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PREDICTED VOLTINISM FOR *SACCHARICOCCUS SACCHARI* (COCKERELL) (HEMIPTERA: PSEUDOCOCCIDAE) ON SUGARCANE IN EGYPT

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Abstract

The experimental study was accomplished in Upper Egypt's El-Mattana Agricultural Research Station, Luxor Governorate, Agricultural Research Centre, Giza Egypt (25° 41'0"N, 32° 39'0"E). The spring sugarcane was planted in late Mar by using GT54-9. Each plot had an area of 42 m^2 (1/100 feddan, 6 m ridges, 7 m long and 1 meter long). Plant samples (30 stalks / plot) were randomly observed at half-month intervals up to harvest using three replicates. The current study concerned four methods for estimating annual *S. sacchari* (SS) generations under two techniques as follows: heat unit (Richmond *et al.*, 1983 method & Jasic Process (1975) Method and population densities techniques (Actual appearance peaks method and Audemard and Milaire (1975) method.

In general, during the current plant (PC) and 1^{st} ratoon crops (1RC) seasons, the generation number was 4-6 and 5-7 generations respectively. However, SS had 4-7 and 5-8 generations during PC and 1RC in future predictions, respectively. Whereas for both seasons tested, the highest generation numbers were recorded at 6 °C climate sensitivity over the 2050 and 2100 seasons.

From the above findings, SS had Multivoltine (polyvoltine). The generation number of SS will increase one generation in 2100 for PC and 1RC. Jasic method gained 2 generation more than Richmond *et al.* Method. The low-temperature cycles below 20 degrees did not allow the generation to complete. This study ascertained the generation number that can be beneficial for expecting infestation with SS during current and future. After everything this study will help the researchers to uncover the critical areas of generation number that many researchers were not able to explore. Moreover it is desirable to apply more than one method to count any object's generation number.

***Keywords* :** *Saccharicoccus sacchari*, Generation numbers, Sugarcane

1. Introduction

Sugarcane is a secondary grown sugar crop in Egypt. It accounts for 37.8 % of total sugar production in Egypt (Sugar Crops Council, 2019). Climate change would increase the water requirements for sugarcane by 12% (Ouda and Zohry 2016). The pink mealybug of sugar cane, *Saccharicoccus sacchari* (Cockerell) (SS), is a common sugarcane pest. Both adult and nymphs of SS absorb and sucks sap from the wax powder belt of the stem or base of the young cane, which secretes honeydew and allows' sooty mold' to form (Huang and Li 2011). SS has an adverse effect on germination, growth, yield and juice quality during heavy infestation mealy bugs and the affected plant shows a chlorotic appearance (Yirefu *et al.* 2009). According to a preliminary investigation, SS's infested sugarcane production is usually reduced by 5–20 %, but it can reach 30 %; the content of sucrose is reduced by 10–30 % (An and Guan 2009). Such an insect is the main insect vector for the transmission of the sugarcane bacilliform virus (Lockhart and Autrey 1991). Knowledge of the thermal requirements of SS is important if it is to be used successfully in to control *S. sacchari* in sugarcane plantations. The thermal unit provides a valuable tool for insect pest control in forecasting infestations monitoring and timing of insecticide applications Zalom *et al.,* 1983.

Forster *et al.* (2020) confirmed that many recently updated climate models show greater warming in the future than before. Separate evidence suggests that their warming levels may be unrealistically high, but the possibility of such eventualities only underlines the need for rapid and profound emission reductions. Smith *et al.* (2012) also predicted that the yield of sugar cane would decrease by 8.4 and 15.2 per cent respectively in 2030 and 2060. The IPCC (Intergovernmental Panel on Climate Change) forecast has been a rise in mean temperature from 1.1 ° C to 5.4 ° C towards the year 2100 (Meehl *et al.* 2007). Continuing climate change is most evident as the average temperature rises. It is expected to have an important impact on biomes around the world. (Jaworski and Hilszczański 2013). Temperature is one of the most important environmental factors affecting insects and it is critical to understand the phenology of insects at different temperatures to predict their seasonality and IPM planning.

