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DRIP IRRIGATION SYSTEM WATER DISTRIBUTION PERFORMANCE IN VEGETABLE GROWING UNDER PLASTIC HOUSES

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ABSTRACT

This study aimed to evaluate the water application performance of drip irrigation systems used for cucumber, eggplant and bell pepper in 11 plastic greenhouses in the Menderes district of İzmir, Türkiye. Two well-known indicators, the Uniformity Coefficient (UC) and the Distribution Uniformity (DU), were computed to determine the water application performance of the emitters. UC values ranged from 72 % to 95 %, so the water distribution class of the drippers ranged from Moderate to Perfect. DU values ranged from 55 % to 91 %, corresponding to classes from Poor to Perfect. The average amounts of irrigation water applied to cucumber, eggplant and bell pepper were 407 mm, 510 mm and 337 mm, respectively. Irrigation water use efficiency (IWUE) ranged from 15.77 to 19.20, from 7.32 to 14.21 and from 11.50 to 15.70 kg/m³ for cucumber, eggplant and bell pepper, respectively. The results indicate that proper water management is needed to achieve satisfactory water application efficiency.

INTRODUCTION

Rapid population growth and economic development, along with climate change and resulting irregular rainfall, are inevitably increasing competition for water resources, leading to a decrease in water available for all sectors particularly agriculture (Wang et al. 2022). Agriculture is the largest user of freshwater, accounting for about 70 % of global freshwater withdrawals (Rockström et al. 2017). Although irrigated land represents only about 20 % of the cultivated area worldwide, it provides about 40 % of food production (Chartzoulakis & Bertaki 2015). To meet food needs of rapidly growing world population, maximizing yield per unit area is vitally important. One of the most suitable growing environments for achieving maximal yield per unit area is greenhouses. Globally, a large share of greenhouse production is concentrated in countries bordering the Mediterranean Sea. Türkiye ranks fourth in the world and second in Europe after Spain in terms of greenhouse production area (Anonymous, 2019).

In agricultural practices, drip irrigation systems, which allow for more controlled delivery of irrigation water and plant nutrients to crops, are of increasing interest.
Especially in vegetable cultivation, drip irrigation system combined with fertilization has proven to be a win-win technology in improving water and nutrient use productivity, thus achieving the fundamental goal of "more yield per each water drop" leading to higher yield potential. This technology is also highly successful for delivering dissolved fertilizers to plants (Kapoor et al. 2022). Efficient nutrient

management is also essential for agricultural production, as mineral fertilization influences the dynamics of major nutrients in the soil-plant system (Dodocioiu & Buzatu, 2024). The main benefits of drip irrigation include maintaining soil moisture at ideal level for plant growth, minimizing irrigation labor use, and ensuring maximum utilization of liquid form of fertilizers by plant roots. As a result, significant increases in both quantity and quality of crop production can be achieved (Yavuz et al. 2016; Acar, 2020). In general, water application efficiency is 55 % in surface irrigation methods, 75 % in sprinkler irrigation, and 90 % or higher in drip irrigation (Uzgur, 2022). Drip irrigation is a common irrigation technique in greenhouse farming, especially for vegetables, because it can notably increase yield and quality of production (Acar, 2020). Precise application of water through drip irrigation system saves water and results in a favorable environment for plants leading to better yield and quality of products (Nikolaou et al. 2019). In addition to efficient water application, the quality of water resources is an important consideration in agricultural irrigation management, particularly when groundwater is used as an irrigation source. Previous studies have examined groundwater quality (Dodocioiu & Buzatu, 2017) and surface water quality in river basins (Dodocioiu et al., 2017), emphasizing the importance of monitoring water resources as part of sustainable agricultural water management. Omofunmi et al. (2019) and Trivedi & Gautam (2019) reported that main objective for all irrigation systems is to apply irrigation water as uniformly as possible to the entire area where plants are located. These researchers recommended that for areas irrigated with drip irrigation, flow rate variation in the drippers should not exceed 10 % to achieve desired uniform water application. According to many researchers (Nassab et al. 2013; Darko et al. 2017; Acar, 2019), irrigation systems that are well-planned and managed appropriately at field scales will distribute irrigation water uniformly in plant root zone environment with low water loss. To achieve target performance from drip irrigation technique, system needs to be well-planned, installed on site by skilled workers, and managed correctly (Hanson & May 2007; Mostafa & Thörmann 2013; Sayman & Acar 2025).

