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The effect of partial root drying and regulated deficit irrigation technique on growth of rock melon (*Cucumis melo* Linn cv. Glamour)

[Kesan teknik pengeringan separa akar dan pengairan defisit terkawal ke atas prestasi pertumbuhan tanaman rock melon (*Cucumis melo* Linn cv. Glamour)]

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Abstract
This study aimed to determine the effect of partial root drying (PRD) and regulated deficit irrigation (RDI) on growth performance of rock melon (*Cucumis melo* Linn cv. Glamour). A randomised complete block design experiment with four replications was conducted at Universiti Putra Malaysia in 2012. Different deficit irrigation levels had significant effects on dry matter production and yield of melon as compared to well-watered (WW) as controls. Maximum and significant yield of melon was from the WW and RDI plants. RDI, a moderate water stress did not drastically reduce fresh fruit weight of melon i.e. a 28% drop in yield, indicating better utilisation of the available water. However, for PRD, the yield drop 80%. Maximum total soluble solids of 14.02, 13.83 and 5.99 ^{o}Brix was from WW, RDI and of PRD treated plant respectively. Total proline concentration in leaf at 76 days after transplanting clearly illustrates that the PRD plants is highly stressed by this deficit system with maximum reading of 21.44 µg/g as compared to only 9.68 and 9.97 µg/g from WW and RDI plants respectively. Results obtained suggest the possibility of applying moderate deficit irrigation at 50% watering capacity while maintaining the quality and yield of melon.

Keywords: partial root drying (PRD), regulated deficit irrigation (RDI) and rock melon

Introduction

Water plays an important role in plant life and to other living things in this world. It is of great concern that water could become scarce in the near future. In fact, the United Nations World Water Development had reported that the problem of water deficit is becoming more serious as a result of the looming crisis of drought and environmental pollution (Davtalabsabet et al. 2013; Davtalab et al. 2014). Scarcity of water could become a great threat to human health, the global food supply and may also threatens global peace especially as countries in Asia and the Middle East are now seeking for ways to cope with shortage of water resources in the world (FAO 2012). Crop production in many of these regions is essentially dependant on at least supplemental irrigation systems or new techniques so as to increase the efficient use of available water. Loveys (1991) had put forth several possible approaches in the irrigation technologies and proper irrigation scheduling could be adapted for more effective and rational use of the limited supply of water (Dry and Loveys 1999).

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It has been shown that application of water at the sub optimal level may result in the activation of various water deficit stress mechanisms in the crop. Hence, water use must be balanced through regulated irrigation. One of the latest techniques introduced to manipulate crop water use is the regulated deficit irrigation (RDI) (English et al. 1990). In this technique, the irrigation input is removed or reduced for specific periods (Battilani, 2000), and is widely used in the horticultural industry to improve fruit quality (Turner 2001). The technique, regulated deficit irrigation (RDI) was developed to overcome the shortcoming of an earlier technique, partial root drying (PRD) where half of the root zone is irrigated, while the other half is allowed to dry out for a certain period of time (Loveys et al. 2000).

Under water deficit, full plant functioning relies on hormonal signals, namely ABA concentration and pH of the xylem sap, originating from the roots in response to the low soil water potential within the dry zone. The ABA will then be transported to the leaves in the transpiration stream, leading to a reduction in growth and stomatal conductance (Davies and Zhang 1991; De Souza et al. 2003). Partial stomatal closure caused by root signaling may lead to a decrease in transpiration and hence increase in water use efficiency (WUE) (During et al. 1997; Loveys et al. 2000). The objective of this study therefore was to evaluate the effectiveness of two irrigation techniques, regulated deficit irrigation (RDI) and partial root drying (PRD) in promoting growth and yield of rock melon as compared to well-watered (WW) plants.

