Agraarteadus
1 • XXXII • 2021 79–85

Journal of Agricultural Science
1 • XXXII • 2021 79–85

BOTTLE GOURD (*Lagenaria siceraria* L.) CROP RESPONSE TO DIFFERENT PLANTING DENSITIES UNDER BOTH DRIP AND WIDE-SPACED FURROW IRRIGATION METHODS

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Saabunud: Received: 25.02.2021
Aktsepteeritud: Accepted: 02.06.2021

Avaldatud veebis: Published online: 02.06.2021

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Keywords: clay loam soil, water productivity, irrigation water use efficiency, arid Mediterranean area.

DOI: 10.15159/jas.21.11

ABSTRACT. Although bottle gourd (*Lagenaria siceraria* L.) is an important vegetable crop in rural communities in the arid Mediterranean region, still no sufficient information regarding its cultivation practices is available. A two-year field experiment (2019 and 2020) was carried out to assess the effects of planting density and irrigation method on bottle gourd yield, following a split-plot experimental design with two planting densities of about 11 111 and 5555 plant ha^{-1}, and two irrigation methods (drip irrigation and wide-spaced furrows as surface irrigation), with three replicates. Significant effects of both factors on bottle gourd fruit characteristics, dry matter, fresh marketable yield, water productivity (WP), and irrigation water use efficiency (IWUE) were found. Seasonal evapotranspiration and irrigation water amounts were considerably reduced by about 20% under drip irrigation as compared with surface irrigation. Moreover, dry matter, fresh marketable yield, WP, and IWUE were doubled. Combining drip irrigation with the lower planting density was the most favourable practice for the bottle gourd crop productivity under the studied context. These findings of high fresh marketable yield and water productivity suggest that bottle gourd crop could be considered as an alternative crop for food security and economic prosperity of rural communities. Adopting drip irrigation can effectively address the water shortage issue and sustain crop production in the arid Mediterranean area.

Introduction

Lagenaria siceraria (Molina) Standl., known as a bottle gourd or the white-flowered gourd, is a member of the Family of *Cucurbitaceae*. Bottle gourd is a very popular vegetable crop in Asia and Africa. Young fruits are commonly consumed by boiling, frying, or stuffing. Shoots, tendrils and leaves are also consumed, while the seeds are used for oil and protein due to their richness of essential amino and fatty acids (Rahman, 2003; Chimonyo, Modi, 2013). The dried hard rind of mature fruits is used as a container, musical instrument, or decorations in some cultures. Moreover, different components of this plant (seeds, tendrils, and young leaves) are used for medical purposes (Ahmad *et al.*, 2011; Milind, Satbir, 2011). Although a lot of information is documented on the medicinal aspects of this plant, its potential as a possible food security crop has been poorly reported (Ahmad *et al.*, 2011; Chimonyo, Modi, 2013; Mabhaudhi *et al.*, 2017). Its high morphological and genetic variability in nature might indicate its wide environmental adaptation (Given, 1987; Koffi *et al.*, 2009). Due to its huge canopy cover, bottle gourd is considered a natural smother of weeds (Koffi *et al.*, 2009). It is often intercropped with other crops and could play a role in live mulching (Ouma, Jeruto, 2010). Bottle gourd is used as rootstock for watermelon and cucumber against low soil temperature and soil-borne diseases. Using bottle gourd as rootstock could also save water and therefore, increase water use efficiency, especially in arid and semi-arid areas (Yetisir *et al.*, 2008; Guler *et al.*, 2013; Yavuz *et al.*, 2020; Aslam *et al.*, 2020). Given such benefits, it is surprising that the bottle gourd crop productivity received the least amount of scientific research attention, as compared with the other members of its family, especially in the arid Mediterranean region.

In Syria, bottle gourd crop is cultivated mostly under irrigated cropping system, due to the lack of rainfall over the production period between April and September (Ragab, Prudhomme, 2002; Turner, 2004).

Surface irrigation method with very low water use efficiency is mostly used. Since water scarcity is a constraint to crop production in this region, efficient irrigation water use is a vital need to sustain crop production for ever-increasing food demands. Higher benefits may be obtained by adopting water-saving irrigation methods such as the drip irrigation method (Goyal, 2014, 2015; Venot *et al.*, 2017). To the best of our knowledge, there are no published field studies conducted on bottle gourd species in Syria under the arid Mediterranean environment. Since bottle gourd is one of the neglected and underutilized species, important scientific outcomes of its cultivation (especially for plant density) and productivity under drip irrigation method are much needed.

