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Effects of shading material on the growth, yield and quality of green pepper (*Capsicum annum* L.) grown under hot and humid climatic conditions

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Abstract
Green pepper (*Capsicum annum* L.) is one of the most popular vegetables in the Kingdom of Eswatini, with its production mainly under irrigation in open fields. Shade nets are used to modify the crop micro-environment to improve plant growth and yield. This experiment was conducted at Mphaphati, under Eswatini Water and Agricultural Development Enterprises, (ESWADE) in the summer of January and April 2018. The objective of this study was to determine the effect of plastic and net covered tunnels on the growth, yield and quality of green pepper (*Capsicum annum* var. Crusader L.). Shading materials were used white fiber plastic tunnel, green net tunnel (40%) and black net tunnel (40%). The treatments were arranged in Randomized Complete Block Design (RCBD) with three replications. The results revealed that plants grown under the green net covered tunnel significantly ($P<0.05$) had higher plant height (46..6 cm), number of leaves (68), number of branches (11), leaf area (90.3 cm^2), number of flowers (16) and total fruit yield (30.8 ton/ha) when compared to plants grown under the black net covered tunnel. All plants grown under the white fiber plastic-covered tunnel died three weeks after transplanting, as a result, no result for the parameters that were observed. Results obtained in this study indicate that green net covered tunnel supported better growth and development of green pepper grown in sawdust media.

Keywords: green pepper, protected cultivation, lowveld, climate-smart agriculture, food-security

1. Introduction

Green pepper (*Capsicum annum* L.) belongs to the family Solanaceae. It is an important vegetable grown extensively and is one of the most varied and widely used vegetables in the world as it is reported that 25% of the world's population consumes and utilises green pepper every day (Aliyu, 2000; United States Department of Agriculture [USDA], 2008). Its popularity is based on reported nutritional and health benefits. It thrives best in a warm climate in a temperature range of 25-35˚C (Namiki, 2005).

Despite the improved level of agricultural productivity, the Kingdom of Eswatini is not self-sufficient in crop production especially in vegetable crops (National Agricultural Marketing Board [NAMBoard], 2017; Dlamini, *et al*., 2020) [27, 19]. Substantial amounts of vegetables such as green pepper, tomatoes, beetroot, carrots, onions, etc., are imported into the country from South Africa (NAMBoard, 2017; Masarirambi *et al*., 2020) [27, 9]. Green pepper is one of the most popular vegetable crops in the Kingdom of Eswatini, produced mainly under irrigation (Masarirambi *et al*., 2009; Xaba, 2013) [21, 22]. Currently, the demand for vegetables in Eswatini is higher than the local production and hence the gap is filled with imports from South Africa. At the NAMBoard fresh produce market, only 11% of the vegetables are from local production and the rest come from South Africa (NAMBoard, 2017) [27].

Green pepper production is significantly influenced by weather conditions suggesting the need to modify the growing environment (Food and Agricultural Organisation [FAO], 2013) [12]. The recent rise in global warming across the world has posed severe challenges to crop production (Critten and Bailey, 2002; Goren *et al*., 2011) [7, 14]. Among others, the challenges include an increase in air temperature and intensity of solar radiation. Sustained high temperatures (35-40°C) as a result of high solar radiation can also increase the incidence of vegetable abiotic disorders as the climate changes impair cell division, leaf expansion and reproductive development (Castellano *et al*., 2008; Singh *et al*., 2011) [6, 35]. The photo-selective shade netting technology has gained popularity worldwide over the years, as it has the potential to improve light quality while improving the crop quality at harvest (Meena *et al*., 2014; Kanwar *et al*., 2014) [24, 17]. Manipulation of light quality is currently applied in horticulture via photo-selective netting or films to improve yield, quality and phytochemical components (Meena *et al*., 2014; Singh *et al*., 2011). [24, 35]. It is a technology that can be used as an alternative to protect crops from adverse environmental conditions, excessive solar radiation, heat and drought stress, wind and hail, flying pests, thus improving crop production, yield and quality (Singh *et al*., 2011; Critten and Bailey, 2002; Buthelezi *et al*., 2016) [35, 7, 5]. Net covered tunnels have been reported to provide suitable conditions to increase the yield of green pepper (Jansen and Collins, 2011; Arthurs *et al*., 2013) [15, 3].

