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Growth and Yield of Fenugreek *(Trigonella foenum graecum* L.), Spinach (*Spinacea oleracea* L.), Coriander *(Coriandrum sativum* L.) and Lettuce *(Lactuca saliva* L.) under Continuous Daylight Condition in Antarctica

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Abstract

A study on growth and yield of fenugreek (*Trigonellafoenum graecum* L,), spinach *(Spinacea oleracea* L.),coriander (*Coriandrum sativum* L.) and lettucse(*Lactuca sativa* L.) during polar summer 1990-91 is described. The plants were grown in peatmoss using NFT culture. The plants maintained a good growth and crops matured within five weeks of emergence. Flowering was observed in fenugreek, coriander and spinach after 33, 27 and 34 days of emergence respectively, while no flowering was observed in lettuce. The yields recorded were fenugreek 0,775 kg/m^2 , spinach 1.007 kg/m^2, coriander 1.317 kg/m^2 and lettuce 0.888 kg/m^2. The growth analysis was carried out by computing RGR, RLA, NAR and LAR. Significant correlation between FW and LA was observed. Exponential regression equations between FW and LA calculated for all four crops are described. The shoot FW/plant of fenugreek, spinach, coriander and lettuce were 1059±101,1802±102, 663±80 and 1189±98 mg, respectively after five weeks of emergence. The average weekly increase in plant height was 4.9±0.3, 4.2±0.3, 5.6±0.5 and 3.1±0.4 cm; the increase in leaf area was 13.30±1.4, 5.80±0.7, 19.82+1.2,14.46±1.7 cm^2 and increase in shoot FW was 235.5+18, 164.0±16, 421.8±19, 292.75±17 mg respectively in fenugreek, coriander, spinach and lettuce.

Performance of six spinach genotypes viz. St. Halens, Barker, Olympia, Jobnergreen, Banarasi and DARL-Selectionis described. The experiment was conducted in the greenhouse in peatmoss-vermiculite substrate (1:1), Cultivar Olympia gave the highest yield : 1.350 kg/m , while Banarasi gave the least yield : 0,375 kg/m^2 . The plants started flowering after 18 to 20 days of emergence and crop was ready to harvest after 30 days of sowing the seed. The average increase in plant height/day 0.6 cm in Banarasi and 12 cm in other cultivars. Four high yielding cultivars were Olympia, Barker, Jobnergreen and St.Halens with green leaf yields of 1.350,1.110,1.063 and 0.900 kg/m^2 respectively.

Abbreviations : NFT = Nutrient film technique; RGR = relative growth rate; RLA = relative leaf area; NAR = net assimilation rate; LAR = leaf area ratio; PAR = photosynthetically active radiation; ppm = parts per million; LA = leaf area; FW = fresh weight; DM = dry matter; PAR = Photosynthetically active radiation

Introduction

Antarctica is an isolated glacial continent having an area of 14 million square km. Only 2 % of this area is free of ice. Apart from snow algae,plant life is limited to these ice free zones. Only two native vascular plants- a grass *Deschampsia antarctica* and the cushion plant *Colobanthus quitensis* grow in Antarctic peninsula. The non-flowering plants include lichens, moss, algae such as Prasiola and Nostoc (prominent in lakes) and microscopic soil fungi (Readers Digest, 1985, Fifield, 1987). A remarkable flora of blue green algae and other microorganisms inhibit the near surface zone within some rocks. These plants also have limited growth because of unavailability of nutrients in Antarctic soil and water (Joshi *et al,* 1988, Lars, 1988).

