Research Article

Growth and Yield responses of Ginger (*Zingiber officinale* Rosc.) varieties to Elevated CO_2

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Abstract

The present study investigated the effects of CO_2 enrichment on growth and yield of ginger (*Zingiber officinale* Rosc.). Three varieties of ginger Aswathy, Athira, and Maran were selected and grown in OTC (Open Top Chamber) enriched with 500 ppm of CO_2 for a period of eight months. Intending to evaluate the impact of elevated CO_2 on growth and yield. Elevated CO_2 had a profound stimulatory effect on number of leaves (230.66), root fresh weight (48.87 g plant^{-1}), shoot fresh weigh (188.83 g plant^{-1}), tiller number (23) in Aswathy followed by Maran and Athira. Maximum fresh weight of rhizome was (228.75 g plant^{-1}) evident in Aswathy. Although there was significant effect of e[CO_2] on the three varieties, Aswathy was performing better when compared to Athira and Maran. Correlation studies revealed that plant height, number of leaves, root and shoot fresh weight, tiller number, were positively correlating to rhizome yield. These results indicate that the plant biomass and yield can be enhanced under controlled CO_2 enrichment.

Keywords: Elevated CO_2, Ginger, varieties, growth, yield

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Introduction

In recent decades, global atmospheric CO_2 concentration has risen at an alarmingly rapid rate exceeding 407 ppm [1], nearly a 30% increase, since the 1950s and is projected to double by the end of this century [2]. The resulting increase in CO_2 will lead to a variety of both positive and negative effects on major agricultural crops used to feed the global population, many of which may yet be unknown.The rising CO_2 concentration has affected almost all crucial biological processes, including photosynthesis, respiration, and antioxidant systems, as well as other key secondary metabolisms in plants [3, 4].

Besides as spices and condiments, the large demand for ginger is attributed to its role in medicines used to treat headaches, nausea, colds, arthritis, rheumatism, muscular discomfort and inflammation [5]. The usable part of the plant is the underground stem or rhizome which can be consumed either fresh for culinary purposes or as a processed product where it may be salted, dried, and/or powdered, used as a paste, or extracted as ginger oil or oleoresin [6]. Our knowledge of plant responses to future CO_2 concentrations rests on the results of experiments conducted at present ambient and the projected concentrations of CO_2. Such experiments have been performed in a wide variety of crop plants, but very less in medicinal and spice plants in general and ginger in particular.

Therefore, understanding the varietal variations for growth and yield under a CO_2 rich atmosphere provides a unique opportunity to improve crop productivity under a changing climate. The objective of this study was to evaluate the impact of e[CO_2] on growth and yield of ginger varieties. The knowledge of which will help to improve crop productivity under a CO_2 rich atmosphere.

Materials

To investigate the impact of elevated CO_2(e[CO_2]) on ginger, an experiment was carried out in Open Top Chamber (OTC) constructed to maintain near natural and e[CO_2] conditions for the experimental study. The experiment was carried out for a duration of 8 months in the OTC facility available at Dept of Plant Physiology at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India. OTC was enriched with 500 ppm of CO_2 to mimic the CO_2 level in the near future as atmospheric CO_2 concentration is predicted to reach 550 ppm by 2050, and probably exceed 700 ppm by the end of this century [7]. The basic structure of OTC is built of metal frame and installed in the experimental field. It is covered with a 200 micron UV poly sheet. The chamber is 3 x 3 x 3 dimension, 45° slope and 1m^2 opening at the top. Elevated CO_2 is released into the chamber from a CO_2 cylinder in a controlled manner. Measurements of microclimatic parameters (temperature, humidity, and light) were done within and outside the OTC with the help of sensors on a real- time basis.

Ginger rhizome bits (15 g each) of three varieties Aswathy, Athira and cv. Maran were procured from Regional Agricultural Research Station, Ambalavayal, Wayanad, Kerala. Treated rhizomes (0.3% mancozeb for 30 min) of all the three varieties were grown in protrays and two month old uniform plants were transplanted to pots. Sand, soil and farmyard manure were mixed in ratio 2:1:1 and filled in each pot. The fertilizer application was carried out as per package of practices of Kerala Agricultural University. One set of plants of 3 months old were transferred to OTC and another set was retained at the ambient CO_2.