This research aim to measure generation numbers for SS in Mattana, Luxor, Egypt and four methods of computation were employed. For the years 2050, 2075 and 2100 the number of future generations was calculated.

2. Materials and Methods

2.1 Estimated annual *S. sacchari* (SS) generations

The experimental study was undertaken at El-Mattana Agricultural Research Station in Upper Egypt, Luxor Governorate, Giza Agricultural Research Centre, Egypt (25° 41'0"N, 32° 39'0"E.). This research was accomplished during the two 2016/17 & 2017/18 seasons. The spring plantation was achieved in late March. Sugarcane cultivar GT54-9 (a common cultivar of sugarcane in Egypt, NCo 310♀ & F. 337/925♂ (Mehareb and Galal, 2017)) had been planted. Each experimental plot was 42 m^2 (1/100 feddan, 6 m ridges,7m long and one meter part). Samples of plants (30 stalks / plot) were randomly observed at half-month intervals up to harvest. Three replicates (10 plants each) had been used. Common performance on agriculture was achieved.

During the current study four methods for estimating annual SS generations were separated into two techniques as follows:-

2.1.1. Population densities Techniques (PD)

2.1.1.1. Actual appearance peaks method (AAPM)

As for annual SS generation, peaks were performed based on the total number of inspected dates relevant to SS.

2.1.1.2. Audemard and Milaire (1975) method (AMM)

Estimated accumulative mean numbers of total SS in percentages of the total population of the year were done according to Audemard and Milaire 1975.

2.1.2. Heat Units Techniques

2.1.2.1. Method (Richmond *et al.*, 1983) (RM):

For each generation, heat units or degree days for SS were calculated using the lower thermal threshold for development (t_0= 17°C) and a lower threshold for development. SS requires degree-days of 339.6 ± 6.0 (Rae & Death 1991). On sugarcane plants, an average of the half-month total of the SS population was estimated.

This method depends on the determination of accumulated daily thermal units for SS, daily maximum, minimum temperature, and SS to Daily Degree Days development threshold by applying Richmond *et al.* (1983) formula following.

2.1.2.2. Jasic Process (1975) Method (JM).

Estimated number and length of annual SS generations in the field was determined using estimated JM formula.

2.2. Predict *S. sacchari* populations during 2050, 2075 and 2100 years compared to the current SS population

For the prediction of population density of SS, the future climate data values of (2048, 2049, 2050, 2073, 2074, 2075, 2098,2099 and 2100 years) were used. Individually using 3 climate sensitivities (low (1.5 °C), medium (3 °C) and high (6 °C)) of MAGICC/SCENGEN (version 5.3.v2) under the IPCC SRES scenario of climate change were used. Climate sensitivity is frequently expressed as the temperature change in deg C associated with a doubling of atmospheric CO_2 concentration (Hawkins *et al.* 2019). Policy model B2-MES was used. The expected temperatures of the years 2048:2050, 2073:2075 and 2098: 2050 were used as the plant and 1st ratoon canes seasons.

Statistical analysis

The data collected using regression model was statistically analyzed based on the polynomial relationship between dependent variable (numbers of insects) and independent variable (temperature). Costat program has been used.

3. Results and Discussion

The annual generation of SS:

Four methods were divided into two heat unit techniques (i.e. Richmond *et al.* (1983) (RM) & Jasic (1975) (JM) methods) and two population density (PD) techniques (i.e. actual appearance peaks method (AAPM) & Audemard and Milaire method 1975 (AMM)).

3.1. Population densities techniques (PD):

Two methods of estimating generation numbers using PD were applied. For to estimate these methods, population density (PD) for AAPM and percent of PD (AMM) during the whole season in both tested seasons were recorded in Table (1).

