https://doi.org/10.1186/s41938-020-00226-z

Egyptian Journal of Biological Pest Control

RESEARCH Open Access

Comparative study between biological and chemical control programs of certain sweet pepper pests in greenhouses

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Abstract

Sweet pepper is an important vegetable crop in Egypt. It is cultivated for local consumption and exportation. The crop is attacked by a large number of pest species such as Western flower thrips, *Frankliniella occidentalis* (Pergande), whitefly, *Bemisia tabaci* (Genn.), the two-spotted spider mite, *Tetranychu surticae* Koch, and the beet armyworm, *Spodoptera exigua* (Hubner). The present study was conducted on the sweet pepper cultivated in greenhouses, during the winter plantation 2016/17 in a commercial farm located at Berkash district, Giza Governorate, Egypt. Three control programs were practiced: the first used biological control agents (BC), the predators, *Orius albidipennis* (Reuter), *Macrolophus caliginosus* (Wagner), *Chrysoperla carnea* (Steph.), and the egg parasitoid, *Trichogramma euproctidis* (Girault); the second was sprayed by the recommended chemical control program of the farm (CC); and the third was untreated as a control. Obtained results revealed that the BC program was the most significant one for controlling the complex of sweet pepper pests. Also, applying the BC program resulted to a high yield of sweet pepper production (35.06% increasing than the control).

Keywords: Sweet pepper, Biocontrol agents, Chemical control, Yield, Greenhouses

Background

Sweet pepper is one of the important vegetable crops in Egypt that cultivated for local consumption and exportation (El-Laithy et al. 2013). The land area devoted to greenhouses production of color sweet peppers has been increased substantially over the past decade. In Egypt, it reached 400 ha with total plant-houses area of 11,300 ha (El Arnaouty et al. 2018). Also, pepper production is affected by different environmental and management systems, where it ranged from 5 to 28.8 kg/m^2 and export percentage ranged from 50 to 90%.

Sweet pepper is attacked by a large number of pests from seedling stage to mature plants. Kortam (2019) recorded 4 major pest species that limit the production and have forced farmers to use chemical insecticides deliberately, those are the following: the Western flower thrips, *Frankliniella occidentalis* (Pergande); the whitefly, *Bemisia tabaci* (Genn.); the two-spotted spider mite, *Tetranychus urticae* Koch; and the beet armyworm, *Spodoptera exigua* (Hubner).

F. occidentalis is a worldwide key pest of most of the greenhouses' flower and vegetable crops, distorting flowers, and leaves by feeding and transmitting viruses (Driesche et al. 2006). Chemical control is the dominant method of the thrips management used by greenhouse growers, but has proved rather unsuccessful. Hence, developing biological control strategies against thrips infestations can be an alternative tool.

The whitefly, *B. tabaci*, is also a serious pest in greenhouses and is often seen on fuchsias, poinsettias, cucumbers, lettuce, and tomatoes causing great damages by feeding and transmitting viruses (Adly 2016).

The two-spotted spider mite, *T.urticae*, is a ubiquitous and economically important agricultural pest feeding on

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a wide range of host plant species (Heikal and Ebrahim 2013). The economic threshold of the spider mite population density should not exceed 3 motile forms per leaf (Warabieda 2015). Under favorable conditions, spider mites can rapidly build up to very high populations as they are characterized by a high reproductive capacity, causing important economic damages as yield losses can reach 90% (Ginette et al. 2014).

The beet armyworm, *S. exigua*, is a polyphagous pest species on many important cultivated crops. It has a worldwide distribution in tropical and subtropical regions (Wakamura 1990). It is known as a greenhouse pest (Lasa et al. 2007). Host plants include various economically important crops such as tomato, Brassica, Capsicum, onion, and maize (Capinera 2014).

Controlling greenhouse pests by chemical pesticides has resulted to several problems such as development of resistance in pests and raising environmental and health concerns. Indeed, greenhouse crops are harvested frequently at short intervals, and thus intensive use of chemicals becomes questionable because of the possible contamination of products with chemical residues. Furthermore, most greenhouse vegetables are consumed fresh, which is another motivation for farmers to reduce intensive control measures and to meet the consumers' demands for offering products of high quality. The possibility to apply biological control programs against greenhouse pests is highly needed. It can overcome the abovementioned problems, and at the same time they can provide an adequate pest control. They will not completely eliminate pest problems but can reduce pest populations and damage to an acceptable level (under the economical threshold). Biological control generally requires more time than pesticides to bring a pest population under an acceptable control level (Kortam 2019).

