characters of groundnut cultivars. The seed length varying from 7 to 21 mm, diameter from 5 to 13 mm and seed wt. from 0.10 to 1.5 g have been reported. Generally, the cultivars belonging to Virginia group have larger and heavier seeds and those of Valencia and Spanish have smaller seeds. However, the seed and pod size distribution are a function of pod maturity and plant age (Williams *et al.*, (1987). The seed size also varied according to the position within a pod and generally basal seeds were smaller than the other in 4, 3 and 2 seeded pods. Light rose to rose colour is most preferred by the people. Generally there are two seeds per pod, the single seeded pods may occur in almost all cultivars but it is not a cultivar specific. Three seeded pods are found in both *hypogaea* and *fastigiata* sub species. Bunch cultivars belonging to var. *Fastigiata* possess predominantly three or four seeded pods.

As groundnut matured the Moisture content decrease, protein content remain unchanged, carbohydrates decrease and oil content increase. Sum of oleic and linoleic acids as percentage of total fatty acid is increased with maturity as did unsaturated fatty acids contents. The number of days and cumulative degree days are the important factor assessing the maturity. Cracking sound when a pod is pressed and blackening of inner surface of shell is the most important criterion for assessing pod maturity.

Yield and yield attributing characters

The yield depends on number of mature pods and 100 kernel weights, thus yield is the summation of the rate of fill for each fruit multiplied by the duration of its filling period. Most of the yield variation are due to differences in three physiological processes; the partitioning of assimilate between vegetative and reproductive parts, the length of the filling period, and the rate of fruit establishment. The number of flowers, branches and pod number per plant were reduced with closer spacing and increased with wider spacing. As a thumb rule, with 2-2.9 lakh plants ha^{-1}, each single seeded pods plant^{-1} adds 100 kg pod ha^{-1} and double seeded pods plant^{-1} 200 kg pod ha-1. So to achieve if pod ha^{-1} each pod should bear 5 double seeded pod and for 10 t pod ha^{-1} each plant should bear 50-75 pods. Thus, high yielding varieties produce more number of pods through higher number of pegs (flower to peg ratio), higher percentage of the pegs forming mature pods (peg to pod ratio) and more number of branches and higher 100-kernel weight. However, in USA, the improvement in yields by newly evolved cultivars over the old one were mainly due to (i) more efficient carbon fixation through efficient leaves, better canopy geometry or greater leaf area duration, (ii) the partitioning factor, and (iii) duration of fruit growth (filling period) (Duncan *et al.,* 1978).

Though only a small percentage of flowers result into pods, conditions favouring rapid flowering early in the season contribute to high yields. The factors affecting yields depend on the environmental, agronomic practices and biotic stresses. This is probably the main reason why the newly evolved high yielding varieties bred for one area do not perform better at other places. The yield is determined by total number of pod as the fruit size for a cultivar is constant at maturity. Higher pod yield was attributed to high photosysnthetic efficiency of the canopy and remobilization of stem reserves resulting in a better partitioning (Narayanan *et al.,* 1981). Due to longer duration and more sunshine hours, the dry season crop produced more pod yield and total dry matter than the wet season crop (Singh and Joshi, 1993). As the dry season crop took 10-14 days more time for its maturity, it received more PI, PAR than the wet season crop (Singh and Joshi, 1993) but the energy harvesting capacity of groundnut do not differ during kharif and rabi-summer seasons (Dwivedi and Saha, 1983).

In bunch groundnuts, under field conditions the total (cumulative) number of flowers produced plant^{-1} was not related to pod yield, however, a positive relationship was observed between the total number of flowers produced during the first 2 weeks after commencement of flowering and pod yield (Sastry *et al.,* 1985). Flower production is therefore not a constraint in productivity. The study indicated that the genotypes having the highest number of developing pods at the 70th day were those, which also produced the highest number of flowers during the first 2 weeks after commencement of flowering. Genotypes, which showed greater synchrony in flowering during the earlier phase of reproductive growth also, showed higher pod yields.

Partitioning

The partitioning of photosynthate to fruit during pod filling stage is the most influential physiological factor in yield determination of groundnut. The high yield is associated with rapid increase in pod number and near cessation of vegetative growth during pod filling. The partitioning coefficient range from 40-98 % and the partitioning of a higher percentage of photosynthate to pods result in higher pod growth rates (g m^{-2} day^{-1}) and higher yields. Duncan *et al.*, (1978) made the first attempt to analyse the physiological factors accounting for increase in yield potential in USA and reported that the partitioning of assimilate had the greatest effect on fruit yield and the estimates of partitioning to fruit ranged from 41% in the `Dixie Runner' released in 1943 to 98% in `Early Bunch' released in 1977.

In India many related released cultivars are phosynthatic efficient and have high yield too. Ravindra *et al.*, (1990) reported that TMV 10 and JL 24 varieties are photosynthetically efficient but their poor yield during drought is associated with poor sink formation and translocation efficiency the partitioning has been forward to be 20-50% depending upon the cultivars and locations and season. In Indian cultivars, the variety MH 2 showed maximum partitioning of 42% followed by GG 2, 39%.

The yield of groundnuts differs mainly because of differences in their ability to develop the reproductive sink rather than differences in their leaf area or crop growth rate (Source). The peg production and pod formation are influenced differently by assimilate supply, the pegs may be initiated even when the plant does not have the assimilate `status' necessary to initiate pods on these pegs, however, once more pegs are initiated the assimilate supply is inadequate for the full achievement of reproductive growth potential which results in a fewer and smaller kernels in each pod (Williams, 1979c). The yield advantages due to moderate water deficit during the pre-flowering phase are associated with greater pod synchrony after the release of water stress, resulting in production of more mature pods (Nageswar Rao *et al.*, 1988). When stress is released, the plant try to set more fruiting sites with the existing assimilates as the vegetative site demanding assimilate supply are reduced.

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