Materials and methods

Experimental site and growth conditions

The experiments were conducted under rain shelters located at Kompleks Taman Pertanian Universiti (TPU), Universiti Putra Malaysia, Serdang Selangor (2° 58'36'' N 101° 43'13'' E / 2.97667° N 101.72028° E), with average maximum/minimum temperatures of 23.0 °C – 33.0 °C. Rock melon (*Cucumis melo* L. cv. Glamour) seeds were sown in germination trays filled with peat and was placed in a growth chamber under controlled conditions for 1 week. At 7 days after emergence, uniform seedlings were selected and gently removed from the trays and transplanted into two jointed poly bags (containers) measuring 27 cm x 23 cm x 50 cm (length x width x height) (1,242 cm^2). Plantlets with well-developed lateral root systems and two true leaves were transplanted to the center of the jointed poly bags (containers) respectively filled with 2 kg of coconut coir dust (CCD). Plants were manually irrigated twice a days and kept well watered for a week until the root system were well established and developed split equally into both parts of the poly bag. The plants were then subjected to three different regimes of water treatments:

T1 – control (WW), both root compartments were watered manually at 100% substrate capacity (SC).

T2 – regulated deficit irrigation (RDI), both sides of the root system received water at 50% SC.

T3 – partial root drying (PRD), one compartment was watered at 50% SC and the other compartment was left to dry for 2 days. The two compartments were alternately irrigated once in every 2 days.

Experimental design and statistical analysis

The experimental design was a randomised complete block design (RCBD) with four replications. Analysis of variance (ANOVA) was performed using the procedures of the Statistical Analysis System (SAS Institute 2011, Cary, N.C.). The Least Significant Difference (LSD) was used for test of significance.

Determination of yield and fruit quality

Total fruit fresh weight was recorded at the end of the growing season i.e. at 76 DAT. In all treatments, the only one fruit located between leaf number 7 until 13 or node 7 to 12 was retained. Total soluble solids (TSS) of rock melon from the respective treatment was assessed at harvest, i.e. at 76 DAT. This coincides with the commercial harvest for melon consumption. The TSS was determined on the juice extracted from the pericarp sliced from the equatorial region of the fruit using a hand held refractometer (Model ATC-1 Atago, Tokyo, Japan), with automatic temperature compensation.

Results and discussion

Leaf area

At 7 DAT, lowest leaf area of rock melon receiving RDI and WW treatment were 58.20 and 51.90 cm^2 respectively (*Table 1*). At harvest, 76 DAT leaf area were significant between all treatments, with maximum of 5665.20 cm^2 in WW treatment followed by the RDI plants (3369.10 cm^2) (*Table 1*). Lowest leaf area was recorded from the PRD plants at all harvests: 7, 31 and 76 DAT.

Plant height

At 7 DAT, plant height was lowest for the RDI treatment (12.45 cm). At 31 DAT, maximum and significant height was recorded from WW plants (182.24 cm) followed by RDI plants (132.48 cm). At 76 DAT, maximum but insignificant readings of 291.69 and 218.74 cm were from WW and RDI plants respectively (*Table 1*). Lowest plant height was recorded from the PRD plants at all three harvests.

Stem diameter

At 7 DAT, stem diameter of PRD and WW plants were 4.18 and 4.05 mm respectively, which was higher than that of RDI treatment (3.39 mm) (*Table 2*). However, at 31 and 76 DAT stem diameter was significantly different between treatments, with maximum of 9.64 mm and 9.93 mm respectively recorded from the WW plants followed by the RDI plants, 8.03 mm and 8.46 mm respectively (*Table 2*).

Stem dry weight

Results obtained showed an increase in stem dry weight with increase in planting time (7 DAT to 76 DAT). A similar trend to that of stem diameter was shown, with significant results obtained between treatments at the second harvest (31 DAT) (*Table 2*). Stem dry weight from WW plants i.e. 13.88 g was maximum and significant to PRD plants at 76 DAT. Result was not significant to RDI with 8.55 g also at 76 DAT (*Table 2*).

Leaf dry weight

Leaf dry weight also showed an increase with increase in plant growth, with maximum and significant results obtained from WW plants followed by RDI plants at the respective 31 DAT and 76 DAT (*Table 3*). Again PRD plants showed the least increase in leaf dry weight at all harvests.

