Crop diversification for sustainable insect pest management in eggplant (Solanales: Solanaceae)

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Abstract

An experiment was conducted to manage the eggplant (brinjal) shoot and fruit borer *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae), the leafhopper *Amrasca biguttula biguttula* (Ishida) (Hemiptera: Cicadellidae), and the whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) during *kharif,* the southwest monsoon season (Jul-Oct), in 2010 and 2011 at an experimental farm at the Division of Entomology, Indian Agricultural Research Institute, New Delhi. The experiment consisted of 7 different treatments with brinjal or eggplant 'Pusa Kranti', *Solanum melongena* L. (Solanales: Solanaceae), as the main crop and coriander, marigold or mint as intercrops, along with a border crop (maize or cowpea) acting as refuge crops. Treatment T1 (maize as border crop and coriander as intercrop) harbored the smallest cumulative mean leafhopper population (6.90 insects per 3 leaves per plant) and the next to smallest mean whitefly population (9.64 insects per 3 leaves per plant) during monsoon season of 2010 and 2011. Treatment T3 (maize as border crop and marigold as intercrop) was second best in reducing the leafhopper population (7.27 insects per 3 leaves per plant), while it was the best treatment in reducing the whitefly population (8.36 insects per 3 leaves per plant). The sole crop (T7) harbored the largest whitefly (20.17 insects per 3 leaves per plant) and leafhopper (12.61 insects per 3 leaves per plant) populations among the 7 treatments. The lowest mean percentage fruit infestation was recorded from treatment T1 (by number: 27.72; by weight: 27.81). All the treatments involving intercrops showed significantly lower percentage fruit infestation by *L. orbonalis* than eggplant alone (T7, control), which showed 37.73% infestation by number of fruits and 38.13% by weight of the fruits. The greatest mean number of coccinellids (1.25 per plant) and largest Shannon-Wiener indices were recorded from treatment T1 (maize and coriander). The smallest mean number of coccinellids (0.37 per plant) and smallest Shannon-Wiener indices were recorded from the sole crop control, T7. Various plant volatiles present in the intercrop were identified by the thermal desorption technique. Twenty one volatile compounds were present in coriander, 7 in marigold, and 18 in mint. The current state of knowledge of the behavioral effects (repellency, attractancy, no effect) of each chemical with respect the various herbivorous insects and natural enemies is summarized and this information will facilitate quantitative studies on how different pest and beneficial insects respond to plant volatiles in polycultures.

Key Words: eggplant shoot and fruit borer; intercrop; border crop; Coccinellidae; pest suppression

Resumen

Se realizó un experimento para controlar al barrenador de brote y fruta de la berenjena [*Leucinodes orbonalis* (Guenne) (Lepidoptera Crambidae)], el saltahoja [*Amrasca biguttula biguttula* (Ishida) (Hemiptera: Cicadellidae)] y la mosca blanca [*Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae)] durante el *kharif,* que es la temporada de monzón del suroeste (de julio a octubre), en el 2010 y 2011 en la Granja Experimental de la División de Entomología, Indian Agricultural Research Institute, de Nueva Delhi. El experimento consistió en 7 tratamientos diferentes utilizando el cultivar de berenjena 'Pusa kranti' como el cultivo principal y cilantro, caléndula y menta como cultivos intercalados junto con 2 cultivos de borde (maíz y caupí) que actúan como refugios. El tratamiento T_1 (maíz como cultivo de borde y cilantro como cultivo intercalado) registró la población de saltahojas más baja (6.90 insectos por 3 hojas por planta) y fue el segundo mejor en el promedio de la población de mosca blanca (9.64 insectos por 3 hojas por planta) durante la epoca de monzón del 2010 y 2011. El tratamiento T_3 (maíz como cultivo de borde y caléndula como cultivo intercalado) fue el segundo mejor en la reducción de saltahojas (7.27 insectos por tres hojas por planta), y a su vez fue el mejor tratamiento en la reducción de la población de mosca blanca (8.36 insectos por 3 hojas por planta). El cultivo único (T_7) registró la poblacion más alta de mosca blanca (20.17 insectos por 3 hojas por planta) y de saltahojas (12.61 insectos 3 hojas por planta) entre los 7 tratamientos. Se registró el menor porcentaje de frutas infestadas en el Tratamiento T_1 (27.72: basado en el número; y 27.81 basado en el peso). Todos los tratamientos con cultivos intercalados tenian el porcentaje de las frutas infestadas por *Leucinodes orbonalis* (Guenne) significativamente menor basado en el número y el peso que sola la berenjena, (T_7, control) lo cual fue una infestación del 37.73% del numero de frutas y 38.13% por el peso de las frutas. El promedio mayor de número de cocinélidos (1.25 por planta) y mayor índice de Shannon-Wiener se registraron en el tratamiento T_1 (maíz y cilantro). El menor número de cocinélidos (0.37 por planta) y menor índice de Shannon-Wiener se registraron de las plantas del tratamiento del cultivo solo, T_7. Varios compuestos volátiles de plantas presentes en el cultivo intercalado se identificaron mediante la técnica de desorción térmica. Veintiún compuestos volátiles

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estuvieron presentes en el cilantro, el 7 de caléndula, y 18 en la menta. El estado actual del conocimiento de los efectos en el comportamiento (repelencia, atrayente, sin efecto) de cada producto químico con respecto a los diversos insectos herbívoros y enemigos naturales se resume y esta información facilitará estudios cuantitativos sobre cómo diferentes plagas y los insectos beneficiosos responder a plantar volátiles policultivos.