Measurement of growth and yield parameters

Observations on growth and yield parameters were recorded at 8MAP (Months After Planting). Plant height, stem diameter, number of tillers and number of leaves were recorder as per DUS (Distinctiveness, Uniformity, and Stability) guidelines available for ginger. Root fresh weight, shoot fresh weight, and fresh weight of rhizome were also recorded. The analysis of variance (ANOVA) was carried out to assess the significance difference between the treatments and their interaction.

Results and Discussion
Growth parameters

There was significant variations among the selected varieties for important growth parameters and are shown in **Table 1**.

Plant height

Aswathy recorded a maximum of 50.18 cm plant height under e[CO_2] followed by Maran (49.36 cm) and Athira (47.13 cm) when compared to ambient CO_2 which is similar to the results obtained by [8] that under e[CO_2] of 550 ppm, height of rice plants was 81.7 cm while in ambient 395 ppm it was 76.9 cm. Although there were varietal variations there was no significant difference in the interaction effect of CO_2 enrichment on varieties at 8 MAP. The percentage increase over control was very less which is ranging from 0.12 – 4.43 %, since the plants had entered a phase of senescence aging after 7MAP [9] (**Figure 1**). Plant responses to e[CO_2] are much greater at early vegetative stages compared to later stages [10].

Number of leaves

Although there is significant increase in the number of leaves for all the three varieties, the increase is more pronounced in the variety Aswathy with a maximum number of leaves of 230.66 (55 % increase over control) when compared to the control 148.33 followed by variety Maran and Athira as indicated in (**Table 1**). The results are similar to [11] study, when *Catharanthus roseus* was grown at ambient and e[CO_2] concentration (600 and 900 ppm) the maximum number of leaves were observed in 900 ppm 114 leaves followed by 600 ppm, 101 leaves and control 62 leaves. Stimulation of early leaf growth has been identified as one of the key physiological traits associated with final biomass and grain yield [12]. Further, it is suggested that the increased availability of soluble carbohydrates from expanding leaf blades is a key factor contributing towards higher leaf elongation rates, leaf area expansion, and whole plant growth observed under e[CO_2].

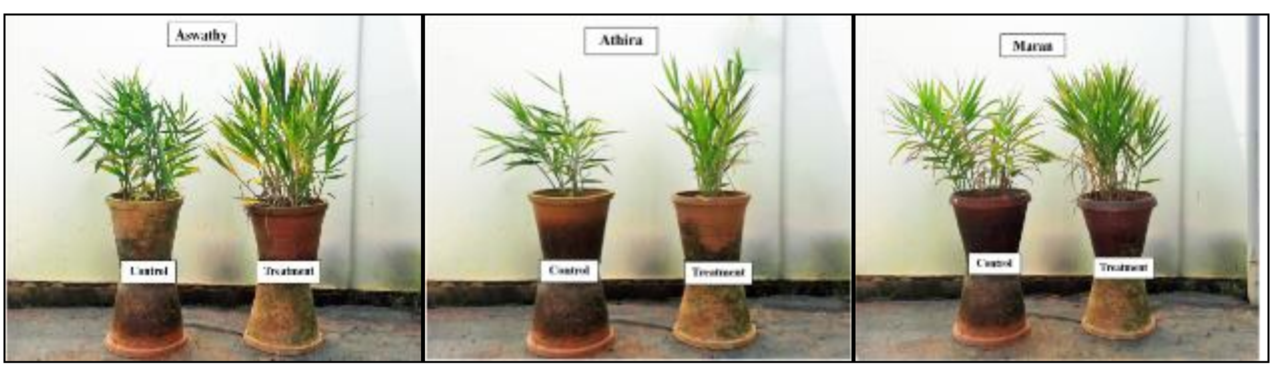

Figure 1 Variability in the growth characters under Control (ambient CO_2) and Treatment (elevated CO_2)