Root dry weight

Root dry weight also showed an increase with increase in planting time (*Table 3*). At the respective 31 and 76 DAT, WW plants showed maximum and significant increase as compared to other treatments (0.38 g and 2.16 g respectively). The RDI plants recorded 0.29 g and 1.19 g at the respective 31 and 76 DAT (*Table 3*). Again PRD showed minimum root dry weight of 0.73 g at the final harvest.

Proline concentration

The lowest and significant proline concentration between treatments was recorded at 7 DAT (*Table 4*). Maximum proline concentration of 17.55 µg/g was from RDI plants at 31 DAT, but was insignificant to 15.79 µg/g of WW plants. At 76 DAT, proline concentration for both treatments above significantly dropped to 9.68 µg/g and 9.96 µg/g respectively, compared to maximum value of 21.44 µg/g from the PRD plants (*Table 4*).

Table 1. Effect of different watering treatments on total plant leaf area and plant height of rock melon at 7, 31 and 76 days after transplanting

Treatment	Days after transplanting					
	7	31	76	7	31	76
	Leaf area (cm^2)			Plant height (cm)		
WW	51.90b	4937.50a	5665.20a	14.89	182.24a	291.69a
RDI	58.20ab	3226.10b	3369.10b	12.45	132.48a	218.74b
PRD	63.64a	477.90c	1582.50c	16.28	40.70b	163.12c
LSD $_{0.05}$	7.02	597.31	478.21	6.12	74.80	44.69
Source	F (Pr >F)					
Treatment	8.38 (0.0183)	169.89 (<0.0001)	219.34 (<0.000)	1.20 (0.3647)	11.03 (0.0098)	24.93 (0.0012)

Means within a column followed by the same letter were not different at $p \leq 0.05$ by the Least significant difference (LSD) test. (WW = Well-watered; RDI = Regulated deficit irrigation and PRD = Partial root drying)

Table 2. Effect of different watering treatments on stem diameter and stem dry weight of rock melon at 7, 31 and 76 days after transplanting

Treatment	Days after transplanting					
	7	31	76	7	31	76
	Stem diameter (mm)			Stem dry weight (g)		
WW	4.05a	9.64a	9.93a	0.08b	9.48a	13.88a
RDI	3.39b	8.03b	8.46b	0.15b	5.49b	8.55ab
PRD	4.18a	7.37c	7.36c	0.32a	0.86c	4.65b
LSD $_{0.05}$	0.41	0.43	0.48	0.07	0.55	7.29
Source	F (Pr >F)					
Treatment	12.10 (0.0078)	84.62 (<0.0001)	86.02 (<0.0001)	32.42 (0.0006)	714.73 (<0.0001)	4.83 (0.0562)

Means within a column followed by the same letter were not different at $p \leq 0.05$ by the least significant difference (LSD) test. (WW = Well-watered; RDI = Regulated deficit irrigation and PRD = Partial root drying)

Table 3. Effect of different watering treatments on leaf dry weight and root dry weight of rock melon at 7, 31 and 76 days after transplanting

Treatment	Days after transplanting					
	7	31	76	7	31	76
	Leaf dry weight (g)			Root dry weight (g)		
WW	0.09b	35.47a	46.62a	0.14a	0.38a	2.16a
RDI	0.30a	18.52b	29.97b	0.06b	0.29b	1.19b
PRD	0.35a	1.35c	9.94c	0.08ab	0.05c	0.73b
LSD $_{0.05}$	0.06	8.42	7.43	0.06	0.07	0.70
Source	F (Pr >F)					
Treatment	54.92 (0.0001)	49.13 (0.0002)	73.15 (<0.0001)	4.38 (0.0672)	58.91 (0.0001)	12.85 (0.0068)

Means within a column followed by the same letter were not different at $p \leq 0.05$ by the least significant difference (LSD) test. (WW = Well-watered; RDI = Regulated deficit irrigation and PRD = Partial root drying)

