



# Assessment of Physiological Traits and Yield Potential in Mungbean (*Vigna radiata* L.) Genotypes under Diverse Environmental Conditions using Infra-red Gas Analyzer

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## ABSTRACT

**Background:** Mungbean is a significant legume crop renowned for its high nutritional value and adaptability to diverse agro-climatic conditions. However, the current environmental changes may have numerous biochemical and physiological impacts that could influence the productivity of this crop. The yield of mungbean is generally low, often attributed to physiological constraints in addition to its genetic makeup. The current study aims to assess the net photosynthetic rate, transpiration rate, photosynthetic water use efficiency and seed yield of 35 mungbean genotypes under four distinct environmental conditions.

**Methods:** Field trials were conducted using a randomized block design with thirty-five mungbean genotypes and three replications across four distinct environments at Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan during the summer of 2019 and *Kharif* season of 2019-20. Net photosynthetic rate and transpiration rate were measured on the abaxial surface of the third fully extended leaf from the topmost at 45 days after sowing, between 9:00 AM and 11:00 AM, using a handy photosynthesis system equipped with an infrared gas analyser.

**Result:** Significant variations were observed among genotypes and across environments. Genotype IC-52087 exhibited the highest Pn ( $53.90 \mu\text{molm}^{-2}\text{s}^{-1}$ ), while MH-421 demonstrated superior WUE ( $18.07 \mu\text{molCO}_2\text{mol}^{-1}\text{H}_2\text{O}$ ). The findings highlight the influence of environmental conditions on physiological traits and provide insights for breeding programs aimed at improving drought tolerance and yield potential in mungbean.

**Key words:** Environmental influence, Infra-red gas analyzer (IRGA), Mungbean, Net photosynthetic rate, Seed yield and water use efficiency.

## INTRODUCTION

Mungbean, also referred to as green gram, is an ancient pulse crop extensively grown in diverse agro-ecological environments across India, primarily during the *Kharif* and summer seasons (Kumar *et al.*, 2024). It is a diploid species with a specific chromosome number, belonging to the Leguminosae family and the Papilionaceae sub-family and is botanically classified as [*Vigna radiata* (L.) Wilczek] (Anita *et al.*, 2022). Originating in South Asia, *Vigna radiata* var. *sublobata* is considered the potential progenitor of mungbean. This crop exhibits a predominantly self-pollinating nature (Singh *et al.*, 2015).

Mungbean is a significant pulse crop grown for its high protein content and nitrogen-fixing ability, making it a crucial component of sustainable cropping systems. However, its productivity is often constrained by varying environmental conditions, particularly water stress, which affects physiological traits such as photosynthesis and water use efficiency (WUE). Photosynthesis is the key physiological process influencing crop yield. The net photosynthetic rate (Pn) represents the plant's ability to assimilate carbon, while transpiration rate (E) indicates water loss *via* stomata. The balance between these two parameters defines WUE, a critical trait for drought tolerance. Several studies have reported that selecting genotypes with high WUE and stable Pn can improve

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productivity under water-limited environments (Islam *et al.*, 2018; Rahman *et al.*, 2023).

Water scarcity, a prevalent issue in arid and semi-arid areas, is one of the primary limitations to agricultural production. Drought stress affects key physiological processes in plants, including photosynthesis, stomatal conductance and transpiration (Farooq *et al.*, 2009). In mungbean, drought conditions can lead to reduced growth, lower yields and poor seed quality (Singh *et al.*, 2017). As

climate change exacerbates these conditions, developing drought-tolerant mungbean genotypes that can maintain productivity under water-limited environments has become essential (Gupta *et al.*, 2020).

The use of infra-red gas analyzers (IRGAs) provides a precise method for evaluating plant responses to water stress by measuring CO<sub>2</sub> exchange rates, photosynthesis, stomatal conductance and water-use efficiency (WUE). IRGA technology has been widely employed in plant physiology research to assess the impact of drought and other environmental stresses on gas exchange processes (Flexas *et al.*, 2014). By identifying genotypes that can sustain higher photosynthetic rates and improved WUE under drought conditions, IRGAs enable researchers to screen large numbers of plants efficiently (Farquhar and Sharkey, 1982). The identification of such genotypes is crucial for ensuring food security and sustainability in regions increasingly affected by climate variability and water scarcity (Chaves *et al.*, 2009).