The present study aimed to compare the feedback of implementing two pest control programs using biocontrol agents and chemical control of sweet pepper pests in greenhouses to outcome with an applicable safe and sanitation production program.

Materials and methods

The study was conducted in commercial greenhouse of 14,040 m^2 (180 mL × 78 mW and 4.5 m height) located at Berkash district, Giza Governorate, Egypt, during the fall-winter pepper plantation season, 2016/17. The greenhouse was divided internally into 3 tunnels for BC, chemical control, and untreated tunnel (control). Three [320 m^2 tunnels (40 L × 8 W/m^2)] were designed by installing plastic partitions, hermetically fixed to the greenhouse structure. This allowed the isolation of the tunnels from each other and avoided insects' transfer from one tunnel to another. Each tunnel included 4 rows of 90 sweet pepper plants (360 plants/tunnel) of Helenscy variety. Fifteen-centimeter-height sweet pepper plants were transplanted directly in soil during late summer (the 3rd week of August). The growing season extended from August 2016 to April 2017.

Population densities of the targeted pests, *T. urticae*, *F. occidentalis*, *B. tabaci*, and *S.exigua*, were estimated biweekly (15 days interval) throughout the plant growing season. Thirty randomized plants from each tunnel from the 3 levels of the plant (top, middle, and down) were directly inspected on the plant using a special magnifying hand lens (× 10).

Counts of moving stages were estimated for *F. occidentalis* and *T. urticae*. Adults, nymphs, and pupae of *B. tabaci* were recorded and the number of *S. exigua* larvae was also counted. Fourteen releases were carried out during the season starting from September 2016 to March 2017. The released bioagents in the biological control greenhouse (BCG) were the predators: *O. albidipennis*, at the rate of 4 nymphs/4 m^2 against *T. urticae* and *F. occidentalis* (releasing rate of *O. albidipennis* to control *T. urticae* and *F. occidentalis* was chosen according to El Arnaouty et al. 2018 and Elimem et al. 2018). For *M. cali ginosus*, it was at the rate of 2 nymphs/2 m^2 against *B. tabaci* (releasing rate of *M. caliginosus* was chosen according to Bonato et al. 2006), *C. carnea* at the rate of 4 larvae/4 m^2 (releasing rate of *C. carnea* was chosen according to El Arnaouty 1991), and the egg parasitoid *T. euproctidis* against *S. exigua* (for experimental release of *T. euproctidis*, a total of 2500 parasitoids were released biweekly in BCG). The bioagents were released before sampling on the same sampling day. All biological agents were obtained from the Laboratory of "Chrysopa mass production, Faculty of Agriculture, Cairo University, Giza, Egypt." In the chemical treated greenhouse (CCG), timing and rate of applications of different pesticides were determined by the grower, based on his assessment of pest populations (Table 1).

The produced yields of sweet pepper from each of the 3 greenhouses were estimated at the end of the season. As well, the cost-benefit estimations of the results of applying different pest control programs were carried out (Goda et al. 2015).

Statistical analysis

A randomized complete block design with 2 factors was used for analysis of all data with 30 replicates for each parameter. Significance between treatment means were compared by the least significant difference (L.S.D.) test as given by Snedecor and Cochran (1994), using Assistant program.

Table 1 A list of pesticides applied to control sweet pepper pests in the greenhouse from September 8, 2016 to March 26, 2017