Table 4. Effect of different watering treatments on proline concentration of rock melon at 7, 31 and 76 days after transplanting

Treatment	Days after transplanting		
	7	31	76
	Proline concentration (μg g^{-1})		
WW	0.128b	15.79a	9.68b
RDI	0.453a	17.55a	9.96b
PRD	0.018c	4.21b	21.44a
$LSD_{0.05}$	0.03	6.47	5.88
Source	F (Pr >F)		
Treatment	455.42 (<.0001)	14.97 (0.0047)	15.59 (0.0042)

Means within a column followed by the same letter were not different at $p \leq 0.05$ by the least significant difference (LSD) test. (WW = Well-watered; RDI = Regulated deficit irrigation and PRD = Partial root drying)

Yield of rock melon

At the final harvest (76 DAT, *Plate 1a*), yield of melon from the WW plants was maximum for all fruit parameters measured compared to RDI or PRD treatments. The selective parameters and their respective individual readings recorded are:

i. Fresh fruit weight – WW (710.74 g) : RDI (511.11 g) : PRD (144.11 g) (*Figure 1a*).
ii. Fruit dry weight – WW (75.37 g) : RDI (62.01 g) : PRD (13.16 g) (*Figure 1b*).
iii. Fruit length – WW (122.47 mm) : RDI (99.03 mm) : PRD (60.94 mm) (*Figure 1c*).
iv. Fruit diameter – WW (109.64 mm) : RDI (98.55 mm) : PRD (66.07 mm) (*Figure 1d*).
v. Flesh thickness – WW (25.70 mm) : RDI (25.98 mm) : PRD (12.32 mm) (*Figure 1e*).
vi. Rind thickness – WW (4.68 mm) : RDI (4.54 mm) : PRD (4.50 mm) (*Figure 1f*).
vii. Total soluble solids – WW (14.02 °Brix) : RDI (13.83 °Brix) : PRD (5.99 °Brix) (*Figure 1g*).

Lowest harvest for all parameters above was from the PRD plants. At 76 DAT, flesh thickness of both WW and RDI plants was maximum but insignificant at 25.70 mm and 25.98 mm respectively (*Figure 1e*).
Rind thickness of 4.68 mm from WW plants was highest and significant compared to only 4.54 mm of the RDI plants (*Figure 1f*). The total soluble solid was maximum for both WW and RDI plants but not significant between these two treatments. Well watered and RDI plants produce sweeter fruits with 14.02 °Brix and 13.83 °Brix respectively, both readings were significantly different to PRD plants with only 5.99 °Brix (*Figure 1g* and *Plate 1b*).

Plate 1a. Rock melon fruit as affected by irrigation techniques
a. WW = Well-watered
b. RDI = Regulated deficit irrigation
c. PRD = Partial root drying