Palabras Clave: barrenador de los brotes y frutas de berenjena; cultivos intercalados, cultivos del borde; Coccinellidae, supresión de plagas

Eggplant, *Solanum melongena* L. (Solanales: Solanaceae), is an important vegetable crop in Southeast Asia. It was cultivated on 18.53 lakh ha (1,853,000 ha) with a production of 48,424,295 tonnes worldwide during 2012 (FAO 2014). Numerous insect pests infest eggplant, among them the fruit borer *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae) and sucking pests like the leafhopper *Amrasca biguttula biguttula* (Ishida) (Hemiptera: Cicadellidae) and the whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), cause major damage in the Indo-Gangetic Plain region of India (Bhadauria et al. 1999). Synthetic broad-spectrum insecticides have been used by farmers to manage the insect menace in India (Alam et al. 2006) and Bangladesh (Rashid et al. 2003). Repeated insecticidal sprays resulted in the development of resistance in *L. orbonalis* to organophosphate and synthetic pyrethroids (Ali 1994; Alam et al. 2003; Botre et al. 2014), besides also resulting in residue on the produce, and in resurgence of non-target insect pests. To manage insect pests in an eco-friendly manner, a pest-suppressive agro-ecosystem has to be considered. A pest-suppressive agro-ecosystem can be designed by identifying a suitable intercrop having insect pest deterrence, and a border crop enhancing natural enemy activity by acting as a refugium (Landis et al. 2000). Since 300 B.C., intercropping has been practiced in Greece, which indicates that polyculture or intercropping is a traditional farming practice (Papanastasis et al. 2004). In India, the impact of intercropping on major insect pests and beneficial insects was studied in a wide range of crops including pulses (Prasad et al. 1987; Prasad et al. 1988; Mehto et al. 1988; Sekhar et al. 1997), cereals and oil seeds (Singh et al. 1991a,b) from the mid 1970s to early 1990s. Practicing multi cropping on a farm increases the vegetation and insect diversity compared with practicing monoculture. The continuous supply of floral rewards and alternate food sources for the natural enemies helps to increase their abundance, diversity and conservation. Herbivorous insect pests of eggplant may be less able to discern and respond to the odors of their host when additional non-host plants in the form of intercrop or border crop are present (Andow 1991). Chemicals from the intercrop exert an odor-masking effect on the insect seeking its host (Bernays & Chapman 1994), ultimately resulting in lower incidence of insect pests in the main crop. Thus, habitat management can be effectively integrated with bio-intensive integrated pest management (IPM) packages. Hence, in the present study, the suitability of 3 intercrops and 2 border crops was evaluated for the management of 3 major insect pests on eggplant in India.

Materials and Methods

Seeds of the eggplant cultivar 'Pusa Kranti' were sown in a raised-bed nursery during Jun 2010 and Jun 2011 with the onset on the monsoon season in India. Thirty day old healthy seedlings free from mechanical damage were chosen for planting on the experimental farm at the Division of Entomology, Indian Agricultural Research Institute, New Delhi 28.08 °N and 77.12 °E. The ratio of fertilizer (N:P:K) applied to the experimental field was 100:80:60/ha. Nitrogen was applied in 2 split doses, 50 per cent at field preparation before transplanting and 50 per cent at flowering to raise a healthy crop. Whenever soil moisture in the field was deficient, it was restored by flood irrigation. Five hand hoeings were done for managing the weeds.

TREATMENTS

The experiment had 7 treatments in a randomized block design, and each treatment was replicated thrice with a plot size of 5 m × 5 m per replicate. A buffer zone of 1 m was maintained between the plots. In each plot spacing (row to row × plant to plant) of 60 cm × 45 cm was maintained. The intercrops, coriander ('Pusa Harit') and mint (land race), were sown and raised in the main field, while the intercrop, marigold ('AF/SR/12-1'), was sown in a raised-bed nursery and 1-month-old healthy seedlings were transplanted to the main field. A ratio of 6:1 was maintained for the main crop to intercrop. The border crops, maize ('PEMH-2') and cowpea ('Pusa Komal') were sown on the same day of eggplant transplantation to the main field. The treatments with intercrop and border crop, respectively, were as follows: T1, coriander and maize; T2, coriander and cowpea; T3, marigold and maize; T4, marigold and cowpea; T5, mint and maize; T6, mint and cowpea; and T7 (sole crop: control), without any intercrop or border crop.

OBSERVATIONS ON INSECT POPULATIONS AND YIELDS

In each treatment, 5 plants were selected randomly and tagged for weekly monitoring and recording of the insect pest and natural enemy populations. Weekly observations on the numbers of leafhoppers (*A. biguttulla bigutulla*) (32nd Standard Meteorological Week [SMW] to 41st SMW; i.e., 06-12-Aug to 08-14 Oct) were recorded from a leaf from the top, middle and bottom of each plant. Similar sampling methodology was followed for recording the white fly (*Bemisia tabaci*) population from 32nd SMW to 41st SMW (06-12-Aug to 08-14 Oct). The numbers of coccinellid beetles present on those 5 tagged plants in each plot were recorded from the 32nd SMW to 41st SMW. Egg plant fruits were harvested regularly every 8–9th day commencing from the first harvest i.e., 75 days after transplanting. The healthy and damaged fruits were sorted out by visual examination, and percentage fruit infestation both by number and weight of fruits were calculated for each treatment.

After 55–60 days of transplanting, the numbers of natural enemies present in eggplant in each treatment were recorded visually and the insects were collected for identification. The numbers of individuals per species and numbers of individuals of all species in different treatments were used for diversity analysis through the Shannon-Wiener index. This index combines species richness and evenness in a habitat and was described by Shannon (1948). It is calculated by using the equation

$$H' = -\Sigma P_i (\ln P_i)$$

where $P_i = n/N$ (n = number of individuals of a species; N = number of individuals in each treatment) and ln = the natural logarithm.

Generally, for a sample size with more than 5 species, the index will range from 0 to 4.5 (Shannon 1948). A value near zero indicates that the treatment was dominated by a single species, and a value near 4.5 indicates that the number of individuals was distributed evenly overall the species.

STATISTICAL ANALYSES

Data were analyzed by using SAS version 9.2. The population data were square-root transformed, and the percentage fruit infestation data were arcsine transformed.

IDENTIFICATION OF INTERCROP (CORIANDER, MARIGOLD, AND MINT) LEAF VOLATILES BY THE THERMAL DESORPTION TECHNIQUE

Gas chromatography coupled with mass spectrometry (GC-MS) was performed with an Agilent 7890 GC equipped with an Agilent 5975 mass quadrupole detector (Agilent Technologies, Palo Alto, California) following the method described by Zunin (2004). Volatiles were sampled by using the thermal desorption (TD) technique. Functioning of the TD auto sampler (TDS2, Markes International, Unity and Ultra, Cincinnati, USA) included initial purging by helium gas for 1 min followed by desorption at 100 °C for 2 min, and volatiles were stored in a temperature trap (-10 °C). Final desorption of the sample was done for 3 min with temperature programming upto 300 °C. In this system, the thermostated block of the TDS2, which contains a tube, formed the extraction unit. A capillary transfer line connected this block with the GC injector, which could be cooled with nitrogen to -10 °C and heated up to 300 °C. Helium flowed through the tube and the transfer line to the injector. For direct sample extraction, the leaf sample (25 mg) was introduced directly into the glass tube and heated. Carrier gas flow favored the stripping of volatiles, which were then trapped and collected on the cooled surface of the injector liner. Volatile compounds were transferred to the cooled injector in splitless mode. An external automatic controller regulated the numerous operating parameters of the extraction unit.

