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Effect of Irradiance on Growth, Physiological Processes and Yield of Melon *(Cucumis melo)* Plants Grown in Hydroponics

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ABSTRAK

Pengaruh radiasi yang berbeza ke atas tanaman tembikai wangi (Cucumis melo) *cv. Birdie, Charity Ball dan Jade Dew yang ditanam di dalam hidroponik telah dikaji. Tanaman diberi rawatan min radiasi yang berbeza iaitu 11.4, 8.2, 6.1 dan 3.0 MJ m^{-2} hari^{-1} yang diperolehi dengan menggunakan teduhan. Hasil berat kering berhubung rapat dengan paras radiasi. Konduksi stomata dan kadar fotosintesis adalah tertinggi bila tanaman berada pada paras radiasi yang tertinggi. Tanaman yang ditanam di bawah radiasi 11.4 MJ $m^{-2}h^{-1}$ menghasilkan berat basah buah dan kandungan pepejal terlarut yang tinggi. Semua kultivar gagal untuk menghasilkan buah pada radiasi 3.0 MJ $m^{-2}h^{-1}$*

ABSTRACT

*The effect of different irradiance levels on melon (*Cucumis melo*) cv. Birdie, Charity Ball and Jade Dew grown in hydroponics was investigated. Plants were exposed to mean daily irradiance levels of 11.4, 8.2, 6.1 and 3.0 MJ m^{-2} day^{-1} achieved by using different levels of shade. The dry matter yield appeared to be directly proportional to the irradiance level received by plants. Stomatal conductance and photosynthetic rate were highest when the plants were grown under the highest irradiance level. Plants grown under 11.4 MJ $m^{-2}d^{-1}$ had the highest fruit fresh weight and total soluble solids. All cultivars failed to fruit when grown under irradiance of 3.0 MJ $m^{-2}d^{-1}$.*

INTRODUCTION

In Malaysia, the area of cultivation of horticultural crops under protected environment expanded rapidly in the late 1980s. This development has been encouraged by many factors such as the unpredictable weather conditions, the demand for quality produce and the introduction of soilless culture. As for open field cultivation, crop productivity under protected environment agriculture is dependent upon optimum environmental factors.

It is a common assumption that light is generally not limiting for the cultivation of crops in the tropics. This assumption is not always true. Malaysia, for example, often experiences periods of haze, which reduce radiation interception by almost 30-40% and this is even more pronounced under rain shelters (Mohd Razi 1991, 1994). Apart from these changes, different designs of rain shelter result in 18-50% reduction in radiation interception (Yeoh 1991). Robinson (1990) also reported that different types of plastic used as roofing material cause variation in light interception.

Nearly all previously reported experiments showing benefits of increased irradiance have involved plants growing in glasshouses in temperate regions, where low levels of radiation are more critical during winter (Hurd and Thornley 1974; Gislerod *et al.* 1989; Cockshull *et al.* 1992). In glasshouses in the tropics, Mohd Razi and Ali (1994) found NFT-grown tomatoes failed to fruit when plants received less than 8.5 MJ $m^{-2}d^{-1}$ despite a 5°C reduction in temperature in the plant canopy under glasshouse conditions in Malaysia.

Melon (*Cucumis melo* L.) of the reticulatus type is a high value crop which can be grown successfully by hydroponics under rain shelters. Apart from a report by Bouwkamp *et al.* (1978), little information is available on the irradiance requirement for the production of melon in the tropics, especially when water and nutrient supply are not limiting factors in crop production, as is the case in hydroponics.

The present study was conducted to examine the effects of different levels of irradiance on growth, stomatal conductance, photosynthesis rate and yield of three melon cultivars, and, based on growth and yield data, to determine the optimal irradiance level for production of melon under protected environment in the tropics.

MATERIALS AND METHODS

The effects of irradiance on three melon (*Cucumis melo*) cultivars grown in a Kyowa deep culture system (Lim and Wan 1984) were investigated at the Hydroponic Unit, Universiti Pertanian Malaysia. Uniform, three-week-old melon plants (cv. Birdie, Charity Ball and Jade Dew) were grown under different shade regimes which gave varying levels of irradiance. Various levels of shade were achieved by placing an increasing number of layers of plastic film of ethylene vinyl acetate (EVA) copolymers over the plant canopy. EVA copolymers are transparent to visible light and allow all wavelengths essential for photosynthesis to pass through (Robinson 1990). Mean irradiance received by plants under various shade levels was 11.4, 8.2, 6.1 and 3.0 MJ $m^{-2}d^{-1}$ as recorded by solarimeters (Delta-T Device, Cambridge, UK). Air temperature and relative humidity in the plant canopy were between 25-37°C and 60-72%, respectively. The plants were supplied with a nutrient solution containing the ion concentrations given by Cooper (1979) with electrical conductivity maintained between 2.4-2.6 mS cm^{-1}. Plants were arranged in a completely randomized design in a split-plot arrangement where irradiance and cultivar were assigned as main plot and subplot, respectively. Each plot contained 12 plants, which were replicated 4 times.