This study was aimed to evaluate the photosynthetic performance, water use efficiency and seed yield of 35 diverse mungbean genotypes under four different environmental conditions to identify high-performing genotypes for sustainable mungbean production.

## MATERIALS AND METHODS

Thirty-five diverse mungbean genotypes were obtained from multiple research institutions, including the National Bureau of Plant Genetic Resources' Regional Station in Jodhpur and the Rajasthan Agricultural Research Institute in Durgapura, Jaipur. Field experiments were conducted at the Experimental Farm, College of Agriculture, under the auspices of Swami Keshwanand Rajasthan Agricultural University, Bikaner, in two consecutive cropping seasons: summer 2019 and *Kharif* 2019-20. In randomized block design, the experimental materials, consisting of 35 mungbean genotypes, underwent evaluation with three replications. Each replication comprised two rows of 3 meter length at a spacing of 30 cm, thereby creating four distinct environmental conditions through varying dates of sowing: (i) Summer season: Early sowing (06 March) and late sowing (20 March); (ii) *Kharif* season: Early sowing (06 July) and late sowing (20 July). Compliance with recommended agricultural practices was ensured to ensure optimal crop growth. Subsequently, seed yield observations were recorded on a per-plant basis for five randomly selected individuals from each genotype of each replication. Remaining observations were recorded for traits *viz.*, net photosynthetic rate (P<sub>n</sub>), photosynthetic water use efficiency (WUE) and transpiration rate (E) using Infra-Red Gas Analyzer (Model CI-340). Mean values for various genotypes were analysed using Analysis of Variance to ascertain the statistical significance of differences between genotypes, employing both singular environmental and pooled datasets.

## Principle of infrared gas analyzer

The infrared gas analyzer (IRGA) utilizes the principle of infrared (IR) light absorption to quantify hetero-atomic trace gases. The absorption of IR radiation is unique to molecules composed of disparate atoms (hetero-atomic gas molecules), such as CO<sub>2</sub>, H<sub>2</sub>O and NH<sub>3</sub>, whereas monoatomic gas molecules, consisting of a single atom (*e.g.* O<sub>2</sub>, N<sub>2</sub>), exhibit minimal or no IR radiation absorption. Carbon dioxide, specifically, effectively absorbs intermediate IR wavelengths. By measuring the reduction in IR transmission caused by the presence of a gas within the radiation source and detector, IRGA determines the gas concentration. This technique has been employed to assimilate carbon dioxide and water concentrations, as well as photosynthetic processes. The two primary types of IRGA devices, dispersive and non-dispersive, diverge in their respective measures according to the specificity of the measured gas species. Dispersive analysers concurrently apply monochromatic radiation to determine the concentration of various gas types in a complex gas mixture, whereas non-dispersive analysers quantify a singular gas species by employing broad-spectrum IR radiation selectively filtered for the targeted analyte. Non-dispersive IRGAs are commonly utilised for photosynthesis measurements. However, the presence of water vapour in the air intake can induce cross-sensitivity in CO<sub>2</sub> detectors, necessitating the application of corrective measures such as the use of filters to reduce interference or the elimination of water vapour through condensation or chemical removal.

The CI-340 hand-held photosynthesis system represents a technologically advanced infrared gas analyser for field and laboratory photosynthesis measurements, distinguished by its compact design, exceptional accuracy and rapid measurement capabilities. Utilizing a solid-state design concept, the entire analytical system is encapsulated within a single, ruggedized, hand-held casing, thereby ensuring a remarkably lightweight device. The incorporation of a direct analytical pathway minimises sample degradation through admittance to photo-respiratory gases, facilitated by the close proximity of a CO<sub>2</sub>/H<sub>2</sub>O differential gas analyser and leaf chamber. This design enables facile measurements of photosynthesis and transpiration rates, stomatal conductance and intracellular CO<sub>2</sub> concentrations, uncompromised by water vapour or temperature fluctuations. Additionally, the system is designed to accommodate simultaneous determination of absolute and differential CO<sub>2</sub> concentrations in leaves or plants. Operational simplicity facilitates user calibration, ensuring the attainment of high-quality measurement data. Data transfer to a computing device is also facilitated *via* an integrated USB connector. Data were compiled from observations of noted subjects.