For the GC-MS analysis of the volatile compounds, a DB-5MS fused-silica capillary column with 30 m × 0.25 mm × 0.25 m film thickness (Agilent) was used at a helium flow rate of 1.2 mL/min. The oven temperature was maintained at 40 °C for 1 min and then increased at 2 °C/min to 70 °C, kept at 70 °C for 5 min under flow-controlled conditions (constant flow 1.2 mL/min), which was followed by an increase at 15 °C/min to 250 °C. The MS interface temperature was set at 250 °C. The temperature of the ion source was 230 °C, electron energy was 70 eV, and quadrupole temperature was 150 °C. The chromatographic plot was obtained by total ion current (TIC) mode: the acquired mass ranges were 50–550amu. To avoid the MS detection of CO_2, a solvent delay of 2 min was used. Compounds were identified by comparison with the Wiley 275 Mass Spectra Library (Wiley 2013).

Results

EFFECT OF BORDER CROPS AND INTERCROPS ON INSECT PEST INCIDENCE

Leafhopper *Amrasca biguttula biguttula*

During the monsoon season of 2010 and 2011, the leafhopper population was significantly smaller in all intercropped treatments (T1-T6) than in the sole crop control (T7). The treatment with coriander as intercrop and maize as border crop (T1) and that with marigold as intercrop and maize as border crop (T3) had the lowest leafhopper incidences from the 1st week of Aug to the 2nd week of Oct (from 32nd SMW to 41st SMW). The cumulative mean numbers of leafhoppers during the 10 week observation periods of 2010 and 2011 were smallest in T1 and T3 (6.90 and 7.27 insects per 3 leaves per plant, respectively), which were followed by treatments: T2< T5,< T4,< T6 < T7. Thus the sole crop control, T7, had the largest leafhopper population (12.61).

Whitefly *Bemisia tabaci*

The whitefly incidences during the monsoon seasons of 2010 and 2011, i.e., from the 1st week Aug to the 2nd week of Oct, were significantly lower in treatments T1, T2, T3 and T4 than in the sole crop T7 (control). The cumulative mean number of whiteflies during the 10 week observation periods revealed that the lowest whitefly population was recorded from T3 during the monsoon seasons of 2010 and 2011 (8.36 insects per 3 leaves per plant) (Table 1). The next best treatment was T1 (9.64 insects per 3 leaves per plant), followed by T4 < T2 < T5 < T6 < T7 (20.17 insects per 3 leaves per plant).

Fruit and Shoot Borer *Leucinodes orbonalis*

The lowest mean percentage fruit infestation during monsoon seasons of 2010 and 2011 by fruit weight (27.81) and fruit number (27.72) was recorded in treatment T1 having coriander as an intercrop and maize as border crop (Table 2). The next best treatments, based on weight and number of infested fruit, were T3 (29.12 and 29.20) and T2 (29.89 and 30.01). All the polyculture treatments (T1 to T6) were superior to the sole crop control (T7), with the latter showing highest percentage fruit infestation by weight and number (38.13 and 37.73, respectively) during the monsoon seasons of 2010 and 2011. Among the 3 intercrops, coriander and marigold were superior to mint in reducing the percentage fruit infestation and achieved the highest percentage reduction in infestation when compared with the sole crop control in both years. The highest mean percentage increase in yield during both years, based on fruit numbers and weight, when compared with the sole crop control, was recorded in treatment T1 (coriander and maize) with percent increases of 85.23 by number and 60.59 by weight.

EFFECT OF BORDER CROPS AND INTERCROPS ON INCIDENCE OF NATURAL ENEMY (COCCINELLIDS)

From the 1st week Aug to the 2nd week of Oct, treatment T1 (maize as border crop and coriander as intercrop) harbored significantly higher numbers of coccinellids than T7 (sole crop) during 2010 and 2011(Table 1). The mean numbers of coccinellids during the 10 week observation period revealed that the largest population was recorded in T1 (1.25 cocinellids per plant) followed by T3 (1.00) > T5 (0.78) > T2 (0.67) > T4 (0.61) > T6 (0.55) > T7 (0.37). Thus, the smallest coccinellid population was recorded in the sole crop control.

The treatments with maize as border crop had more natural enemies than those with cowpea as border crop (Table 3, Table 4). Maize as a border crop attracted many unique natural enemies like *Paederus* sp. (Coleoptera: Staphylinidae), *Chrysoperla zastrowi* (Esben-Petersen) (Neuroptera: Chrysopidae), *Eristalis* sp. (Diptera: Syrphidae) and *Brachymeria* sp. (Hymenoptera: Chalcididae), apart from *Cheilomenes sexmaculata* (F.) (Coleoptera: Coccinellidae) and other ladybird beetles.

The Shannon-Wiener index for natural enemies present in different treatments varied from 2.356 to 1.171 and 2.462 to 1.241 in the years 2010 and 2011, respectively (Table 4). The highest index was recorded in treatment T1 followed by T3 > T5 > T2 > T4 > T6 during both years. Thus, coriander as intercrop and maize as border crop with eggplant had the highest diversity index. The lowest index was obtained in the sole crop control; all of the intercropped treatments had a higher index than the sole crop control.

Table 1. Effect of intercrops and border crops on incidences of the leaf hopper, *A. bigutula biguttula*, the whitefly, *B. tabaci* and the coccinellid predators on eggplant (brinjal) during *kharif* (monsoon season) of 2010 and 2011.

	Mean insect population per 3 leaves per plant for 10 weeks[a]		Mean insect population per plant for 10 weeks[a]
Treatments	*A. bigutula biguttula*	*B. tabaci*	Coccinellid predators
T1	6.90 (2.72)[a]	9.64 (3.18)[b]	1.25 (1.32)[a]
T2	8.16 (2.94)[b]	12.41 (3.59)[d]	0.67 (1.08)[d]
T3	7.27 (2.78)[a]	8.36 (2.98)[a]	1.00 (1.22)[b]
T4	9.36 (3.14)[c]	10.70 (3.35)[c]	0.61 (1.05)[d,e]
T5	8.68 (3.03)[b]	13.83 (3.78)[e]	0.78 (1.13)[c]
T6	10.13 (3.26)[d]	15.45 (3.99)[f]	0.55 (1.02)[e]
T7	12.61 (3.62)[e]	20.17 (4.54)[g]	0.37 (0.93)[f]
S.E. (±)	0.05	0.08	0.02
CV	2.78	3.74	3.26
CD (p < 0.05)	0.10	0.16	0.04

[a]Figures in parenthesis are square root transformed. In a column means followed by same letter are not significantly different from each other ($P > 0.05$). The treatments with intercrop and border crop, respectively, were as follows: T1, coriander and maize; T2, coriander and cowpea; T3, marigold and maize; T4, marigold and cowpea; T5, mint and maize; T6, mint and cowpea; and T7 (sole crop: control), without any intercrop or border crop.