This two-year field experiment aimed to evaluate the response of bottle gourd to different planting densities under both drip irrigation and traditional surface (wide-spaced furrows) irrigation methods. The results may contribute to introduce a practical alternative that would sustain crop productivity with efficient water use.

Materials and methods

Field experiments were carried out during the 2019 and 2020 growing seasons at the Agricultural Experiment Station, Deir Al-Hajar, Damascus Countryside in Syria (33°20′ N, 36°26′ E, 600 m above sea level). The arid Mediterranean climate dominates the study region, with annual potential evapotranspiration (ET_0) of more than 2000 mm, as estimated using the FAO Penman-Monteith formula (Allen *et al.*, 1998). The mean annual precipitation based on 20 years' record (2000–2019) is about 120 mm. Table (1) shows some climatic data of the study site, collected during both studied growing seasons.

Table 1. Some climatic data for the study site during both growing seasons 2019 and 2020

Year	Parameter	Apr.	May	Jun.	Jul.	Aug.	Sep.
2019	T_{min}, °C	8.1	15.0	19.0	19.4	20.1	17.6
	T_{max}, °C	22.2	34.2	36.6	37.3	38.0	34.7
	T_{mean}, °C	15.1	24.6	27.8	28.3	29.0	26.1
	RH, %	56.1	61.1	56.9	55.7	56.5	59.9
	ET_0, mm day^{-1}	5.22	8.70	9.26	9.81	9.17	7.19
	Rain. mm	11.6	0.0	0.0	0.0	0.0	0.0
2020	T_{min}, °C	9.7	13.4	16.5	20.0	20.2	20.6
	T_{max}, °C	24.3	31.6	34.7	40.0	37.7	39.5
	T_{mean}, °C	17.0	22.5	25.6	30.0	28.9	30.0
	RH, %	62.8	56.6	55.6	59.0	58.8	67.6
	ET_0, mm day^{-1}	5.82	8.23	9.01	10.47	9.01	9.05
	Rain, mm	6.7	3.0	0.0	0.0	0.0	0.0

T_{min} = minimum temperature, T_{max} = maximum temperature, T_{mean} = average temperature, RH = relative air humidity, ET_0 = reference evapotranspiration.

The top 30 cm of the soil profile had a clay loam texture with sand 27.8%, silt 42.7%, clay 29.5%, bulk density 1.35 g cm^{-3}, organic matter of about 1%, pH of 8.0, EC of 0.6 dS m^{-1}, available P of 22.0 ppm, $NH4^+$ of 13.3 ppm, and NO_3^- of 20.0 ppm. The volumetric soil water content at field capacity was 0.38 cm^3 cm$^{3\,-1}$, and that at the permanent wilting point was 0.18 cm^3 cm$^{3\,-1}$. Irrigation water characteristics were NH_4^+ 1.99 ppm, NO_3^- 1.05 ppm, EC_w 0.46 d Sm^{-1}, and pH of 8.4.

At the beginning of the spring season, the studied field was ploughed to a depth of 0.30 m with a mouldboard plough. Experimental units (plots), 12×3 m each, were prepared. Two different irrigation methods were tested: drip and surface irrigation methods. For drip irrigation, lateral driplines of 16 mm diameter with a built-in 40-cm emitter spacing with a discharge of 10 L h^{-1} m^{-1} were used. One lateral dripline per plant row was installed. The lateral dripline spacing was 3.0 m. For the surface irrigation method, wide-spaced furrows (3.0 m apart) adopted by local farmers were used in this study. The depth and width of each furrow were 25 and 75 cm, respectively.

Due to the dimensions of experimental units, it was more practical to make the furrow length equal to the length of the units, therefore, short furrows (12 m) were used. This allowed furrow to be irrigated more efficiently as it is much easier to keep the percolation losses low. A local variety "Baladi" of bottle gourd (*Lagenaria siceraria* L.), extensively planted by farmers in Syria, was used. Bottle gourd seeds were planted on April 25th and May 15th in 2019 and 2020, respectively. Rows were spaced 3.0 m apart. Under both irrigation methods, two different distances between planting holes of 0.6 and 1.2 m were studied. After establishment, plants were hand thinned to two plants per hole. This resulted in 11 111 (Pd1) and 5555 (Pd2) plants per hectare, respectively. Experiments were arranged in a split-plot design involving two irrigation methods (drip and surface) as main plots and two planting densities (Pd1 and Pd2) as sub-plots, with three replicates.