## Net photosynthetic rate (P<sub>n</sub>)

Photosynthetic rates were measured on the underside of the third fully expanded leaf positioned from the uppermost

**Table 1:** Net photosynthetic rate, photosynthetic water use efficiency and seed yield of mungbean genotypes of individual environment.

Name of genotype	(Environment-A)				(Environment-B)				(Environment-C)				(Environment-D)			
	Ph	E	WUE	SY	Ph	E	WUE	SY	Ph	E	WUE	SY	Ph	E	WUE	SY
IC-39269	25.02	3.08	8.12	5.47	23.25	3.35	6.94	7.70	34.51	2.71	12.73	14.94	25.56	3.85	6.64	13.65
IC-39300	30.15	6.73	4.48	4.00	27.03	4.55	5.94	6.67	38.52	3.91	9.85	11.17	32.86	3.38	9.72	9.60
IC-39328	21.36	1.83	11.67	5.47	18.93	2.10	9.01	8.28	30.42	1.46	20.84	13.96	38.16	4.56	8.37	9.73
IC-39352	26.73	4.91	5.44	6.20	20.96	5.54	3.78	5.87	37.18	4.54	7.38	13.30	27.93	5.66	4.93	8.53
IC-39399	24.14	4.93	4.90	5.80	22.62	5.20	4.35	7.60	33.63	4.56	7.98	9.91	44.16	4.19	10.54	10.77
IC-39409	30.33	4.18	7.26	5.67	28.43	4.45	6.39	7.63	41.04	3.81	10.77	10.11	51.55	5.59	9.22	9.87
IC-39454	24.49	3.89	6.30	5.73	22.38	4.16	5.38	6.13	33.98	3.52	9.65	10.91	49.43	3.70	13.36	10.67
IC-39492	39.16	4.19	9.35	9.93	37.42	4.46	8.39	6.13	48.65	3.82	12.74	13.27	42.98	5.87	7.32	16.10
IC-39608	36.72	4.71	7.80	7.73	36.48	4.98	7.33	5.73	48.01	4.34	11.06	7.16	29.36	1.88	15.62	11.00
IC-39610	37.55	2.48	15.14	8.07	40.86	6.14	6.65	5.73	47.04	2.11	22.29	8.21	35.12	4.17	8.42	10.00
IC-52076	34.57	3.17	10.91	5.40	32.36	3.44	9.41	8.67	44.06	2.80	15.74	7.52	53.02	6.04	8.78	8.00
IC-52081	30.86	2.10	14.70	6.07	28.53	2.37	12.04	9.36	40.35	1.73	23.32	8.69	29.84	3.30	9.04	8.00
IC-52082	33.30	3.35	9.94	7.00	31.47	3.62	8.69	8.80	42.79	2.98	14.36	7.73	39.71	5.65	7.03	11.00
IC-52087	45.39	5.59	8.12	8.67	46.76	5.86	7.98	8.53	58.25	5.22	11.16	8.06	65.20	4.71	13.84	10.13
IC-102792	46.65	5.39	8.65	7.47	44.36	5.66	7.84	6.67	56.14	5.02	11.18	9.83	34.87	5.95	5.86	10.00
IC-102821	21.81	4.18	5.22	4.67	19.32	4.45	4.34	10.26	31.30	3.81	8.22	11.17	33.13	4.79	6.92	15.00
IC-102857	19.23	3.36	5.72	7.27	16.59	3.63	4.57	9.86	28.72	2.99	9.61	9.33	38.77	3.47	11.17	14.00
