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# Variability in growth and yield response of maize genotypes at elevated CO$_2$ concentration

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## Abstract

Three contrasting maize (Zea mays L.) genotypes- DHM-117 (single cross hybrid), Varun (synthetic) and Harsha (composite) with different yield potentials were selected to assess their growth and yield performance at ambient (390ppm) and elevated (550ppm) CO2 condition in Open Top Chamber (OTC) facility. The phenology, biomass accumulation, grain yield and HI was quantified of these three maize genotypes at both CO2 levels. The phenology of flowering was early by 1.5 to 2days, while the anthesis silking interval (ASI) was not influenced by elevated CO2 in DHM-117 and Varun, where as it was reduced by two days in Harsha. Response of selected three maize genotypes was different to elevated CO2 (550ppm) condition in terms of biomass, grain yield and HI. The improvement in biomass ranged from 32% to 47%, grain yield 46% to 127% with 550ppm CO2 as compared with ambient control. The improvement in grain yield was due to increased grain number (25-72%) as well as improved test weight (8-60%). The overall response of less efficient maize genotype Harsha with elevated CO2 concentration was found to be significantly high especially the grain yield and its components. Elevated CO2 also improved the maize HI (11% to 68%) indicating that influence of elevated CO2 was there on partitioning of biomass of this C4 crop.

**Keywords:** maize, elevated CO2, genotypes, ASI, grain yield, grain number; HI

## Introduction

The changing climatic conditions are expected to increase the atmospheric CO$_2$ concentration, temperatures and alter the precipitation pattern. Atmospheric CO$_2$ concentration is predicted to reach 550ppm by 2050, and probably exceed 700ppm by the end of this century.[1] These changes are anticipated to affect the production and productivity of agricultural crops and influence the future food security. The impact analysis of climate change on global food production discloses a 0.5% decline by 2020 and 2.3% by 2050.[2,3] The development of climate ready germplasm to offset these losses is of the upmost importance.[4]

The C$_4$ grass maize (*Zea mays* L.) is the third most important food crop globally in terms of production and its demand is predicted to increase by 45% from 1997 to 2020.[5] Studies with maize response to double the ambient CO$_2$ showed varying effects on growth ranging from no stimulation of biomass[6] to 50% stimulation.[7] These studies reveal that C$_4$ plants do have the potential to respond to elevated CO$_2$. The basis for the observed enhancement of growth of C$_4$ plants under elevated CO$_2$ is not as clear as in C$_3$; plants. The present study was aimed to assess the response variability of maize genotypes at elevated CO$_2$ condition in terms of phenology, biomass and yield components.

## Materials and methods

The seed material of the maize genotypes DHM-117, Varun and Harsha were obtained from DMR Regional station at Hyderabad and raised in open top chambers (OTCs) at ambient (390ppm) and elevated (550ppm) CO$_2$ levels during post rainy season (Rabi) 2012. The OTCs having 3mx3mx3m dimensions lined with transparent PVC (polyvinyl chloride) sheet having 90% transmittance of light were used. The elevated CO$_2$ of 550ppm was maintained in two OTCs and other two OTCs without any additional CO$_2$ supply served as ambient control. The CO$_2$ concentrations within the OTCs were maintained and monitored continuously throughout the experimental period as illustrated by Vanaja et al.[8]

Each chamber had 6 plants of each genotype planted in two rows of 1.0m with 0.35m spacing within row and 0.75m between rows. The recommended dose of fertilizers 60kg N ha$^{-1}$ and 60kg P ha$^{-1}$ as diammonium phosphate, 30kg K ha$^{-1}$ as muriate of potash was applied as basal dose; second dose of 30kg N ha$^{-1}$ at knee- high stage and third dose of 30kg N ha$^{-1}$ as urea and 30kg potassium ha$^{-1}$ as muriate of potash was side dressed at tasseling stage. The crop was irrigated at regular intervals and maintained pest and disease free with plant protection measures.

The phenological observations such as days to 50% tasseling, anthesis and silking and maturity were recorded. At harvest the observations on plant height, total biomass, stover weight, cob weight, grain yield, test weight and other yield contributing traits were recorded. The analysis of variance (ANOVA) was carried out to assess the significance of CO$_2$ levels and genotypes and their interaction.

## Results and discussion

The analysis of variance (ANOVA) revealed that the selected three maize genotypes- DHM-117, Varun and Harsha recorded significant difference ($p<0.01$) for plant height, total biomass, stover weight, cob weight, grain yield, test weight and HI. The CO$_2$ levels were significant for total biomass, cob weight, grain yield, grain number and test weight at $p<0.01$ level and for plant height and harvest index at $p<0.05$ level (Table 1), whereas the interaction of genotypes x $CO_2$ levels was significant only for test weight.

