

# Farmers' Knowledge and Practices in the Management of Insect Pests of Leafy Amaranth in Kenya

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## Abstract

Amaranth (*Amaranthus* L.) species are grown for their grain or leaves and contribute to farmers' livelihoods and nutritional food security. Leafy amaranth (LA) is consumed widely as a vegetable in Kenya. An assessment of current farmers' knowledge of pest management practices provides information about future educational needs. Six-hundred LA farmers were interviewed, focus group discussions with farmers, and interviews with key informants were completed in four Kenyan counties. The majority (71%) of survey respondents grew LA on less than 0.25 acre (<0.1 ha) and 59.2% were female. Constraints of LA production differed by counties surveyed. Farmers indicated insects and birds were important in Kiambu and Kisumu counties, whereas in Vihiga and Kisii, capital, markets, and land area for production were important. Farmers stated and ranked importance of the insects they observed during LA production. Eighty-seven percent stated aphids (Hemiptera: Aphididae), as a major pest and 96.8% ranked aphids as the number-one insect pest of LA in all four counties. Two other pests of LA included cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae) (0.8%) and spider mites, *Tetranychus* spp (Trombidiformes; Tetranychidae) (0.7%). Forty-two percent of all LA farmers managed aphids, with 34% using synthetic insecticides and 8% using nonsynthetic methods. Biological controls and host-plant resistance were not mentioned. Educational programs that train farmers about integrated pest management (IPM) in LA production are needed. Future research should determine successful IPM strategies for aphids on LA to reduce insecticide use and improve sustainability and nutritional food security for small-landholder farmers and consumers.

**Key words:** farmer knowledge, *Amaranthus* spp., aphid, pesticide, integrated pest management

*Amaranthus* L. is classified into 60 recognized species (National Research Council 1984, Xu and Sun 2001, Brickell 2008). Most *Amaranthus* species are found in warm temperate and tropical regions of the world (Mosyakin and Robertson 2003). Amaranth was cultivated over 6,000 yr ago in Puebla, Mexico (Brenner et al. 2000). Both its grain and leaves are consumed, and it has a worldwide distribution and adoption (Brenner et al. 2000, Mlakar et al. 2010, Trucco and Tranel 2011), similar to quinoa (*Chenopodium quinoa* Willd.), another crop in Amaranthaceae (Bazile et al. 2016).

In Kenya *Amaranthus hybridus* L. and *A. dubius* Mart. ex Thell. are grown as leafy vegetables, while *A. cruentus* L. is cultivated for grain and *A. hypochondriacus* L. is a dual-use species grown for leaves or grain (Muriuki et al. 2014). Leafy amaranth (LA) production is inexpensive and the crop grows well in many environments (Wambugu and Muthamia 2009). LA reaches harvest maturity between 20 and 45 d after seeding depending on the cultivar and

growing season (Ebert et al. 2011). Cultivation of LA has increased for both commercial production and household consumption in Sub-Saharan Africa (Achigan-Dako et al. 2014). The environmental adaptability and nutritional value of amaranth have had a positive impact on farmers in rural and peri-urban farming communities in Kenya (Monica et al. 2011). In 2016, the total land area under LA production in Kenya was 1,518 hectares with 12,544 metric tons valued at US\$3,075,798 (Kenya National Bureau of Statistics 2016). A small, 500 m<sup>2</sup> (5,382 ft<sup>2</sup>) plot of LA can provide a supplementary annual income of US\$250 for a Tanzanian farmer (Ebert 2014).

Major constraints hindering the production of LA include arthropod pests (Banjo 2007, Aderolu et al. 2013, Kagali et al. 2013). Insect orders causing losses to LA are Coleoptera, Diptera, Hemiptera, and Lepidoptera (Clarke-Harris et al. 2004, Aderolu et al. 2013). Pests in these insect orders have caused losses of LA in

Kakamega, Kiambu, Machakos, Meru, Nairobi, and Narok counties in Kenya (Kagali et al. 2013, Mureithi et al. 2015).

Understanding farmers' current pest management practices and determining any knowledge gaps for production can help to increase sustainable LA productivity through development of educational programs to train farmers. Farmer knowledge and practices used to control insect pests of LA in Kenya are unknown. A farmer's baseline survey was conducted in LA-growing regions of western and central Kenya to establish the current production and pest management practices used to manage pests in LA. Specific objectives of the baseline survey in four Kenyan counties were to: 1) identify the major constraints of LA production, 2) identify key LA pests, and 3) determine practices farmers use to control key LA pests. We hypothesized that constraints to LA production, key LA pests, and pest management practices used by farmers were similar across the four counties of Kenya.