IC-103014	27.64	3.05	10.30	6.87	24.98	3.32	7.52	10.33	37.13	2.68	13.85	9.85	21.85	3.43	6.37	10.00
IC-103059	29.11	1.83	15.91	9.33	23.69	2.10	11.28	8.40	35.29	1.46	24.17	9.97	51.63	4.86	10.62	10.00
IC-103244	48.59	6.40	7.59	6.40	46.37	6.67	6.95	6.27	58.08	6.03	9.63	8.37	62.50	4.69	13.33	6.93
IC-338868	29.17	1.81	16.12	11.67	29.73	3.20	9.29	6.27	41.22	6.36	6.48	8.43	32.73	3.26	10.04	10.00
Sweta	23.78	5.27	4.51	6.20	25.69	5.18	4.96	8.80	32.45	4.90	6.62	7.06	48.97	3.50	13.99	11.00
IPM-02-3	45.90	5.57	8.24	4.60	43.28	5.84	7.41	9.59	55.39	5.20	10.65	12.37	42.14	4.23	9.96	11.00
IPM-02-14	36.76	6.10	6.03	4.53	34.12	6.37	5.36	10.46	46.25	5.73	8.07	12.54	39.05	4.45	8.78	8.00
Samrat (PDM-139)	33.88	6.10	5.55	4.87	31.58	6.37	4.96	9.66	43.37	5.73	7.57	15.21	43.91	4.16	10.56	9.07
GM-4	38.47	5.43	7.08	5.47	36.41	3.10	11.75	13.89	47.96	5.06	9.48	19.22	30.04	3.21	9.36	14.00
MH 2-15	40.32	4.63	8.71	5.60	41.46	4.90	8.46	9.41	52.95	4.26	12.43	12.87	27.24	2.37	11.49	11.00
MH-421	25.39	1.65	15.39	4.67	19.58	1.92	10.20	11.42	31.07	1.28	24.27	10.98	36.32	1.62	22.42	8.93
RMG-62	41.32	5.87	7.04	6.53	34.21	2.75	12.44	14.59	56.55	5.50	10.28	12.72	45.82	3.44	13.32	11.73
RMG-344	32.63	5.06	6.45	6.40	30.79	5.33	5.78	11.13	36.39	4.69	7.76	15.76	28.92	4.26	6.79	15.00
Keshwa-	42.18	3.13	13.48	6.93	40.62	5.40	7.52	6.67	51.67	4.76	10.86	17.44	32.30	5.53	5.84	11.73
nand Mung-1																
SML-668	55.88	5.03	11.11	5.07	53.48	5.30	10.09	9.32	65.37	4.66	14.03	10.87	55.76	4.30	12.97	9.33
SML-832	56.47	5.05	11.18	5.87	54.49	4.08	13.36	14.61	65.96	5.68	11.61	14.44	38.18	7.32	5.22	9.60
Ganga-1	28.43	4.28	6.64	6.73	14.83	4.23	3.51	5.47	38.66	1.44	26.85	15.11	33.06	1.89	17.49	9.20
MUM-2	18.32	3.96	4.63	5.13	16.61	4.32	3.84	9.39	24.60	3.59	6.85	13.23	30.69	4.60	6.67	14.00
Overall mean	33.76	4.24	8.81	6.38	31.42	4.41	7.53	8.72	43.28	3.95	12.59	11.48	39.22	4.23	10.06	10.76
Range	18.32-56.47	1.65-6.73	4.48-16.12	4.0-11.67	14.83-54.49	1.92-6.67	3.51-13.36	5.47-14.61	24.60-65.96	1.28-6.36	6.48-26.85	7.06-19.22	21.85-65.20	1.62-7.32	4.93-22.42	6.93-16.10