The experimental field was fertilized in early spring before each cropping season, with 100 kg P_2O_5 per hectare as triple superphosphate. However, 200 kg N ha^{-1} as urea was supplied to prevent any nitrogen deficiency. It was applied in two equally split applications: two weeks after thinning and one month later. Thus, all plants received the same quantities of both chemical fertilizers.

Regarding irrigation scheduling, the soil water content (SWC) status in the root zone was observed using the neutron scattering technique. Irrigating plants was initiated immediately after sowing. The active roots depths were set to 0.30 m from sowing until the early flowering, and then to 0.60 m till termination. Bottle gourd was irrigated once a week when the soil water content in the specific soil layer reached 75–80% of the field capacity. In all treatments, plants received 100% of the depleted water amount between two consecutive irrigation events, so that the SWC in the root zone was replenished to the field capacity. Crop evapotranspiration (ETc) was calculated using the water balance relationship as follows (Mubarak, Janat, 2020):

$$ET_c = I + P – D_p – R_o \pm \Delta(SWC), \quad (1)$$

where I = the amount of irrigation water applied (mm); P = the precipitation (mm); D_p = the deep percolation (mm) and R_o = the amount of runoff (mm), $\Delta(SWC)$ = the change in soil water content (mm) in the specified soil profile.

Under controlled water application, R_o was assumed to be zero. Monitoring SWC indicated that D_p was negligible below the depth of 0.60 m. P was also negligible during both cropping seasons (Table 1). Due to the small canopies of young plants and the wide row spacing (3 m), a reduction factor (k_r) was used. The ground cover, GC, which is the fraction of the total surface area covered by the foliage of the plants, was measured every two weeks. The reduction factor was estimated as follows (FAO, 1980):

$$k_r = (GC + 0.1) \ or \ 1, \quad (2)$$

whichever is the smallest.

The volumes of applied amounts of irrigation water were measured by inline flow meters, under both irrigation methods.

For appearance and marketing purposes, the young bottle gourd fruits were harvested at the tender green stage to prevent hard seeds and coarse dry skin, which are not palatable for consumers and do not provoke a good price for farmers. For that, the marketable size fruits were harvested carefully using a knife, three times weekly during morning hours. A 4-m row length from the centre of each plot (experimental units) was selected for plant sampling. The weight (FW), length (FL) and largest diameter (FD) of fresh fruits were measured. Subsamples were air-dried for few days then oven-dried at 70 °C until a constant mass was obtained for determining fruit dry matter yield (DM). Fresh and dry weights were converted into t ha^{-1}. Crop water productivity (WP, kg m$^{3\,-1}$), also called water use efficiency, and irrigation water use efficiency (IWUE, kg m^{-3}) were calculated as follows (Mubarak, Janat, 2020):

$$WP = \frac{Yield}{seasonal\ ET_c} \quad (3)$$

$$IWUE = \frac{Yield}{Irrigation\ water\ amount} \quad (4)$$

The measured parameters (FL, FD, FW, Yield, DM, WP and IWUE) were subjected to the analysis of variance (ANOVA) using the DSAASTAT add-in (Onofri, 2007). A combined analysis of data over both years was achieved to identify treatment whose mean effect over years is high and stable (Gomez, Gomez, 1984). Mean separation was conducted after combined analysis using the least significant difference test (LSD) at the 5% level of significance.

Results

No significant interactions were detected between year and treatment, or between planting density and irrigation method. Hence, the effects of studied factors on the measured parameters were averaged over both years (Table 2). Moreover, ANOVA showed that both studied factors significantly influenced the measured parameters, indicating that both factors play an essential role in bottle gourd production in the studied region.