Higher plants can't survive in Antarctica as these require a minimum temperature of 1 to 16 °C (Kononkov, 1988). These can only be grown by the way of protected cultivation in greenhouses. Increasing scientific activity and prolonged stay of scientists in Antarctica raised the need for fresh food. This led expeditioners to grow vegetables within stations or in greenhouses (Readers Digest, 1985). In order to study the growth and yield of vegetable crops DARL was included in the Antarctic Research Programme and the mission was named as Polar Horticulture. The first Indian study on horticulture in Antarctica was carried out by Joshi and Banerjee (1988) during Fifth Indian Scientific Expedition to Antarctica. Data on plant growth and yield are not available from this study. An experiment was planned in the greenhouse at Maitri station during Tenth Expedition; to study growth and yield of two leafy vegetables:spinach and fenugreek, and two salad crops : coriander and lettuce. The results of this study are reported in this paper.

Spinach is a popular leafy vegetable rich in minerals and vitamins A and C. Selection of suitable high yielding cultivars is necessary for good production. Therefore another experiment was also conducted to study yield performance of spinach cultivars under continuous daylight condition.

Materials and Methods

The experiment was conducted in the greenhouse at India's permanent research station Maitri (70°45'39.4": 11°44'48.6") during Tenth Indian Scientific Expedition to Antarctica. The greenhouse was sufficiently airtight for snow and cold winds and well controlled. Temperature (20°C) was maintained by hot water radiators and electrical heaters. Relative humidity (60 %) was maintained by humidifiers. Plants were grown in the natural light. The experiment was performed in plastic trays in randomised block design with three replicates. Peatmoss was used as the growing medium. The nutrient solution consisted of Yamasaki recipe (for macro nutrients) and Hoagland solution (for micronutrients). Sterilised seeds of fenugreek (var :

Kasuri), spinach (var: Jobnergreen), coriander (var : Bulgarian) and lettuce (Butter head) were sown on 2 Jan 1991 which germinated within one week (Figs 1 and 2).

Plant height, fresh weight, leaf area, number of leaves, root length and dry weights were recorded regularly by periodic sampling.

Seeds of six spinach cultivars viz. St. Halens, Barker, Olympia, Banarasi, Jobnergreen and DARL-Sel.; pre-sterilised were sown on 16^{th} Jan'91. Experiment was conducted in RBD manner with three replicates. Growing media was peatmoss and vermiculite (1:1). Seeds germinated within 10 days. Plant height after emergence was regularly recorded. The crop was harvested on 16^{th} Feb'91 and data on shoot fresh weight, plant height, number of leaves, leaf area and yield were recorded. Five randomly selected plants of each cultivar were sampled. The plants were irrigated daily with nutrient solution.

The temperature and relative humidity inside greenhouse were recorded by a thermohygrograph, while ambient temperature was recorded by mercury thermometers. PAR was recorded by a digital luxmeter (Yorko make). The temperatures of nutrient solution and growing media were recorded by an electronic thermometer (PT-100 sensor). The leaf area was measured by an optical planimeter. FW and DW were measured by an electronic balance. Dry weights were measured after heating samples in a ventilated oven for seven days. Carbon dioxide level inside greenhouse was measured by a gas analyser. Growth analysis was carried out by computing RGR, RLA, NAR and LAR as described by Hunt (1978), Fawusi (1981) and Nilwik (1981).

All experiments were conducted in accordance with agreed measures of Antarctic Treaty, using only sterilized media and seeds.

Results and Discussion

Tables 1 and 2 show the comparative growth and development of the crops. Fig.3 shows the growth analysis: RGR.(mg mg^{-1} day^{-1}), RLA (cm^2 day^{-1}), NAR (mg mm^2 day^{-1}) and LAR (mm^2 mg^{-1}). The yields recorded were : fenugreek 0.775 kg/m^2, coriander 1.317 kg/m^2, spinach 1.007 kg/m^2 and lettuce 0.888kg/m^2. The average weekly growth in plant height was found to be 4.9±0.3, 4.2±0.3, 5.6±0.5, 3.1±0.4 cm; the increase in LA was 13.30±l.40, 5.80±0.7, 19.82±1.2, 14.46±1.7 cm^2 and the increase in shoot FW was 235.50±18.0,164.00±16.0,421,80± 19.0 and 292.75±17.0 mg fenugreek, coriander, spinach and lettuce respectively. The rate of increase in plant height was maximum in spinach followed by fenugreek. The rate of increase of LA and FW was maximum in spinach (Table 1). Lettuce had the least growth. The yields (green leaf) recorded were 0.775, 1.317, 1.007 and 0.888 kg/m^2 for fenugreek, coriander, spinach and lettuce respectively. Flowering was observed in fenugreek, coriander and spinach after 33, 27 and 34 days of emergence respec-