This current work mainly investigated drip irrigation system water application performance and amount of irrigation water applied to cucumbers, eggplants, and bell peppers grown in 11 plastic-covered greenhouses in the Menderes district of İzmir province, Türkiye.

MATERIAL AND METHODS

The material for this research consists of 11 drip irrigation systems located in 11 different plastic-covered greenhouses producing cucumber, eggplant, and bell pepper in the Menderes district of İzmir province of Türkiye. The research was conducted between July and November 2023. Menderes district is bordered by Gaziemir and Karabağlar districts to the north, Torbalı district to the east, Seferihisar district to the west, and Selçuk district to the south (Figure 1).

Menderes region, research site, has similar climatic characteristics to Izmir province, with a long-term average rainfall of 712.1 mm. According to long-term climate data, air temperatures in Izmir province generally do not fall below zero, and its climate is close to typical Mediterranean characteristics.

The research area has included approximately 40 greenhouses using drip irrigation systems for vegetable farming, and 11 of these (27.5 %) that engage in modern vegetable production were included in our current study. Four of selected greenhouses used for eggplant, four for cucumber, and three for bell pepper

production. In examined greenhouses, the lateral pipes were new in 2 systems and three years old in the other 9. All lateral lines were oval type having inline emitters non-pressure-compensating.

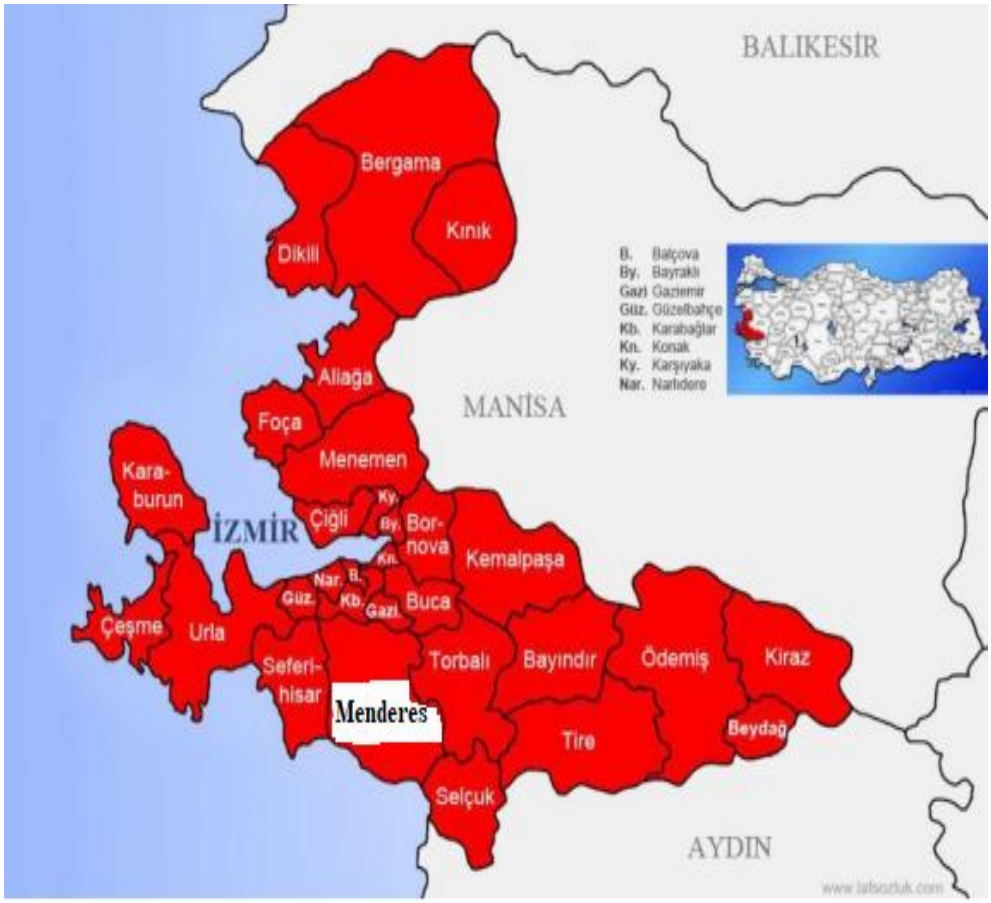


Figure 1. Menderes location in both İzmir and Türkiye (Engindeniz, 2025).