During two seasons, SS PD infestation began on 1 July and 15 June during the plant cane (PC) and 1st ratoon (1RC) cane, respectively. The highest DP was registered as of 1 Sep 2016 (PC) and 15 Aug 2017 (1RC). The high infestation (> 100) was detected during PC and 1RC, respectively, at 15 Aug -15 Dec 2016 and 1 July 2017-15 Jan 2018. The majority of the dates examined were under 100.

The change in the population increases greatly from 15-Jun to 1-Sep (hot periods) and does not vary much from 15-Sep to 1-Mar (cold periods). These results revealed that the population of such insect depended on the temperature changes.

Table 1: Population density (PD) of SS in seasons 2016/17 & 2017/18

Dates	2016/17		2017/18	
	PD	%	PD	%
15/06	-	-	17.67	0.53
01/07	25.00	0.86	148.67	4.98
15/07	67.67	3.18	180.67	10.39
01/08	79.33	5.90	261.33	18.21
15/08	296.00	16.05	280.67	26.61
01/09	414.67	30.28	243.00	33.89
15/09	349.00	42.25	234.00	40.89
01/10	316.67	53.11	268.67	48.93
15/10	264.00	62.17	258.67	56.68
01/11	188.33	68.63	213.22	63.06
15/11	229.33	76.49	253.67	70.65
01/12	156.67	81.87	140.83	74.87
15/12	151.00	87.05	216.00	81.33
01/01	91.00	90.17	218.67	87.88
15/01	80.00	92.91	135.33	91.93
01/02	80.67	95.68	94.67	94.76
15/02	65.00	97.91	86.33	97.35
01/03	61.00	100.00	88.57	100.00
Mean	171.49		185.59	

% =Accumulative half-month counts had been calculated at percentages of the total year

3.1.1. Actual appearance peaks method (AAPM)

According to AAPM, there were 5 generation numbers during both checked seasons, (Figure 1 & Table 2). After 92 and 59 days the 2nd and 5th generations finished, respectively. Nevertheless, only 1st, 3rd and 4th generations were completed at ~30 days through PC. During 1RC season, the lowest duration was observed for1st and 4th generation (30 days) followed by 3rd (47 days), 2nd (62 days) and the highest one was done at 5th generation (90 days).