In the Kingdom of Eswatini, most vegetable production is carried out under open field conditions; however, to ensure availability of vegetables all year round and reduce imports, few local farmers in Mphaphathi have adopted a climate-smart method known as plastic-covered tunnels to produce horticultural crops such as green pepper, tomato and onions (NAMBoard, 2017) [27].

Sustainability and profitable utilisation of the plastic-covered tunnel for green pepper production is threatened by high temperatures and lack of air circulation caused by the plastic cover material. During summer months, temperatures inside the plastic tunnels can be as high as 50-60˚C, thus causing the crops grown to wilt or die and often resulting in flower abortion and poor yield. These have resulted in 80% of the farmers abandoning the idea of tunnel utilisation especially in hot summer months and only grow vegetables such as green pepper in the cool winter season. Therefore, there is a need to identify alternative shading material for the tunnels which will ensure proper ventilation, promote good crop growth and yield of the vegetables such as green pepper, especially during the summer growing season. Therefore, this study aimed to determine the effect of plastic and shade net tunnel houses on the growth, yield and quality of green pepper to ensure food security and increase income for Eswatini farmers.

2. Materials and Methods

2.1 *Experimental site*

The experiment was carried out in plastic tunnels owned by ESWADE, at Mphaphati in the Lubombo region of Eswatini, Lowveld agro-ecological zone. The geographic location of Mphaphathi is 26°40’35.51” S and 31°’32’ 46.63” E at an altitude of 294 m. Yearly rainfall range from 500-900 mm per year, with most of the rain falling in summer. Summer temperatures range from 25-35℃ and cold winter temperatures range from 15-20℃ (Murdoch, 1968) [25]. The experiment was carried out from the January-April 2018.

2.2 *Plant materials*

Six weeks old green pepper seedlings of the cultivar “Crusader” used in this study were bought from Vickery seedlings at Malkerns, Eswatini. All cultural practices were followed when raising the plants and this included irrigation through drippers, fertilisation, weeding and spraying against pests and diseases. The green pepper seedlings were transplanted into 10-liter black polyethylene bags filled with old and fresh sawdust.

2.3 *Experimental design*

The experiment was laid out in Randomised Complete Block Design (RCBD). There were three treatments; white fiber plastic tunnel (control), black net tunnel (40% light transmission) and green net tunnel (40% light transmission) and these were replicated three times. A total of 60 seedlings were transplanted for each treatment per replicate.

2.4 *Data collection*

2.4.1 *Temperature inside each shading material*

Daily minimum and maximum temperatures were recorded using a digital thermometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) throughout the experiment.

2.4.2. *Growth parameters*

For all vegetative growth parameters measured, 20 plants per replication were randomly selected and tagged in each treatment.

2.4.2.1 *Plant height*

The height of the plants was measured using a meter ruler from the base of the plant to the tip of the apical bud.

2.4.2.2 *Number of leaves per plants*

The total numbers of leaves per plant were determined by counting all fully opened leaves on the plants leaving the bud primordial at the shoot apex.

2.4.2.3 *Number of branches per plant*

The total number of branches per plant was counted on all fully developed branches on the plant stem.

2.4.2.6 *Leaf area*

Fully developed leaves of green pepper plants had leaf height and width measured using a 30 cm ruler and then calculated using a formula by Yeshitila and Taye (2016): -193.518 + 8.6327 L (cm) + 14.017 W (cm)

2.4.3 *Reproductive growth parameters*

2.4.3.1 *Number of flowers*

The numbers of flowers per plant were counted from the selected and tagged plants.

2.4.3.2 *Number of fruits per plants*

The fruit number per plant was counted and recorded.

2.4.3.3 *Total soluble solids (TSS)*

The total soluble solids (ºBrix) content was measured using a digital Refractometer (Master 53T Brix~53%, Ohio, USA). Few drops of the green pepper juice was put on the prism which was then closed to allow the taking of the readings.

2.4.3.4 *Fruit firmness*

Fruit firmness (Newtons) was measured using a Penetrometer, probe 8 mm (Wagner, Fruit Test Model FT, and Italy). A single green pepper fruit was placed against a hard surface and the plunger tip forced vertically into the fruit at a constant speed, the handle was then released completely and compression in mm was noted after approximately 5 seconds (Masarirambi and Nxumalo, 2012).

