Assessing the variability in intrinsic water use, mesophyll and carboxylation efficiencies of gibberellin-treated tea (*Camellia sinensis* L.) accession using gas exchange approach

Although essentially a biochemical process, photosynthesis is often regarded as a diffusive process also[1]. The rate of diffusion of CO_2 is largely controlled by two factors: stomatal conductance (g_s) and CO_2 concentration gradient between the carboxylation site and the ambient air[2,3]. Significant research effort has gone into understanding the implications of gas exchange measurements and also to relate the gas exchange traits with biochemistry of photosynthesis[4]. Gas exchange techniques have been used to quantify the relative stomatal and mesophyll limitations[5], carboxylation efficiency and limitations imposed by the photochemical and biochemical reactions[4–6]. The response of photosynthesis to increase in CO_2 concentration (dA/dCi) is often considered as a fairly good estimate of intrinsic carboxylation efficiency. Alternatively, the ratio of intercellular CO_2 concentration (Ci) to g_s has been demonstrated as a rapid estimate of mesophyll efficiency[5]. Through rapid and snapshot measurements, gas exchange holds potential while screening genotypes/accessions for higher photosynthetic efficiency under a given environmental condition[5,7].

Here, we demonstrate increased intrinsic leaf water-use, mesophyll and carboxylation efficiencies with the application of plant hormone gibberellins (GA_3). GA_3 concentrations (50, 100 and 150 ppm) along with untreated control were used to examine the variation in gas exchange traits in a leading tea accession, namely U-9. GA_3 was sprayed to foliage two days prior to the measurement. The study was carried out at the tea gardens of Hindustan Lever Ltd (HLL), Valparai, Tamil Nadu, India. A five-year-old bush of field-established tea accession U-9 was used for the study. A healthy branch was selected and the third fully expanded foliage from the apex was used for measurement of gas exchange traits and intrinsic carboxylation efficiency (dA/dCi; through $A–Ci$ curve).

A portable photosynthesis system (LICOR 6400, Licor Inc., Nebraska, USA) was used to measure gas exchange parameters such as assimilation rate (A), stomatal conductance (g_s), intercellular CO_2 concentration (Ci) and transpiration rate (T) in both GA_3-treated and untreated plants at light intensity of 700 μmol $m^{-2} s^{-1}$. The built-in CO_2 dosing system of the LICOR 6400 was employed to generate various CO_2 concentrations ranging from 50 to 1000 ppm. The carbon assimilation rates recorded at each CO_2 concentration were plotted against their corresponding Ci and a second degree polynomial function was fitted. The slope of the initial linear region of the CO_2 response curves (dA/dCi) is often considered as a reflection of intrinsic carboxylation efficiency.

Gas exchange parameters showed significant variation across the treatment (Table 1). The photosynthetic rate and stomatal conductance values observed in the study were relatively low compared to a few other perennial species[8]. However, these values remained more or less consistent even after several repeated measurements. Since tea is a shade-loving plant, it is not uncommon to observe such a low value. In fact, tea at higher light intensities shows typical signs of 'burns' expected due to photo-oxidation and photo-inhibition, which get activated under such conditions[9]. There are a few similar reports, where it was shown that tea had lower photosynthetic rate compared to other crop species[10,11]. The ratios of assimilation rate to stomatal conductance (A/g_s), and intercellular CO_2 (Ci) concentration to g_s (Ci/g_s) were computed as measures of intrinsic water use and mesophyll efficiencies.

The GA_3-treated plants showed considerable improvement in both intrinsic water use and mesophyll efficiencies. The increment in intrinsic water-use efficiency was around 15.5, 40.5 and 47.8% with 50, 100 and 150 ppm GA_3 treatment compared to control plants. The significant increment in water-use efficiency from 100 to 150 ppm suggested that GA_3 at lower concentration might be sub-

Table 1. Variations in gas exchange traits, intrinsic water-use, mesophyll and carboxylation efficiencies in tea clone (U-9) treated with different concentrations of GA_3

Treatment	A	g_s	Ci	T	A/g_s	Ci/g_s	dA/dCi
Untreated–control	2.03	0.071	249	1.87	28.98	0.36	0.43
50 ppm	2.40	0.075	235	1.74	34.29	0.34	0.51
100 ppm	3.90	0.085	231	2.35	48.69	0.29	0.53
150 ppm	6.20	0.113	211	2.98	55.55	0.19	0.61
CD at $P = 0.05$	0.63	0.011	33.1	0.084	15.88	0.11	0.09

A, Assimilation rate (μmol $m^{-2} s^{-1}$); g_s, Stomatal conductance (mol $m^{-2} s^{-1}$); Ci, Intercellular CO_2 concentration (ppm); T, Transpiration rate (mmol $m^{-2} s^{-1}$); A/g_s, Intrinsic water-use efficiency; Ci/g_s, Intrinsic mesophyll efficiency; dA/dCi, Intrinsic carboxylation efficiency.