Weeks of application	Trade name	Active ingredient	Target pest	Rates of application (cm^3/L)
3	Match 5% EC	Lufenuron	*S. exigua*	150 cm^3/100 L
5	Vertimec 1.8% EC	Abamectin	Mites	200 cm^3/200 L
6	Radiant 12% SC	Spinetoram	*S. exigua*	200 cm^3/200 L
7	Vertimec 1.8% EC	Abamectin	Mites	200 cm^3/200 L
9	Alverde 24% SC	Metaflumizone	*S. exigua*	150 cm^3/100 L
9	Calypso 48% SC	Thiacloprid	sucking pests	200 cm^3/200 L
14	Radiant 12% SC	Spinetoram	*S. exigua*	200 cm^3/200 L
16	Kanemite 15% SC	Abamectin	Mites	200 cm^3/200 L
17	Alverde 24% SC	Metaflumizone	*S. exigua*	150 cm^3/100 L
20	Oberon 24% SC	Spiromesifen	Mites	200 cm^3/200 L
21	Kanemite 15% SC	Acequinocyl	Mites	175 cm^3/200 L
23	Kanemite 15% SC	Acequinocyl	Mites	175 cm^3/200 L
24	Vertimec 1.8% EC	Abamectin	Mites	200 cm^3/200 L
25	Vertimec 1.8% EC	Abamectin	Mites	200 cm^3/200 L
26	Mospilan 20% SP	Acetamiprid	sucking pests	30 gm/100 L
27	Calypso 48% SC	Thiacloprid	sucking pests	200 cm^3/200 L
28	Actra 25% WG	Thiamethoxam	sucking pests	25 gm/100 L
29	Calypso 48% SC	Thiacloprid	sucking pests	200 cm^3/200 L

Results and discussion

In CCG, 3 pesticides (Match 5% EC, Radiant 12% SC, and Alverde 24% SC) were applied against *S. exigua* started from the 3rd week after transplanted; 3 pesticides (Vertimec 1.8% EC, Oberon 24% SC, and Kanemite 15% SC) were applied against *T. urticae* started from the 5th week post cultivation. For the sap sucking pests including *B. tabaci* and *F. occidentalis* (Calypso 48% SC, Mospilan 20% SP, and Actra 25% WG) were applied (Table 1). In the BCG, the bioagents were released on biweekly bases (at the same inspection day).

The mean numbers of thrips/flower are presented in Table 2. The mean numbers of thrips/flower in BCG and CCG were significantly lower than in the untreated

Table 2 Mean counts of thrips/flower in the sweet pepper greenhouse during the winter plantation of season of 2016–17

Weeks of inspection	Mean numbers of thrips/flower for different treatments			$LSD_{0.05}$	*F* value
	Control	BCG	CCG		
1	1.11 ± 0.13[a]	1.13 ± 0.15[a]	1.13 ± 0.14[a]	0.31	0.06
3	1.63 ± 0.21[a]	1.43 ± 0.22[a]	1.57 ± 0.25[a]	0.51	0.12
5	2.20 ± 0.19[a]	1.17 ± 0.18[b]	1.67 ± 0.2[ab]	0.58	9.95
7	4.40 ± 0.53[a]	1.83 ± 0.52[b]	3.83 ± 0.54[a]	1.59	6.3
9	5.27 ± 0.77[a]	1.88 ± 0.95[b]	3.00 ± 0.8[b]	1.52	32.15
11	7.41 ± 0.14[a]	1.80 ± 0.56[c]	3.36 ± 0.45[b]	1.32	38.05
13	7.59 ± 0.45[a]	1.64 ± 0.64[b]	6.75 ± 0.5[a]	2.14	10.12
15	9.94 ± 0.58[a]	2.17 ± 0.71[c]	5.74 ± 0.56[b]	1.69	3.12
17	11.38 ± 0.51[a]	2.77 ± 0.72[b]	4.37 ± 0.57[b]	1.77	3.45
19	16.82 ± 0.84[a]	2.50 ± 1.02[c]	6.60 ± 0.81[b]	1.94	26.84
21	19.82 ± 0.94[a]	3.25 ± 1.15[c]	7.59 ± 0.91[b]	2.33	32.13
23	22.50 ± 0.83[a]	2.64 ± 1.02[c]	8.18 ± 0.86[b]	2.07	26.48
25	23.11 ± 1.07[a]	2.90 ± 1.31[b]	4.80 ± 1.21[b]	2.71	47.6
27	29.47 ± 1.46[a]	2.55 ± 1.79[b]	7.14 ± 1.66[b]	6.23	27.5
29	30.40 ± 1.27[a]	2.18 ± 2.2[c]	12.40 ± 1.8[b]	7.14	21.63

Means followed by the same letter at the same row are not significantly different ($p \leq 0.05$)

greenhouse (control). Thrips infestation started on September 8, 2016, (1st week) when the mean numbers of thrips/leaf were similar in the 3 experimental greenhouses. In the control, the population density of the thrips increased and continued until the end of the season to reach the highest number of thrips/leaf (30.40 ± 1.27 thrips/leaf) at week 29th.