2.4.4 *Fruit yield (ton/ha)*

The total fruit yield was calculated by multiplying the weight of the fruits (kg) per plant by the plant population per hectare and dividing it by 1000 to convert to tons (t/ha).

2.5 *Data analysis*

The data collected were subjected to analysis of variance (Anova) using GEN-STAT Statistical package (Payne, 2009) [29]. Where significant differences were detected, the mean separation was done using Duncan New Multiple Range Test (DNMRT) at 5% probability level (Gomez and Gomez, 1984).

3. Results

3.1 Temperature taken inside the different shading material from January to April 2018.

Table 1. Mean monthly minimum and maximum temperatures inside each shading material tunnel from January-April 2018.

Material	White fiber Plastic cover		Green net cover (40%)		Black net (40%)	
	Maximum (Max) and minimum (Min) temperature (°C) inside each shading material					
Month	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)
January	24.3	42	20.4	38.3	21.6	39.3
February	26.8	47.3	24.2	39.1	24.2	40.2
March	27.5	49.1	24.3	39.4	24.8	41.4
April	27.7	50.1	24.3	39.8	23.1	38.3

3.2 *Plant height*

Due to excessive heat inside the white fiber plastic tunnel, all the green pepper plants died three weeks after planting; as a result, no readings were obtained from plants grown under the plastic white fiber covered tunnel. There were significant (P<0.05) differences in plant height of green pepper plants grown in a different net covered tunnels (Figure 1). At 10 WAT, the tallest plants (46.6 cm) were attained in green pepper grown in the green net covered tunnel, while the lowest plant height (43.1 cm) was obtained in green pepper grown in the black net covered tunnel. (Figure 1).

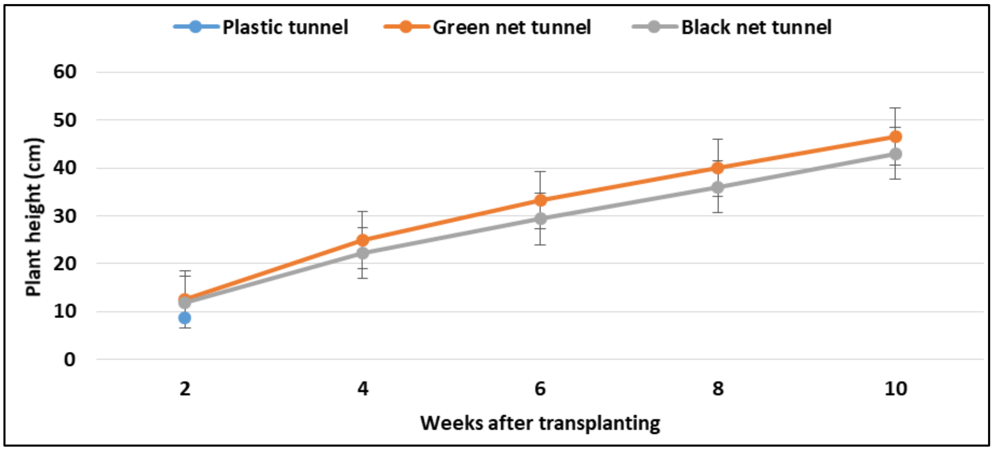

Fig 1: Effect of net covered tunnels on the plant height of green pepper. Vertical bars represent standard error (SE) below and above the mean at P= 005. Mean separation by DNMRT.

3.3 *Number of leaves*

There were significant (P<0.05) differences in the number of leaves of green pepper plants grown in a different net covered tunnels (Figure 2). At 10 WAT the highest number of leaves (68) was recorded in the green pepper plants grown in the green net covered tunnel, while the lowest number of leaves (61) was obtained in plants grown under the black net covered tunnel (Figure 2).