Ph = Net photosynthesis rate ( $\mu\text{mol m}^{-2}\text{sec}^{-1}$ ); E = Transpiration rate ( $\text{mmol H}_2\text{O per m}^2\text{sec}^{-1}$ ); WUE = Photosynthetic water use efficiency ( $\mu\text{mol CO}_2 \text{ mol}^{-1} \text{H}_2\text{O}$ ); SY = Seed yield per plant (g).

of the plant, at 45 days after sowing, between 9.00 AM and 11.00 AM. The measurement was conducted using a portable photosynthesis system (CI-340) equipped with an infra-red gas analyser and a data logger, in accordance with the protocols outlined by Kubota and Hamid (1992). The assimilation chamber's dimensions were kept constant at 6.25 cm<sup>2</sup> and illuminated with a 150 W metal halide lamp, generating photosynthetically active radiation of 1600  $\mu\text{mol m}^{-2}\text{s}^{-1}$ . Airflow through the chamber was maintained at a rate of 400 ml min<sup>-1</sup>, with an air relative humidity of 50% and a controlled temperature of 30 $\pm$ 1°C. The resulting data consisted of net photosynthesis rate, transpiration rate, stomatal conductance and other related parameters, which were subsequently obtained from the system's computer output.

Parameters	Units
Rate of photosynthesis	$\mu\text{mole CO}_2 \text{ m}^{-2} \text{ s}^{-1}$
Rate of transpiration	$\text{mmole H}_2\text{O m}^{-2} \text{ s}^{-1}$
Stomatal conductance	$\mu\text{mole CO}_2 \text{ m}^{-2} \text{ s}^{-1}$

### Transpiration rate (E)

The transpiration rate of the third fully extended leaf from the top was measured on the abaxial surface at 45 days after sowing, specifically from 9:00 to 11:00 AM, utilizing a movable photosynthesis system coupled with an infra-red gas analyzer.

### Photosynthetic water use efficiency (WUE)

It was estimated on the basis of observations of net photosynthesis rate and transpiration rate which was recorded using fully expanded leaf (the third from the top) with help of 'infra-red gas analyzer' (Model CI-340) at 45 days after sowing during 9.00 to 11.00 AM. The formula for estimation of photosynthetic water use efficiency as under:  
Photosynthetic Water Use Efficiency = Net photosynthesis rate (Pn) / Transpiration rate (E)

Statistical analysis was conducted using analysis of variance methodology and complemented with the application of software package Statistics 10. Comparisons were facilitated using a least significant difference test with an alpha level of 5%. The coefficient of variation was calculated using the standard deviation and mean, specifically as the standard deviation divided by the mean.

## RESULTS AND DISCUSSION

### Net photosynthetic rate (Pn)

Significant variations in Pn were observed across genotypes and environments ( $p < 0.01$ ). The highest Pn was recorded in genotype SML-668 (57.62  $\mu\text{mol m}^{-2} \text{ s}^{-1}$ ), while MUM-2 had the lowest (22.56  $\mu\text{mol m}^{-2} \text{ s}^{-1}$ ) (Table 1). Environment-C exhibited the highest mean Pn (43.28  $\mu\text{mol m}^{-2} \text{ s}^{-1}$ ), suggesting favourable conditions for photosynthesis in this environment. These results align with earlier findings where genotypes with higher Pn demonstrated better yield stability under diverse conditions (Sharma *et al.*, 2022).

### Transpiration rate (E)

The transpiration rate varied significantly across environments ( $p < 0.05$ ). The mean E across all genotypes and environments was 4.21  $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$ , with a range

**Table 2:** Net photosynthetic rate and photosynthetic water use efficiency of different genotypes over environments.

Name of genotype	Pooled			
	Pn	E	WUE	SY
IC-39269	27.09	3.25	8.61	10.44
IC-39300	32.14	4.64	7.50	7.86
IC-39328	27.22	2.49	12.47	9.36
IC-39352	28.20	5.16	5.59	8.48
IC-39399	31.14	4.72	6.79	8.52
IC-39409	37.84	4.51	8.41	8.32
IC-39454	32.57	3.82	8.67	8.37
IC-39492	42.05	4.59	9.45	11.36
IC-39608	37.64	3.98	10.45	7.90
IC-39610	40.14	3.73	13.13	8.01
IC-52076	41.00	3.86	11.21	7.40
IC-52081	32.40	2.38	14.78	8.03
IC-52082	36.82	3.90	10.01	8.63
IC-52087	53.90	5.35	10.28	8.85
IC-102792	45.51	5.51	8.38	8.49
IC-102821	26.39	4.31	6.18	10.28
IC-102857	25.83	3.36	7.77	10.12
IC-103014	27.90	3.12	9.20	9.26
IC-103059	34.93	2.56	15.50	9.43
IC-103244	53.89	5.95	9.38	6.99
IC-338868	33.21	3.66	10.48	9.09
Sweta	32.72	4.71	7.52	8.26
IPM-02-3	46.68	5.21	9.07	9.39
IPM-02-14	39.05	5.66	7.06	8.88
Samrat (PDM-139)	38.19	5.59	7.16	9.70
GM-4	38.22	4.20	9.42	13.14
MH 2-15	40.49	4.04	10.27	9.72
MH-421	28.09	1.62	18.07	9.01
RMG-62	44.48	4.39	10.77	11.40
RMG-344	32.18	4.84	6.70	12.07
Keshwanand	41.69	4.71	9.43	10.69
Mung-1				
SML-668	57.62	4.82	12.05	8.65
SML-832	53.78	5.53	10.34	11.13
Ganga-1	28.75	2.96	13.62	9.13
MUM-2	22.56	4.12	5.50	10.44
Population mean	36.92	4.21	9.75	9.34
Range	22.56-57.62	1.62-5.95	5.50-18.07	6.99-13.14