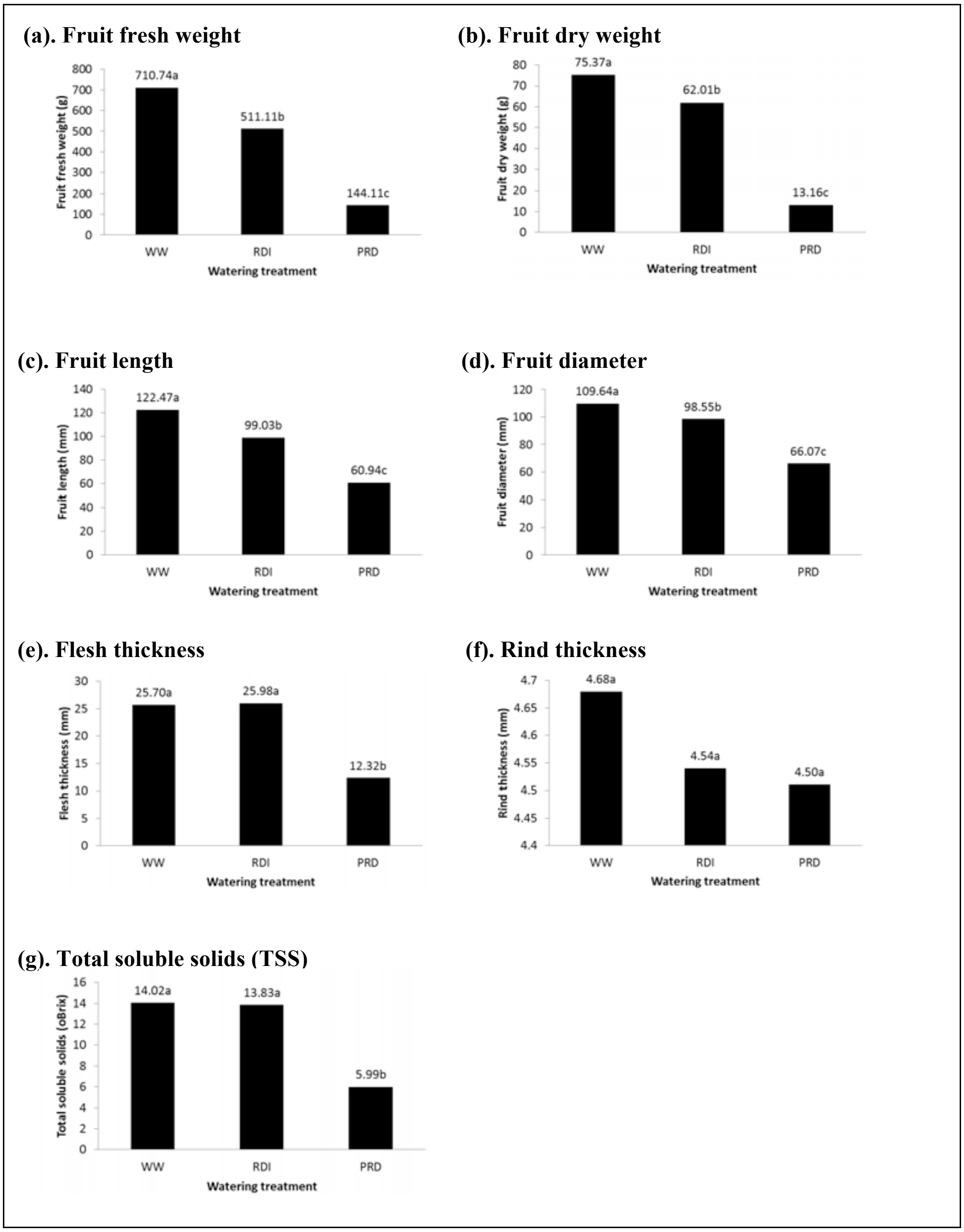

Figure 1. Effect of watering treatment on (a) Fruit fresh weight (g); (b) Fruit dry weight (g); (c) Fruit length (mm); (d) Fruit diameter (mm); (e) Flesh thickness (mm); (f) Rind thickness (mm) and (g) Total soluble solids (^{o}Brix) of rock melon at harvest stage (76 DAT). Means followed by the same letter in each sub figure were not different at $p \leq 0.05$ by the least significant difference (LSD) test. (WW = Well-watered, RDI = Regulated deficit irrigation and PRD = Partial root drying). The F (Pr > F) for (a); (b); (c); (d); (e); (f) and (g) were 348.85 (<0.0001); 248.65 (<0.0001); 164.46 (<0.0001); 1301.13 (<0.0001); 43.58 (0.0003); 0.44 (0.6660) and 23.98 (0.0014) respectively