Fig. 1. Spinach grown in greenhouse al Maitri.

Fig. 2. Methi grown in Maitri greenhouse.

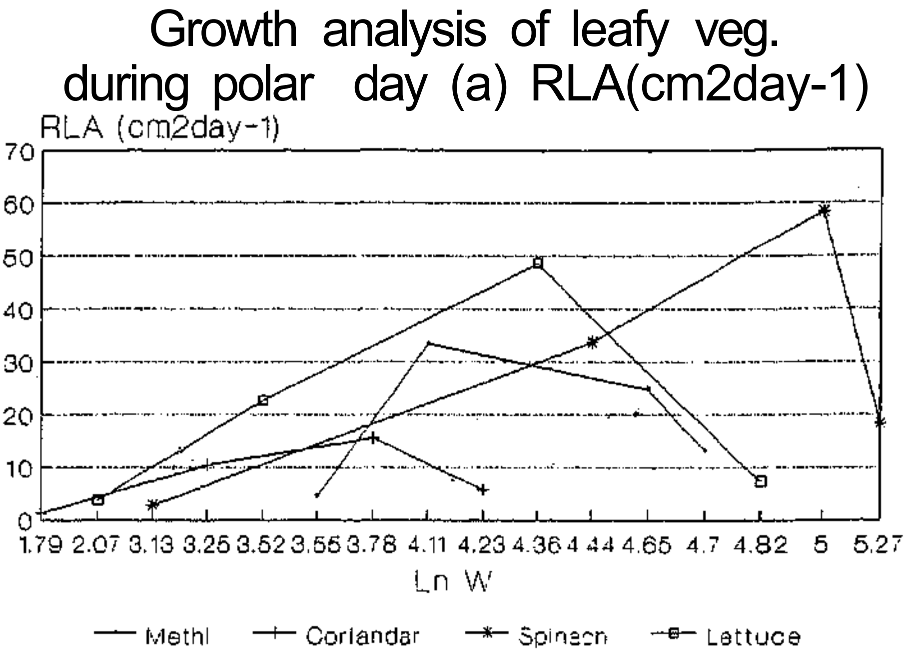
Growth analysis of leafy veg.
during polar day (a) RLA(cm2day-1)
RLA (cm2day-1)
70
60
50
40
30
20
10
0
1.79 2.07 3.13 3.25 3.52 3.55 3.78 4.11 4.23 4.36 4.44 4.65 4.7 4.82 5 5.27
Ln W
Methi
Coriandar
Spinach
Lettuce