PLANT VOLATILES PRESENT IN THE INTERCROPS

The presence of different hydrocarbons at varying levels was observed in intercrops. About 21 volatile compounds were present in coriander, 7 in marigold, and 18 in mint (Table 5 and Fig. 1, 2 and 3). The current state of knowledge of the behavioral effects (repellency, attractancy, no effect) of each chemical with respect the various herbivorous insects and natural enemies is summarized in Table 5. Some the volatiles emitted by coriander and mint are known to be repellent to certain herbivorous insects and others are known to be attractive to certain natural enemies. Very little is known about the behavioral effect of individual chemical constituents of the volatiles emitted by marigold. These data provide specific information that must be taken into account when conducting quantitative studies on how different pest and beneficial insects respond to plant volatiles in polycultures.

Discussion

Pest outbreaks are rare in polycultures due to the ability of the diverse plant culture to self-sustain through natural pest control by increasing the occurrence of natural enemies (Altieri 1994; Scherr & McNeely 2008). The cumulative mean leafhopper population of 2010 and 2011 was smallest in treatments T1 and T3, followed by T2, T5, T4, T6, and T7. In other words, eggplant with maize as border crop (T1 & T3) and coriander as intercrop (T1) or marigold as intercrop (T3) had the lowest leafhopper incidence. All those treatments having maize as border crop (T1, T3 & T5) recorded lesser leafhopper population than cowpea as border crop (T2, T4 & T6). Maize likely acted as a barrier crop for the movement of leafhoppers, as maize plants were much taller than the main crop and when planted in the border, maize is known to act as barrier crop (Root 1973; Fereres 2000; Elanchezhyan et al. 2008). Insect movements in and out of the system are affected by the permeability of the vegetation. In and out migration patterns of insects in polycultures have been studied by Bach (1984), Risch (1981) and Wetzler & Risch (1984). Similarly leafhopper populations in pigeonpea were reduced by sorghum intercropping (Sekhar et al. 1997). During the present investigation it was noticed that maize harbored large numbers of coccinellids and syrphids, which might have helped to reduce the leafhopper nymphs on eggplant in those treatments. The border crop and intercrop change the microclimate of the main crop, which in turn hinders insect pest development and favors natural enemy proliferation by providing supplementary food and refugia (Staver et al. 2001). Moreover, the volatiles from coriander and marigold likely acted to repel leafhoppers, resulting in smaller populations in T1 and T3 compared with the sole crop control, T7. Insect pests have difficulty in locating their host plants due to presence of intercrops and border crops that emit volatiles that have either masking effects or repellency (Goel & Tiwari 2004; Gupta & Chourasia 2004). The 3 intercrops (coriander, marigold and mint) are odoriferous in nature. The odoriferous plants, when raised with host plants of insect pests, can deter recognition, feeding and reproduction of the pests on their host plants (Dethier et al. 1960; Schoonhoven 1968).

The whitefly population was smallest in treatment T3 followed byT1, T4, T2, T5, T6, and T7. The results indicated that maize as border crop and marigold as an intercrop effectively reduced the whitefly population in eggplant. The volatiles from marigold have repellent action against whiteflies (Zavaleta-Mejía & Gomes 1995), explaining why treatments T3 and T4 had small whitefly populations. Coriander was the second best intercrop in reducing whitefly populations. Maize was a very good barrier crop against whitefly colonization and migration. Hence, the treatments having maize as border crop (T3, T1, and T5) had smaller whitefly populations than the other treatments and sole crop control, T7. Marigold intercropping in tomato reduced whitefly and nematode populations (Abid & Magbool 1990; Zavaleta-Mejía & Gomes 1995). Similarly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) was repelled by *Tagetes* spp. (Asterales: Asteraceae) (Endersby & Morgan 1991). This bottom-up effect of marigold intercropping was accompanied by a top-down effect, as the marigold increased longevity and fecundity of natural enemies by providing nectar and pollen (Baggen 1999). Next to marigold, coriander supported the smallest whitefly populations in our study. Under greenhouse conditions, planting melon (*Cucumis melo* L.) or watermelon (*Citrullus la-*

Table 2. Effect of intercrops and border crops on infestation of eggplant by the fruit and shoot borer *L. orbonalis* during the 2010 and 2011 monsoon season.

Treatment	Total fruit yield per hectare		Marketable fruit yield per hectare		Damaged fruit yield per hectare		Fruit infestation (%)^{b}		Reduction in infestation over control (%)^{c}		Increase in yield over control (%)^{c}	
	Number (× 10^{3})	Weight (t)	Number (× 10^{3})	Weight (t)	Number (× 10^{3})	Weight (t)	By number	By weight	By number	By weight	By number	By weight
T1	206.67^{a}	15.095^{a}	162.13^{a}	11.809^{a}	44.53^{a,b}	3.286^{a,b}	27.72^{a}	27.81^{a}	26.25	27.07	85.23	60.59
T2	182.33^{a,b}	14.177^{a,b,c}	136.93^{b}	10.663^{a,b}	45.40^{a,b}	3.514^{a,b}	30.01^{b,c}	29.89^{c}	20.24	21.61	56.44	44.99
T3	156.67^{b,c}	11.606^{c}	119.27^{b}	8.850^{b,c}	37.40^{a}	2.756^{a}	29.20^{b}	29.12^{b}	22.37	23.63	36.26	20.35
T4	183.80^{a,b}	13.497^{a,b,c}	135.00^{b}	9.909^{a,b}	48.80^{b}	3.588^{a,b}	31.05^{c}	31.05^{d}	17.53	18.58	54.23	34.74
T5	182.13^{a,b}	13.261^{a,b,c}	129.13^{b}	9.426^{b}	53.00^{b}	3.834^{b,c}	32.65^{d}	32.54^{e}	13.32	14.66	47.53	28.18
T6	202.20^{a}	14.573^{a,b}	139.00^{b}	9.923^{a,b}	63.20^{c}	4.650^{d}	34.11^{e}	34.41^{f}	9.49	9.76	58.80	34.94
T7	139.73^{c}	11.865^{b,c}	87.53^{c}	7.354^{c}	52.20^{b}	4.512^{c,d}	37.73^{f}	38.13^{g}	n/a	n/a	n/a	n/a
SEM	5.09	0.48	4.43	0.38	1.49	0.16	0.52	0.52	n/a	n/a	n/a	n/a
CV	12.64	15.72	13.08	15.36	13.20	17.48	3.13	1.93	n/a	n/a	n/a	n/a
CD (P< 0.05)	26.69	2.49	20.04	1.76	7.66	0.77	1.17	0.73	n/a	n/a	n/a	n/a