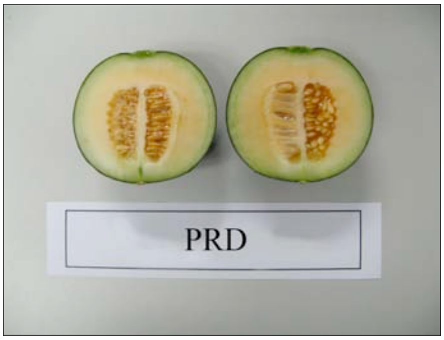

Plate 1b. Rock melon fruit as affected by irrigation techniques

a. WW = Well-aatered
b. RDI = Regulated deficit irrigation
c. PRD = Partial root drying

Effect of partial root drying and regulated deficit irrigation techniques on plant growth

Water is essential for crop production since plants need water for growth, tissue expansion and yield production. Growth and yield of rock melon was significantly affected by the watering system. Plants receiving full water capacity (WW) grew better at both vegetative and the reproductive stage. At 76 DAT, total leaf area of WW plants (5665.2 cm^2) is 41% higher than that of RDI plants (3369.1 cm^2) and 72% higher than that of PRD plants (1582.5 cm^2). Significant leaf area is strongly supported by production of massive root systems of WW plants, allowing more efficient uptake of nutrients by these plants. The RDI plants produce 50% less roots followed by minimum root production by the PRD plants. In case of fruit diameter, effects of the irrigation techniques were significant between treatments. It is obvious that WW and RDI plants have almost similar fruit diameter, with lowest diameter of 66.0 mm recorded from the PRD plants. Fresh fruit weight of 710.74 g was also significantly higer from the WW plants given full watering capacity.

Overall, the RDI plants showed superior results as compared to PRD plants in terms of fruit size, unit weight and diameter of fruit. Fruit weight of RDI plants was only reduced by 29% while that of PRD plants showed a reduction of 72% (144.11 g). Results obtained contradicts fruit yield of apple and citrus, where PRD treatment did not affect fruit yields of these two crops (Hutton and Loveys 2011). For RDI plants, water supply in deficit is usually applied during the period of slow fruit growth when shoot growth is rapid. This is useful in reducing excersive vegetative vigour while minimizing irrigation and nutrient loss through leaching (Du et al. 2015). Hence the plants receive the benefit of full fertilisation to support good growth of melon. Growth limitation of rock melon under PRD could be attributed to the following: the alternate drying of PRD root system in contact with dry coconut coir dust generate increased flux of chemical signals that move to the shoot to restrict shoot growth hence disrupting the functioning maintenance of turgor in the shoot which is of importance in maintaining fruit growth and development (Morison et al. 2007).

Stressed plants have also been shown to accumulate substantially higher level of proline than the non-stressed plants. Maximum and significant proline concentration at 76 DAT as shown by the PRD plants is a clear indication that these plants were duly stressed under this watering technique. The rate of accumulation of proline has earlier been regarded as a tolerance mechanism and adaptation of plant genotypes to drought stress through osmoregulation in several crops such as tomato (Hassan et al. 2003); durian (Ismail et al. 1994) and banana (Siamak et al. 2012). Results obtained supports the three findings above.

Effect of water deficit at vegetative and reproductive growth stage on biomass and physiological of melon

Melon (*Cucumis melo* L.) is a plant with shallow root depth and requires soil water to be maintained at a minimum of 65% capacity (Suat et al. 2007). The alternate drying and wetting of these roots over a two days period under PRD watering system, significantly reduced its vegetative and reproductive growth at 31 and 76 DAT respectively as compared to controls (WW) or RDI treated plants. Water deficit has been shown to alter ratio of photosynthetic product between root and canopy (Cui et al. 2009). Effect of water deficit under the PRD system has significantly decreased fresh and dry biomass production of melons (Kusvuran 2010) and hence a significant drop in yield (>50%) when compared to the other two treatments. Of all treatments applied, PRD plants gave maximum (21.44 μg/g) and very significant difference in proline content at the final harvest of 76 DAT. WW plants produce 55% less proline while RDI produce 53.5% as compared to PRD plants. This clearly illustrates that the PRD plants is highly water stressed especially as the plant aged. Hence the significant drop in fruit yield and quality. Hence, RDI technique will be adopted in the subsequent experiment with AM fungi.

