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Photosynthesis Rate does not relate with Dry Matter Accumulation in Chickpea

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Seedlings growth rates of chickpea, mustard and wheat were significantly different. The growth rate of mustard was the highest followed by wheat and chickpea. Seedling growth rates were analysed in relation to net CO_2 assimilation rates and leaf area development. Mustard seedlings had the fastest rate of leaf area development while chickpea seedlings exhibited very slow leaf area development. CO_2 assimilation rates of chickpea, wheat and mustard leaves in the seedling stage were quite similar. Differences in seedling growth rates among chickpea cultivars were correlated more to leaf area development. Seedling growth rates and leaf area development of chickpea cultivars obtained support from the hypothesis that differences in dry matter accumulation of wheat, mustard and chickpea seedlings are related more to the rate of leaf area development rather than CO_2 assimilation rate per se. Chickpea seedling growth and leaf area development is limited by photosynthate supply under adequate nitrogen nutrition.

Key Words : Chickpea, Photosynthesis rate, Seedling growth, Leaf area growth rate

Introduction

Chickpea the major pulse crop of India is grown in North India after cessation of monsoon rains. Germination and seedling establishment of chickpea is dependent on the soil moisture status. Seedling growth in chickpea is very slow and the delay in the closure of crop canopy has been identified as one of the factors limiting biomass production (Khanna-Chopra & Sinha 1987).

Symbiotically grown legume seedling growth may be C-limited or N-limited. This is specifically true for the early period of seedling establishment wherein root nodules are not formed as yet. Nitrogen nutrition of chickpea seedlings is met by the addition of urea (20 kg N ha^{-1}) at planting which is sufficient to support 77 g dry matter m^{-2}. Dry matter accumulation in 1 month old chickpea seedlings is only 22 gm^{-2}. Moreover, increasing the urea dosage does not promote seedling growth but inhibits nodulation and nitrogen fixation (Khanna-Chopra, personal observation). Hence, contrary to the published reports on soybean, nitrogen availability may not be the factor limiting seedling growth in chickpeas (Williams et al. 1981, Mahon & Child 1979).

Is chickpea seedling growth C-limited? Do chickpea leaves develop slowly due to lack of photosynthate availability? Although, it is recognised that leaf area index is an important determinant of plant productivity (Watson 1952), studies elucidating the mechanism of leaf area development are very few.

The present paper compares the photosynthetic characteristics of chickpea leaves with wheat and mustard which show comparatively much higher seedling growth rates under similar environmental conditions. In addition the effect of CO_2 enrichment on seedling growth and leaf area development in chickpea is also examined.

Materials and Methods

Five chickpea cultivars diverse in genetic origin, namely JG-62 (Desi), M 109, BG 261, BG 267 and BG 256, were grown in the field in a randomised block design with the plot size of 5 m × 5 m Chickpea rhizobium culture was obtained from the Microbiology Division of the Indian Agricultural Research Institute and applied to the seeds before planting. Plant population was 35 plants m^{-2}. Fertilizer 20 kg N ha^{-1} as urea and 40 kg P ha^{-1} as superphosphate was added before planting the seeds. Irrigation was given as and when desired.

Wheat cv. Kalyansona, NP 761 and HD 2454 were grown in the field following recommended agronomic practices. Plot size was 3 m × 6 m and plant population

was 200 m^{-2}. At the planting time fertilizer was applied @ 40 kg N ha^{-1} as urea, 60 kg P ha^{-1} as superphosphate and 60 kg K ha^{-1} as murate of potash. Irrigation was given.

Mustard cv. Pusa Kalyani was grown in the field in the plot of 5 m × 5 m. Plant population was 40 plants m^{-2}. Fertilizer was applied @ 40 kg N ha^{-1} as urea, 60 kg P ha^{-1} as superphosphate and 60 kg K ha^{-1} as murate of potash.

For growth analysis 35 day old seedlings of chickpea cultivars, wheat and mustard were harvested from 1 metre length per replicate. There were four replications per sampling. Leaf area was recorded on an automatic leaf area metre (Hayashi Denkoh Ltd., Japan) and dry weight of the seedlings without roots was recorded after oven-drying at 80°C for 48 hr. Data are expressed on m^{-2} basis.