[a]In a column, means followed by the same letter are not significantly different from each other ($P > 0.05$).
[b]Figures in parentheses are arcsine transformed.
[c]n/a = not applicable. The treatments with intercrop and border crop, respectively, were as follows: T1, coriander and maize; T2, coriander and cowpea; T3, marigold and maize; T4, marigold and cowpea; T5, mint and maize; T6, mint and cowpea; and T7 (sole crop: control), without any intercrop or border crop.

natus [Thunb.] Matsumara & Nakai) (Cucurbitales: Cucurbitaceae) with coriander reduced infestation by *B. tabaci* (Costa & Bleicher 2006). Similarly, Hilje & Stansly (2008) reported that *B. tabaci* abundance and begomovirus incidence were low on tomato intercropped with coriander. Our treatments using maize as border crop (T1, T3, and T5) had the smallest whitefly populations. Maize as barrier crop in beans reduced the *B. tabaci* population below economic threshold levels in Guatemala (Smith & McSorley 2000; Smith et al. 2000). Similarly, the whiteflies *Aleurotrachelis socialis* Bondar and *Trialeurodes variabilis* (Quaintance) (Hemiptera: Aleyrodidae) on cassava, *Manihot esculenta* Crantz (Malpghiales: Euphorbiaceae), were less abundant when cassava was intercropped with maize (Gold et al. 1990).

The presence of non-host plants might have repelled the adult moths resulting in less fruit infestation in polyculture treatments (T1 to T6) than in the sole crop control (T7). The repellency to different lepidopterous pests of various non-host crops was reported by Khan et al. (2000), McNair et al. (2000) and Liu et al. (2005). The results clearly revealed that maize acted as an effective barrier for the movement of adult fruit borer moths, thereby reducing the percentage fruit infestation in treatments T1 and T3. Non-host plants mixed in with host plants either act as a mechanical barrier to the dispersal of the insect pest (Kennedy et al. 1959; Root 1973) or physically repel them because of unpleasant morphological features such as hairy leaves (Levin 1973). Similarly, Nwilene et al. (2011) reported that intercropping maize and cassava with NERICA rice varieties had reduced stem borer attack on rice. They also concluded that cassava acted as refugia for generalist predators against stem borer. Coriander and marigold as intercrop resulted in lowering the numbers of sucking and borer pests than mint as intercrop and the sole crop control. Intercropping coriander with eggplant reduced *L. orbonalis* infestation and the amount of insecticide used by farmers (Khorsheduzzaman et al. 1997), and intercropping marigold with cabbage reduced oviposition by *Pieris brassicae* L. and larval incidence of *Pieris rapae* L. (Lepidoptera: Pieridae) on cabbage (Koehler et al. 1983; Metspalu et al. 2003). *L. orbonalis* orientation and oviposition on eggplant was reduced when it was planted along with coriander or fennel (Satpathy & Misra 2011). In the present study, the highest percentage increase in yield (based on numbers of uninfested fruit) compared with the sole crop control was recorded from treatment T1 during both years, and this result agrees with that of Hasheela et al. (2010).

High diversity in predatory insect and parasitoid species was recorded from treatments T1, T3, and T5 wherein maize supplied pollen and nectar as supplementary feed to the natural enemies (Bianchi et al. 2006). The ample availability of pollen and nectar from the tassel and silk of maize crop attracted many natural enemies. Apart from this, maize also offers honeydew produced by *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae) which attracts aphidophagous predators and parasitoids. This supplementary food resource increases the parasitoid fecundity, longevity (Tylianakis et al. 2004) and also favors rapid colonization of generalist predators (Symondson et al. 2002). The dense vegetation created by the presence of eggplant with intercrop and border crop had led to rapid colonization and occurrence of natural enemies in higher densities. This is in accordance with reports of Sprenkel et al. (1979); Horn (1981). Similarly, Letourneau & Altieri (1983) and Letourneau (1990) also suggested that predator colonization rates could be manipulated through vegetational diversification of the crop habitat.

Natural enemies harbored by maize consist primarily of ants, spiders, rove beetles, predaceous mites, and ground beetles (Rose & Dively 2007). Similar report of intercrops increasing natural enemy diversity is reported by Singh et al. (1991a). They found that sorghum as an intercrop significantly increased the natural enemies like *Laius mallifer*, *C. septumpunctata*, *Orius* sp. and *C. sexmaculata* which had controlled

Table 3. List of natural enemies recorded in various treatments with intercrops and border crops to determine infestation levels of eggplant pests.