In contrast, McCarthy (2000) found no significant reduction in grape yield due to PRD treatment, even when the irrigation amount was halved. Fruit quality was also maintained if not improved.

Overall, the RDI treatment showed superior results over PRD in increasing plant vegetative growth, dry matter production, and yield of melon. Dry matter production (leaf and root dry weight and leaf area) was significantly lower than that of WW plants resulting in a slight drop in fresh fruit weight by 28.08% and total soluble solids by 1.4%. The moderate water deficit in RDI plants can effectively regulate the photosynthetic capacity of melon plants in reducing transpiration.

This treatment will enhance the activity of leaf superoxide dismutase and solar energy capturing capacity of leaves (Lu et al. 1996), thus improving photochemical efficiency and photosynthesis and significantly increased water use efficiency (Wang et al. 2008). Hueso and Cuevas (2008) found that water deficit treatment during the entire growth stages of loquat tree increased WUE by 40%, but did not result in the reduction of fruit yield and quality.

Conclusion

In conclusion, water stress strongly affects photosynthesis, vegetative and reproductive growth of melon in soilless culture. Results obtained from the current study indicates that both vegetative and reproductive growth of *Cucumis melo* plants was strongly affected by levels of watering technique applied. Compared to the full watering capacity (control), alternating wet and dry watering capacity (PRD) significantly reduced dry matter production and hence fruit quality and yield of these plants. Maintenance of water supply even at 50% substrate capacity (RDI) throughout the plant growth resulted in higher dry matter production and hence fruit quality and yield of melon, almost at par to the well-watered plants (WW). Overall fruit yield at the final harvest in decending order is: WW (710.74 g) > RDI (511.11 g) > PRD (144.11 g). Total soluble solids in decending order is: WW (14.02 ^{o}Brix) > RDI (13.83 ^{o}Brix) > PRD (5.99 ^{o}Brix).

Although the initial goal of RDI was to improve yield and / or fruit quality, in arid and semi-arid regions, the focus is related primarily to the efficient management of limited water resources (Du et al. 2015). However under field conditions, it is difficult for farmers to optimise their application. Hence several researchers have put forth suggestions that deficit irrigation i.e. RDI is more suitable for green house crops where it can improve or maintain yield with a higher water use efficiency (WUE) and hence better fruit quality (Zhao et al. 2013).

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Abstrak
Kajian ini bertujuan untuk menentukan kesan pengeringan separa akar (PRD) dan pengairan defisit terkawal (RDI) terhadap prestasi pertumbuhan melon (*Cucumis melo* Linn cv. Glamour). Reka bentuk blok rawak lengkap (RCBD) dengan empat ulangan telah dijalankan di Universiti Putra Malaysia pada tahun 2012. Aras pengairan defisit yang berbeza memberi kesan bererti ke atas berat kering tanaman dan hasil melon berbanding dengan rawatan kawalan (WW). Hasil melon tertinggi dan bererti diperoleh daripada tanaman WW dan RDI. RDI merupakan ketegasan air sederhana yang tidak menurunkan berat basah buah melon. Penurunan hasil sebanyak 28% menunjukkan penggunaan air yang lebih baik. Walau bagaimanapun, untuk rawatan PRD hasil menurun sebanyak 80%. Jumlah maksimum pepejal mudah larut sebanyak 14.02, 13.83 dan 5.99 ^{o}Brix adalah daripada rawatan WW, RDI dan PRD masing-masing. Jumlah kepekatan prolin dalam daun 76 hari lepas tanam (HLT) jelas menunjukkan tanaman PRD mengalami ketegasan air yang teramat dengan bacaan 21.44 µg/g berbanding dengan bacaan 9.68 dan 9.97 µg/g daripada tanaman WW dan RDI satu-satunya. Keputusan yang diperoleh mengesyorkan aplikasi pengairan defisit sederhana pada aras 50% dengan tidak menurunkan kualiti dan hasil melon.