Genetic improvement of peanut in Argentina between 1948 and 2004: Light interception, biomass production and radiation use efficiency

Ricardo J. Haro [a],[*], Jorge Baldessari [a], María E. Otegui [b]

[a] *Estación Experimental Agropecuaria Manfredi del Instituto Nacional de Tecnología Agropecuaria (INTA), CC 5988, Córdoba, Argentina*
[b] *Facultad de Agronomía, Universidad de Buenos Aires, and Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET) at INTA Pergamino, Argentina*

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ABSTRACT

An important milestone in Argentina peanut (*Arachis hypogaea* L.) breeding was the shift in the 1970s from cultivars with erect growth habit (CEGH) to cultivars with procumbent growth habit (CPGH). CPGH improved seed yield but also lengthened growth cycle. However, there is no information if the change in growth habit (GH) may have involved a phenotype with a canopy architecture that makes a differential capture and use of resources. Field experiments were performed to compute leaf are index (LAI), the fraction of incident photosynthetically active radiation intercepted by the crop (fIPAR), biomass production, radiation use efficiency (RUE) and harvest index (HI). Four cultivars of each GH, released between 1948 and 2004, were evaluated. The LAI was always larger among CPGH than among CEGH. Only the former reached the critical LAI. Likewise, fIPAR of CPGH was higher than that of CEGH throughout the crop cycle. Maximum fIPAR differed between GHs ($P < 0.001$), with interannual mean values of 0.95 for CPGH and 0.77 for CEGH. Final total biomass of CPGH was 37% larger than that of CEGH. RUE values ranged between 1.88 and 2.46 g MJ^{-1}, and differed significantly ($P \leq 0.008$) between GHs (CEGH > CPGH), Years (Year 1 > Year 2) and GH × Year (CPGH Year 1 > CPGH Year 2 = CEGH Year 2 = CEGH Year 1). CPGH improved pod yield (+64%), seed yield (+101%), HI of pods (+29) and HI of seeds (+56%) respect to CEGH. Considering the effects of GH on the capacity of cultivars for achieving the critical LAI with current crop management, future research should focus on alternative sowing patterns (e.g., reduced row spacing among CEGH).

1. Introduction

During most of the 20th century, peanut breeders aimed almost exclusively at developing cultivars with enhanced seed yield (Holbrook and Stalker, 2003). Consequently, selection was focused on yield per se and was conducted in trials at sites representative of the target environment, a common practice in extensive grain crops (Betran et al., 2004; Orf et al., 2004). This process produced an increase in the number of reproductive structures, reproductive efficiency (Coffelt et al., 1989; Haro et al., 2013; Seaton et al., 1992)

and seed weight (Haro et al., 2013) of new cultivars as compared to the old ones.

Until the mid-1970s, processing and export peanut companies from Argentina required grains with high levels of oil. Farmers achieved this demand by sowing cultivars of erect growth habit (CEGH), representative of the subspecies *fastigiata*, since these cultivars were characterized by producing grains with oil levels close to 48%. These cultivars had a growth cycle of 1209–1365 °C day (ca. 120–135 calendar days), which was computed in a previous study (Haro et al., 2015) using a base temperature of 11 °C (Williams and Boote, 1995). From 1975 onwards, the demands, therefore the objectives, of the export market changed to confectionery peanut, which led breeders to focus on new cultivars with enhanced yields and seed grade. Since that moment, farmers have attempted to produce large volumes of grains. This new phase started with the release of the first CPGH (Virginia 5 INTA), representative of the subspecies *hypogaea*, with significant results in terms of yield with respect to the preceding CEGH (Haro et al., 2013). Introduction of CPGH brought an extended growth cycle

(1667–1697 °C day computed as explained above, ca. 140–145 calendar days), whereas seed oil content remained unchanged (Giandana, 2006). This lengthening of the crop cycle was 31%, comparing GHs averages (Haro et al., 2015), which was caused by an extension from R5 stage onwards (57% of increase of CPGH respect to CEGH). Prior to the R5 stage, CPGH just extended the cycle 13% compared to CEGH, which caused similar time occurrence for R5 stage between GHs. Over the last decades, the demand for improved seed yield was met via the release of CPGH, suggesting that other traits may have accompanied the increase in growth cycle for producing increased seed yields. On the one hand, change in growth habit (GH) may have involved a phenotype with a canopy architecture that makes a differential use of resources with respect to the CEGH. On the other hand, reducing crop duration in order to promote the occurrence of more floral cohorts in environments of high photothermal levels (i.e., high temperature and solar radiation) without yield penalty became the greatest challenge to Argentine peanut breeders.

In maximizing yield, the crop must maximize the acquisition and conversion of a resource into assimilates (i.e., biomass production), as well as the allocation of assimilates to economic yield (i.e., biomass partitioning). For example, when water is not a limiting factor, biomass can be expressed as the product of incident photosynthetically active radiation (IPAR) on the crop, the fraction of IPAR that is intercepted by its canopy (fIPAR) and the efficiency of conversion of radiation to the amount of assimilate partitioned to economic yield components (Charles-Edwards, 1982; Monteith, 1977). fIPAR is a function of leaf area, leaf distribution and leaf orientation relative to the sun. Under well-watered conditions, the GH (i.e., branching pattern and insertion of branches with respect to the main stem) of peanut cultivars defines a canopy architecture that affects light capture and light attenuation within the peanut crop (Boote and Loomis, 1991). Radiation use efficiency (RUE) expresses the crop mass accumulation relative to the amount of light intercepted by the leaves. When growth is not limited by other factors, the most appropriate measure of RUE is obtained by fitting a linear function to the relationship between cumulative biomass and cumulative intercepted IPAR (IPARi). RUE is the slope of this function (Sinclair and Muchow, 1999).