## Materials and Methods

### Study Area

The study was conducted in one central and three western Kenyan counties: Kiambu, Kisii, Kisumu, and Vihiga. Counties were selected because their communities cultivate and consume African leafy vegetables, including LA (Abukutsa-Onyango 2007). Kiambu County is in central Kenya and has temperatures between 7 and 34°C, July and August are months with the lowest temperatures, and January to March have the highest temperatures. The county experiences a bimodal type of rainfall (Kiambu County Government 2014). Fresh fruits and vegetables have a high value that makes their production appropriate in the county (Government of Kenya 2012). The topography is characterized by hills, plateaus, and high-elevation plains; steep slopes and some areas covered by forests are not suitable for farming (Kiambu County Government 2013). Census data from 2009 showed a population of 1,623,282, with 50.6% female and 49.4% male; population living in urban centers was 57.7% (Kiambu County Government 2013). Kisii County is in western Kenya, southeast of Lake Victoria, with temperatures ranging between 15 and 30°C. The months of July and January remaining relatively dry and the county exhibits a bi-modal rainfall (Kisii County Government 2017). It is characterized by a hilly topography with several ridges and valleys (Kisii County 2013). The population of Kisii County listed in the 2009 census was 1,152,282, with 52.2% female and 47.8% male; 10.9% of the population lived in major town centers (Kisii County Government 2013). Kisumu County is in western Kenya along the eastern shores of Lake Victoria and has temperatures ranging between 25 and 35°C and a dry period in January and February (Kisumu County Government 2018). The county is characterized by the Kano Plain, a flat stretch which ends along the Winham Gulf of Lake Victoria (Kisumu County Government 2018). The county's population listed in the 2009 census was 968,909, comprised of 51% female and 49% male with 30.6% living in urban centers (Kisumu County Government 2013). Vihiga County is located in western Kenya in the Lake Victoria basin (Vihiga County Government 2018). The average temperature is 24°C with February having the highest temperatures (Institute of Economic Affairs 2011). Census data from 2009 listed 554,622 people living in Vihiga County with 52.6% female and 47.4% male. The percentage of people living in main urban centers was 15.6 (Vihiga County Government 2013).

### Research Methods

Farmer surveys, focus group discussions of farmers, and key informant interviews were used in the four counties. Two extension specialists from Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kenya and one social scientist from Makerere University of Uganda tested all surveys, question guides, and sampling procedures. Pretesting of the farmer survey and farmer focus group discussion questions was completed in Kiambu County in Juja constituency (electoral division), a location not part of the research study. Pretesting sessions with farmers convened outdoors at Juja Farm, Kiambu County (1°09'12" S, 37°05'24" E). Ten amaranth farmers (five female and five male) pretested the farmer survey and six amaranth farmers (four female and two male) pretested the focus group questions. Three key informants in Kiambu County in Juja constituency pretested the key informant questions at their place of employment and included one agricultural teacher at Kalimoni Senior Secondary School, one agricultural student at JKUAT, and one agricultural dealer selling inputs of agricultural chemicals and seeds at Juja trading center. LA farmers in the pretesting groups were identified by the agricultural extension officer of Juja and were selected at random for pretesting the survey. Farmers represented various farm sizes, levels of production experience, and insect pest management practices. Female respondents completed the farmer survey in approximately 30 min and male respondents in 45 min, while the focus group discussions, separated by gender, were completed by both genders in 20 min and questions were answered by key informants in 15 min. Feedback was provided and the survey and focus group and interview questions refined to improve simplicity and understandability by farmers and key informants. All questions asked of farmers during pretesting were translated into Kiswahili, an official language spoken by the majority of farmers, and asked in person. Questions for key informants were asked in person using English, an official language in Kenya.

A questionnaire to determine farmers' management practices included participants' demographics, farm size, and LA production and pest management practices, including aphids (e.g., [Supp Table S1 \[online only\]](#)). Survey populations were determined by using numbers of registered voters in the four study counties (Schulz-Herzenberg et al. 2015). The sample size was computed as follows:  $A/B \times 150$ , where A is the registered voter population of the constituency and B is the registered voter population of the county. The sample size of each constituency within each county was determined based on data of registered voters for the 2013 general elections in Kenya. The individual participants were selected through a non-probability survey sampling technique, the snowball sampling method (Snijders 1992); three LA participants were identified initially by the agricultural extension officer of each constituency. One hundred and fifty current and previous LA farmers were interviewed per county for a total of 600 farmers in all the four counties (150 × 4). The number of constituencies included in each county varied for the farmer survey because the distribution of registered voters differed among constituencies. The number of constituencies for each county was Kiambu, 11; Kiisi, 9; Kisumu, 6; and Vihiga, 4. Two enumerators fluent in English and native speakers of Kiswahili were trained on survey methods and questionnaire administration for face-to-face survey interviews of 600 farmers in four counties. The farmers who were interviewed had grown or were growing LA at the time of the survey. Farmer surveys were completed in Kiswahili from May to July 2014. The interviews lasted approximately 30 min for female and 1 h for male respondents.

Focus group discussions of farmers were completed in each of the four counties in one constituency different from the constituencies of

the farmer survey and with the highest number of registered voters. The agricultural extension officer of each constituency identified the first three LA farmers and all additional farmers were identified through the snowball sampling method. In each constituency and in each county, two focus discussions of LA farmers were held. One group had 12 males and another had 12 females. The groups were separated within genders by two age ranges, age 26–35 yr, considered youth, and 36–40 yr, considered adults. Concurrent discussions of both female and male focus groups were held in each constituency to prevent respondents from exchanging ideas and influencing each other's responses before participation (Elias 2013). Discussion questions were translated into Kiswahili (e.g., [Supp Table S2 \[online only\]](#)).