Photosynthesis rate: CO_2 assimilation rate of chickpea, wheat and mustard leaves was recorded 3 and 6 weeks after sowing with a portable Infra-red gas analyser (IRGA) from Analytical Development Co. Ltd., Heddesdon Herts, England, fitted with a Parkinson leaf chamber. This is an open system with an air flow of 200–300 ml min^{-1} over a leaf area of 6.25 cm^2. CO_2 depletion/min was measured at 10 am on six different leaves in 3 and 6 wks old seedlings. The leaf temperature was 20 ± 1°C. Light intensity was 1500 $\mu Em^{-2}s^{-1}$ and relative humidity in the leaf chamber was 46%. Leaf area of young chickpea leaves enclosed for CO_2 assimilation rate was also measured. Light-dependent CO_2 assimilation rate of 35 days old seedlings, was measured in all crops. Light intensity was made to vary using one or more layers of thin muslin cloth.

CO_2 enrichment studies: Chickpea seedlings of cultivar JG-62, M109 and M119 were grown in pots in glass-house at 25°C day/15°C night temperature in the Australian National University, Canberra, Australia. There were four seedlings in each pot. Half of the pots containing germinated seedlings were transferred to a glass-house having CO_2 640 ± 15 μbar and maintained at 25°C day/15°C night temperature. The pots were given full Hoagland nutrient solution daily. Growth data and leaf area were measured in plants growing at ambient and enriched CO_2 concentration after 7 and 42 days of growth. Each replicate contained 12 plants and the results are mean of four replicates. CO_2 assimilation rates of chickpea leaves at ambient and high CO_2 concentration were derived from CO_2-dependent CO_2 assimilation curves drawn using gas exchange system as described by Osmond (1983).

Result and Discussion

Dry matter accumulation in mustard, wheat and chickpea seedlings after 5 weeks sowing is shown in table 1. Dry matter accumulation in mustard was 3 and 6.5 times that of wheat and chickpea seedlings respectively. Leaf area of mustard seedlings was 2.4 and 8 times that of wheat and chickpea seedlings respectively. A comparison of crop growth rate (CGR) and leaf area growth rate (LAGR) of mustard, wheat and chickpea clearly indicated the drastic differences in growth rates of these species (table 2). CGR and LAGR of mustard seedlings was 28.9 and 12 times higher than chickpea seedlings and 3.2 and 2.5 times higher than wheat seedlings. The results clearly showed that species having high LAGR accumulated more dry matter. Chickpea cultivars differing in dry matter accumulation and leaf area development during seedling growth exhibited strong direct correlation between CGR and LAGR ($r^2 = +0.91$) (figure 1).

Dry matter accumulation is determined primarily by the product of net assimilation rate and the assimilatory surface which is primarily leaf area in the seedling stage (Sinha & Khanna 1975). It could be argued that differences in dry matter accumulation between the above species could be due to differences in the CO_2 assimilation rate also. CO_2 assimilation rate of mustard, wheat and chickpea was determined in three- and six-weeks-old leaves in the forenoon (table 3). CO_2 assimilation rates of the chickpea leaves examined were

Table 1 *Seedling dry matter and leaf area in 35 day old seedlings of chickpea, wheat and mustard. Data is average of four replicates ± SE*

	Dry matter g m^{-2}	Leaf area dm^2m^{-2}
Chickpea cv.		
JG–62	24 ± 4	28 ± 3
M–109	27 ± 7	32 ± 3
BG–261	20 ± 3	19 ± 2
BG–267	29 ± 5	37 ± 4
BG–256	26 ± 6	25 ± 3
Average	25 ± 5	28 ± 3
Wheat cv.		
HD 2454	45 ± 6	126 ± 15
NP 761	62 ± 8	73 ± 9
Kalyansona	58 ± 7	92 ± 14
Average	55 ± 7	97 ± 12
Mustard cv.		
Pusa Kalyani	162 ± 18	229 ± 30