Although both the shape and size of bottle gourd fruits vary widely within or among varieties (Chimonyo, Modi, 2013), the shiny green fruits produced herein were somewhat uniform with long and necked shape. The fruit shape was represented in this study by two indicators: fruit length (FL) and diameter (FD). Both planting densities produced fruits of similar sizes with no significant differences. However, fruits produced under the drip irrigation method were considerably longer by about 16% than those produced under surface irrigation. No significant difference in fruit diameter was detected between both irrigation methods (Table 2). The fruit dimensions recorded herein were in agreement with published data (Sivaraj, Pandravada, 2005). According to Sivaraj and Pandravada (2005), fruit sizes vary from 5 to 40 cm for diameter and from 20 to 90 cm for length.

Table 2. Mean comparisons of crop responses as a function of both planting density and irrigation method

Factor	FL, cm	FD, cm	FW, g	DM, t ha^{-1}	Yield, t ha^{-1}	WP, kg m$^{3\,-1}$	IWUE, kg m$^{3\,-1}$
Planting density							
Pd1 (11 111 plant ha^{-1})	17.22^{a}	4.60^{a}	288.8^{b}	1.73^{a}	44.67^{b}	8.12^{b}	7.29^{b}
Pd2 (5 555 plant ha^{-1})	17.68^{a}	4.75^{a}	342.9^{a}	2.09^{a}	49.60^{a}	9.05^{a}	8.13^{a}
$LSD_{0.05}$	1.82	0.43	27.7	0.61	3.87	0.76	0.69
Irrigation method							
Drip	18.74^{a}	4.65^{a}	358.3^{a}	2.58^{a}	61.37^{a}	11.92^{a}	10.66^{a}
Surface	16.16^{b}	4.70^{a}	273.3^{b}	1.24^{b}	32.90^{b}	5.25^{b}	4.76^{b}
$LSD_{0.05}$	0.97	0.19	22.4	0.68	2.11	0.33	0.31

In each column and for each tested factor, means followed by different letters are significantly different according to LSD test at 5% level.
FL = fruit length, FD = fruit diameter, FW = fruit weight, DM = dry matter, Yield = fresh marketable yield, WP = water productivity, IWUE = irrigation water use efficiency.

Regarding the FW, the mean value of FW under drip irrigation (358.3 g) was significantly higher by about 31% than that obtained under surface irrigation (273.3 g) (Table 2). Moreover, lower planting density Pd2 produced fruits significantly heavier by about 19% than those produced under Pd1. The mean values of FW were 288.8 and 342.9 g under Pd1 and Pd2, respectively (Table 2).

Fruit dry matter yields under both planting densities were similar with no significant differences. However, the DM yield of drip-irrigated fruits (2.58 t ha^{-1}) was higher than that of surface-irrigated fruits (1.24 t ha^{-1}), with a significant increase of more than 100% (Table 2).

Moreover, using the drip irrigation method significantly enhanced the fresh marketable yield with a mean value of 61.37 t ha^{-1}, which represented about twice that obtained using the surface irrigation method (32.90 t ha^{-1}). In addition, the fresh marketable yield under lower planting density Pd2 (49.60 t ha^{-1}) was significantly higher by 11% than that obtained under the higher planting density Pd1 (44.67 t ha^{-1}).

Figure (1) shows fresh marketable yield distribution among the tested treatments. It is evident that fresh marketable yield widely varied from 31.93 to 65.34 t ha^{-1}, according to the studied treatments. The minimum value was found in the treatment combining between the higher planting density (Pd1) and surface irrigation method, while the maximum value was found in the treatment combining between the lower planting density (Pd2) and drip irrigation method.

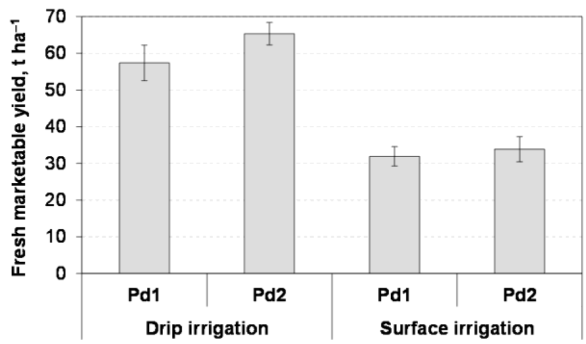

Figure 1. Fresh marketable yield distribution according to the studied treatments for the combined data of both growing seasons. Pd1 and Pd2 represent planting densities. Error bars represent the standard deviations.