Interviews with key informants were completed in each of the four counties in the same constituency as the farmer focus group discussions. Key informant interviews collected experts' perceptions using semi-structured interviews (Harrell and Bradley 2009). These interviews, aimed at obtaining the experts' input, were conducted by the principal investigator in English and a Kiswahili translator assisted if a participant requested clarification (e.g., [Supp Table S3 \[online only\]](#)). The agricultural extension officer of each constituency identified the key informants. The interview was conducted one-on-one at the participant's place of employment in a location that provided privacy in each of the four counties.

### Research Approval

Approval for research involving human participants was granted by the Director, Directorate of Performance Contracting and Appraisal and Associate Professor, College of Agriculture and Natural Resources, School of Agricultural and Environmental Sciences, Department of Horticulture and Food Security, JKUAT. Additional approval was granted by the Director Board of Post Graduate Studies, JKUAT.

### Data Analysis

Quantitative data were summarized. Data recorded in the survey questionnaire were coded and entered into a Microsoft Excel spreadsheet and subsequently transferred to SPSS (release 11.0, SPSS Inc., Chicago, IL) so that descriptive and correlation analysis could be used to address objectives of the study. Pearson  $\chi^2$  was used to test for differences in variables of interest across the four counties. Cross tabulations were used to determine the relationships among counties and included 3 degrees of freedom. Associations and correlations between variables were conducted using Fisher exact test and Cramer's V test, respectively. Analyzed variables included constraints of production, key pests, and practices used by farmers for pest control in LA. Qualitative data were summarized, narrated, and described.

## Results

### Demographics of Farmers

A majority of the farmers in the survey were female (59.2%) ([Table 1](#)). Kisii County respondents had a higher percentage of females (80.7%) compared with Kisumu (56.7%), Vihiga (50.7%), and Kiambu (48.7%) counties. The age range was between 22 and 85 yr, with an average age of 37 yr. The education level of respondents showed 48.8% had attended primary school and 79.3% were married. A majority of the respondents (71%) had less than 0.25 acres (<0.1 ha) of land in LA production; the highest numbers in Vihiga (79.3%), Kiambu (77.3%), and Kisii (74.7%) counties had less than

0.25 acres (<0.1 ha) for LA production. The number of respondents who grew LA on 0.5 acres (0.2 ha) was higher in Kisumu (17.3%) and Kiambu (7.3%) compared with Kisii (2.7%) and Vihiga (0.7%) counties.

### Gender Similarities and Differences

A Cramer's V test showed a positive correlation (0.70 to 0.71) between female and male respondents for demographics, production, major constraints, major insects, synthetic insecticide use, frequency, application rates, and effectiveness and nonsynthetic control. Thirty-two percent and 47% of female and male respondents, respectively, had attained primary education. Of the women who attained primary education, 26% and 2% completed secondary and university levels, respectively, as compared to 32% and 7% of the men who attained the same levels. Nineteen and 11% of the women and men respondents, respectively, did not attend school. The average age of female respondents was 39 yr, whereas it was 35 yr for male respondents. Two percent of the women and 0.8% men did not know their actual age. Forty-one percent of the women and 48% of men grew LA more than five times, while, 13% of the women and 13% men did not grow in the last 2 yr. Ninety percent of the women and 94% men grew LA one to five times in the previous season. Nine percent of the women and 5% men did not grow LA in the previous season. For women, capital (39%), market (30%), and land (21%) were constraints compared with 24% of men who said capital and markets were constraints, and 9% who mentioned land. More than 31% of women used synthetic insecticides, of these 3% of the women could not remember the insecticides they used, whereas 38% of men used insecticides and all of them remembered the insecticides that they used. Eighty-six percent of the women and 90% of the men used ordinary wood ash as an alternative to synthetic insecticides. However, 17.3 and 9% of women and men, respectively, used other alternatives such as plant teas of marigold (*Tagetes erecta* L.), chili pepper (*Capsicum annum* L.), intercropping, and rouging of plants infested with aphids.