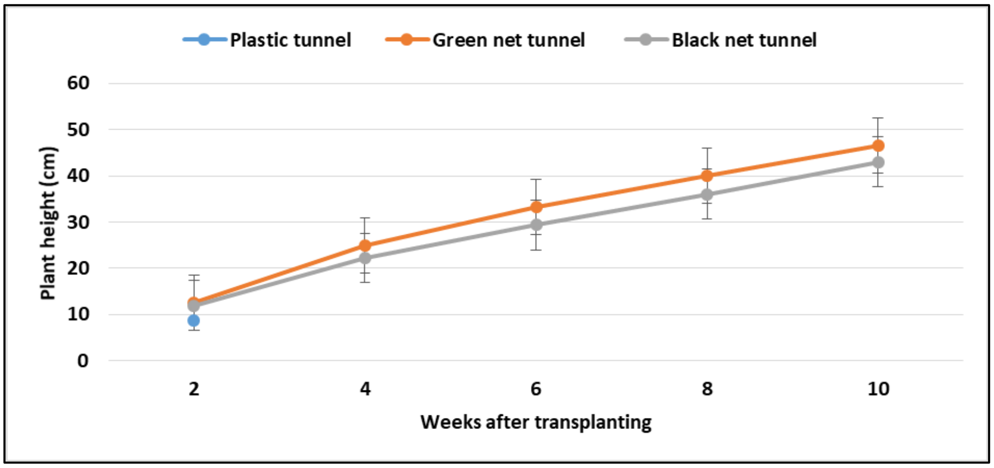

Fig 2: Effect of net covered tunnels on the number of leaves of green pepper. Vertical bars represent standard error (SE) below and above the mean at P= 005. Mean separation by DNMRT.

3.4 *Number of branches*
There were significant (P<0.05) differences in the number of branches of green pepper plants grown in different net covered tunnels. At 10 WAT, the highest number of branches (11) was obtained in green pepper plants grown under the green net covered tunnel, while the lowest number of branches (9) was obtained in plants grown under the black net covered tunnel (Figure 3).

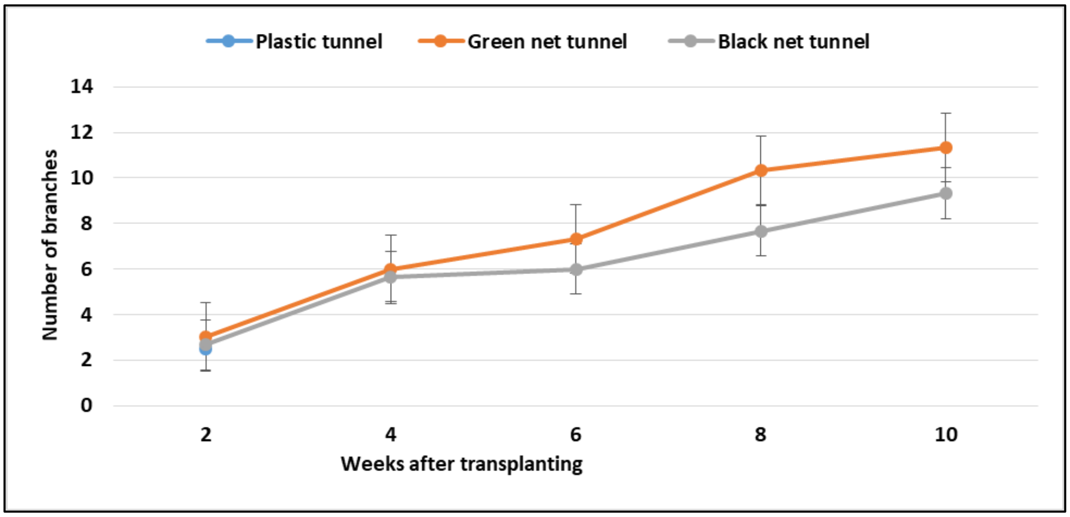

Fig 3: Effect of net covered tunnels on the number of branches for green pepper. Vertical bars represent standard error (SE) below and above the mean at P= 005. Mean separation by DNMRT.

3.5 *Leaf area*
There were significant (P<0.05) differences in leaf area of green pepper plants grown in a different net covered tunnels (Figure 5). At 10 WAT. Green pepper plants in the green net covered tunnel had the highest value (90.3 cm²), while the lowest leaf area (79.83 cm²) was obtained in plants grown under the black net covered tunnel Figure 4).