Fig. 3a

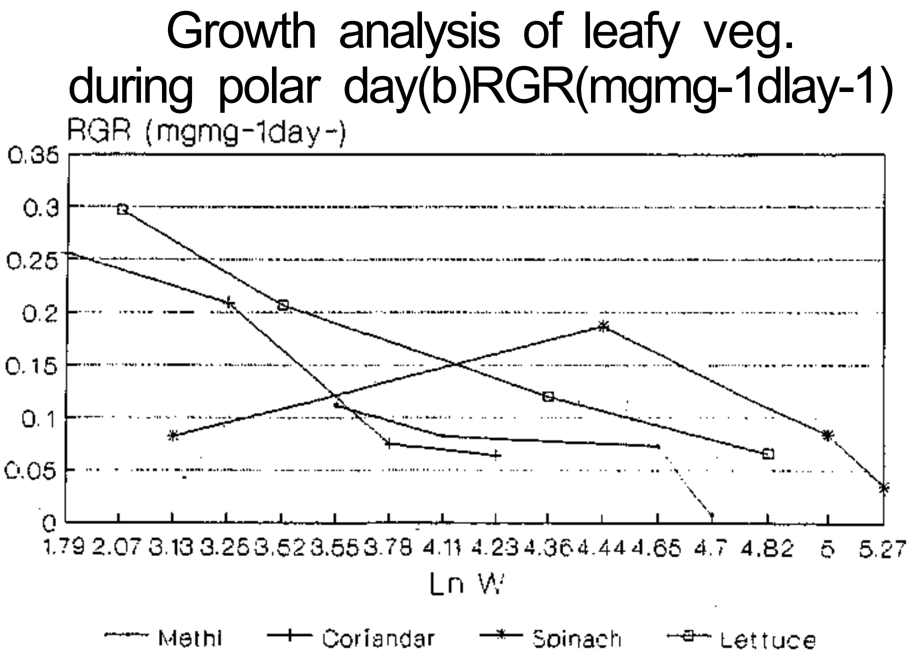
Growth analysis of leafy veg.
during polar day(b)RGR(mgmg-1dlay-1)
RGR (mgmg-1day-)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1.79 2.07 3.13 3.25 3.52 3.55 3.78 4.11 4.23 4.36 4.44 4.65 4.7 4.82 5 5.27
Ln W
Methi
Coriandar
Spinach
Lettuce

Fig. 3b

Growth analysis of leafy veg. during polar day (c)NAR (mgmm2day-1)

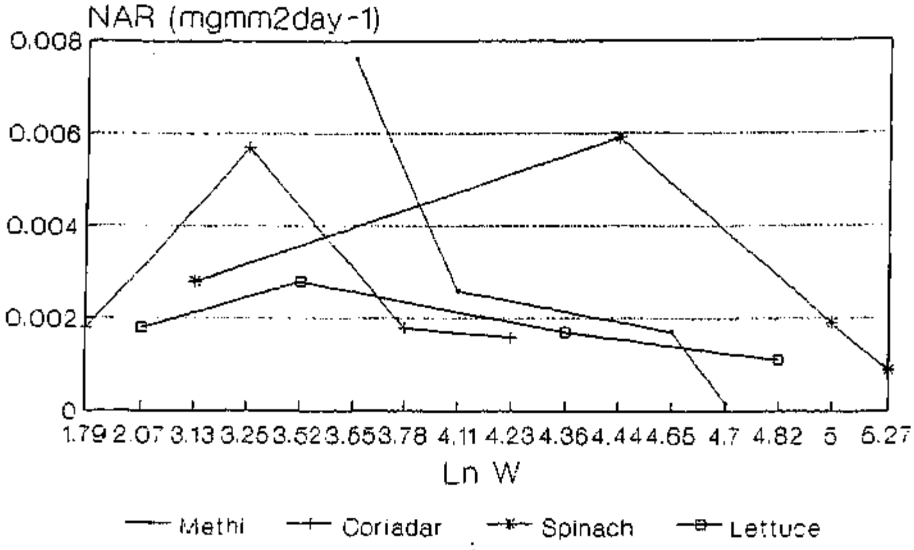

Fig. 3c

Growth analysis of leafy veg. during polar day (d)LAR (mm2mg-1)