At harvest, leaf length and breadth were measured with a ruler and the leaf area determined using an automatic leaf area meter (Delta-T Cambridge, UK). The shoot and root dry weights were determined after drying at 80°C for 48 hours. Destructive sampling was performed at 0, 4 and 9 weeks for determination of relative growth rate (RGR) and net assimilation rate (NAR). At each harvest, 4 plants were harvested from each treatment and RGR and NAR were calculated using formulae given by Hunt (1982).

Measurements of the stomatal conductance (gs) and net photosynthetic rate (Pn) for intact leaves were determined using an infrared gas analyser IRGA (LCA-2 Portable Photosynthesis System, ADC Hoddesdon, UK). The measurements were made 4-5 h after sunrise on clear days on the abaxial surface of young fully expanded leaves (3^{rd} - 5^{th} leaf from shoot apex). All measurements were carried out in the differential mode at IRGA with Emax set at 1.0 and boundary layer resistance at 0.3 mmol m^{-2} s^{-1} predetermined by placing the chamber on a mock leaf (of moist filter paper).

Fruits were harvested from each plant at maturity when signs of cracks appeared at the basal part of the fruit. Fruit diameter was measured at harvest using a Vernier caliper and their fresh weight was deter-

TABLE 1

Effect of irradiance and cultivar on leaf length, breadth, area and dry weight of leaf, root and stem at day 56. Data are means of the main effect as interaction between irradiance × cultivar is not significant except for leaf area

Treatments	Mean Leaf Length (cm)	Mean Leaf Width (cm)	Leaf Area (cm^2)	Mean Dry Weight Leaf (g/plant)	Root	Stem
Irradiance ($MJ\ m^{-2}\ day^{-1}$)						
11.4	16.24 a	21.24 a	6190 a	34.28 a	7.66 a	17.40 a
8.2	13.56 b	18.27 b	4774 b	27.26 b	5.90 b	16.23 a
6.1	12.92 b	16.84 c	3959 c	12.22 c	3.58 c	12.24 b
3.0	7.40 c	9.93 d	965 d	5.63 d	1.13 d	2.22 c
Cultivar						
Birdie	12.50 a	16.60 a	4644 a	21.86 a	5.21 a	13.19 a
Charity Ball	12.37 a	16.51 a	3659 b	20.26 a	4.55 a	12.03 a
Jade Dew	12.72 a	16.68 a	3613 b	17.42 b	3.94 b	10.84 a
Interaction ($P < 0.05$)						
Irradiance × Cultivar	ns	ns	**	ns	ns	ns

Mean values in each column with the same letter are not significantly different at $P < 0.05$ according to DMRT. For the interaction effects; ** = significant at $P < 0.05$.

mined. A fresh sample weighing 20g was placed in a weighed glass petri dish and oven dried at 80°C for 60 h, and total fruit dry matter was estimated. Data were obtained on soluble solids content with a hand refractometer (Currence and Larsen 1941) on all fruit harvested from each plant.

RESULTS AND DISCUSSION

Table 1 shows the growth responses of melon cultivars to different levels of irradiance. There was no significant interaction ($P > 0.05$) between irradiance and cultivar on the leaf length and width and dry weight of leaf, stem and root. Leaf length and width were reduced significantly ($P < 0.05$) with irradiance below 6.1 $MJ\ m^{-2}d^{-1}$. Similarly, low irradiance resulted in a significant reduction ($P < 0.05$) in leaf dry weight. This is consistent with the fact that intercepted radiant energy determines the dry matter production in plant species (Lawlor 1992). Root dry weight was reduced to 22, 53 and 88% in plants grown under 8.2, 6.1 and 3.0 $MJ\ m^{-2}d^{-1}$ respectively, relative to 11.4 $MJ\ m^{-2}d^{-1}$. The reduction in leaf growth with decreased irradiance was reported to inhibit root growth and subsequently