Root fresh weight

The maximum fresh weight of the root was shown by Aswathy (48.86 g plant^{-1}) followed by Maran and Athira under e[CO_2] when compared to the control conditions. Root fresh weight showed significant differences among all three varieties. The similar results were reported by [13] that fine roots were strongly stimulated by e[CO_2]. [14] claim that the increase in root biomass at e[CO_2] is associated with increased starch levels in roots and an increase in the levels of ABA that may have caused more carbon to be allocated to root growth. Plant growth is influenced by both above ground and below-ground processes under e[CO_2]. Below ground processes of plants facilitate photosynthesis through nutrient and water uptake, which then influence above ground biomass production [15].

Table 1 Variability of varieties for growth parameters under ambient and e[CO_2] and its % change over control at 8MAP

	CO_2 level	Plant height (cm)		Number of leaves		Root fresh weight (g plant^{-1})		Shoot fresh weight (g plant^{-1})		Tiller Number	
Aswathy	Ambient	49.26		148.33		26.61		99.15		19.33	
	Elevated	50.18		230.66		48.86		188.83		23.00	
	% Change	1.87		55.50		83.61		90.44		18.98	
Athira	Ambient	45.13		106.33		23.72		74.74		15.00	
	Elevated	47.13		157.00		34.90		95.64		18.00	
	% Change	4.43		47.65		47.13		27.96		20.00	
Maran	Ambient	49.30		139.00		21.97		87.31		18.00	
	Elevated	49.36		189.66		41.17		126.48		21.33	
	% Change	0.12		36.44		87.39		44.86		18.50	
		SE±(m)	CD(0.05)	SE±(m)	CD(0.05)	SE±(m)	CD(0.05)	SE±(m)	CD(0.05)	SE±(m)	CD(0.05)
	V	0.36	1.14	0.73	2.28	0.63	1.96	0.55	1.74	0.43	1.34
	T	0.30	0.93	0.59	1.86	0.51	1.60	0.45	1.42	0.35	1.09
	V X T	0.52	NS	1.03	3.22	0.89	2.78	0.79	2.46	0.60	NS

Shoot fresh weight

The response of selected ginger varieties was different to e[CO_2] conditions in terms of shoot fresh weight. Enhanced CO_2 concentration significantly improved the shoot fresh weight as compared with the ambient condition and the response was maximum in Aswathy (188.83 g plant^{-1}) followed by Maran (126.48 g plant^{-1}) and Athira (95.64 g plant^{-1}). Aswathy had the highest per cent increase over control 90.44 % (roughly twofold) of all the parameters studied followed by Maran and Athira (Table 1). It is noteworthy that a strong correlation is evident between the rhizome yield and the shoot fresh weight ($P < 0.01$) under e[CO_2] and shoot weight has no significant contribution to the rhizome yield under ambient CO_2 (**Table 2**) which can be one of the reasons for an increase in yield. The results are parallel to the study conducted by [16] reported that when two *Zingiber officinale* varieties (*Halia bentong* and *Halia bara*) were exposed to different CO_2 concentrations (400 and 800 ppm) resulted enhancement of dry weight of leaves, stems, and rhizomes by 47.6% in Halia Bentong and 76.3% in Halia Bara. Plant growth responses to CO_2 enrichment are also linked to the source-sink status of the whole plant [17]. Elevated CO_2 increases the carbon source activity that results in a higher rate of photosynthetic CO_2 assimilation providing more carbohydrates [18] which is used by plants to develop additional sinks such as new tillers and secondary shoots. As a consequence of these changes, the relative growth rate of the plants increases at e[CO_2] [19] that leads to an increase in biomass and yield.