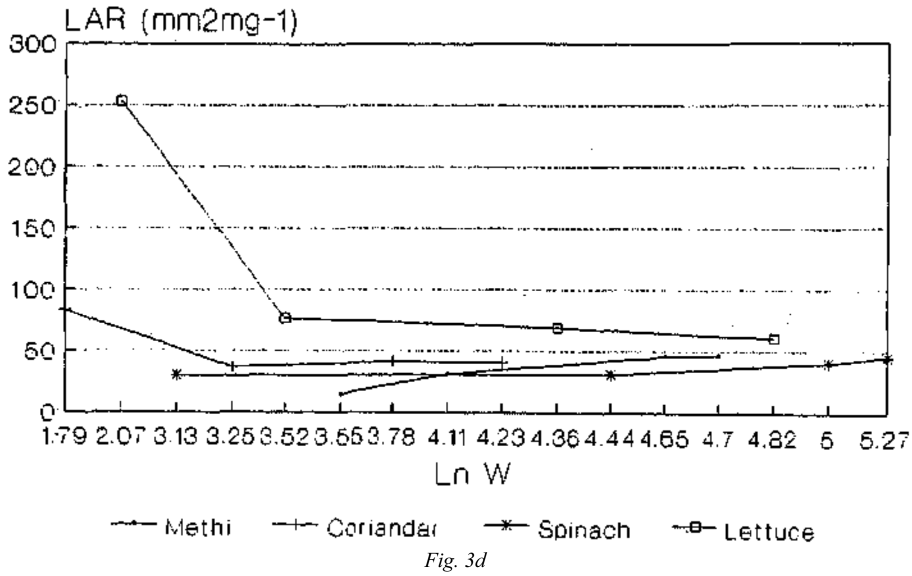

Fig. 3d

Table1: Growth and Development of Four Leafy Vegetables in Antarctica during Continuous Daylight Condition

Cultivar	Days after emergence				
	7	14	21	28	35
Shoot fresh wt (mg/plant)					
Fenugreek	117±20	260±21	549±23	994±42	1059±105
Coriander	7±2	57±5	239±22	412±35	663±83
Spinach	115±20	205±25	772±65	1368±115	1802±172
Lettuce	18±2	78±11	295±28	767±98	1189±110
Root fresh wt (mg/plant)					
Fenugreek	49±5	50±6	51±5	52±5	53±5
Coriander	2±1	10±1	16±1	23±2	25±2
Spinach	20±2	25±2	76±6	120±9	130±9
Lettuce	3±1	10±1	30±3	45±4	55±5
No. of leaves					
Fenugreek	3	5	8	10	12
Coriander	2	3	5	6	7
Spinach	2	4	6	11	13
Lettuce	2	4	6	6	6
Leaf area (cm^2 /plant)					
Fenugreek	2.22±0.30	5.38±0.80	28.87±1.90	46.28±2.20	55.33±2.10
Coriander	1.30±0.20	2.22±0.40	9.50±0.90	20.40±1.50	24.48±1.40
Spinach	4.21 ±0.40	6.22±0.70	29.84±1.20	70.65±2.10	83.50±2.90
Lettuce	4.20±0.40	6.90±0.70	22.73±1.98	56.88±2.40	62.05±2.69
Stem length (cm)					
Fenugreek	5±0.2	9±0.3	15±0.3	20±0.5	24.5±0.4
Coriander	5.1 ±0.2	9.5±0.3	14.9±0.4	17±0.4	22.0±0.5
Spinach	3.2±0.2	5.5±0.2	13.5±0.3	21±0.3	25.5±0.6
Lettuce	3±0.2	5±0.2	11.7±0.3	15±0.3	15.3±0.3
Root length (cm)					
Fenugreek	2.5±0.2	4.5±0.2	5.5±0.3	7.5±0.3	7.6±0.3
Coriander	1.4±0.2	2.5±0.3	3.2±0.2	6.3±0.2	7.0±0.3
Spinach	2.4±0.2	3.5±0.3	4,5±0.4	7.5±0.4	7.6±0.4
Lettuce	2.1±0.2	3.0±0.2	3.2±0.4	6.5±0.2	7.1±0.3
W root/W shoot					
Fenugreek	0.580	0.330	0.096	0.051	0.048
Coriander	0.280	0.170	0.060	0.050	0.030
Spinach	0.170	0.120	0.090	0.080	0.070
Lettuce	0.160	0.120	0.100	0.050	0.040