No.	Order	Family	Common name	Species	Present in treatments[a] 2010	2011
1	Coleoptera	Coccinellidae	Ladybird beetle	*Adonia variegata*(Goeze)	T1,T3	T1,T3
2	Coleoptera	Coccinellidae	Ladybird beetle	*Coccinella septempunctata* L.	T1,T2,T3,T4,T5,T6,T7	T1,T2,T3,T4,T5,T6,T7
3	Coleoptera	Coccinellidae	Ladybird beetle	*Coccinella transversalis* F.	T1,T3,T5	T1,T3,T5
4	Coleoptera	Coccinellidae	Ladybird beetle	*Cheilomenes sexmaculata* (F.)	T1,T2,T3,T4,T5,T6,T7	T1,T2,T3,T4,T5,T6,T7
5	Coleoptera	Coccinellidae	Ladybird beetle	*Micraspis allardi*(Mulsant)	T1,T3,T5	T1,T3,T5
6	Coleoptera	Coccinellidae	Ladybird beetle	*Micraspis discolor* (F.)	T1,T3	T1,T3
7	Coleoptera	Coccinellidae	Ladybird beetle	*Propylea dissecta* (Mulsant)	T1,T3	T1,T3
8	Coleoptera	Staphylinidae	Rove beetle	*Paederus* sp.	T1,T3,T5	T1,T3,T5
9	Neuroptera	Chrysopidae	Green lacewing	*Chrysoperla zastrowi* (Esben-Petersen)	T1,T3,T5	T1,T3,T5
10	Hemiptera	Lygaeidae	Bigeyed bug	*Geocoris tricolor* F.	T1, T2,T3, T4,T5,T6,T7	T1, T2,T3, T4,T5,T6,T7
11	Diptera	Syrphidae	Hoverfly	*Eristalis* sp.	T1,T3,T5	T1,T3,T5
12	Hymenoptera	Chalcididae	Chalcidid wasp	*Brachymeria* sp.	T1,T3,T5	T1,T3,T5
13		Sphecidae	Mud dauber	*Sceliphron madraspatanum pictum* (F. Smith)	T2,T4,T6	T2,T4,T6
14		Vespidae	Paper wasp	*Ropaldia* sp.	T2,T4,T6	T2,T4,T6
15	Odonata	—	Dragonfly	Genus undetermined	T1,T2,T3,T4,T5,T6	T1,T2,T3,T4,T5,T6,
16		—	Damselfly	Genus undetermined	T1,T2,T3,T4,T5,T6	T1,T2,T3,T4,T5,T6,
17	Dictyoptera	Mantispidae	Praying mantis	Genus undetermined	T1,T3,T7	T1,T3,T7

[a]The treatments with intercrop and border crop, respectively, were as follows: T1, coriander and maize; T2, coriander and cowpea; T3, marigold and maize; T4, marigold and cowpea; T5, mint and maize; T6, mint and cowpea; and T7 (sole crop: control), without any intercrop or border crop.

thrips infesting groundnut. Treatment T1 yielded the highest numbers of natural enemy individuals and species and the highest Shannon-Wiener index in 2010 and 2011. The present finding is in agreement with that of Amin et al. (2005), who reported that eggplant with coriander as intercrop had the highest diversity index during the early growth phase of eggplant. The present result is also in concurrence with the reports of Midega & Khan (2003). They concluded that habitat management for maize stem borers by using “push pull system” had increased the abundance of natural enemies like *Cheilomenes* sp, *Chrysopa* sp., ants earwigs and spiders concurrently with reducing target pest i.e. stem borers.

Push – pull strategy involves manipulation of insect and natural enemy behavior through the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests are subsequently removed (Cook et al. 2007). The push-pull strategy was well established for cereal stem borer management in Africa, wherein the molasses grass, *Melinis minutiflora* P. Beauv. or silver leaf desmodium, *Desmodium uncinatum* (Jacq.) DC. or *D. intortum* is used as push component and napier (*Pennisetum purpureum* Schumach) or sudan grass (*Sorghum sudanense* Stapf) is used as pull component. The adult moths were pushed from maize by the molasses grass or by *Desmodium* sp. simultaneously they were pulled by napier grass or sudan grass, as these 2 are preferred for oviposition by the adults (Khan et al. 2000, 2006). The pull components used here were putative trap crops (i.e., they would not support larval feeding) the stem borer population starts reducing by the use of this push–pull strategy. This strategy not only reduced cereal stem borers but also reduced the parasitic weed*,* *Striga hermonthica* (Del.) Benth. and thereby sustained the cereal production in sub Saharan Africa (Khan et al. 2010).

Coriander leaf volatile consists of carvyl acetate and carvone in the present investigation. Carvacrol from coriander leaf volatiles was reported to strongly deter oviposition by the cotton leafhopper, *Amrasca devastans* (Hemiptera: Cicaidae), and the volatiles suppressed the nymph arrival (Saxena & Basit 1982). The colonization and residence time of the leafhopper on a host plant were influenced by the presence of the nonhost plants. The airborne volatiles of *Melinis minutiflora* P. Beauv. (Poales: Poaceae) a non host plant of spotted maize stem borer had repelled it from ovipositing on maize. This is due to the presence of the plant volatiles ocimene and nonatriene from the intercrop (Kimani et al. 2000). Farnesene present in the coriander leaves is an aphid alarm pheromone and thus helps in repelling aphids and acts as

Table 4. Predatory insect diversity in various treatments with intercrops and border crops to determine infestation levels of eggplant pests.

Treatment	Number of species 2010	Number of species 2011	Number of individuals 2010	Number of individuals 2011	Shannon-Wiener index[a] 2010	Shannon-Wiener index[a] 2011
T1	15	15	66	88	2.356	2.462
T2	7	7	38	50	1.554	1.709
T3	15	15	52	72	2.333	2.391
T4	7	7	25	39	1.538	1.707
T5	11	11	35	45	2.040	2.001
T6	7	7	23	33	1.518	1.664
T7	4	4	18	23	1.171	1.241

The treatments with intercrop and border crop, respectively, were as follows: T1, coriander and maize; T2, coriander and cowpea; T3, marigold and maize; T4, marigold and cowpea; T5, mint and maize; T6, mint and cowpea; and T7 (sole crop: control), without any intercrop or border crop.

[a]Note: A value near zero indicates that the treatment was dominated by a single species, and a value near 4.5 indicates that the number of individuals was distributed evenly overall the species.

Table 5. Constituent volatiles present in leaves of coriander, marigold and mint.