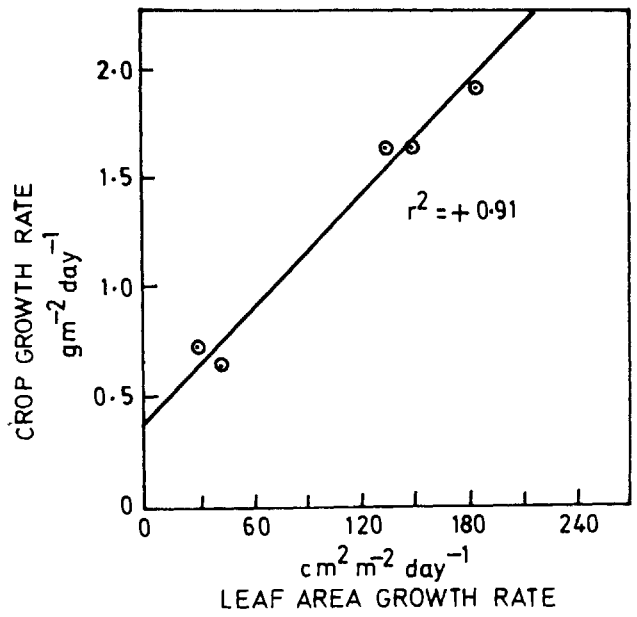

Figure 1

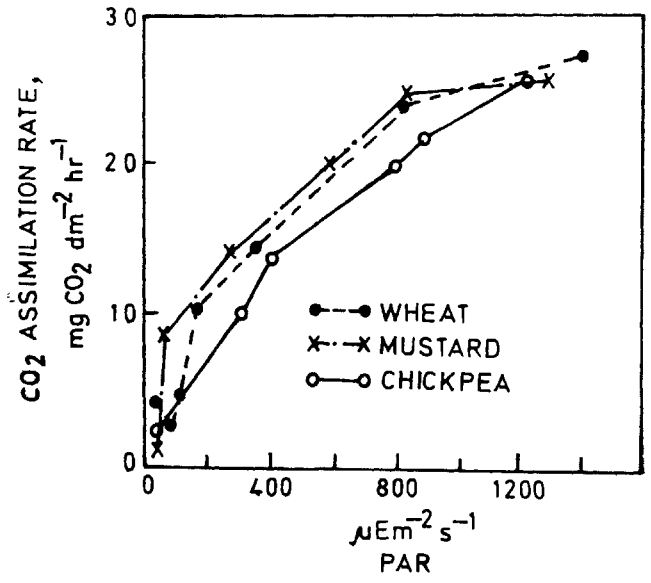

Figure 2

Table 2 *Crop growth rate and leaf area growth rate of mustard, wheat and chickpea seedlings for the first 35 days after planting. Data is average of four replicates ± SE*

Crop	CGR $gm^{-2}day^{-1}$	LAGR $cm^2m^2\ day^{-1}$
Mustard	4.62 ± 1.0	654 ± 69
Wheat cv. Kalyansona	1.47 ± 0.3	262 ± 31
Chickpea cv. BG 261	0.16 ± 0.03	54 ± 9

Table 3 *CO_2 assimilation rate of mustard, wheat and chickpea leaves, in three and six week old seedlings. Each observation is a mean of three independent determinations ± SD.*

Crop	Cultivar	CO_2 assimilation rate mg CO_2 dm^{-2} hr^{-1} 3 weeks	6 weeks
Mustard	Pusa Kalyani	24.6 ± 1.5	22.6 ± 1.6
Wheat	NP. 761	27.0 ± 2.3	19.6 ± 1.9
	Kalyansona	25.4 ± 3.0	23.0 ± 2.0
Chickpea	JG-62	25.5 ± 1.0	24.6 ± 1.8
	M-109	26.7 ± 0.9	27.5 ± 1.6

quite similar to those observed for wheat or mustard leaves. Light response curves of CO_2 assimilation in mustard, wheat and chickpea leaves were also similar (figure 2). CO_2 concentration dependent CO_2 assimilation rate of chickpea leaves was similar to that observed for other C_3 species (Khanna-Chopra 1984, Farquhar & Sharkey 1984). Hence CO_2 assimilation rate is not a factor responsible for differences in dry matter accumulation in mustard, wheat and chickpea seedlings.