Flow measurements in emitters

Accurate results for dripper flow rate tests can only be obtained by taking water measurements at all drippers over a specific time period. However, since this is both time-consuming and quite cumbersome, scientific research suggests that water measurements can be done at 24-36 drippers (Goyal, 2007). These tests were performed using plastic containers with capacities of 500 mL in a total of 27 emitters: 9 in lateral tube nearby head of manifold (3 at near to head of lateral, 3 at near to middle section of lateral, and 3 at near to end of lateral), 9 in lateral tube in nearby middle of manifold (3 at near to head of lateral, 3 at near to middle section of lateral, and 3 at near to end of lateral), and 9 in lateral line at nearby end of manifold (3 at near to head of lateral, 3 at near to middle section of lateral, and 3 at near to end of lateral). After placing containers under test drippers, system was run around 10 minutes in each test. The volume of water collected in the containers was measured

with a graduated plastic cylinder, and then volumes of water obtained from individual drippers were converted to L/h.

Average dripper flow rate

The average flow rates of emitters were computed using following formula (Zamaniyan et al. 2014);

$$q_{avr} = \frac{1}{n}\sum_{i=1}^{n} q_i$$

Where; q_{avr} - Average emitter discharge (L/h), q_i- Individual emitter discharge (L/h), and n- Number of test emitters.

Emitter Watering Uniformity

In that regard, two famous uniformity indicators namely Uniformity Coefficient (UC) and Distribution Uniformity (DU), were calculated. UC was computed by following equation as suggested by Wu and Gitlin (1974) derived by Christiansen (1942);

$$UC = \left[(1 - (\frac{\Delta q}{qavr}) \right] \times 100$$

where; UC- Uniformity Coefficient (%), and Δq – Mean absolute deviation of each emitter flow rate from average emitter flow rate (L/h). The results were assessed by Table 1.

Table 1

UC-Water application performance relationships (Asif et al. 2015; Jatoth et al. 2017)

UC (%)	Water distribution class
> 90	Perfect
80 – 90	Well
70– 80	Moderate
60 – 70	Poor
< 60	Unacceptable

DU was calculated by following formula (Wilcox & Swailes 1947; Zamaniyan et al. 2014);

$$DU = \frac{q_{a\%25min}}{qavr} x100$$

Where; DU-Distribution Uniformity (%), and $q_{a\%25min}$- Average of the lowest quarter of the emitter discharge (L/h).

Table 2.

Relationships between DU and water distribution class

DU (%)	Merriam & Keller (1978); Kumari et al. (2018)
< 70	Poor
70-80	Acceptable
80-90	Well
>90	Perfect

Applied water for drip-irrigated vegetables

In calculating seasonal applied irrigation water to cucumbers, eggplant, and bell peppers, following two steps were performed:

1- Drippling Rate

$$Dr = \frac{q_{avr}}{EsxLs}$$

Where; Dr- Drippling rate (mm/h), and Es- Emitter space (m), and Ls- Lateral space (m).

2- Seasonal Applied Water

$$IW = DrxTa$$

Where; IW- Seasonal Applied Water (mm), and Ta-Irrigation duration (h).

Irrigation Water Use Efficiency (IWUE)

IWUE, which expresses the marketable yield per unit of irrigation water applied, was calculated as follows (Pinnamaneni et al. 2020; Piri & Naserin 2020);

$$IWUE = \frac{Y}{I}$$

Where; Y- Total marketable yield (kg), and I-Irrigation water amount (m^3).

RESULTS AND DISCUSSIONS

Properties of examined plastic houses

All greenhouses in the research area were block-type with plastic cover (Figure 2).