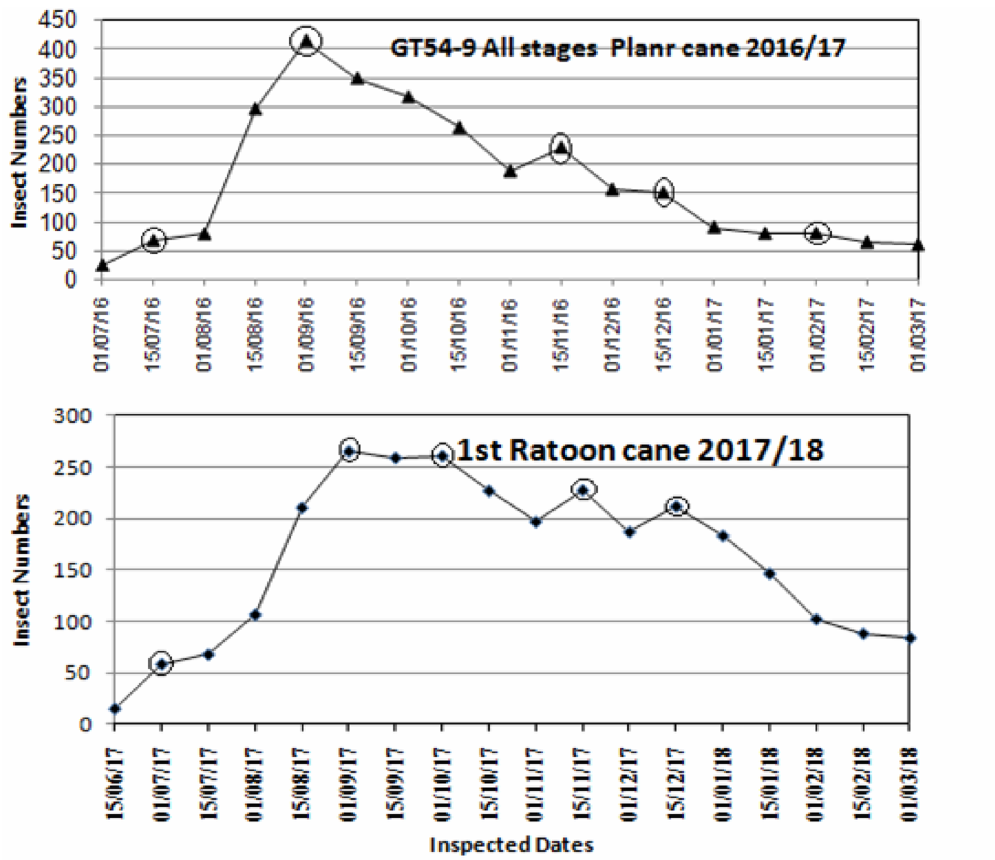

Fig. 1 : All stages number of *S. sacchari* field generations, according to AAPM during 2016/17 and 2017/18 seasons, at Mattana, Luxor, Egypt.

Table 2 : Generation numbers of SS by AMM and AAPM during the seasons 2016/17 and 2017/18, in Mattana, Luxor Governorate, Egypt.

Generation No	Actual appearance Peaks (AAPM)			Audemard and Milaire (1975) (AMM)		
	Start	End	Duration in days	Start	End	Duration In days
Plant cane 2016/17						
1st	01/07/16	01/08/16	31	01/07/16	01/08/16	31
2nd	01/08/16	01/11/16	92	15/08/16	01/10/16	47
3rd	01/11/16	01/12/16	30	15/10/16	15/12/16	61
4th	01/12/16	01/01/17	31	01/11/16	01/03/17	120
5th	01/01/17	01/03/17	59	--	--	--
1st ratoon cane 2017/18						
1st	15/06/17	15/07/17	30	15/06/17	15/07/17	30
2nd	15/07/17	15/09/17	62	01/08/17	15/09/17	45
3rd	15/09/17	01/11/17	47	01/10/17	15/11/17	45
4th	01/11/17	01/12/17	30	01/12/17	01/01/18	31
5th	01/12/17	01/03/18	90	15/01/18	01/03/18	45

3.1.2. Audemard and Milaire, 1975 method (AMM)

In Figure (2) and Table (2) data of AMM pointed out that generation numbers were 4 for PC and 5 for 1RC. The duration in days increased by increasing plant ages in PC and the fourth generation was the largest length time (120 days). The lengths for 1RC in days had not increased by more than 45 days were reported for 2nd, 3rd, and 5th generations. The minimum period for 1st generation was reported (30 days).