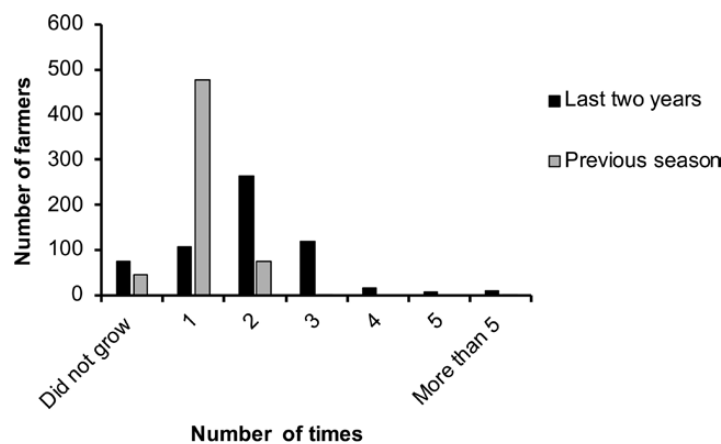
### Amaranth Production

Survey respondents who reported growing LA in 2014 before the survey were 92.5% of the total farmers; of those farmers producing LA in the previous season, 85.9% grew LA once in the season, 13.5% twice, and 0.5% three times and one farmer grower LA crops more than three times in a season ([Fig. 1](#)). Respondents who reported that they grew LA in the two previous years (2012 and 2013) and before the previous season included 87.7% of the 600 farmers, and of these, 20.5% grew one LA crop, 50.2% grew two LA crops, 22.6% grew three LA crops, and 3% grew four LA crops. Between 0.2% and 1.5% of farmers grew between five and 12 LA crops in the 2-yr period. Of all 600 survey participants, 39.3% grew LA as a monocrop, 47% as an intercrop, 2.7% used both monocrop and intercrop production systems, and 11% did not grow LA in the previous 2 yr. LA farmers grew additional leafy vegetables of kale and collards (*Brassica oleracea* L.), African nightshade (*Solanum scabrum* Mill.), Swiss chard (*Beta vulgaris* L.), cat's whiskers (*Cleome gynandra* L.), slender leaf (*Crotalaria brevidens* Benth), and sunn hemp (*Crotalaria juncea* L.) in monocrop and intercrop production systems.

In Kisumu, 55.3% of farmers saved seed from previous harvests compared with farmers in Kiambu (13.3%), Kisii (18%), and Vihiga (8.6%) counties. Forty-six percent of LA farmers in Kiambu and 18% in Kisumu obtained seed from agricultural and veterinary

**Table 1.** Demographic characteristics of leafy amaranth farmers surveyed in four counties in Kenya,  $n = 600$ 

Characteristics	Number of farmers				Total no. of farmers	Percentage (%) of total farmers
	County					
	Kiambu	Kisii	Kisumu	Vihiga		
<b>Gender</b>						
Male (M)	77	29	65	74	245	40.8
Female (F)	73	121	85	76	355	59.2
<b>Average age (y)</b>						
Below 25	3	8	11	13	35	5.8
26–40	67	83	76	51	277	46.2
41–60	49	44	44	47	184	30.7
Over 60	25	12	19	37	93	15.5
Don't know	5	2	0	2	9	1.5
No response	1	1	0	0	2	0.3
<b>Education level</b>						
None	29	14	36	17	96	16.0
Primary	63	80	81	69	293	48.8
Secondary	43	51	30	48	172	28.7
Tertiary/UN	14	2	2	9	27	4.5
No response	1	3	1	7	12	2.0
<b>Marital status</b>						
Single	10	6	6	13	35	5.8
Married	111	128	119	118	476	79.3
Separated/divorced	8	0	2	2	12	2.0
Widowed	21	16	23	17	77	12.8
<b>Farm size (acres)</b>						
None	2	26	0	27	55	9.2
<0.25	116	112	79	119	426	71
0.25	14	8	24	2	48	8
0.5	11	4	26	1	42	7
1.0	3	0	17	1	21	3.5
2.0	2	0	3	0	5	0.8
>2.0	2	0	1	0	3	0.5

**Fig. 1.** Number of farmers reporting the number of times they grew leafy amaranth in the last 2 yr (2012 and 2013), the previous season (2014), both time periods (2012 and 2013, 2014), or not at all. Survey included 600 farmers in four counties in Kenya.

supply stores, while farmers in Kisii and Vihiga did not purchase seed, but used farmer-saved seed or other sources. In Kisii, 6.6% of the respondents obtained seed from a Kenyan government agricultural program. Alternative sources of seed that was not purchased included other farmers, extension officers, relatives, friends, churches, neighbors, universities, and rural outreach programs. In Vihiga and Kisii, 63.3% and 54.7% of the respondents grew LA for home consumption only, while 44% and 44.7% in Kiambu and Kisumu grew it for sale only.

### Major Constraints to LA Production

Survey respondents reported pests of insects (54.8%) and birds (49.3%), market (27.8%), capital to invest in LA production (27.2%), and land for production (15.8%) as the major constraints of LA production in all the four counties (Fig. 2). A higher number of respondents listed insect pests as a major constraint in Kiambu and Kisumu counties, whereas in Kisii, the number of respondents indicating insects as a major constraint was lower than that of Vihiga. Aphid ( $\chi^2 = 83.1$ ,  $df = 3$ ,  $P = 0.001$ ), cutworm (*Agrotis*