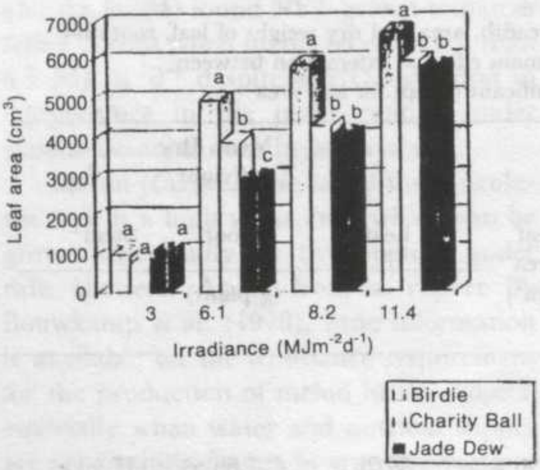

Fig. 1: The effect of irradiance and cultivar on lead area of melon plant. Means separation by DMRT ($p < 0.05$)

water uptake (Smith *et al.* 1984). The reduction in plant growth with decreasing irradiance involves many physiological and biochemical attributes which have been reported elsewhere (Blackman and Wilson 1951; Lawlor 1992). Between cultivars, Birdie produced greater root dry weight than either Charity Ball or Jade Dew. A significant irradiance and cultivar interaction ($P < 0.01$) was observed for leaf area. Cultivar Birdie produced a greater leaf area when grown under irradiance levels above 6.1 MJ m^{-2} day^{-1} (*Fig. 1*).

In general, the RGR and NAR were affected by different irradiance levels (Table 2). In the first four weeks, RGR and NAR decreased proportionately with reduction in irradiance levels. During weeks 4 - 9, no significant difference in RGR and NAR between plants grown under 11.4 and 8.2 MJ m^{-2}d^{-1} was observed. RGR and NAR were significantly reduced ($P < 0.05$) with irradiance levels below 8.2 MJ m^{-2}d^{-1}. A similar trend of increased NAR and RGR with increased irradiance had been reported for tomatoes (Hurd and Thornley 1974; Logendra *et al.* 1990), and tomatoes, sweet pepper and cucumber (Bruggink and Heuvelink 1987). There was no significant interaction ($P > 0.05$) observed between irradiance and cultivar for NAR and RGR.

TABLE 2
Effects of irradiance on relative growth rate and net assimilation rate of melon plants. Data on cultivar are not presented as no significants were observed within cultivars. Interaction irradiance and cultivar are also not significant.

Interval/Irradiance Treatments	Relative Growth Rate (g g^{-1} week^{-1})	Net Assimilation Rate (g cm^{-2} week^{-1} × 10^{-3})
0-4 weeks		
11.4 MJ m^{-2}d^{-1}	0.26 a	1.6 a
8.2 :	0.20 b	1.3 b
6.1 :	0.15 c	1.1 c
3.0 :	0.06 d	0.7 d
4-9 weeks		
11.4 MJ m^{-2}d^{-1}	0.30 a	3.6 a
8.2 :	0.32 a	3.7 a
6.1 :	0.24 b	2.6 b
3.0 :	0.20 c	1.4 c

Means separation by DMRT ($P < 0.05$), Mean values in each column with the same letter are not significantly different.

TABLE 3

Effects of irradiance and cultivar on photosynthesis rate (Pn) and stomatal conductance (gs) measured at day 24 and 40 after treatments (DAT) on melon plants. Data presented as mean from main effect as the interaction irradiance × cultivar is not significant.

	24 DAT		40 DAT	
Treatments	Pn ($\mu mol\ m^{-2}s^{-1}$)	gs ($mol\ m^{-2}s^{-1}$)	Pn ($\mu mol\ m^{-2}s^{-1}$)	gs ($mol\ m^{-2}s^{-1}$)
Irradiance $MJ\ m^{-2}day^{-1}$				
11.4	17.96 a	0.63 a	21.11 a	0.67 a
8.2	16.37 a	0.47 b	15.94 a	0.51 b
6.1	3.65 b	0.29 c	3.64 c	0.27 c
3.0	0.73 c	0.10 d	0.69 d	0.09 d
Cultivar				
Birdie	10.36 a	0.38 a	11.16 a	0.39 a
Charity Ball	9.94 a	0.39 a	10.31 a	0.39 a
Jade Dew	8.81 a	0.35 a	9.56 a	0.36 a
Interaction ($P < 0.05$				
Irradiance × Cultivar	ns	ns	ns	ns

Mean values in each column with the same letter are not significantly different at $P < 0.05$ according to DMRT. ns = not significant.