The plant height of all the maize genotypes showed a significant ($p<0.01$) increase with enhanced $CO_2$ concentration (550ppm) as compared with ambient grown plants (Table 1). Driscoll et al.,[9] observed increase in maize plant height by 23% at 700ppm $CO_2$ and affirmed that being a $C_4$ crop, maize plant can show improved performance to increased $CO_2$ concentration. Elevated $CO_2$ also influenced the phenology of flowering in maize and it was observed that day to 50% tasseling, anthesis and silking was early by 1.5 to 2 days as compared with ambient controls (Figure 1). However, anthesis-silking interval (ASI) in DHM-117 and Varun was not influenced by elevated $CO_2$ as both anthesis and silking were early, whereas in Harsha, elevated $CO_2$ could reduce only the days to silking and not anthesis there by ASI was shortened to the extent of two days. In the life cycle of plant, the flowering time is very critical stage and in many crops it determines the number of seeds and final yield[10] and the environmental conditions which affect the plant growth tend to influence the flowering dynamics.[11] Review of 60 studies on flowering time and elevated atmospheric $CO_2$ by Springer et al.,[12] revealed that this response is crop and variety specific. The enhanced $CO_2$ condition reduced the days to initiation and 50% flowering in castor bean,[13] whereas a delay in phenology of flowering was observed in soybean.+Leakey et al.,[15] from their FACE experiments reported that 550ppm $CO_2$ didn't influenced the duration of anthesis and silking of maize cv 34B43 (Pioneer Hi-Bred International).

The response of selected maize genotypes was different to elevated $CO_2$ (550ppm) condition in terms of total biomass, grain yield and HI. Enhanced $CO_2$ concentration significantly improved the total biomass as compared with ambient condition and the response was maximum with Varun (47%) followed by Harsha (34%) and DHM-117 (32%). Studies on impact of elevated $CO_2$ on maize crop revealed varying effects from no stimulation of biomass[6] to 3-6%,[16] 20%,[17,18] 24%,[19] 36%[20] and up to 50%.[7] This differences in magnitude of response of maize to elevated $CO_2$ could be due to genotypic variability,[21] strength of source and sink, management of the crop such as water and nutritional status, duration of exposure, light intensity, temperature, and even pot size.[22,23]

The increase in biomass can be explained by the ability of the high $CO_2$ grown plants to maintain elevated photosynthetic rates and there was a 1.5 to 2 fold increase in internal $CO_2$. Ghannoum et al.,[24] proposed two major mechanisms that may be responsible for increasing $C_4$ plant growth under elevated $CO_2$. The first potential mechanism operates through $CO_2$-induced increases in net photosynthetic rates and second mechanism deals with $CO_2$-induced reductions in stomatal conductance which can improve overall plant water relations and facilitate greater biomass production. In addition, reductions in transpirational water loss may slightly increase leaf temperature, thereby stimulating rates of photosynthesis and biomass production. Increased photosynthetic rate to synthesize the more sucrose and starch, and to utilize these end products of photosynthesis to produce extra energy by respiration, may contribute to the enhanced growth of maize under elevated $CO_2$.

The impact of elevated $CO_2$ was observed to be different in enhancing the vegetative and reproductive biomass of selected maize genotypes. With enhanced $CO_2$ greater vegetative growth was recorded by Varun (36%), whereas reproductive biomass by Harsha (94%). It is interesting to observe that in all the genotypes the increased response of reproductive biomass was much higher with enhanced $CO_2$ condition than vegetative biomass and indicating its function in triggering the partitioning of biomass more towards cob or grain weight (Figure 2). The improved grain yield due to 550ppm $CO_2$ was 46% in DHM-117, 61% in Varun and 127% in Harsha as compared with respective ambient control (Table 1). The improvement in grain yield was contributed by both increased grain number to the extent of 34%, 25% and 72% as well as enhanced test weight by 8%, 29% and 60% in DHM-117, Varun and Harsha respectively. Elevated $CO_2$ also significantly improved the HI of maize genotypes to the extent of 11% (DHM-117 and Varun) to 68% (Harsha). The simulation study using CropSyst model on the impact of elevated $CO_2$ on major cereal crops revealed that maize response was more than $C_3$ rice and wheat as well as $C_4$ pearl millet[25] and even the increase in yield was observed up to 3°C rise in temperature under doubled $CO_2$ situation. It was concluded that the improved response of maize being a $C_4$ crop could be due to more efficient use of increased $CO_2$ than the other $C_3$ crops.