Table 2: Regression Analysis for Leafy Vegetables in Antarctica during Polar Day

Cultivar	*r* between FW and LA	Regression equation
Fenugreek	0.994 (p<0.001)	FW=l60.7*exp(0.044*LA)(p<0.001)
Coriander	0.979 (p<0.001)	FW=20.5*exp(0.1838*LA)(p<0.05)
Spinach	0.993 (p<0.001)	FW=161.9*exp(0.037*LA)(p<0.00l)
Lettuce	0.971 (p<0.001)	FW=35.12*cxp(0.0696*LA)(p<0.02)

tively. No head formation and flowering was observed in lettuce. Reduction in vegetative phase was recorded with early flowering and crops (except lettuce) matured within five weeks of emergence. Correlation coefficient (r) between FW and LA were calculated (Bailey, 1981). Significant (p 0.001) values of *r* were observed. Significant regression equations between FW and LA were computed and are listed in Table 2.

The plant environment in Antarctica was totally different from that one existing on the main land. Plants were subjected to a CO_2 level of 400 ppm (normal level is 350 ppm), average temperature of 22 °C, 64 % RH and 24 hr daylength. The PAR level inside greenhouse varied from 100 lux to 45000 lux and a minimum of 100 lux was always available to the plants. The plants followed the usual thermoperiodism i.e. a higher day temperature was followed by a lower night temperature. Although there was no night but time interval between which the light intensity level dropped below 1000 lux was treated as night/dark period.

The yield of spinach, fenugreek, coriander and lettuce have been reported as 0.9 to 1.0, 0.9 to 1.0, 0.9 to 1.0 and 0.7 to 1.0kg/m^2 by Chauhan (1989) and I.C.A.R. (1989). We obtained yields of 1.007, 0.775, 1.317 and 0.888 kg/m^2 in spinach, fenugreek, coriander and lettuce respectively. All these are cool season crops but in Antarctica they were grown at higher temperature resulting in poor growth.However, continuous irradiance (24 hr daylength) resulted in reduction in vegetative phase and early flowering and maturity.

In his study on spinach, Borowski (1984) concluded that highest yield of vegetative mass was obtained under the natural light and Tamura (1988) revealed that increasing the CO_2 level greatly increased the DM production at high planting densities. Similar observations have been recorded in Antarctica.

Various studies on lettuce for studying the effect of CO_2 concentration, photoperiod and light intensity by Coporn (1989), Toop *et al.* (1989) and Ikeda *et al.* (1988) have revealed that CO_2 enrichment increased the rate of emergence and expansion of leaves and the growth of young plants. Early maturity of spinach, fenugreek, coriander confirms this view. The poor growth of lettuce seems due to some problem with growing medium.

For the purpose of studying the growth and effect of environmental conditions on plant growth a number of techniques and concepts of growth analysis have been developed (Hughes and Freeman, 1967; Hunt, 1978). Periodic sampling during growth period provides not only information on the increase in plant weight as influenced by environmental and ontogenetical stage but also shows how plant morphology and the distribution pattern of the newly formed assimilats is affected by these factors.

Growth parameters in general exhibit a strong ontogenetical pattern. Strong changes in RLA, RGR, NAR and LAR were observed. The quantities were plotted against the total dry weight, since this representation provides a better measure of the ontogenetical stage of the plants as compared to experimental time scale. For the same reason mean values were not calculated for a certain time interval but rather during two dates between which a certain dry matter increment was realised. It should be remarked that the identity RGR = NAR * LAR was not valid. This indicates that growth pattern was totally altered in Antarctica. The average values of RLA, RGR, NAR and LAR for first five weeks were 1.9 $cm^2 day^{-1}$ 0.067 mg mg^{-1} day^{-1}, 0.003 mg mm^2 day^{-1}, 34.658 mm^2 mg^{-1} for fenugreek; 0.82, 0.151, 0.003, 50.661 for coriander; 2.82, 0.097,0.003, 36.609 for spinach and 2.06, 0.173, 0.002, 114.981 for lettuce respectively. Schwabe (1956) has studied the growth of short and long day plants in Arctic latitudes and revealed that high rate of photosynthesis results in continuous light. Similar observation we recorded in Antarctica.

