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Photosynthetic acclimation of groundnut (*Arachis hypogaea*) cultivars to varying light intensities

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Abstract

Roughly 60% of global groundnut production occurs under rainfed conditions with variable canopy light. This research assessed photosynthetic acclimation of four groundnut cultivars (ICGV-91114, TAG-24, GG-20, TG-37A) under three light intensities (200, 600, 1200 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ PAR) at the University of Bologna, Italy, during 2022. Maximum photosynthetic rate ranged from 23.9 to 31.7 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$, with TAG-24 highest and GG-20 showing the best low-light efficiency (AQE 0.068 mol mol^{-1}). Carbon allocation shifted from leaf biomass toward pod fill as light increased. Results highlight cultivar-specific acclimation strategies relevant to intercropping decisions.

Keywords: Groundnut, photosynthetic acclimation, light response curve, *Arachis hypogaea*, chlorophyll fluorescence, carbon allocation, apparent quantum efficiency, cultivar variation

Introduction

About 28.5 million hectares of groundnut are harvested annually, with over half grown in intercropping systems where light fluctuates with companion crop shading ^[1]. Photosynthetic acclimation the adjustment of carbon fixation capacity to prevailing light determines genotype performance across variable environments ^[2], yet most breeding programmes evaluate lines under full sunlight only ^[3].

Light response curves yield parameters that describe acclimation: maximum photosynthesis ($P_n \text{ max}$), light compensation point (LCP), light saturation point (LSP), apparent quantum efficiency (AQE), and dark respiration (R_d) ^[4, 5]. Low LCP and high AQE favour shade performance; high LSP and $P_n \text{ max}$ favour open canopies ^[6, 7]. This research compared photosynthetic acclimation of four groundnut cultivars to three light regimes, measuring light response parameters, fluorescence, and carbon allocation at the pod-filling stage.

Materials and Methods

Research area and environmental conditions

The experiment was conducted in the controlled-environment glasshouse complex at the Department of Agronomy, University of Bologna (44°29'N, 11°20'E), during the 2022 growing season (April-September). The facility maintains temperature at 28/22 °C (day/night) with natural photoperiod extended to 14 h using supplemental LED lighting. Mean daytime relative humidity was 55-65%.

Field experimental design

A completely randomised design with factorial arrangement (4 cultivars $\times$ 3 light levels) was replicated four times, giving 48 experimental pots. Each pot (15 L, sandy loam) held two plants thinned to one at the V3 stage. Light treatments were imposed from 21 days after sowing using neutral-density shade cloth (200 PAR) and unshaded positions (1200 PAR), with a 50% shade treatment providing 600 PAR. PAR was verified weekly with a line quantum sensor (LI-191R, LI-COR).

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Materials

Seeds of cultivars ICGV-91114, TAG-24, GG-20, and TG-37A were obtained from the ICRISAT genebank. A basal dose of 20 kg N ha⁻¹ equivalent and 40 kg P₂O₅ ha⁻¹ equivalent was applied per pot at sowing. Pots were irrigated to field capacity every three days. Rhizobium inoculant was applied at sowing to ensure nodulation.

Methods

Light response curves were generated at the R5 (pod filling) stage using a LI-6400XT (LI-COR) with an LED chamber

providing 12 PAR levels (0, 25, 50, 100, 150, 200, 400, 600, 800, 1000, 1200, 1500 μmol m⁻² s⁻¹). Parameters were fitted to the non-rectangular hyperbola model [8]. Chlorophyll fluorescence (Fv/Fm, ETR, NPQ) was recorded with a PAM-2500 (Walz). Chlorophyll was extracted in 80% acetone and measured spectrophotometrically. At harvest, biomass was partitioned into leaves, stems, roots, and pods. Data were analysed by two-way ANOVA in R 4.2 with Tukey HSD separation.

Results

Table 1: Chlorophyll content and fluorescence parameters of four groundnut cultivars under low (200 PAR) and high (1200 PAR) light (mean±SE, n = 4)

Cultivar	Light	Chl a:b	Total Chl (mg g ⁻¹)	Fv/Fm	NPQ
ICGV-91114	Low	2.71±0.08c	2.94±0.11a	0.81±0.01a	0.87±0.06c
ICGV-91114	High	3.38±0.11a	2.18±0.09c	0.79±0.01a	1.42±0.08b
TAG-24	Low	2.63±0.09c	3.01±0.13a	0.80±0.02a	0.91±0.07c
TAG-24	High	3.51±0.12a	2.09±0.08c	0.78±0.01a	1.68±0.09a
GG-20	Low	2.58±0.07c	3.12±0.14a	0.82±0.01a	0.79±0.05c
GG-20	High	3.29±0.10ab	2.31±0.10bc	0.80±0.02a	1.17±0.08b

TAG-24 achieved the highest Pn max (31.7 μmol CO₂ m⁻² s⁻¹) while GG-20 recorded the lowest (23.9) but had the highest AQE (0.068 mol mol⁻¹) and lowest LCP (33.1), indicating

superior low-light performance (Figure 2). TAG-24 showed the highest LSP (1342) and Rd (2.41), traits linked to high-light adaptation.