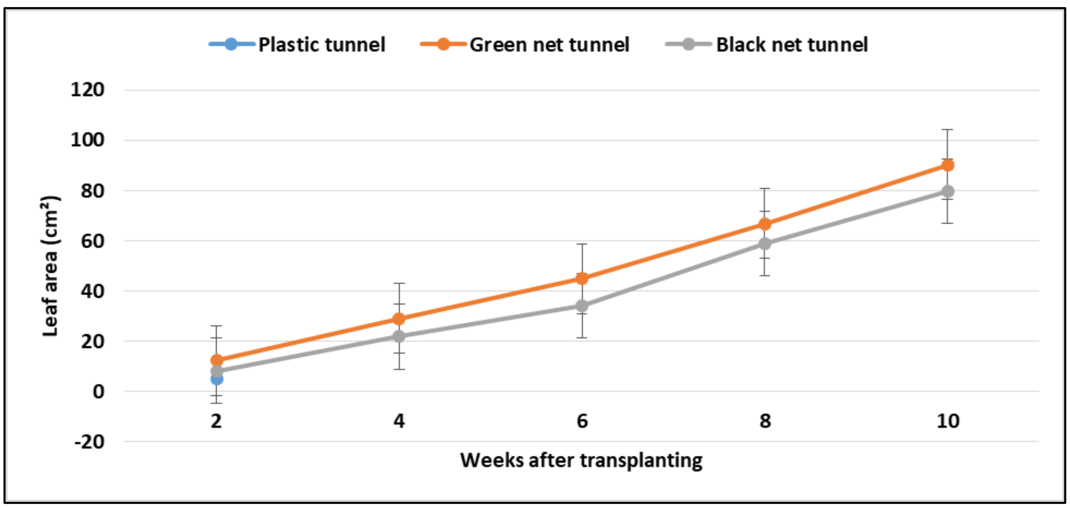

Fig 4: Effect of net covered tunnels on the leaf area of green pepper. Vertical bars represent standard error (SE) below and above the mean at P= 005. Mean separation by DNMRT.

Table 2: Effects of shading material on reproductive, quality and yield parameters

Shading material	Parameters determined				
	Average no. of flowers/plant	Average no. of fruits/plant	Fruit firmness (N)	TSS (ºBrix)	Total yield (t/ha
Fiber plastic	0c	0c	0c	0b	0b
Green net	17a	11a	4.4a	5.6a	30.8a
Black net	14b	9b	4.1b	5.7a	29.5b

Means followed by the same letter not significantly different from one another. Mean separation by Duncan's New Multiple Range Test at P=0.05

4. Discussion

At 10 WAP, the plant height of green pepper was highest under the green net covered tunnel. This may be due to enhanced photosynthesis and respiration caused by the favourable micro-climate conditions in the shade net house. Green pepper plants grown in the green net covered tunnel showed the highest value of plant height than the green pepper grown in the black net covered tunnel, which obtained the lowest plant height because the black colour absorbed heat which resulted in increment of temperatures inside the tunnel, causing stress to the plant. The results agreed with the findings of Ramesh and Arumugam (2010) [31], who reported that green pepper grown in black and green net covered tunnel, produced the highest plants than green pepper grown under white fiber plastic-covered tunnel conditions.

The effect of net covered tunnels on the number of leaves was highest under plants grown in the green net tunnel. Similar results were obtained by Rajshekar *et al*. (2013) [30] who reported that net shade houses increased the number of leaves per plant. The lowest number of leaves was obtained in plants grown in the black net tunnel. Shahak (2008) [34] reported that superior results concerning the number of leaves per plant were found in green pepper grown in net tunnels. It was reported that green pepper plants in net covered tunnels received the highest light intensity compared to plants grown under the plastic tunnel. Under low light, plants undergo morphological changes to maximize light use.

The number of flowers per plant showed significant deviation for different net covered tunnels. The highest number of flowers per plant was obtained from the green net covered tunnel at 10 WAT, while the least number of flowers were obtained from green pepper plants grown in the black net covered tunnel. Similar results were obtained by Shahak (2008) [34] who reported that green pepper plants grown under net protection accumulated the highest number of flowers per plant compared to green pepper cultivated under plastic protection. Niederwieser (2001) reported that temperatures lower than 15˚C result in poor plant growth, whereas temperatures higher than 32˚C result in flower drop and poor fruit set of green pepper.