Crop	Retention time	Compound	Insect name: Repellent (R) /Attractant (A)/Neither (N)	Reference
Coriander	6.834	α-Pinene	*Rhynchophorus ferrugineus*: (R) *Phthorimaea operculella*: (R)	Guarino et al. 2013 Sharaby et al. 2009
	7.200	Camphene	*Phthorimaea operculella*: (R)	Sharaby et al. 2009
	7.452	β-Phellandrene	*Phthorimaea operculella*: (R)	Sharaby et al. 2009
	7.721	β-Pinene	Aphid (R) alarm pheromone	Pickett & Griffiths 1980
	7.990	Carvyl acetate	Lice (R)	Eini & Tamarkin 1993
	8.344	Thymene	N	
	8.430	Limonene	*Empoasca vitis*: (R) *Harmonia axyridis*: (A)	Zhang et al. 2014 Alhmedi et al. 2010
	8.545	p-Cymene	*Empoasca vitis*: (R)	Zhang et al. 2014
	8.739	Ocimene	*Helicoverpa armigera*: (A)	Bruce & Cork 2001
	8.957	Terpinene	N	
	9.786	Nonanal	*Paragus quadrifasciatus* and *Orius similis*: (A)	Yu et al. 2008
	11.572	Dihydrocarvone	*Sitophilus oryzae* contact toxicity	Tripathi et al. 2003
	11.692	Decanal	N	
	12.493	Carvone	*Sitophilus oryzae* contact toxicity	Tripathi et al. 2003
	12.796	Decenal	N	
	14.524	Undecenal	N	
	15.594	β-Caryophyllene	*Harmonia axyridis*: (A)	Alhmedi et al. 2010
	15.989	Cadinene	N	
	16.069	Farnesene	Whiteflies toxic	Klinjstra et al. 1992
	16.161	α-Caryophyllene	*Chrysopa carnea* (A)	Flint et al. 1979
	16.246	3-Dodecenal	N	
Marigold	5.508	Allylisothiocyanate	N	
	6.126	Butane-4-isothiocyanate	N	
	8.380	Cinamaldehyde	N	
	8.529	Phenol, m-tert-butyl-	N	
	8.735	Chrysanthenone	N	
	8.947	Piperitenone	*Helicoverpa armigera*: (A)	Bruce & Cork 2001
	9.113	Piperitenone oxide	N	
Mint	7.700	β-Pinene	Aphid (R) alarm pheromone	Pickett & Griffiths 1980
	7.974	Carvyl acetate	Lice (R)	Eini & Tamarkin 1993
	8.180	α-Terpinene	Manduca sexta: (A)	Fraser et al. 2003
	8.335	p-Cymene	N	
	8.426	Limonene	*Empoasca vitis*: (R) *Harmonia axyridis*: (A)	Zhang et al. 2014 Alhmedi et al. 2010
	8.730	β-Ocimene	*Helicoverpa armigera*: (A)	Bruce & Cork 2001
	9.107	g-Terpinene	N	
	9.531	Dimethylstyrene	N	
	9.788	Nonanal	*Paragus quadrifasciatus* and *Orius similis*: (A)	Yu et al. 2008
	10.143	2-Octene	N	
	11.619	Dihydrocarvone	*Sitophilus oryzae* contact toxicity	Tripathi et al. 2003
	12.552	Carvol	N	
	12.712	Piperitone	Stomoxys calcitrans (R)	Hieu et al. 2014
	13.359	Carvacrol	*Phthorimaea operculella*: (R)	Sharaby et al. 2009
	13.902	Dihydrocarvyl acetate	N	
	15.590	β-Caryophyllene	*Harmonia axyridis*: (A) *Phthorimaea operculella*: (A)	Alhmedi et al. 2010 Sharaby et al. 2009
	16.065	β-Farnesene	*Episyrphus balteatus*: (A)	Alhmedi et al. 2010
	16.157	α-Caryophyllene	*Chrysopa carnea*: (A)	Flint et al. 1979

a kairomone for carabid beetles (Keilty et al. 1996). Similarly, whiteflies are known to avoid plant species that contain aromatic oils such as ginger oil. Hence, aromatic plants like coriander and marigold might have repelled the whitefly from the eggplant (Zhang et al. 2004). Repellent and antifeedant properties of mint against agricultural pests were reported by Koschier et al. (2002), Odeyemi et al. (2008), and Kumar et al. (2009). Similarly, Rattan (2010) reported that mint volatiles blocked the chemosensory receptor cells of lepidopteran larvae. Hence in the present study the intercrops (coriander, marigold and mint) repelled the leafhoppers, whitefly and eggplant fruit borers significantly. This is evident from the sucking pest population and fruit damage in control (T7).

These inter crops can be employed as a "push factor" in line with the well established push-pull management strategy employed in cereal stem borers in Africa (Khan et al. 2000, 2006). The border crop maize and cowpea acted as refugia for generalist natural enemies and these also helped in further reducing the pest populations in eggplant. Beyond this, maize also acted as a barrier to fruit borer and sucking

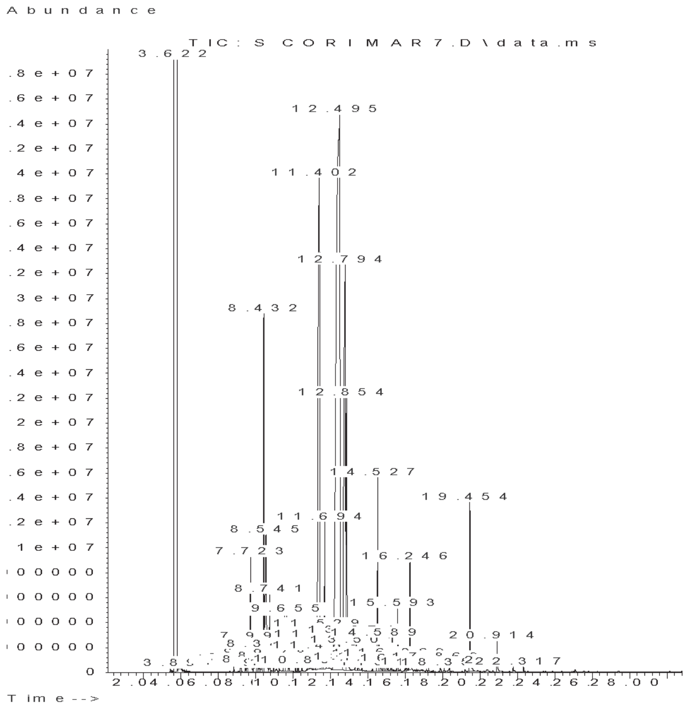

Fig. 1. Total ion current (TIC) mode chromatographic plot of coriander leaf volatiles sampled and analyzed by the thermal desorption (TD) technique.