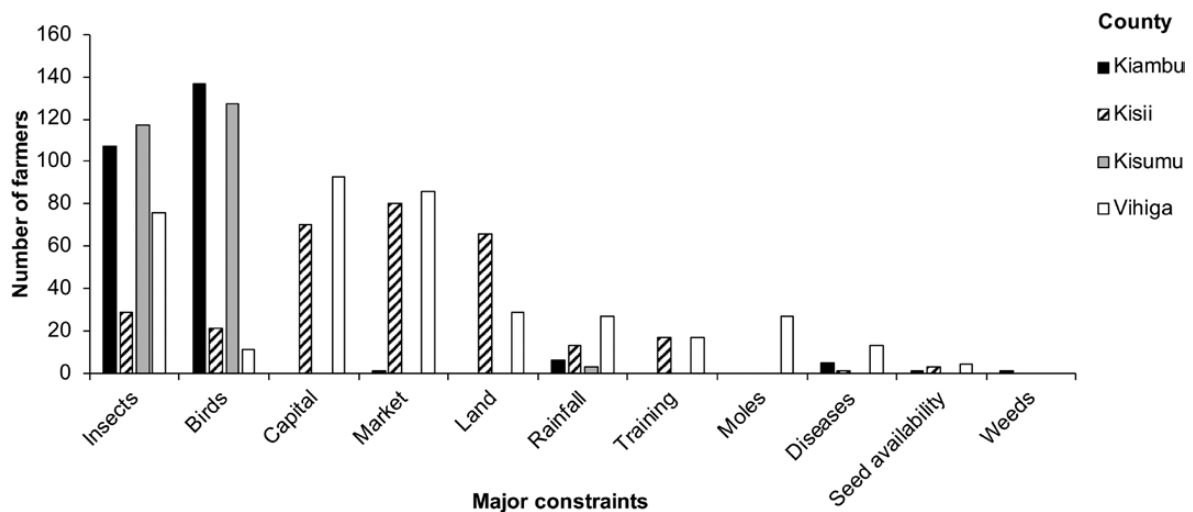


Fig. 2. Number of farmers in four counties in Kenya who stated various constraints of leafy amaranth production. Survey included 600 farmers and more than one constraint could be stated.

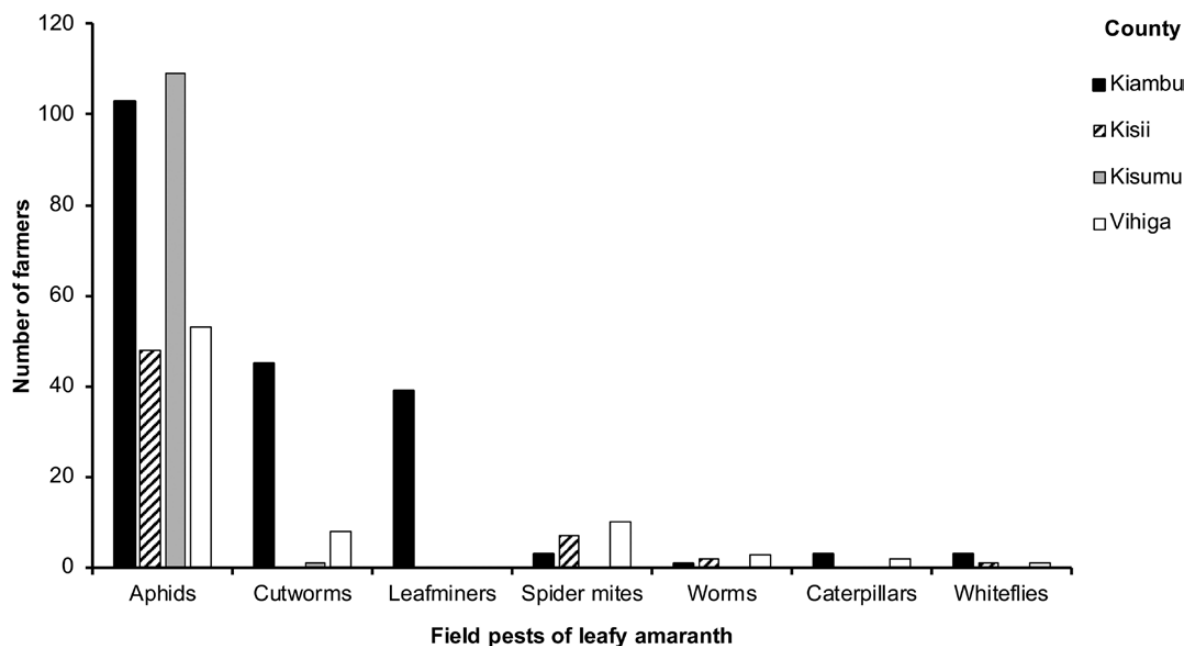


Fig. 3. Number of farmers in four counties in Kenya who stated various field pests of leafy amaranth production. Survey included 600 farmers and more than one pest could be stated.

spp), ( $\chi^2 = 110.8$ ,  $df = 3$ ,  $P = 0.001$ ), leafminer (*Liriomyza* spp Diptera; Agromyzidae), ( $\chi^2 = 125.1$ ,  $df = 3$ ,  $P = 0.001$ ), and spider mite (*Tetranychus* spp Trombidiformes; Tetranychidae) ( $\chi^2 = 12.0$ ,  $df = 3$ ,  $P = 0.007$ ) were reported as the major insect pests of LA in the four counties (Fig. 3). Among the 329 respondents who reported insect pests as a major constraint, 87.2% indicated that aphids were the main field pest of LA. Aphids as a pest in LA production were cited by 52.2% of all survey respondents and varied across counties surveyed Kisumu (72%), Kiambu (68%), Vihiga (38%), and Kisii (32%). Among the respondents who cited aphids as a major insect pest, 96.8% ranked it as the number-one and key field insect pest of LA. Fisher's Exact Test showed a strong association between farmers indicating insect pests as a major constraint to LA production and aphids as the major pest ( $P = 0.001$ ), and Cramer's V test indicated a positive correlation (0.77) between the two variables of insect pests

and aphids. Both female and male participants of the focus group discussions and key informants also ranked aphids as the major pest of LA.