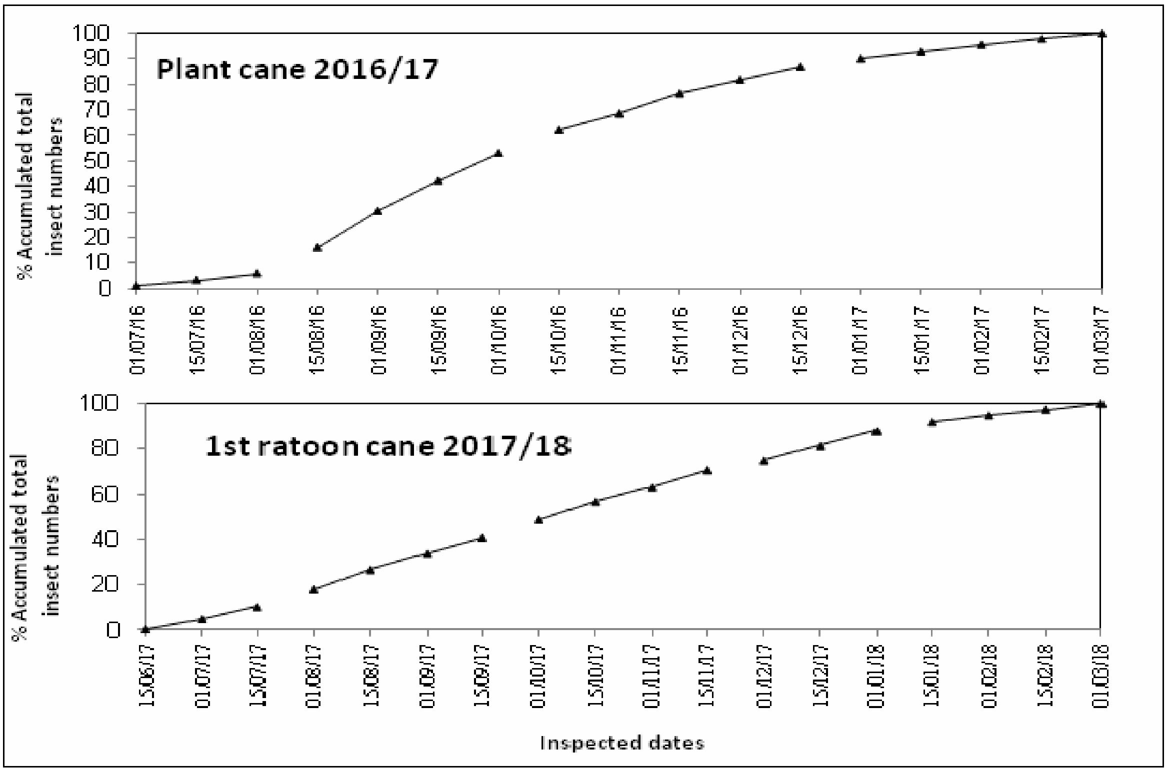

Fig. 2 : Accumulated total insect numbers % of *S. sacchari* field generations, according to AMM method during 2016/17 and 2017/18 seasons, at Mattana, Luxor Governorate, Egypt.

3.1.3. Comparing AMM to AAPM

RM & AMM gained 4 and 5 generations for PC and 1RC, respectively. JM & AAPM during PC gained 5 generations which increased 1 generation than RM. However, AAPM had 5 generation numbers as RM did. Meanwhile, JM earned 7 generations at 1RC which increased 2 generations than other tested methods. Broad-spectrum, the generation numbers of SS ranged between 4 to 7.

Generally, using AMM during PC and RM during 1RC, the generation numbers were the least one (4 generations). The highest generation number was observed by using JM at 1RC (7 generations). The rest of the methods at the tested PC or 1RC were 5 generations. Only four literatures about SS generation numbers is available. Hafez and Salama (1969) reported 4-5 generations in Lab. Tohamy and Abd El-Raheem (2008) exemplified 3 to 5 generations. Nonetheless, only 2 generations registered in Qena Governorate in the field by Sadan (2015). In the Governorate of El-Minia, by applying AAPM, Yakoub (2012) recorded 5 generations.

3.2. Heat unit techniques

In order to study the probability of predicting the accumulation of heat units, the temperature could be converted into heat units and serves as a method for measuring the dynamics of the insect population and predicting the presence of *S. sacchari* in the field during the two successive seasons described above.

3.2.1. Richmond *et al.* Method (1983) (RM):

Table (3) showed that the PC and 1RC generation numbers were 4 and 5, respectively. The lengths for hot (> 30 °C) cycles in days per one generation were ~30 for both seasons. While the daytime duration of one generation was 44 (23.81: 29.33 °C) for PC and 91 (15.4: 24.22 °C) for 1RC (cold periods beginning). For both seasons measured, through the low-temperature cycles below 20 degrees allows the generation not complete. Because of the periods between each inspected date (15 days) accumulated heat units were > 500.