As no effective rain precipitated during both cropping seasons, large volumes of irrigation water were added to meet crop water requirements. During the 1st growing season (2019), the seasonal crop evapotranspiration (ETc) calculated using Eq. (1) was about 490 and 589 mm under drip and surface irrigation methods, respectively; while in the 2nd season (2020), they were about 542 and 666 mm, respectively. Respective values for irrigation water amount applied were about 533 and 636 mm in 2019 and 626 and 750 mm in 2020.

The mean values of WP and IWUE under the lower planting density (Pd2) were significantly higher by 11.5% than those obtained under Pd1. In addition, both traits were highly significantly ameliorated using the drip irrigation method with mean values of 11.92 and 10.66 kg m^{-3}, respectively; which corresponded to more than twice those found using the surface irrigation method (5.25 and 4.76 kg m^{-3} for WP and IWUE, respectively). Figure (2) shows all mean values of both parameters (WP and IWUE) obtained for studied treatments. It is clear that WP ranged from 5.09 to 12.69 kg m^{-3} and IWUE ranged from 4.62 to 11.36 kg m^{-3} depending on the tested treatments. The highest values of WP and IWUE were recorded by combining the drip irrigation method and Pd2; while the lowest values were determined under the combination between the surface irrigation method and Pd1. The higher fruit yield resulted in higher WP and IWUE.

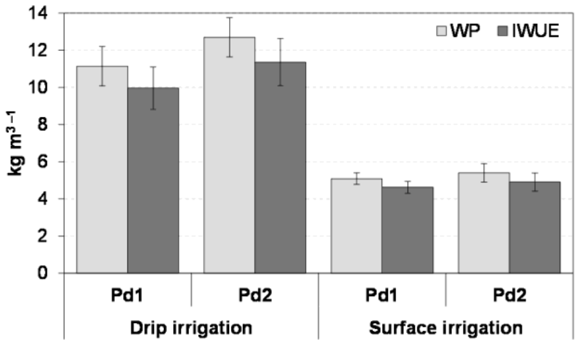

Figure 2. Water productivity (WP) and irrigation water use efficiency (IWUE) distribution according to the studied treatments for the combined data of both growing seasons. Pd1 and Pd2 represent planting densities. Error bars represent the standard deviations.

Discussion

The impacts of different planting densities and irrigation methods on bottle gourd yield were evaluated in an arid Mediterranean environment. Both tested planting densities produced fresh fruits of similar sizes. However, lower planting density (5555 plant ha^{-1}) produced fruits considerably heavier than those produced under the higher density (11 111 plant ha^{-1}). This could be explained by the less competition between the plants as they were widely cultivated. This result was in agreement with those of Jan *et al.*, (2000) and El-Seifi *et al.*, (2015), who reported that the significant highest average fruit weight was related to plants grown at low planting density.

Moreover, the higher yield of fresh marketable fruits obtained under Pd2 could be due to the better use of nutrients and light with less competition between plants. However, this was not in a line with other findings reported by other studies (Shukla, Prabhakar, 1987; Jan *et al.*, 2000; El-Seifi *et al.*, 2015), who reported that the total yield per hectare of bottle gourd was increased with the increase in plant density. This disagreement could be related to the differences in the studied contexts, especially to the differences in planting geometries and harvested fruits. In those studies, the total yield of fruits was determined at the maturity stage with very few harvests at the end of the growing season; while in our study, the young fruits were harvested three times weekly for human consumption in local marketing. Moreover, under the same plant population, planting geometry plays an important role in the total yield of bottle gourd crop. Rosin *et al.*, (2017) evaluated the response of the total yield and irrigation water use efficiency of bottle gourd to three cropping geometries (row spacing×plant spacing): 3×0.5 m, 2×0.75 m, and 1×1.5 m. Even though the planting density was identical, their findings indicated that 3×0.5 m was the most valuable geometry in terms of fruit length, diameter, and weight, the number of fruits/vine, vine length, total yield, and irrigation water use efficiency. This optimal planting configuration is in agreement with our results, where rows were spaced 3.0 m apart and holes with two plants in each were spaced 120 cm for Pd2. The superiority of lower planting density in the fresh marketable yield could be related to the enhanced stretching (trailing) of bottle gourd plants. This may stimulate roots to grow up and absorb the required nutrients from the soil. This also indicates that the relationship between fresh marketable yield and planting density of bottle gourd is of significant agronomic interest (El-Seifi *et al.*, 2015).