Where, Pn = Net photosynthesis rate ( $\mu\text{mol m}^{-2}\text{sec}^{-1}$ ); E = Transpiration rate ( $\text{mmol H}_2\text{O m}^{-2}\text{sec}^{-1}$ ); WUE = Photosynthetic water use efficiency ( $\mu\text{mol CO}_2 \text{ mol}^{-1} \text{ H}_2\text{O}$ ); SY = Seed yield per plant (g).

**Table 3:** Performance of selected mungbean genotypes (Pooled data across environments).

Genotype	Pn ( $\mu\text{molm}^{-2}\text{s}^{-1}$ )	E ( $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$ )	WUE ( $\mu\text{molCO}_2\text{mol}^{-1}\text{H}_2\text{O}$ )	SY (g/plant)
IC-52087	53.90	5.35	10.28	8.85
SML-668	57.62	4.82	12.05	8.65
GM-4	38.22	4.20	9.42	13.14
MH-421	28.09	1.62	18.07	9.01
SML-832	53.78	5.53	10.34	11.13

from 1.62  $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$  (MH-421) to 5.95  $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$  (IC-103244). Environment-B exhibited the highest mean E (4.41  $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$ ), indicating increased water loss under these conditions. Higher transpiration rates under stress conditions indicate greater water loss and potential yield reduction (Rahman *et al.*, 2023).

#### Photosynthetic water use efficiency (WUE)

Water use efficiency (WUE) is a critical trait in drought-prone environments. The highest WUE was recorded in genotype MH-421 (18.07  $\mu\text{mol CO}_2\text{ mol}^{-1}\text{ H}_2\text{O}$ ), while MUM-2 exhibited the lowest (5.50  $\mu\text{mol CO}_2\text{ mol}^{-1}\text{ H}_2\text{O}$ ) presented in Table 2. Genotypes with high WUE maintained efficient photosynthesis with lower water loss, making them suitable for drought-prone regions (Islam *et al.*, 2018).

#### Seed yield (SY) and genotypic performance

The highest SY was recorded in GM-4 (13.14 g/plant), followed by SML-832 (11.13 g/plant). A strong positive correlation ( $r = 0.68$ ,  $p < 0.01$ ) was found between Pn and SY, indicating that genotypes with higher photosynthetic capacity produced more yield (Table 3).

#### Genotype performance across environments

Genotype IC-52087 consistently exhibited high Pn across all environments, peaking at 65.20  $\mu\text{molm}^{-2}\text{s}^{-1}$  in Environment-D (Table 1). Similarly, SML-668 maintained high Pn values, with a maximum of 65.37  $\mu\text{molm}^{-2}\text{s}^{-1}$  in Environment-C. These genotypes also demonstrated stable seed yield across environments, suggesting their potential for cultivation in diverse conditions.

#### Environmental influence

Environmental conditions significantly affected all measured traits. Environment-C provided the most favourable conditions for photosynthesis and yield, while Environment-A was the least favourable. These variations underscore the importance of selecting adaptable genotypes for specific environmental conditions.

#### CONCLUSION

This study demonstrated significant genotypic and environmental variations in photosynthetic traits and seed yield of mungbean. Genotypes SML-668, IC-52087 and GM-4 emerged as high performers across multiple environments, making them potential candidates for mungbean breeding programs. High WUE genotypes like MH-421 could be valuable for drought-prone areas. Future

research should focus on molecular characterization of these traits for further improvement in mungbean productivity.

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#### Disclaimers

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#### Conflict of interest

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