Table 3 : The number of SS field generations according to Richmond *et al*. (1983) method (RM) during two seasons.

Generation Numbers	Generation periods		Duration in days	Accumulated heat units
	Start	End		
Plant cane 2016/17 season				
1^{st}	01/07/16	01/08/16	31	528.9
2^{nd}	02/08/16	01/09/16	30	508.8
3^{rd}	02/09/16	01/10/16	29	418.9
4^{th}	02/10/16	15/11/16	44	433.7
5^{th}	16/11/16	Not Completed		
1^{st} ratoon cane 2017/18 season				
1^{st}	15/06/17	15/07/17	30	532.2
2^{nd}	16/07/17	15/08/17	30	550.2
3^{rd}	16/08/17	15/09/17	30	509.9
4^{th}	16/09/17	15/10/17	29	364.3
5^{th}	16/10/17	15/01/18	91	340.8
6^{th}	16/01/18	Not Completed		

3.2.2. Jasic Method (1975) (JM).

The estimation of JM process generation numbers were 5 and 7 generations for PC and 1RC, respectively (Table 4). For each generation (hot periods) the duration in days ranged from 15 June to 9 Sep and duration in days were between 20 to 23 days in the PC and 19-22 days in the RC. The average generation period in days during relatively cold periods was 29 days in PC, and in 1RC between 36 and 116 days.

Table 4 : Number of generations of SS field in two seasons according to JM.

Generation Numbers	Generation periods		Duration in days	Accumulated heat units
	Start	End		
Plant cane 2016/17 season				
1st	01/07/16	21/07/16	20	346.9
2nd	22/07/16	11/08/16	20	352.7
3rd	12/08/16	02/09/16	21	351.8
4th	03/09/16	26/09/16	23	345.1
5th	27/09/16	26/10/16	29	342.8
6th	27/02/17	Not Completed		
1st ratoon cane 2017/18 season				
1st	15/06/17	04/07/17	19	345.8
2nd	05/07/17	24/07/17	19	343.3
3rd	25/07/17	13/08/17	19	355.6
4th	14/08/17	03/09/17	20	351.6
5th	04/09/17	26/09/17	22	343.4
6th	27/09/17	02/11/17	36	342.2
7th	03/11/17	27/02/18	116	339.9
8th	28/02/18	Not Completed		

3.2.3. Comparing between RM and JM

From Tables 3 & 4 appeared that calculation of generation numbers by RM were 4 and 5 generation numbers or PC and 1RC, respectively. However, JM revealed that the generation numbers for PC and 1RC were 5 and 7 generation numbers, respectively. From the findings mentioned earlier, it is clear that the generation numbers for PC and 1RC were increased in comparing to RM by 1 and 2 generations, respectively. These shifts in the generation's numbers for JM heat units were assessed per day; however, the average heat units over two weeks were estimated for RM.

3.3. Current and forecasted SS population densities in Mattana, Luxor, Egypt during the current and future seasons

For both PC and 1RC, a polynomial regression approach was used to calculate SS's population density predicted (PPD) during seasons of the future. Those were the following formula:

For PC:

$$PPD1 = 2276.0 - 330.67\,T + 15.8\,T^2 - 0.23\,T^3$$
$$R^2 = 0.479^*$$

For 1RC :

$$PPD2 = 19991.7 - 6865.1\,T + 924.6\,T^2 - 63.0\,T^3 + 2.3\,T^4 - 0.04\,T^5 + 3.3e\text{-}4\,T^6$$

$$R^2 = 0.383$$

1,2 = season 1, 2

T= Temperature degree (°C)

R^2 = Regression coefficient

Figure (3) exposed *S. sacchari*"s current and PPD under 3 climatic sensitivities during current and future seasons in Mattana, Luxor, Egypt.