Other field pests of LA stated by respondents included cutworms (ranked as first by 0.8% of respondents) and spider mites (ranked as first by 0.7% of respondents). In Kiambu County, 30% of respondents stated cutworms and 26% indicated leafminers were important concerns. In Vihiga, 6.6% of respondents indicated that spider mites were an important pest. Additional pests of LA were described by participants of the farmer focus group discussions and included beet webworm (*Spoladea recurvalis* Fabricius) and generally described others, including caterpillars, cutworms, stem borers, thrips, whiteflies, and spider mites. Key informants described whiteflies, spider mites, and moles. Constraints to LA production in addition to insects varied among counties and included birds ( $\chi^2 = 361.6$ ,

df = 3,  $P = 0.001$ ), capital ( $\chi^2 = 232.7$ , df = 3,  $P = 0.001$ ), markets ( $\chi^2 = 226.5$ , df = 3,  $P = 0.001$ ) and land available for production ( $\chi^2 = 147.1$ , df = 3,  $P = 0.001$ ) (Fig. 2). Weeds, seed availability, diseases, training, moles, and rainfall were cited by less than 27% of the respondents.

Key informants stated constraints for farmers were lack of information on how to acquire seeds, competition with other leafy vegetables that are consumed, a lack of knowledge about the production of LA, infertility of the soil, small production fields, and diseases. Birds and domestic animals, including chickens, also are stated as constraints of LA production by participants of the focus group discussions with farmers and key informant interviews.

Survey respondents were asked to describe the symptoms of aphid infestation on LA. They summarized the symptoms of aphids as leaf curling, stunted growth, leaf holes, wilt, and low yields. Respondents in Kisumu (49%), Kiambu (43.2%), Vihiga (4.8%), and Kisii (3.0%) considered leaf curling as the most important symptom of aphids, followed by stunted growth. Leaf curling was stated by 35.3 and 32% respondents in Vihiga and Kiambu counties, respectively, who indicated aphids were a problem. In Kisumu and Kiambu, 72.6 and 68.6% respondents, respectively, also indicated leaf curling from aphids was a problem (Fig. 3).

### Seasonal Infestations of Aphids on Amaranth

In Kiambu and Kisumu aphid infestations were considered a serious problem only during the second season, as reported by 51.3 and 50% of the survey respondents, respectively. Seasons differ in their time and rainfall. The first season occurs in March through May, has a higher total rainfall with continuous precipitation than the second season, and corresponds with the major East African agricultural season. The second season occurs in the months of October through December and is characterized by lower rainfall totals from continuous precipitation. In Kisii and Vihiga, less than 50% of farmers considered aphid as a serious pest and stated that higher severity

occurred during the dry season (January through February). More than 50% of respondents did not relate a season with incidence of aphid populations. Key informants stated that LA is grown in the seasons with rains and harvested before the warmer dry season, to avoid higher infestations of aphids.

### Insect Management Practices

Survey respondents who managed aphids used two methods to control insect pests, synthetic insecticides ( $\chi^2 = 56.8$ , df = 3,  $P = 0.001$ ) and nonsynthetic methods ( $\chi^2 = 29.6$ , df = 3,  $P = 0.001$ ) (Table 2). Weak correlations between counties and pest control methods occurred, an  $r$  value of 0.31 for synthetic insecticides and 0.22 for nonsynthetic pest control methods. Percentage of respondents who controlled insects using insecticides was 34.1 and 7.6% used nonsynthetic methods. The primary nonsynthetic method was dusting with wood ash. Other nonsynthetic methods included various plant teas of marigold, chili pepper and/or a local mix of plants applied to foliage. Two percent of respondents controlled aphids using cultural practices of intercropping and 2% of the farmers rogued infested plants (Table 2). Biological controls, such as pathogens, parasites and predators or using host-plant resistance were not mentioned by any respondents in the farmer survey, focus group discussions, or key informant interviews.

The main synthetic insecticides or insecticide mixes stated by farmers using insecticides ( $n = 205$ ) included diazinon 600 g/liter (Dizon 60EC) (31.7%), lambda-cyhalothrin 50 g/liter, (Duduthrin, Karate and Pentagon SECTM) (27.3%), cypermethrin 10% wv + chlorpyrifos 35% w/v (Cyclone505EC) (13.2%), deltamethrin 25 g/liter (Decis 2.5EC) (4.4%), alpha-cypermethrin 10 g/liter (Tata Alpha 10EC) (4.4%), thiamethoxam 250 g/Kg (Actara 25WG) (1.9%), dimethoate 400 g/liter (Twigathoate 40 EC) (1.9%), permethrin 20, 40, and 60% (Ambush 25DC, formerly permethrin 25WP) (1.5%), propargite 21.2%+ tetradifon 7.5% (Dictator Plus 28.7EC) (1.0%) (Table 3). Three farmers reported using metalaxyl-M 40 g/Kg +