O. albidipennis proved to be an efficient predator in maintaining the number of thrips under the economic threshold which is assumed to be 4.9 individuals/flower according to Ramchandra and Niann (2013). The lowest number of thrips/flower (2.18 ± 2.2 thrips/leaf) was recorded in BCG. However, the mean number of thrips varied from 7.59 ± 0.91 thrips/leaf at week 21st to 12.40 ± 1.8 thrips individuals/leaf at the week 29th in the CCG (Table 2).

In the BCG, the number of thrips/leaf (2.18 ± 2.2) was under the economic threshold by using 14 releases of *O. albidipennis* at the rate of 4 nymphs/4 m^2. Similar results were obtained by Kececi and Gurkan (2017), when they released *O. laevigatus* twice at the rate of 4 adults/m^2 to control *F. occidentalis* on sweet pepper in greenhouse. Elimem and Chermiti (2012) recorded that *F. occidentalis* population decreased to low average values of 0.42 and 0.06 thrips per flower, as a result of using the insect predator *O. laevigatus*on sweet pepper in a greenhouse in Tunisia. Additionally, Arno et al. (2008) reported that *Orius* species could serve as an important biological control agent for use in crops in which *B. tabaci* and *F. occidentalis* occur together.

The mean number of the whitefly/leaf in BCG and CCG was significantly lower than in the control. At the beginning of the experiment, the mean number of whitefly/leaf was similar in the 3 experimental greenhouses. In the control, the population density of the whitefly increased and continued up to the end of the season to reach the highest number (20.62 ± 0.88 individuals/leaf) at the week 29th (Table 3).

Obtained results indicated that *M. caliginosus* proved to be efficient in maintaining the number of whitefly under the economic threshold as the lowest number of whitefly/leaf (2.56 ± 1.12) was recorded in the BCG. The economic threshold for *B. tabaci* was 4 adults/leaf (Shen et al. 2005). However, the mean number of whitefly ranged from 1.75 ± 0.37 whitefly/leaf at the week 21st to 11.33 ± 0.91 at the week 29th at CCG (Table 3). The results agree with that of Rasdi et al. (2009) who reported that *M. caliginosus* is mainly used as a biological control auxiliary against the whitefly, *Trialeurodes vaporariorum* Westwood in the vegetable greenhouses (eggplant, tomato, and cucumber).

As shown in Table 4, in the control treatment, the number of the spider mite increased from the 3rd week and continued until the end of the season. According to Warabieda (2015), the economic threshold of the spider mite population density should not exceed 3 motile forms per leaf. The mean numbers of *T. urticae*/leaf are presented in Table 4. Analysis of data showed that there was a significant difference between each of the BCGs and CCG and the control. The mean numbers of *T. urticae*/leaf in the BCG and CCG were significantly lower than in the control. At the beginning of the experiment, the mean number of *T. urticae*/leaflet was similar in the 3 experimental greenhouses. In the control treatment, the population density of *T. urticae* increased gradually

Table 3 Mean counts of whitefly individuals/leaf on sweet pepper leaves in the greenhouse during the winter plantation of 2016/17