Leaf area development is a complex process involving leaf initiation and leaf growth. Leaf growth depends upon a co-ordinated pattern of division and enlargement by constituent cells which is genetically determined and modified by environmental conditions. Leaf area expansion requires less photosynthate but is strongly dependent on turgor and mineral availbility (Kriedemann 1986, Constable & Rawson 1980). Cell division in dicotyledonous plants continues even during leaf expansion period and is strongly dependent on photosynthate supply. If leaf area development is slowed by photosynthate supply CO_2 enrichment should alleviate this constraint.

Chickpea seedlings of three cultivars were subjected to CO_2 enrichment. CO_2 assimilation rate of chickpea

Table 4 *Effect of ambient and high CO_2 concentration on chickpea seedlings*

Cultivars	JG-62		M-109		M-119	
	LC	HC	LC	HC	LC	HC
10-day-old seedlings						
Leaf area cm^2 $plant^{-1}$	11.0 ± 0.3	12.0 ± 0.7	14.0 ± 0.3	17.0 ± 0.4	12.3 ± 0.4	14.3 ± 0.22
Dry matter mg $plant^{-1}$	77.0 ± 6.0	97.4 ± 8.0	97.3 ± 9.0	130.0 ± 15	88.3 ± 9.0	106.8 ± 2.0
45-day-old seedlings						
Dry matter mg $plant^{-1}$	898 ± 61	2065 ± 158	1288 ± 110	3397 ± 290	1059 ± 59	3535 ± 250
Leaf area $cm^2 plant^{-1}$	106 ± 80	294 ± 19	165 ± 19	474 ± 39	143 ± 15	520 ± 55
CGR mg wk^{-1}	273.6	562.2	396.4	933.4	336.9	948.0
RGR $gg^{-1}wk^{-1}$	0.3560	0.3789	0.3739	0.4049	0.3646	0.4303

LC, ambient CO_2 concentration 340μbar ± 10 bars
HC, High ambient CO_2 concentration 640μbar ± 15 bars

leaves grown at 340μbar and 640μbar was 25μmoles $CO_2m^{-2}s^{-1}$ and 37μmoles $CO_2m^{-2}s^{-1}$. After 7 days of transfer to enriched CO_2 atmosphere dry matter accumulation and leaf area in chickpea cultivars increased by 20–33% and 9–21% over seedlings growing in ambient CO_2 concentration (table 4). Increase in leaf area in all chickpea cultivars by short term exposure to CO_2 enrichment indicated that photosynthate availability limits leaf initiation and development in this crop during seedling stage when adequate nitrogen nutrition had been supplied. Similar responses have been observed in tomatoes (Calvert & Slack 1975), cucumber (Kriedemann & Wong 1984) and *Brassica pekinensis* (Kriedemann 1986). Continued growth in enriched CO_2 further magnified the differences in dry matter accumulation and leaf area development as compared to seedlings grown in ambient CO_2 concentration. CO_2 enrichment increased both the crop growth rate (CGR) and relative growth rate of chickpea seedlings (table 5).

The present study emphasizes the importance of leaf area as an important determinant of dry matter accummlation. Crops having similar photosynthesis rates maintain different leaf growth rates leading to wide variations in dry matter accummulation (Khanna Chopra et al. 1984). Leaf growth and development is dependent upon the availability of minerals and photosynthates provided turgor is maintained. If assimilates are partitioned in favour of leaf area development the rate of dry matter accumulation increases over time as the increased leaf area assimilates more carbon. Chickpea leaves had photosynthesis rates similar to the leaves of wheat and mustard (table 3) but the rate of leaf area development was very slow. Photosynthate availability was one of the factors limiting leaf growth under conditions of adequate water supply and nutrition as revealed by enchanced leaf growth and seedling dry matter under CO_2 enriched atmosphere. More studies are needed to understand the interaction on nitrogen nutrition and carbon availability in symbiotically grown legume seedlings to understand the cause of slow seedling growth. As carbon fixation is dependent on the nitrogen status, it is analytically complex to analyse as to which process is more limiting.

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