**Table 2.** Practices used by farmers who controlled aphids on leafy amaranth in four counties in Kenya

Insect pest control methods	Number of farmers				Farmers using control <sup>a</sup> (no.)	All farmers surveyed <sup>b</sup> (%)	$\chi^2$	P-value
	Kiambu	Kisii	Kisumu	Vihiga				
Synthetic insecticides	89	37	37	42	205	34.17	56.8	0.0001
Lambda-cyhalothrin	39	1	16	0				
Cypermethrin + chlorpyrifos	17	0	10	0				
Diazinon	1	31	0	33				
Other types	31	7	20	9				
Cannot remember	1	2	1	0				
Nonsynthetic methods	3	2	21	20	46	7.67	29.6	0.0001
Ordinary wood ash	2	0	21	17				
Mexican marigold ( <i>Tagetes spp.</i> )	0	0	0	2				
Hot pepper or chilies ( <i>Capsicum annum L.</i> )	0	1	0	0				
Local mix <sup>c</sup>	0	1	0	0				
Intercropping	0	0	0	1				
Roguing	1	0	0	0				

The Chi-square test ( $\chi^2$ ) was used to determine the value of the Chi-square test statistic. Significance indicated by  $P$ -value.

<sup>a</sup>Farmers using pest management practices of synthetic insecticides or nonsynthetic control methods,  $n = 251$ .

<sup>b</sup>Percent of all farmers surveyed includes total farmers who used synthetic insecticides or nonsynthetic control methods divided by the total number of farmers in the survey ( $n = 600$ ).

<sup>c</sup>Local mix is created by a mixture of plant extracts from a local source; formulations vary.

mancozeb 640 g/Kg (Ridomil Gold MZ 68WGTM) a fungicide, to control insect pests on LA. Pesticides were received by farmers in labeled and unlabeled containers.

In Kiambu, 46 and 28% respondents applied insecticides once per week or every 2 wk, respectively, whereas farmers in Kisumu (59.4%) and Kisii (37.8%) applied them every 2 wk (Fig. 4). In Vihiga, 23.8% of the respondents could not estimate the number of times they applied insecticides and 30.9% could not estimate an application rate. Farmers reported using an application rate ranging from less than 5 ml or g to more than 20 ml or g of the insecticide in 15 or 20 liters of water. Application rates varied among counties with the most common as 5 to 20 ml of pesticide per 15 or 20 liters of water. Farmers in Kiambu used higher application rates compared to farmers in the other three counties. Farmers who were unable to estimate the rate of application stated they had purchased small quantities of insecticides at the time of application.

The highest number of respondents who used synthetic insecticides to control aphids in LA and found them to be medium and highly effective was in Kiambu County (Fig. 5). Vihiga respondents rated their insecticide use as low in effectiveness. Kiisi County had the highest number of respondents who did not know how to rate the effectiveness of the insecticides they used in aphid control (Fig. 5).

## Discussion

LA production as a vegetable is regarded as a predominantly female occupation in Kenya (Muyonga et al. 2010, Onyango et al. 2016). Female farmers have access to, but limited control over, land. If the land is available for vegetable production, females typically grow vegetables including LA to provide food for the family and to generate personal income (Ogunlela and Mukhtar 2009, Nambiri 2010). Although more women are involved in LA production as compared with men, they are more challenged by land, capital, and markets (Twyman et al. 2015, Cheryl 2018). Gender inequalities in vegetable production have been investigated by Coles and Mitchell (2011).

Women lack access and ownership to land, access to credits and markets, in addition to higher illiteracy rates, all of which resulted to an economic disadvantage (World Bank 2009, Laven et al. 2012). The customary land laws deny women access to land, since land traditionally is inherited by men, thereby creating an insecure situation for women regarding the land they cultivate (Leavens and Anderson 2011). Men dominate the sale processes, resulting in higher income for men in small-landholder agriculture (Osori et al. 2014). All this hinders women positive development in regard to benefiting from LA production.

The majority of survey respondents were between the ages of 26 and 40 yr, when individuals are more likely to be innovative, and thus open to learning new production and pest management practices. Ayua and Omware (2013) noted that people of average age of 35 yr in another Kenyan county were passionate about innovation.

Over half of the survey participants had no or only primary school education, which may limit farmers' understanding of integrated pest management (IPM) concepts and practices to manage aphids on LA. Both men and women had attained some primary education. Free primary education in Kenya has increased access to primary education in the past decade (Glennester et al. 2011). However, primary to secondary transition rate has been low (Ministry of Education 2010). From the age of 14 yr school attendance begins to decline with more male than female youth attending, due to marriage and giving birth (Kenya National Bureau of Statistics and ICF Macro 2010). The same demographic and health survey also noted that more women than men had never attended school. Women in this study had limited formal or no education which might affect their ability to read and understand synthetic insecticide labels for correct and safe use of insecticides, and to avoid exposure risks (Al-Zadjali et al. 2015).