Finally, peanut economic yield depends upon the allocation rate of biomass into reproductive organs, which is represented as a harvest index (HI). Matthews et al. (1988) expressed HI as a function of assimilate partitioning to pods (HI_{POD}); this partitioning index has the greatest effect on pod yield under both well-watered conditions (Dwivedi et al., 1998) and terminal drought (Wright et al., 1991). The use of cultivars that combine the ability to intercept more IPAR, use it more efficiently and partition more assimilates to pods, should be advantageous. Accordingly, it is expected that capture and use of environmental resources as solar radiation will be different between GHs, and that those differences be enhanced under the strict crop implantation practices applied in Argentina since the release of the first cultivar, which means a single row spacing of 0.7 m and a stand density of 14 plants m^{-2}.

There is no evidence of the trends caused by peanut breeding on resource capture and resource use efficiency. A better understanding of the differences between GHs and how these differences are related to the yield potential of both cultivar types may contribute to the selection process and future yield improvement in peanut. The objective of our study was to compare biomass production, fIPAR, RUE and partitioning of assimilates among peanut cultivars of contrasting growth habit (erect and procumbent) released in Argentina between 1948 and 2004. The present manuscript completes a broader study of the changes involved in the move from CEGH (subspecies *fastigiata*) to CPGH (subspecies *hypogaea*), with previous papers (Haro et al., 2013, 2015) focused on the effects of differences in phenology, source/sink relationships, seed yield and its components.

2. Materials and methods

2.1. Experimental design and crop husbandry

Two field experiments were conducted during the 2010–2011 (Year 1) and 2011–2012 (Year 2) growing seasons at the research station of the National Institute of Agricultural Technology (INTA), located in Manfredi (31°49′ S, 63°46′ W), Córdoba Province, Argentina. A detailed description of cultivars, crop husbandry and measurements can be found in Haro et al. (2013). Briefly, eight cultivars of contrasting GH developed for this region and released between 1948 and 2004 were sown on 19-Oct-2010 (Year 1) and 01-Nov-2011 (Year 2). Seeds were hand-planted at the row spacing (0.7 m apart) and stand density (14 plants m^{-2}) traditionally used by farmers. Treatments (cultivars) were arranged in a completely randomized block design with three replicates; plots were four rows wide and 15 m long. The soil was a silty loam Typic Haplustoll (USDA Soil Taxonomy) and experiments received drip irrigation to keep the uppermost 1 m of the soil profile near field capacity throughout the growing season. Weeds and foliar diseases were adequately controlled.

Daily values of incident global solar radiation and air temperature were obtained from a weather station (LI-COR 1200, Lincoln, NE) installed at the experimental field. Mean daily air temperature (T_{mean}) was computed as the average between daily minimum (T_{min}) and daily maximum (T_{max}) temperatures. An optimum temperature (T_{opt}) of 34 °C (Vara Prasad et al., 1999a) was used for computation of the number of days with $T_{max} > T_{opt}$ as indicative of heat stress. Incident solar radiation was converted into IPAR by multiplying by 0.45 (Monteith, 1965).

2.2. Measurements

Crop phenology (Boote, 1982) was monitored on three plants tagged at R1 (first flower visible in at least 50% of the plants) per plot. fIPAR measurements and biomass sampling started at R1 in both experiments and continued fortnightly up to maturity at R8. Total biomass (roots excluded) was surveyed fortnightly between R1 and R8 (final harvest). For this purpose, plants within a 0.35 m^2 area of the two central rows were harvested, separated into leaves plus stems (vegetative biomass) and pods (reproductive biomass) when present, and dried at 70 °C until constant weight. Corrected total biomass (in g m^{-2}) was calculated as vegetative biomass plus reproductive biomass multiplied by a 1.65 energy correction factor (Duncan et al., 1978). Details of these measurements were given in Haro et al. (2015). From R3 (beginning pod) onwards, the HI of pods (HI_{POD}) was calculated as pod weight divided by total biomass weight. At R8, pods were weighed to quantify final pod and seed yields, and the HI of seeds was calculated as seed weight divided by total biomass weight. On each sampling date, leaf area was measured using an LI-3000 leaf area meter (Li-Cor, USA), and leaf area index (LAI) was calculated as the ratio of sampled leaf area to harvested ground area.

fIPAR was estimated from measurements performed above and below the green leaf portion of the canopy at intervals of ca. fifteen days, as described in Haro et al. (2015). Daily values of fIPAR were obtained by linear interpolation, and applied to daily IPAR values for obtaining daily intercepted IPAR (IPARi). RUE (in g MJ^{-1}) was estimated as the slope of the relationship between energy-corrected cumulative total biomass (in g m^{-2}) and cumulative IPARi (in $MJ\ m^{-2}$).