Weeks of inspection	Mean numbers of whitefly individuals/leaf for different treatments			$LSD_{0.05}$	F value
	Control	BCG	CCG		
1	1.40 ± 0.15^{a}	1.30 ± 0.2^{a}	1.17 ± 0.17^{a}	0.78	0.71
3	2.75 ± 0.21^{a}	1.43 ± 0.29^{b}	1.71 ± 0.22^{b}	0.63	4.97
5	4.80 ± 0.24^{a}	1.90 ± 0.30^{b}	2.00 ± 0.26^{b}	0.82	24.28
7	9.62 ± 0.35^{a}	1.50 ± 0.5^{b}	1.92 ± 0.37^{b}	1.25	50.54
9	5.17 ± 0.38^{a}	2.64 ± 0.54^{b}	4.17 ± 0.4^{ab}	0.92	4.62
11	5.47 ± 0.40^{a}	2.87 ± 0.42^{b}	5.23 ± 0.42^{a}	1.41	11.33
13	4.47 ± 0.56^{a}	2.45 ± 0.58^{b}	4.50 ± 0.58^{a}	1.70	5.44
15	3.94 ± 0.42^{a}	2.12 ± 0.43^{b}	2.33 ± 0.43^{b}	1.12	6.17
17	4.05 ± 0.28^{a}	2.06 ± 0.31^{b}	2.30 ± 0.39^{b}	1.60	13.60
19	3.17 ± 0.41^{a}	1.93 ± 0.36^{b}	1.75 ± 0.5^{b}	1.14	3.73
21	3.75 ± 0.26^{a}	2.13 ± 0.29^{b}	1.75 ± 0.37^{ab}	1.50	4.01
23	7.19 ± 0.35^{a}	2.89 ± 0.45^{b}	2.45 ± 0.37^{b}	2.15	45.34
25	9.94 ± 0.55^{a}	3.09 ± 0.69^{b}	3.88 ± 0.56^{b}	3.27	37.48
27	15.60 ± 0.93^{a}	2.88 ± 1.18^{b}	7.64 ± 0.96^{b}	3.54	34.32
29	20.62 ± 0.88^{a}	2.56 ± 1.12^{b}	11.33 ± 0.91^{b}	4.12	70.76

Means followed by the same letter at the same row are not significantly different ($p \leq 0.05$)

Table 4 Mean counts of *T.urticae*/leaf on the sweet pepper in the greenhouse during the winter plantation of 2016/17

Weeks of inspection	Mean numbers of *T.urticae*/leaf on different treatments			$LSD_{0.05}$
	Control	BCG	CCG	
1	1.56 ± 0.5	1.62 ± 0.08	1.50 ± 0.4	0.78
3	4.11 ± 0.2	1.75 ± 1.2	1.70 ± 0.6	0.63
5	6.32 ± 2.2	3.00 ± 1.3	4.00 ± 1.2	0.82
7	6.57 ± 1.5	2.78 ± 2.1	6.83 ± 1.9	1.25
9	7.21 ± 2.3	3.00 ± 1.1	4.57 ± 1.2	0.92
11	10.57 ± 2.3	4.40 ± 1.23	6.73 ± 1.3	1.41
13	10.43 ± 3.1	3.43 ± 0.2	7.07 ± 1.3	1.70
15	10.57 ± 2.2	2.73 ± 0.8	10.17 ± 2.5	1.12
17	9.97 ± 3.4	1.13 ± 0.9	7.37 ± 2.1	1.60
19	15.12 ± 3.5	1.83 ± 0.5	8.37 ± 2.4	1.14
21	12.03 ± 2.9	1.63 ± 0.6	11.13 ± 3.1	1.50
23	19.11 ± 2.4	4.30 ± 0.7	12.48 ± 4.2	2.15
25	28.24 ± 5.6	6.68 ± 0.8	21.44 ± 5.3	3.27
27	36.33 ± 5.3	4.93 ± 1.5	17.25 ± 4.5	3.54
29	42.70 ± 7.4	2.90 ± 1.2	20.13 ± 3.9	4.12

and continued up to the end of the season to reach the highest number/leaf (42.70 ± 7.4 mite individuals/leaf) at the week 29th.

Although the 3pesticides (Vertimec 1.8% EC, Oberon 24% SC, and Kanemite 15% SC) were applied 8 times against *T. urticae*in CCG, the mean number of *T. urticae*/leaf in the CCG continued to increase to reach 20.13 ± 3.9 mites/leaflet. The pesticide application started from the 5th week post cultivation in the CCG.

The economic threshold of *S. exigua* was 2.3 larvae per plant (Capinera 2014). *T. euproctidis* releases were efficient in controlling *S. exigua* since the lowest number of *S. exigua* larvae (1.6 ± 2.06 larvae/plant) was recorded in the BCG. However, in the CCG, the mean number of *S. exigua* larvae varied from 4.7 ± 0.79 larvae/plant on the 3rd week to 8.8 ± 1.32 larvae/plant on the 21st week. Fourteen releases of *T. euproctidis* resulted in reducing the mean number of *S. exigua* larvae (1.6 ± 2.06 larvae/plant; Table 5). These results confirmed those obtained by Mahmoud et al. (2011) who reported that releasing of *T. evanescens* West. reduced the numbers of *S. exigua* larvae than their numbers in control fields.