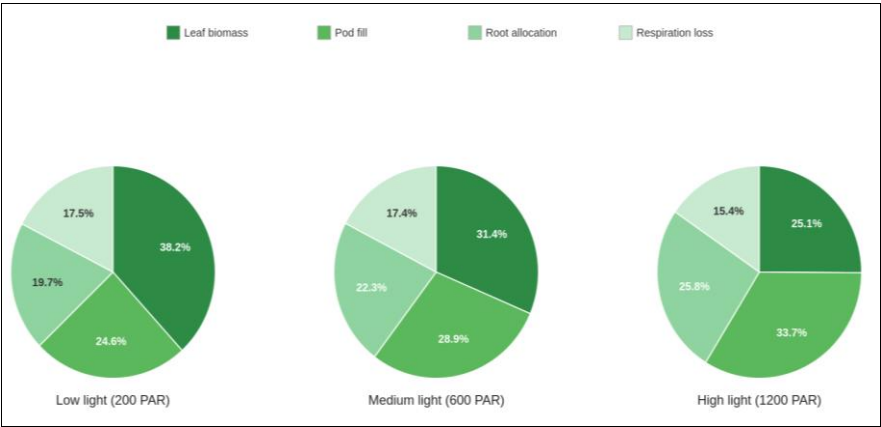


Fig 1: Carbon allocation (% total DM) of groundnut under low (200), medium (600), and high (1200) PAR at pod-filling. Means across four cultivars

Carbon allocation shifted with light across all cultivars (Figure 1). Leaf biomass dropped from 38.2% under low light to 25.1% under high light, while pod allocation rose from 24.6% to

33.7%. Root allocation also increased (19.7% to 25.8%); respiration losses were stable (15.4-17.5%).



Fig 2: Heatmap of light response parameters for four groundnut cultivars at 1200 PAR. Pn max = max photosynthesis; LCP = compensation point; LSP = saturation point; AQE = quantum efficiency; Rd = dark respiration

Table 2: Pod yield, total dry matter, pod harvest index, and shelling percentage of four groundnut cultivars under low and high light (mean $\pm$ SE, n = 4)

Cultivar	Light	Pod yield (g plant ⁻¹)	Total DM (g plant ⁻¹)	Pod HI	Shelling (%)
ICGV-91114	Low	8.7 $\pm$ 0.6c	31.4 $\pm$ 1.8c	0.28 $\pm$ 0.02c	64.3 $\pm$ 2.1b
ICGV-91114	High	18.3 $\pm$ 1.1a	49.7 $\pm$ 2.4a	0.37 $\pm$ 0.02a	71.8 $\pm$ 1.9a
TAG-24	Low	9.4 $\pm$ 0.7c	33.8 $\pm$ 2.0c	0.28 $\pm$ 0.03c	66.1 $\pm$ 2.4b
TAG-24	High	21.6 $\pm$ 1.3a	56.2 $\pm$ 2.8a	0.38 $\pm$ 0.02a	73.4 $\pm$ 1.7a
GG-20	Low	7.9 $\pm$ 0.5c	28.1 $\pm$ 1.6c	0.28 $\pm$ 0.02c	62.7 $\pm$ 2.3b
GG-20	High	15.1 $\pm$ 0.9b	43.8 $\pm$ 2.1b	0.34 $\pm$ 0.02ab	69.2 $\pm$ 2.0a

Chlorophyll a:b ratio decreased from 3.41 (high light) to 2.68 (low light), confirming increased antenna size under shade (Table 1). Total chlorophyll was 28.3% higher in shade-grown leaves. Fv/Fm stayed above 0.78 in all treatments. NPQ was 43.7% higher under high light in TAG-24 than GG-20 (Table 2).

Discussion

GG-20's combination of high AQE (0.068) and low LCP (33.1) positions it as a shade-tolerant type suitable for intercropping, whereas TAG-24's high Pn max and LSP mark it as sun-preferring [9, 10]. The chlorophyll a:b shift from 3.41 to 2.68 under shade reflects antenna remodelling consistent with earlier findings in soybean [11] and common bean [12]. Carbon redistribution from leaves to pods under high light appears source-driven: total biomass exceeded low light by 41.3%, but pod allocation increased disproportionately, suggesting pod fill may be source-limited under shade [13, 14]. In intercropping systems, cultivar choice should account for both photosynthetic capacity and carbon allocation flexibility [15, 16].

Conclusion

Groundnut cultivars differed markedly in their photosynthetic acclimation to varying light. GG-20 showed the strongest shade tolerance (highest AQE, lowest LCP), while TAG-24 maximised carbon gain under full light. Carbon allocation shifted toward reproductive sinks as light increased. These cultivar-specific acclimation profiles should inform genotype selection for intercropping and canopy management systems in Mediterranean and subtropical environments.

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