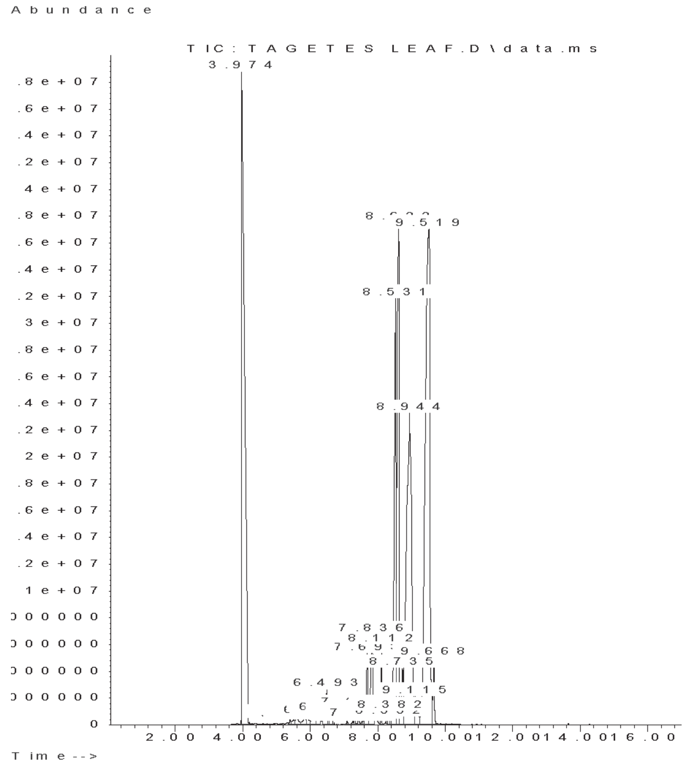

Fig. 2. Total ion current (TIC) mode chromatographic plot of marigold leaf volatiles sampled using the thermal desorption (TD) technique.

pest of eggplant, thereby preventing the pest colonization in eggplant. Hence this system can be called as "push & prevent" strategy for managing the eggplant insect pest. Cook et al. (2007) has listed various cues that affect insects' long range and short range stimuli during the host searching process. The presence of non host volatiles and visual cues have under long range action, while ovipositional deterrents and antifeedancy serve as short range cues. In the present investigation the presence of non host volatiles from coriander, marigold and mint might have either repelled or confused the pest of eggplant, ultimately resulting in smaller pest population in the polyculture treatments. The latter case of confusion is attributed to the odor masking effect of the volatiles produced from intercrops. Similar report of non host volatiles of angiosperms resulted in reduction of colonization of bark beetles in conifers (Zhang & Schlyter 2004).

In a crop diversification system like coriander or marigold or mint with eggplant will result in poor quality or dilution of eggplant volatiles. This diluted or mixed odor may signal as poor quality host to the insect pest leading to repellent behavior. In polyculture, the odors released by some plants may mask the effect of those released by other plants. The codling moth (*Cydia pomonella*) was repelled by the odors of apple at inappropriate phenological stages Vallat & Dorn (2005). Under these circumstances, the insects find it difficult to locate the hosts on which to feed and reproduce (Altieri 1986).

In summary, the treatments (T1 to T6) recorded significantly reduced leafhopper, whitefly, and fruit borer populations compared with the sole crop control (T7) in eggplant during the years 2010 and 2011. Treatment T1, using coriander as an intercrop and maize as a border crop with eggplant, had the lowest mean number of leafhoppers (*A. biguttulla biguttulla*) per 3 leaves per plant (6.90). Treatment T1 also had the lowest percentage fruit infestation by *L. orbonalis* determined by number and weight of infested fruit (by number: 27.72%; by weight: 27.81%). The mean number of whiteflies (*B. tabaci*) per 3 leaves per plant on eggplant was lowest (8.36) in treatment T3, using marigold as intercrop and maize as border crop, followed by T1 (9.64). The highest number of coccinellids per plant on eggplant was recorded from treatment T1 (1.25), followed by T3 (1.00), T5 (0.78), T2 (0.67), T4 (0.61), and T6 (0.55). Maize as a border crop attracted many unique natural enemies like *Paederus* sp., *C. zastrowi*, *Eristalis* sp., and *Brachymeria* sp. in treatments T1, T3, and T5. In contrast, the sole crop control (T7) harbored only a few natural enemies. This was reflected in the higher Shannon-Wiener index recorded in the treatments T1, T3, and T5 compared with T7. We concluded that intercropping eggplant with either marigold or coriander coupled with border cropping with maize offers great potential for suppressing sucking pest and fruit borer pest populations besides conserving natural enemy populations. Thus the intercropping of coriander or marigold with eggplant and border cropping with maize can be used as "push & prevent" strategy for reducing the fruit and shoot borer and sucking pest especially jassids and whiteflies. This "push & prevent" management system will help in sustaining the ecosystem as well as productivity and profitability of farmers. Thus crop diversification in eggplant with intercrop and border crop will help in reducing the insecticidal application on fruit and thereby reducing environmental pollution in one hand simultaneously helping as a good strategy in insecticide resistance management. As crop diversification manipulates insect behavior, it is a sustainable solution for managing the insect herbivores of eggplant in an eco-friendly manner.

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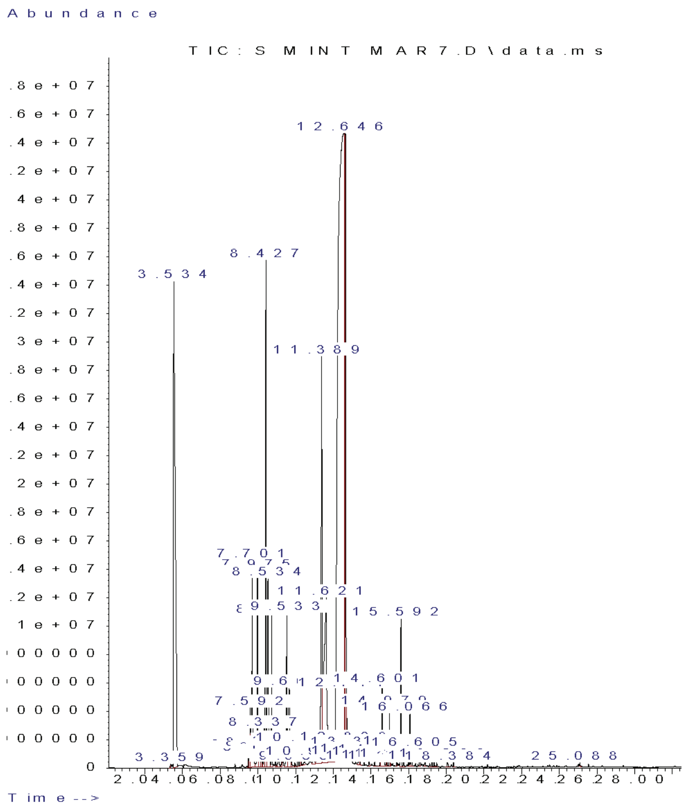

Fig. 3. Total ion current (TIC) mode chromatographic plot of mint leaf volatiles sampled using the thermal desorption (TD) technique.

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