In this study, stomatal conductance and photosynthesis rate were reduced significantly ($P < 0.01$) with decrease in irradiance (Table 2). Turcotte and Gosselin (1989) reported a similar result for glasshouse cucumber. Low dry weight values in the various plant parts indicated that less carbon was fixed in the leaves that could be translocated to other parts of the plant including fruits. For tomatoes, Ho and Hewitt (1986) showed that photosynthesis rate is mainly affected by irradiance and CO_2 concentration and that the export rate of assimilates from a leaf during the light period is proportional to the concurrent photosynthesis rate. Furthermore, leaf reserves are very low in plants grown in low light and the rate of export from such leaves can be reduced in unfavourable light conditions. This is in agreement with our study on melon where plants grown under low irradiance showed a significant decrease in fresh and dry fruit weights (Table 4). With decreased irradiance from 8.2 to 6.1 $MJ\ m^{-2}d^{-1}$, yield was reduced by 20-60% relative to the plants grown under 14 $MJ\ m^{-2}d^{-1}$. The proportional yield and intercepted radiant energy have already been established in tomatoes. Cockshull *et al.* (1992) showed that 2 kg m^{-2} fruits were produced for every 100 $MJ\ m^{-2}$ of solar radiation received by the crop. Their study also showed that average fruit size was reduced with decrease in intercepted irradiance, which was also observed in this study. Within cultivars, cv. Birdie

TABLE 4
Fruit diameter, fresh weight and dry matter and total soluble solids as influenced by irradiance and cultivar. Data presented are the mean from the main effect as interaction irradiance x cultivar is not significant

Treatments	Fruit Diameter (cm)	Fruit Fresh Weight (g/plant)	Fruit Dry Weight (g/plant)	Total Soluble Solids (% Brix)
Irradiance MJ $m^{-2}day^{-1}$				
11.4	10.52 a	0.90 a	45.13 a	10.40 a
8.2	9.38 a	0.73 b	36.41 b	7.16 b
6.1	7.13 b	0.39 c	21.88 c	5.21 c
3.0	–	–	–	–
Cultivar				
Birdie	10.05 a	0.68 a	30.27 a	8.03 a
Charity Ball	9.20 a	0.63 a	26.10 b	7.32 a
Jade Dew	8.78 b	0.56 b	22.20 b	7.41 a
Interaction Irradiance × Cultivar	ns	ns	ns	ns

Mean values in each columm with the same latter are not significantly different at $P < 0.05$ according to DMRT.

and Charity Ball produced greater fruit fresh weight than Jade Dew. No significant interaction ($P > 0.05$) was found between cultivar and irradiance levels.

All melon cultivars failed to fruit at the lowest irradiance level. The disturbance in the photosynthetic activities might have inhibited assimilate partitioning which subsequently resulted in a failure in reproductive processes. The benefit of high irradiance to the reproductive processes has been reported for a wide range of crops (tomatoes: Boivin *et al.* 1987; Cockshull *et al.* 1992; strawberry: Ceulemans *et al.* 1986; rose: Zieslin and Mor 1990).

Total soluble solids (TSS) is a good measure of sweetness of melon. The relative degree of irradiance reduction was well reflected in decreased TSS. Table 4 shows TSS was reduced by approximately 3 and 5% with a reduction in irradiance interception from 11.4 to 8.2 and 6.1 MJ $m^{-2}d^{-1}$, respectively. Winsor and Adams (1976) showed a similar trend of increased TSS with high irradiance in tomatoes. Our results, however, disagree with those of Bouwkamp *et al.* (1978) who found soluble solids content decreased with increased light intensity in most of the melon cultivars they studied. This discrepancy may be due to the amount of intercepted irradiance. In their study, soluble solids decreased when irradiance increased from approximately 19 to 25 MJ $m^{-2}d^{-1}$ for 6 days prior to harvesting. This high light intensity may cause fruits to accumulate heat and attain temperatures exceeding air temperature; this subsequently results in higher respiration rates, thus lowering soluble solid content. Throughout the duration of the experiment, the maximum irradiance recorded in the present study was only approximately 16.2 MJ $m^{-2}d^{-1}$. We suggest that when plants are grown under unlimited water and nutrient supply, environmental factors that inhibit photosynthesis rate and limit the distribution of assimilate to various plant parts including the fruit play a significant role in yield and quality.

CONCLUSION

The response of melon to the amount of irradiance varies. Irradiance lower than 8.2 MJ $m^{-2}d^{-1}$ reduced dry weight accumulation and yield. None of the cultivars was tolerant of the lowest irradiance level (3.0 MJ $m^{-2}d^{-1}$). The reduction in net photosynthesis may have contributed to reduction in yield. This result has practical applications in showing the need to maximize light transmission under protected environment.

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