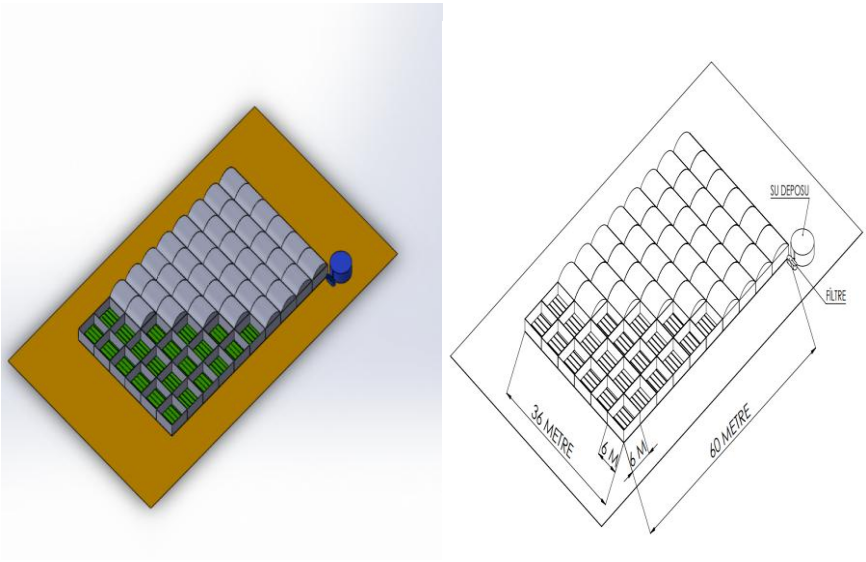


Figure 2. Sample block-style plastic house for cucumber production

Steel materials were used as skeletal system in examined greenhouses because they are strong, durable, and highly resistant to bending.

Characteristics of Drip Irrigation Systems

In greenhouses, irrigation water sources were water tanks or wells. The properties of drip irrigation system components are given in Table 3.

In all examined drip irrigation systems, lateral diameter and emitter space are 16 mm and 20 cm, respectively.

The lateral spacing was between 110-150 cm. Farmers stated that this arrangement has created satisfactory wetting volume within the soil rooting depths.

Table 3.

Features of drip irrigation systems in examined greenhouses

Greenhouses	Vegetables	Emitter discharge (L/h)	Lateral space (cm)	Mainline diameter (mm)	Manifold diameter (mm)
1	Cucumber	2.2	110	50.8	50.8
2			110	50.8	50.8
3			110	50.8	50.8
4			110	50.8	50.8
5	Eggplants		150	63.5	63.5
6			150	63.5	63.5
7			150	63.5	63.5
8			150	63.5	63.5
9	Bell pepper		110	50.8	50.8
10			110	50.8	50.8
11			110	50.8	50.8

Analysis of Average Dripper Flow Rates

Figure 3 shows the average dripper discharges obtained from watering tests on 27 drippers in the lateral pipes on the selected laterals on test manifold in each research greenhouse.

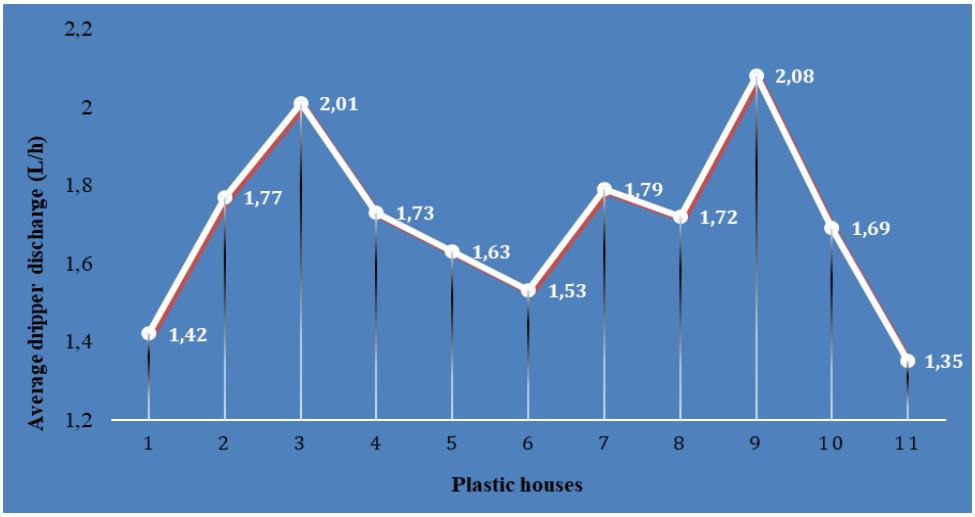


Figure 3. Average dripper flow rates of drip irrigation systems

In Figure 3, average dripper flow rate in drip irrigation system used in research areas was determined between 1.35 and 2.08 L/h. The average flow rates were generally lower than 2.2 L/h value given in production company catalog. The difference between the highest and the lowest average flow rates among the systems was approximately 35 %. Flow rate variation within each system should be evaluated against the 10% limit recommended by Omofunmi et al. (2019) and Trivedi & Gautam (2019).