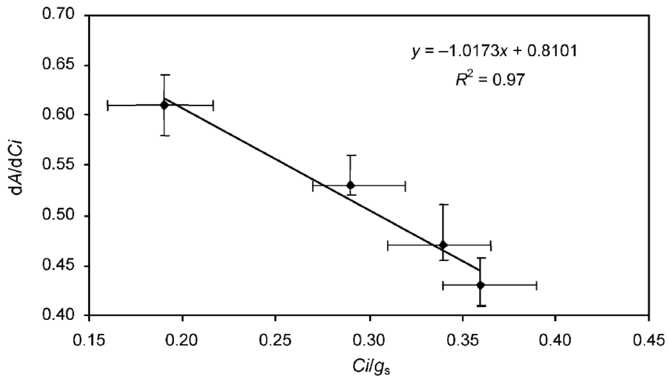

Figure 1. Relationship between intrinsic mesophyll (Ci/g_s) and carboxylation (dA/dCi) efficiencies in GA_3-treated tea clone (U-9). Standard error bar represents spread in both variables.

optimal to induce any appreciable effect in the case of tea. This is in agreement with a few reports on other crops, wherein it was shown that the GA_3 effect is concentration and species-dependent[12]. The Ci/g_s values were relatively low in all GA_3-treated plants than that of control plants (Table 1), suggesting that the hormone-treated plants fix carbon efficiently at a given stomatal conductance, supporting our earlier findings in a few crop species[5–7].

The intrinsic carboxylation efficiency (dA/dCi) of control tea plant was 0.43 μmol $CO_2\ m^{-2}\ s^{-1}\ ppm^{-1}$. The dA/dCi of 50, 100 and 150 ppm GA_3-treated plants was 0.51, 0.56 and 0.61 μmol $CO_2\ m^{-2}\ s^{-1}\ ppm^{-1}$, indicating an apparent improvement in intrinsic carboxylation efficiency of 9, 19 and 30% respectively.

Ci/g_s showed a significant inverse relationship with dA/dCi in our study (Figure 1), which is in corroboration with our earlier findings in other crop species like sunflower, groundnut and cowpea[5,13,14]. A reduction in Ci levels can be expected either when the g_s is low or when the efficiency of carbon assimilation by the RuBisCO is high[14]. At a given g_s, therefore, variations in Ci are predominantly a function of carbon assimilatory capacity[13,14].

One of the formative effects of GA_3 has been on cell elongation, thereby maintaining cell turgidity[12]. The turgidity induces more cell growth leading to improvement of carbon exchange to water vapour ratio. In other words, to a given input of water, carbon assimilation would increase and hence the intrinsic water-use efficiency[13–17]. Steady tissue water status also improves the activities of photosynthetic carbon assimilatory enzymes, leading to efficiency of carbon fixation[12]. The increased efficiencies in water use and carboxylation in the case of tea plants treated with GA_3 in the present experiment might be a result of any one or collective effects of these physiological functions. This aspect needs to be re-examined by determining the content and activity of photosynthetic carbon assimilatory enzymes.

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Utility of OCEANSAT-1 OCM data in deciphering Antarctic features

The Antarctic ice (sea ice, icebergs, continental ice sheet) plays a significant role in determining the global climate. Remote sensing techniques are an obvious means to monitor and study the inaccessible region of the icy continent. Passive microwave remote sensing has been extensively used to monitor the extent, seasonal variation and secular trends of sea ice, information about icebergs, continental ice and geomorphic features of the Antarctic region[1–3]. However, due to low resolution, retrieving information about the small-scale features of the area is not possible. Therefore, optical remote sensing could emerge as a useful tool for detailed study at micro level, mainly due to its high resolution. In the Antarctic region long polar nights, extreme weather conditions and presence of clouds restrict the utility of optical remote sensing. Accordingly, in Antarctica optical remote sensing techniques can only be applied during austral summer when days are bright and sunny, and the sky is cloud-free.

In view of the above, data from Ocean Colour Monitor (OCM) sensor (which is an optical remote sensing sensor) of OCEANSAT-1 have been used in the present study to highlight distinct geological and geomorphic features. The Indian remote sensing satellite (IRS-P4), renamed later as OCEANSAT-1, was launched on 26 May 1999, on-board the indigenously developed Polar Satellite Launch Vehi-