Prolonged growth in continuous irradiance results in leaf yellowing and leaf drop (Nilwik, 1981). The same results were obtained by Kristofferson (1963), who attributed it to a slowly decreasing turger pressure. A dark period would be necessary to restore the leaf turger. Leaf yellowing and leaf drop was absent in Antarctica. The study was conducted during polar day and it is continuous light for 24 hr during this period. In the case of plants below a certain light level : compensation point, plants reduce (stop) photosynthesis and time till which light level remains below this level can be treated as dark period for plants. Bohning and Brunside (1956) have suggested this level as 1000 lux to 16000 lux for *Phaseolus vulgaris.* Thus plants enjoyed a dark period of 2 to 4 hr in Antarctica when PAR level dropped below 1000 lux .

Table 3 shows the comparative response of spinach cultivars during continuous daylight condition. Polar day is characterised by a 24 hr day length. Highest yield was obtained in Olympia: 1.350 kg/m^2 followed by Barker: 1.100 kg/m^2 . Banarasi gave the least yield only 0.375 kg/m^2 . Four high yielding cultivars were Olympia, Barker, Jobnergreen and St. Halens with yields: 1.350, 1.100, 1.063, and 0.900 kg/m^2 respectively. Leaf area were highest in St.Halens and Barker, while the fresh weights were highest in Jobnergreen and Olympia. Barker and DARL-Sel had the maximum plant height on harvest, followed by St.Halens and Olympia. Banarasi

Table 3:Comparative Response of Spinach Cultivars during Continuous Daylight Condition

Cultivars	Days to emergence	Plant height (cm)	Fresh wt/plant (shoot) (gm)	No. of leaves	Leaf area/plant (cm^2)	Yield (kg/m^2)	Days to flowering
St.Halens	5	33.9±0.5	1.798±0.080	12	127.71±I.21	0.900	21
Olympia	4	31.1±0.6	2.694±0.060	10	70.92±1.31	1.350	22
Barker	5	35.0±0.7	2.197±0.060	11	123.88±1.05	1.100	NF
Banarasi	8	14.9±0.5	1.517±0.090	5	42.35±0.95	0.375	NF
Jobnergreen	4	33.0±0.5	2.128±0.()90	7	82.60±1.00	1.063	NF
DARL-Sel.	4	35.1 ±0.7	0.852±0.050	9	40.77±0.90	0.425	18

Average data of three observations

NF. No flowering observed

had the least plant height and fresh weight. Fig. 4 shows the variation of plant height. The average increase in plant height/day was 0.6 cm in Banarasi and 1.2 cm in other cultivars. Flowering was observed in St.Halens, Olympia and DARL-Sel after 21,22 and 18 days of emergence respectively.

The average green leaf spinach yield in India during season (in open field) according to Indian Council Of Agricultural Research (1987) is 0.7 kg/m^2 to 1.0 kg/m^2. The average spinach yield in Antarctica was 0.868kg/m^2 . The yield in Antarctica was higher.

The plants grown in Antarctica had lesser vegetative growth, lesser height and fresh weight as compared with corresponding plants grown in the mainland (in open) during season. Early flowering and reduction in vegetative phase were observed in Antarctica. This happened due to long photoperiod and little dark period (Knott, 1934), increased photosynthesis and high levels of integrated PAR as described by Devlin (1975), Smith (1938) and Berry & Downton (1982).