Plants grown in the green net covered tunnel showed the highest number of branches among the different net covered tunnels. These results are in agreement with findings by Kittas *et al*. (2009) [18], who reported that green pepper grown in a green net covered tunnel accumulated the highest number of branches compared to other coloured nets. No significant difference was observed in the stem girth of green pepper plants grown under the green and black net covered tunnel. Farooq *et al*. (2015) [11] also reported that green pepper plants grown under the green net, grey net, blue net and black net tunnels were not significant on the stem girth values.

The highest leaf area was obtained from green pepper plants grown in the green net covered tunnel, while the lowest leaf area was obtained from plants grown in the black net covered tunnel. Dıaz-Perez (2013) [8] reported that changes in green pepper growth (leaf area, plant height) habit and leaf weight ratio with increased shading indicated that plants underwent modifications in the allocation of assimilates, resulting in maximized light interception under net shaded conditions. According to Santana *et al*. (2012) [32], plants grown in a concussive environment tend To have a larger leaf area because cells expand more under low light intensities to receive light for photosynthesis. Increases in leaf area and reduction in the thickness of the leaf blade under shade conditions are usually met in environments with low light intensity. Results of this experiment for utilisation of coloured net covered tunnels increasing leaf area of green pepper plants are in agreement with those of Bertina *et al*. (2009).

The highest fruit firmness was obtained in plants grown under the green net covered tunnel. The lowest fruit firmness was obtained in plants grown under the black net covered tunnel. The results are in agreement with findings by Alarcon *et al*. (2006) [1], who revealed that fruit firmness of lemon fruits grown under shade nets was higher than that from plants grown under the plastic-covered tunnel.

The highest total fruit yield was recorded in green pepper grown under the green net covered tunnel. Variable responses of green pepper yield to different coloured nets may be attributed to the particular environmental conditions created by the net tunnel. Similar results were found by El-gizawy *et al*. (2007) [10], who reported that tomato plants grown in the green net covered tunnel developed faster with higher total yield compared to those under black net covered tunnel. Similarly, Milenkovic *et al*. (2012) [23] confirmed that green pepper fruit yield was higher in plants grown in green net tunnels compared to those grown in black and blue net tunnels. Green pepper plants under the green net covered tunnel accumulated higher fruit weight, diameter and length compared to green pepper in the black net covered tunnel. Lopez *et al*. (2007) [16] reported that green net covered tunnels led to increased fruit diameter, weight, and length of tomatoes grown in hot summer temperatures.

Shade nets may improve subsequent post-harvest shelf-life of green pepper. Plants previously grown under the green net covered tunnels had fruits which subsequently achieved the longest shelf-life compared to green pepper in the black net covered tunnel. Similar results were reported by Tinyane *et al*. (2015) [36], who indicated that production under green net covered tunnel compared to black net covered tunnel resulted in less decay incidence, increased fruit firmness and ascorbic acid content of bell pepper fruits. Similarly, Shahak *et al*. (2004) [33] also reported that bell pepper fruits grown under green net covered tunnel had the longest shelf life compared to those grown under other net colours (black, blue, and grey).

No significant differences were observed in the TSS values of fruits grown under green net tunnel conditions and fruits grown in black net tunnels. Valverde *et al*. (2002) [38] found similar results of no significance in the total soluble solids of tomatoes grown under black net tunnel compared to plants in the green net tunnel.

5. Conclusion and recommendation

The green net (40%) created a favourable micro-climate during the hot summer weather of the Lowveld of Eswatini resulting in better growth, yield and quality of green pepper compared to other tunnel cladding materials.

Based on the results obtained in this study;

1. It is recommended that a green net tunnel should be used for green pepper production using hydroponics in the Lowveld (especially in Siphofaneni) of Eswatini where temperatures are extremely high during the summer season.

2. Further studies should be conducted to evaluate the use of different net sizes in other agro-ecological zones of Eswatini for other high-value horticultural vegetable crops.

Conflict of interests
The authors declare no conflict of interest.

5. Author contributions
This work was carried out in collaboration among all authors. Author BM, KAN and TOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BM and KAN managed the analyses of the study. Author MTM managed the literature searches. All authors read and approved the final manuscript.

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