In 1st season, current PD was lower during 1-Jul: 1 Aug and 1-Nov: 1-March than three tested climate sensitivities for three future dates. On the contrary, current PD was higher during the period from15-Aug: 15-Oct than previous dates and climate sensitivities. PD at 1.5 °C climate sensitivity were higher than 3°C followed by 6 °C during 1-Jul: 1-Nov then after this date, the PD at 1.5 °C were lower than 3°C followed by 6 °C.

During the 2nd season, current PD was higher than PD at three tested sensitivities except at 15th –Jun, 15-Aug and 15th Jan: 1-Mar during 2050. During 2075 and 2100, the current PD was lower than 6°C at 15-Jun and 15-Jan: 1-Mar for 3 and 1.5 °C.

The current PD was less than 3 climate sensitivities during PC, except for the periods between Aug 15 and Oct 15. On the other hand, at 1.5 °C, the PD was above 3 °C.

PPD decreased by increasing climate sensitivities in the 1st season and vice versa in the 2nd season. The variations in PPD among climate sensitivities were observed in 2100 than in 2075 and 2050. Also, the variations were obviously in the 2nd season. The change in the PPD greatly from 15-Jun to 1-Sep (hot periods) and does not vary much from 15-Sep to 1-Mar (cold periods). These results revealed that the population of such insect depended on the temperature changes.