The increased yield in Antarctica was due to higher CO_2 level and high integrated PAR (natural light: because of 24 hr daylength) confirming findings of Borowski (1989). Tamura (1989) has studied spinach in water culture under high CO_2 level and concluded that increasing the CO_2 level greatly increased dry matter production at high planting densities and similar observations we have recorded in Anatarctica.

Enhancement of photosynthesis and improvement of its efficiency can improve productivity and yield. The photosynthesis itself is a complex function of light, temperature, humidity, CO_2 level, nutrient supply and plant age. The effect of environmental factors on photosynthesis is an important area of study (Leopold, 1964; Walls, 1983). This information helps in producing more quantities of food

Plant height of spinach during polar clay

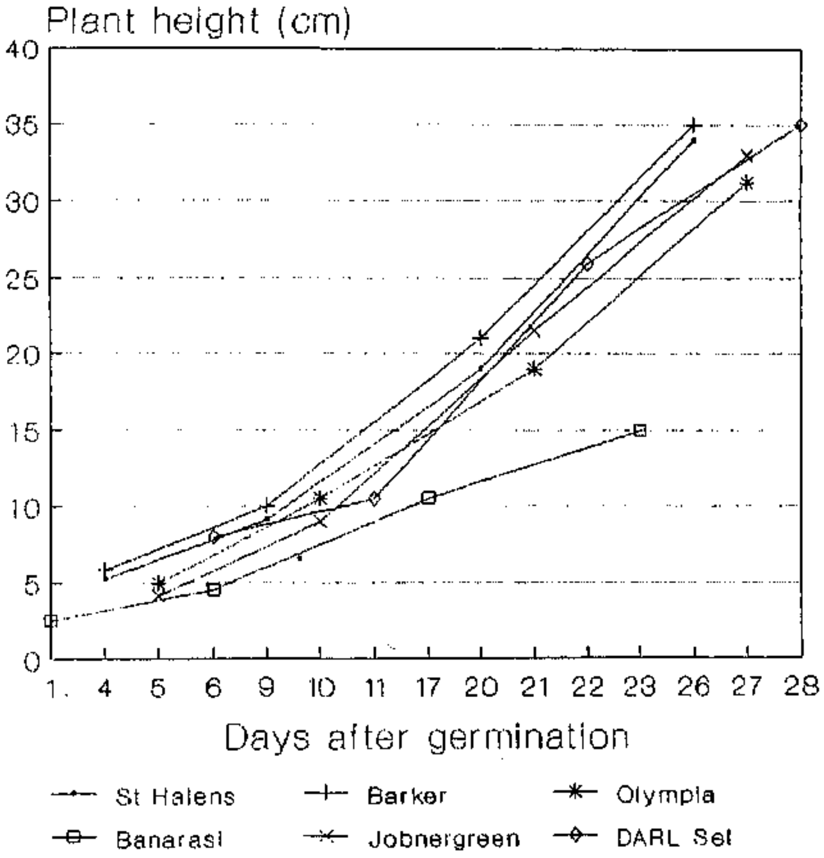

Fig. 4

through the proper control of the environmental factors and has led to the development of plant factories (Sase *et al.,* 1988; Davis 1988). Plant factories are greenhouses where environment is precisely controlled. The greenhouse microclimate has got special attention (Edmondson, 1989; Cockshull, 1989; Roose, 1987; Anderson, 1984). Advanced environmental control systems, employing highly efficient heating / cooling / lighting / CO_2 enrichment devices have made the crop production highly safe, economic, optimised and automated (Jones *et al.,* 1989; Manera et al.; 1988, Bakker *et al,* 1988).

This study reports the performance of spinach fenugreek, coriander and lettuce during continuous day/light condition. It is concluded that longer photoperiod results in earliness. However, interacting effects of temperature, light level, CO_2 level and photoperiod need further study. This study will help in developing vegetable factory type production system for fresh food in Antarctica and elsewhere.

Acknowledgements

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