Sweet pepper yield

The highest yield production of sweet pepper (913.76 kg; 35.06% increase than control) was recorded in the BCG, followed by the CCG (750.2 kg; 17.88% less) than in the BCG (Table 6). Obtained results confirmed those obtained

Table 5 Mean counts of *S. exigua* larvae/sweet pepper plant in greenhouse during the winter plantation 2016–2017

Week of inspection	Mean counts of *S. exigua* larvae/sweet pepper plant for different treatments			$LSD_{0.05}$	*F* value
	Control	BCG	CCG		
1	2.1 ± 0.5^{b}	2.9 ± 0.05^{ab}	2.3 ± 0.54^{a}	0.85	3.15
3	2.3 ± 0.52^{b}	3.6 ± 0.56^{ab}	4.7 ± 0.79^{a}	1.59	4.5
5	5.1 ± 0.79^{a}	2.6 ± 1.12^{b}	7.1 ± 0.81^{a}	2.25	8.4
7	8.3 ± 1.61^{a}	2.2 ± 2.03^{b}	10.2 ± 1.61^{a}	1.45	5.85
9	10.0 ± 1.02^{a}	3.4 ± 1.44^{b}	7.4 ± 1.02^{a}	2.89	10.49
11	21.2 ± 1.53^{a}	3.7 ± 2.17^{c}	8.4 ± 1.51^{b}	4.36	34.73
13	18.1 ± 1.68^{a}	4.7 ± 1.68^{c}	12.5 ± 1.85^{b}	2.01	15.93
15	19.1 ± 2.42^{a}	4.1 ± 3.09^{b}	15.1 ± 3.39^{b}	7.42	9.28
17	25.2 ± 3.39^{a}	3.2 ± 3.42^{b}	21.4 ± 2.14^{a}	6.86	14.22
19	27.4 ± 2.82^{a}	2.1 ± 3.99^{c}	12.8 ± 2.28^{b}	7.99	16.82
21	29.2 ± 1.45^{a}	1.6 ± 2.06^{c}	8.8 ± 1.32^{b}	4.13	37.74

Means followed by the same letter at the same row are not significantly different ($p \leq 0.05$)

Table 6 Total yield production, controlling costs, and cost benefits of sweet pepper after using biological and chemical control, and the untreated control in the experimental tunnels

Treatments	Yield/treatment (kg)	Production price (L.E.)	Controlling costs (L.E.)	Cost benefits (L.E.)
Control	593.36	7417	0	7417
BC	913.76	11,422	577	10,845
CC	750.2	9377.5	801.22	8576.2

by Adly (2015) who recorded (40%) increase achieved in cucumber yield, when applied biological control program in a cucumber greenhouse.

Cost benefits

The cost of releasing biocontrol agents/treatment was 112 L.E. for *O. albidipennis*, 280 L.E for *M. caliginosus*, 80 L. E for *Ch. carnea*, and 105 L.E. for *T. euproctidis* (Table 5). Throughout the whole growing season, the 14 releases of bioagents' cost was 577 L.E. (about 35.4 US $). However, the 18 applications of the pesticides cost was 801.22 L.E. (about 49.1 US $). The cost benefits of the BC program were (31.61 and 26.45%) higher than the control and the chemical control program, respectively.

Conclusion

Implementing a biological control program, by releasing different predators and parasitoids, achieved an applicable safe and sanitation production program of sweet pepper greenhouse production, compared with the recommended chemical control program under the same circumstances. For the yield, the biological control program resulted about 35.06 and 17.88% increase over the control and the chemical control program, respectively. Also, applying BC program resulted the highest cost benefits to sweet pepper production (31.61 and 26.45% higher than the control and chemical control program).

Acknowledgements
The writers express their deep thanks to STDF project number 30009 for funding this study, also to Techno green farming company, especially to Eng. Mohamed Kamal who offered the opportunity to carry out the present assay in the farm greenhouses. Special thanks for the Chrysopa Mass Production laboratory at Faculty of Agriculture, Cairo University.

Authors' contributions
Field Application was carried out by MNK. SAEA performed the design of the study. SAEA, A HE, AIA, and IHH revised the manuscript. SAEA and A HE were major contributors in revising the manuscript. All authors read and approved the final manuscript.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests

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Received: 10 October 2019 Accepted: 26 February 2020
Published online: 18 March 2020

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