3.4. Predicting the SS field generations under future climate dates (2050, 2075 & 2100)

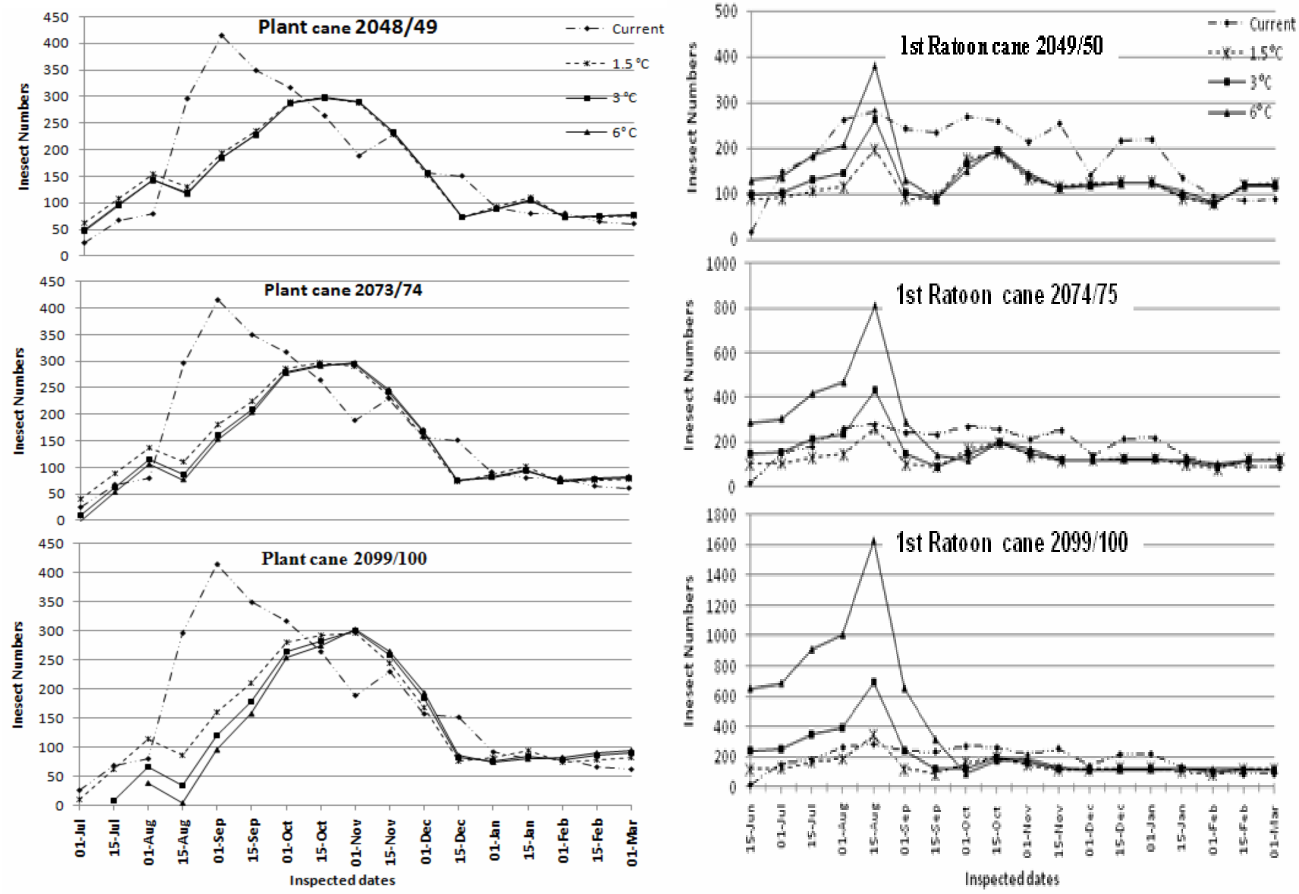

Fig. 3 : Current and predicted population densities of *S. Sacchari* during current and future seasons in Mattana, Luxor, Egypt.

Table 5 : Current and predicted Generation Numbers of *S. Sacchari* in Egypt.

Dates	**Climate sensitivities**		
	1.5°C	**3°C**	**6°C**
1st season (Plant cane)			
Current	4 (6)		
2049 (2048/49)	4♠ (6)♦	4(6)	4(6)
2074 (2073/74)	4 (6)	5(6)	5(7)
2099 (2098/99)	5(6)	5(6)	5(7)
2nd season (1st ratoon cane)			
Current	5(7)		
2050 (2049/50)	5(7)	5(7)	5(7)
2075 (2074/7)	5(7)	5(7)	5(8)
2100 (2099/100)	5(7)	5(7)	6(8)

♠ According to RM
♦ According to JM

For the current PC, according to RM, the generation numbers had not changed during 2048/49 for all tested climate sensitivities as well as 1.5 °C for the season 2073/74. Only one generation had increased for the rest of the future years and climate sensitivities (5 generations). At 1RC during all tested future seasons; only 2098/99 season gained one generation (6 generations) more the current season (5 generations).

JM in the plant and 1st ratoon cane at current seasons, the generation numbers had not changed at all tested future seasons except seasons 2073/74 and 2098/99 at 6 °C and 2074/75 and 2099/100 at also 6 °C. These variations were one generation more than current seasons in both tested seasons.

Generally, in future predication, SS had 4-7 generations during PC, while in 1RC the generation numbers were 5-8 generations. However, during the current PC and 1RC seasons, generation numbers were 4-6 and 5-7 generations, respectively. The highest generation numbers were recorded at 6 °C during 2050 and 2100 seasons for both tested seasons. Therefore, it is preferable to use more than one method for counting the number of generations of any object.

Conclusion

The lengths for hot (> 30 °C) cycles in days per one generation were ~30 for both seasons. While the daytime duration of one generation was 44 (23.81: 29.33 °C) for PC and 91 (15.4: 24.22 °C) for 1RC (cold periods beginning). For both seasons measured, the generation may not be complete through the low-temperature cycles below 20 degrees.

Generally, in future predication, SS had 4-7 generations during PC, while in 1RC the generation numbers were 5-8 generations. However, during the current PC and 1RC seasons, generation numbers were 4-6 and 5-7 generations, respectively. The highest generation numbers were recorded at 6 °C during 2050 and 2100 seasons for both tested seasons. Therefore, it is preferable to use more than one method for counting the number of generations of any object. Thus a new hypothesis on generation number may be arrived by using more than one method to estimate generation number.

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