**Table 1** Growth, biomass and yield traits under ambient (390ppm) and elevated (550ppm)CO<sub>2</sub> conditions of maize genotypes DHM-117, Varun and Harsha

| Parameters/plant | DHM-117 | | Varun | | Harsha | | Significant differences | | |
|---|---|---|---|---|---|---|---|---|---|
| | $aCO_2$ | $eCO_2$ | $aCO_2$ | $aCO_2$ | $aCO_2$ | $aCO_2$ | G | $CO_2$ | G x $CO_2$ |
| Plant height (cm) | 281 | 292 (3.9) | 254 | 283 (11.4) | 227 | 237 (4.2) | ** | ** | ns |
| Total biomass (g) | 264.9 | 349.4(32) | 145.2 | 213.6(47) | 133.5 | 179.4(34) | ** | ** | ns |
| Cob dry weight (g) | 110.8 | 157.6(42) | 60.2 | 96.5(60) | 44.9 | 92.6 (106) | ** | ** | ns |
| Stover biomass (g) | 185.5 | 233.9 (26) | 93.97 | 130.9 (39) | 99.44 | 102.1 (2.7) | ns | ** | ns |
| Grain yield (g) | 79.4 | 115.3 (46) | 51.3 | 82.7(61) | 34.1 | 77.3 (126.8) | ** | ** | ns |
| Number of grains/cob | 389 | 522 (34) | 346 | 431 (24.5) | 282 | 484 (71.5) | ** | ns | ns |
| 100 grain weight (g) | 20.5 | 22.0(7.6) | 14.7 | 18.9(28.7) | 10.9 | 17.4 (60) | ** | ** | |
| Harvest Index (%) | 30.3 | 33.07(11) | 35.1 | 38.9(11) | 25.6 | 42.8(68) | ** | ns | ns |

*, ** Significant at P<0.05 and 0.01, respectively; ns indicates non-significant; G-genotypes, $CO_2$-$CO_2$ levels $aCO_2$- ambient (390ppm) and $eCO_2$- elevated (550ppm) $CO_2$ conditions; Values in parenthesis indicate the % increase over ambient.

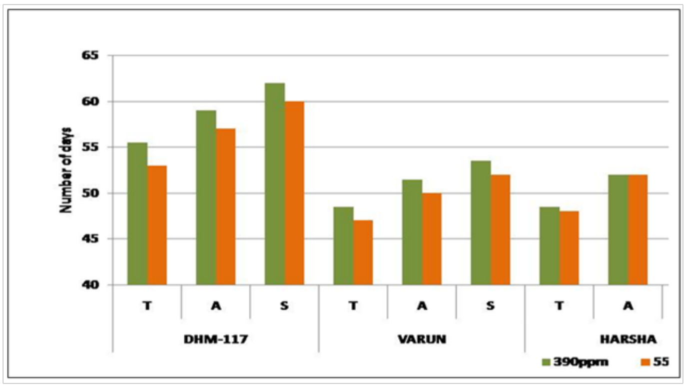

**Figure 1** Days to tasseling (T), anthesis (A) and silking (S) of three maize genotypes- DHM-117, Varun and Harsha at ambient (390ppm) and elevated (550ppm) $CO_2$ conditions.

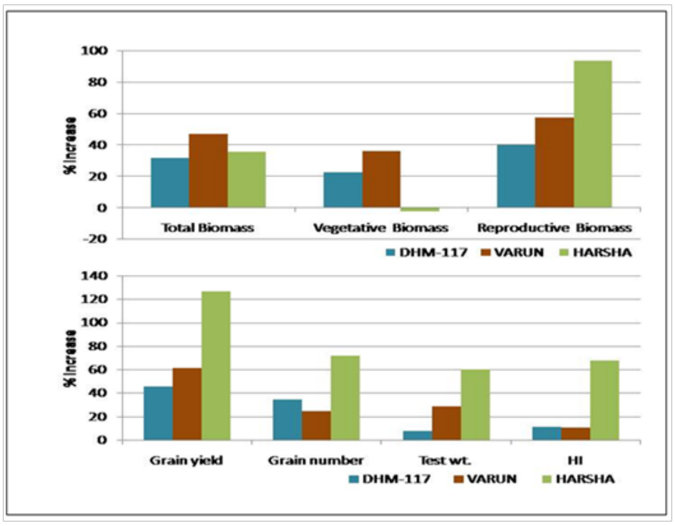

**Figure 2** The impact of elevated CO2 (550ppm) on increase (%) of biomass, grain yield and HI of three maize genotypes- DHM-117, Varun and Harsha over ambient control (390ppm).

## Conclusion

The evaluation of maize genotypes at elevated $CO_2$ (550ppm) for their biomass and yield revealed that maize crop though having $C_4$ photosynthetic pathway was able to respond positively with enhanced atmospheric $CO_2$ concentration. It is also evident that there is a significant variability between maize genotypes in response to elevated $CO_2$. The positive and significant response of elevated $CO_2$ on maize HI was due to higher partitioning of biomass towards reproductive parts than vegetative parts makes this crop more climate resilient.

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## Conflict of interest

The author declares no conflict of interest.

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