Evaluation of drip irrigation system water application performances

The calculated UC values of drippers obtained from 11 drip irrigation systems were 81, 75, 78, 95, 72, 82, 84, 77, 87, 82, and 86 %, respectively (Table 4). In Table 4, only one greenhouse had a "Perfect" water distribution. In addition, 6 greenhouses had a "Well", and 4 greenhouses had a “Moderate” water distribution performance. The reason why some drip irrigation systems in greenhouses scored "Moderate" dripper uniformity could be wear and tear on some components of the drip irrigation system over time, design failures in system, or absence or malfunction of filter systems**.**

Table 4

UC values and corresponding equal water distribution level

Greenhouses	Vegetables	UC (%)	Water application class
1	Cucumber	81	Well
2		75	Moderate
3		78	Moderate
4		**95**	**Perfect**
5	Eggplant	72	Moderate
6		82	Well
7		84	Well
8		77	Moderate
9	Bell pepper	87	Well
10		82	Well
11		86	Well

UC value was determined to be an average of 88% in Kırklareli province of Türkiye (Özer et al. 2020); 87-98 % in Konya province of Türkiye (Sayman & Acar 2025); and 96 % in India (Arya et al. 2017). The UC values obtained in the present study (mean 81.7 %) are slightly lower than those reported by the findings of aforementioned researchers.

In our study, DU values were calculated to be between 55 % and 91 % (Table 5). According to DU, dripper watering class was determined to be ‘’Perfect’’ in one greenhouse, ‘’Acceptable’’ in 6 greenhouses, and ‘’Poor’’ in four greenhouses. In general, there is a similarity between water distribution classes based on UC value and distribution classes based on the DU value.

In studies conducted, DU values were as 65-99 % in Altınekin district of Konya province (Ünal et al. 2015); 23-82 % around İzmir (Acar et al. 2015); 68-96 % in Kırklareli (Özer et al. 2020); 44-71 % in Konya province (İnciman & Acar 2020); 92.2 % in Ethiopia (Borena & Seyoum 2021); and 82.41%-97.80 % in Konya province (Sayman & Acar 2025).

Table 5

DU values and corresponding water distribution class

Greenhouses	Vegetables	DU (%)	**Water distribution class** (Merriam & Keller 1978; Kumari et al. 2018)
1	Cucumber	71	Acceptable
2		63	Poor
3		62	Poor
4		**91**	**Perfect**
5	Eggplant	55	Poor
6		76	Acceptable

7		74	Acceptable
8		63	Poor
9	Bell pepper	76	Acceptable
10		72	Acceptable
11		75	Acceptable

Applied Water for vegetables

In present study, average amount of applied water to cucumber was determined to be approximately 406.55 mm (Table 6). In field studies conducted on different cucumber varieties irrigated with drip irrigation system, amount of irrigation water applied to cucumber plant was found to be 243.6-671.5 mm in Hama region of Syria (Yaghi et al. 2013); 330.3-479.9 mm in Erzurum province of Türkiye (Şahin et al. 2015); 148-287 mm in Tulkarm region of Palestine (Rashid & Qanadillo 2015); 300 mm in Kırklareli province (Çakır et al. 2017); 202.6-506.2 mm in Nigeria (Omotade & Babalola 2019); and 20.5-32.7 mm in Texas, US (Parkash et al. 2021).