As stated earlier, wide-spaced furrows with an inter-distance of 3 m were used as a surface irrigation method. Under such a method, irrigation water amount was not applied on the whole land-area basis, but it was related to the fraction of ground covered by foliage of the plants as in drip irrigation scheduling. So, it was reduced by a reduction factor (k_r) calculated using Eq. (2). This attenuated the huge water amounts usually applied under surface irrigation in the case that the whole land area would be concerned. The evolutions of ground cover under all tested treatments were somewhat similar (data are not shown). Despite that, it is very important to notice that about 20% of the irrigation water amount and seasonal crop water needs were saved when the drip irrigation method was used as compared with the wide-spaced furrow irrigation. Moreover, fruit characteristics, fruit dry matter, fresh marketable yield, WP, and IWUE were considerably increased when using drip irrigation. Considering these results, water might be lost by evaporation and other losses under the surface irrigation method and, therefore, decreasing fresh marketable yield relative to drip irrigation. This confirmed the essential role of drip irrigation in terms of a significant decrease in crop water requirements, even under an arid environment.

Combining the drip irrigation method with the lower planting density produced the highest values of fresh marketable yield, WP, and IWUE, while the lowest values were obtained under the combination between the surface irrigation method and the higher planting density. Furthermore, under the lower planting density, more nutrients, water, and photosynthetically active light could be effectively explored by plants without competing with each other. Nutrients reach roots by mechanisms directly related to the water availability in the soil; therefore, crops express their maximum production potential in a favourable soil-water status (Santos *et al.*, 2018). Again, this proves that the crop production and in-field water use efficiency are enhanced under the drip irrigation method as compared with other methods (Goyal, 2014, 2015; Venot *et al.*, 2017).

WP and IWUE are measures of productivity of water used by plants or added by irrigation. They are vital tools for the assessment of irrigation methods and agricultural water management, especially in arid and semi-arid environments where water is precious. Efficient water management and practices should be considered in this context to produce more yields with less water. Moreover, it is important to notice that the water productivity values of bottle gourd crop found herein (5.02–13.49 kg $m^{3\,-1}$) are much higher than those reported for some other crops planted in the same studied climate: 0.02–0.63 kg $m^{3\,-1}$ for quinoa (Mubarak, Janat, 2020), 0.85–2.18 kg $m^{3\,-1}$ for sweet corn (Mubarak, 2020), 0.83–6.98 kg $m^{3\,-1}$ for onion (Mubarak, Hamdan, 2018), 3.84–7.15 kg $m^{3\,-1}$ for potato (Mubarak *et al.*, 2018), but similar with other crops of its crop family as a cucumber with 5.6–15.3 kg $m^{3\,-1}$ (Yaghi *et al.*, 2013) and summer squash up to 15.7 kg $m^{3\,-1}$ (Kuslu *et al.*, 2014). This is related to the higher fresh marketable yield of bottle gourd crop. For that, the potential of bottle gourd, which is considered a neglected and underutilized crop, needs to be unlocked to contribute to food security in the dry Mediterranean area, especially under changing climatic conditions and serious poverty.

Conclusions

Significant effects of different irrigation methods and planting densities on bottle gourd fruit characteristics, dry matter, fresh marketable yield, WP, and IWUEwere found. Seasonal crop water requirements were considerably reduced and dry matter, fresh marketable yield, WP, and IWUE were doubled under the combination of drip irrigation and lower planting density of 5555 plant ha^{-1}.

These findings of high yield and water productivity suggest that bottle gourd can be considered as an alternative crop for food security and economic prosperity of rural communities. Adopting drip irrigation can effectively address water shortage and its consequences and sustain bottle gourd production in the arid Mediterranean area.

Acknowledgements

The authors would like to thank the Atomic Energy Commission of Syria (AECS) for encouragement and financial support. The authors are also grateful to the Editor-in-chief and both reviewers for their time and very constructive and valuable comments and suggestions that have been considered in this improved manuscript.

Conflict of interest

The authors declare no conflict of interest, financial or otherwise.

Author contributions

IM (50%) and MJ (50%) – study conception and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical revision and approve the final manuscript.

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