Table 2 Correlation between the fresh weight of rhizome to a few growth related parameters analysed in the study (**p<0.01, *p<0.05)

	Fresh weight of Rhizome (g plant^{-1})	
	Ambient CO_2	Elevated CO_2
Plant height (cm)	0.01^{NS}	0.82^{**}
Number of leaves	0.95^{**}	0.99^{**}
Root fresh weight (g plant^{-1})	0.69^{*}	0.97^{**}
Shoot fresh weight (g plant^{-1})	0.24^{NS}	0.99^{**}
Tiller Number	0.71^{*}	0.85^{**}

Tiller Number

The maximum number of tillers were found in Aswathy (**Table 1**) under e[CO_2] when compared to ambient CO_2 however, there was no significant difference between varieties interacting with e[CO_2] in the tiller number. It is found to be positively correlating to yield at ($P < 0.01$) and ($P < 0.05$) at ambient and e[CO_2] respectively.[20] demonstrated that plants exposed to e[CO2] produced higher levels of ethylene than plants grown under ambient [CO_2]. Increase in ethylene production is one of a key feature of accelerated growth and development in rice under e[CO_2] that accelerates tiller number and auxiliary bud development, potentially leading to higher grain yield. The per cent increase over control ranged between 18-20% which was similar to the study conducted by [21] in *Agrostis capillaris*, growth in e[CO_2] increased tiller number by 20%. Also, increased photosynthesis rates at e[CO_2] results in higher sugar production, including glucose, fructose, and raffinose, across a range of plant species [22]. These additional sugars are available for the development of new sink organs such as leaves, stems, tillers, and seeds. The developmental plasticity of these organs determines the final growth response to e[CO_2].

Yield

Yield which is the weight of rhizome in ginger was recorded at 8MAP. Elevated CO_2 had a profound effect on the fresh weight of rhizome which was evident in all the three varieties. However maximum rhizome weight was found in Aswathy of 228.75 g $plant^{-1}$ under e[CO_2] followed by Maran and Athira (**Table 3**). Results are in accordance with the study conducted by [23] which showed that e[CO_2] (580 ppm) increased seed yields of two soyabean varieties Dongsheng 7 and Suinong 14 by 35% and 13%, respectively. Whilst the yield enhanced for all the three varieties under e[CO_2] there exists a significant difference among them because when the sink strength is not sufficient to accommodate all the assimilates from photosynthesis, sugar accumulation in source tissues will decrease the photosynthesis rates through feedback inhibition. This will reduce the ratio of source to sink activity and adjust the photo-assimilate production towards equilibrium. Therefore, both source and sink activities are strongly cross regulated to sustain desirable plant growth rates at different development stages [24].

Correlation studies were performed to divulge the parameters conferring to the enhancement of yield under e[CO_2] in the present study. Plant height, number of leaves, root fresh weight, shoot fresh weight, tiller number [25], correlated positively ($p<0.01$) directly affecting the weight of the rhizome. Under ambient CO_2 number of leaves, root fresh weight and tiller number correlated positively (**Table 2**).

Table 3 Yield under ambient and elevated CO_2 and its % change over control at 8MAP

	CO_2 Level	Fresh weight of Rhizome (g $plant^{-1}$)
Aswathy	Ambient	165.35
	Elevated	228.75
	% Change	38.34
Athira	Ambient	150.90
	Elevated	169.19
	% Change	12.12
Maran	Ambient	160.20
	Elevated	192.25
	% Change	20.00
	SE±(m)	CD(0.05)
V	0.0651	2.029
T	0.532	1.657
V x T	0.921	2.870

Conclusion

All growth and yield parameters studied in the present experiment were more strongly influenced, enhancing the yield under e[CO_2] conditions. Varietal variation was found to be existing in response to e[CO_2] which gives us better scope for the selection of suitable varieties for a changing climatic scenario. To conclude, the overall performance of Aswathy recorded better followed by Maran and Athira. These varieties can be utilised for studying the influence of e[CO_2] on the carbon partitioning to secondary metabolites which have been a focus of attention in recent years due to its antioxidant properties and health preservation functions. With experimentation on e[CO_2] generally conducted under controlled temperatures and adequate water supply, it is difficult to predict the results of these actual situations.

Hence there is essentiality of performing further studies amalgamating e[CO_2], increased temperature and varying water levels which are crucial addressing future food security targets under a changing climate.

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