Table 6

Drippling rate, irrigation durations, and applied water

Greenhouses	Vegetables	Drippling Rate (mm/h)	Seasonal Irrigation Time Ta, (h)	Seasonal Applied water (mm)
1	Cucumber	6.45	52	335.40
2		8.04	50	402.00
3		9.13	50	456.50
4		7.86	55	432.30
5	Eggplant	5.82	89	517.98
6		5.46	76	414.96
7		6.39	84	536.76
8		6.14	93	571.02
9	Bell pepper	9.45	46	434.70
10		7.68	43	330.24
11		6.13	40	245.20

The average amount of irrigation water applied to eggplant was determined as 510 mm. On the other hand, in studies conducted under field conditions on different eggplant varieties irrigated with drip irrigation system, amount of applied water varied depending on the conditions: 242-427 mm in Antalya province (Özbek & Kaman 2017); 245-450 mm in Tarsus district of Mersin province in 2013 and 240-418 mm in 2014 (Çolak et al. 2017); 122-305 mm in Bandırma district of Balıkesir province (Al Ali et al. 2018); 283-693 mm in Tekirdağ province in 2015 and 293-711 mm in 2016 (Yenigün & Erdem 2019); 35.3-587 mm in Yalova province in 2016 and 25.2-595.7 mm in 2017 (Tekin, 2020); and 148.45-365.8 mm in Antalya conditions (Can, 2020).

In this study, water applied to bell peppers irrigated with drip irrigation was determined to be approximately 245-435 mm.

In some previous studies conducted under field conditions on different pepper varieties irrigated with drip irrigation, amount of irrigation water to peppers was found to be 652-1010 mm in Harran district (Taş & Kırnak 2011); 481-724 mm in Spain (Abdelkhalik et al. 2020); and 352-857 mm in Tekirdağ province (Azder et al. 2020).

Yield and IWUE

Fruit yields in cucumber plants ranged from 64.4 to 73 t/ha with an average yield of 69.35 t/ha (Table 7).

Table 7

Amount of applied water, marketable vegetable yields and IWUE values for cucumbers, eggplants, and bell peppers

Greenhouses	Vegetables	Seasonal applied water (mm)	Marketable fruit yield (t/ha)	IWUE (kg/m^3)
1	Cucumber	335.40	64.40	19.20
2		402.00	68.00	16.91
3		456.50	72.00	15.77
4		432.30	73.00	16.88
5	Eggplant	517.98	61.75	11.92
6		414.96	59.00	14.21
7		536.76	60.00	11.17
8		571.02	41.80	7.32
9	Bell pepper	434.70	50.00	11.50
10		330.24	40.00	12.11
11		245.20	38.50	15.70

Studies conducted on different cucumber varieties irrigated with drip irrigation showed that cucumber fruit yields ranged from 37.7-63.9 t/ha in the Hama region of Syria (Yaghi et al. 2013); 42.74-64.13 t/ha in Erzurum region (Şahin et al. 2015); 45.10-59.52 t/ha in Tulkarm region of Palestine (Rashid & Qanadillo 2015); and 20.51-32.75 t/ha in Texas, US (Parkash et al. 2021).

Eggplant yields in greenhouses ranged from 41.8 to 61.75 t/ha; average yield was 55.64 t/ha.

Bell pepper yield ranged from 38.5 to 50 t/ha; average yield was 42.8 t/ha in this present study.

IWUE value of cucumber plants was found to be 15.77-19.20 kg/m^3, with an average of 17.19 kg/m^3. These values for eggplant were found to be 7.32-14.21 kg/m^3; average was 11.15 kg/m^3. IWUE value for bell pepper production was calculated to be between 11.50 and 15.70 kg/m^3; average was 13.10 kg/m^3.

CONCLUSIONS

The flow rate variation of drippers exceeded the recommended limit of 10% in the studied greenhouses. To minimize this, it is strongly recommended that broken

or damaged components of the drip irrigation systems be repaired first and, if possible, that components which have lost their functionality or are not working properly be replaced. In addition, regular dripper flow rate tests would be a very useful way to obtain information on the water application performance of the drippers. The average amount of irrigation water applied was about 407 mm for cucumber, 510 mm for eggplant and 337 mm for bell pepper. These values are consistent with local farming practice. Average yields were 69.4 t/ha for cucumber, 55.6 t/ha for eggplant and 42.8 t/ha for bell pepper. Although yields were satisfactory, the Poor DU values recorded in four greenhouses indicate that water distribution can be improved. Therefore, to maximize the benefits of drip irrigation systems, they should be properly planned, installed and managed.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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