Small land areas, less than 0.25 acre (<0.1 ha), were used by a majority of the farmers surveyed although farmers in Kiambu and Kisumu counties grew LA on larger land areas (0.5 acre, 0.2 ha), possibly due to a proximity advantage for vegetable markets

**Table 3.** Formulation and application rates of synthetic insecticides used to control aphids as stated in a survey of leafy amaranth farmers in Kenya, *n* = 205

Trade name and type of formulation in Kenya	Common name and active ingredient	Common name and active ingredient	Application rate used by farmers (ml in 15/20 liters of water)
Dispersible granules			
Actara 25WG	Thiamethoxam 250 g/Kg	Thiamethoxam 250,000 mg/ha	5 and 20
Ridomil Gold MZ 68 WG	Metaxyl -M 40 g/Kg + mancozeb 640 g/Kg	Metaxyl -M 40,000 mg/ha + mancozeb 640,000 mg/ha	Cannot estimate
Wettable powder			
Ambush 25DC (formerly permethrin 25 WP)	Permethrin; 20, 40, and 60%	Permethrin 200,000 mg/ha 400,000 mg/ha and 600,000 mg/ha	10 and 20
Emulsifiable concentrates			
Cyclone 505 EC	Cypermethrin 10% w/v + chlorpyrifos 35%w/v	Cypermethrin 100,000 mg/ha w/v + chlorpyrifos 350,000 mg/ha w/v	5, 10, 15, 20 > 20
Decis 2.5 EC	Deltamethrin 25 g/liter	Deltamethrin 25,000 mg/ha	5, 15, 20
Dizon 60 EC	Diazinon 600 g/liter	Diazinon 600,000 mg/ha	5, 10, 15 and 20
Dictator Plus 28.7 EC	Propargite 21.2% + tetradifon 7.5%	Propargite 212,000 mg/ha + tetradifon 75,000 mg/ha	5 and 20
Duduthrin 5 EC	Lambda-cyhalothrin 50 g/liter	Lambda-cyhalothrin 50,000 mg/ha	<5, 5, 10, 20, and >20
Karate 5 EC	Lambda-cyhalothrin 50 g/liter	Lambda-cyhalothrin 50,000 mg/ha	10
Pentagon 5 EC	Lambda-cyhalothrin 50 g/liter	Lambda-cyhalothrin 50,000 mg/ha	5 and 20
Tata Alpha 10 EC	Alpha-cypermethrin 10 g/liter	Alpha-cypermethrin 10,000 mg/ha	5, 10, 15, and 20
Thunder 145 O-TEQ	Imidacloprid 100 g/liter+ betacyfluthrin 45 g/liter	Imidacloprid 100,000 mg/ha + betacyfluthrin 45,000 mg/ha	Cannot estimate
Twigathoate 40 EC	Dimethoate 400 g/liter	Dimethoate 400,000 mg/ha	15 and 20

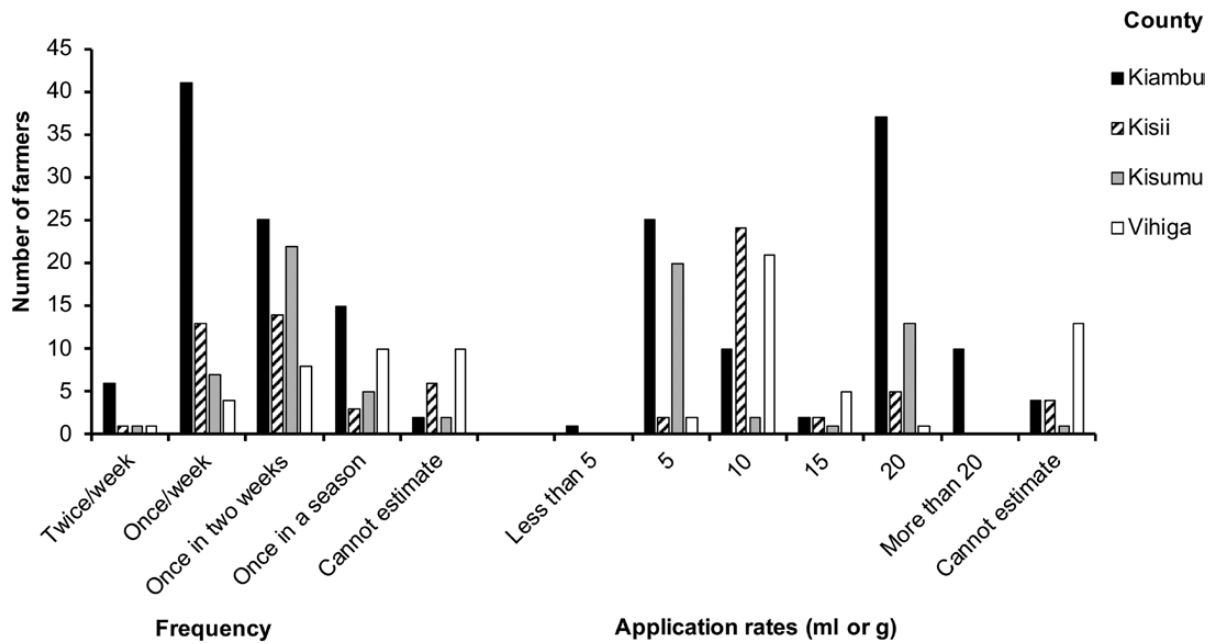


Fig. 4. Number of farmers in four counties in Kenya stating the frequency and rate of insecticides application they used to control aphids in leafy amaranth production. Survey included 600 farmers.

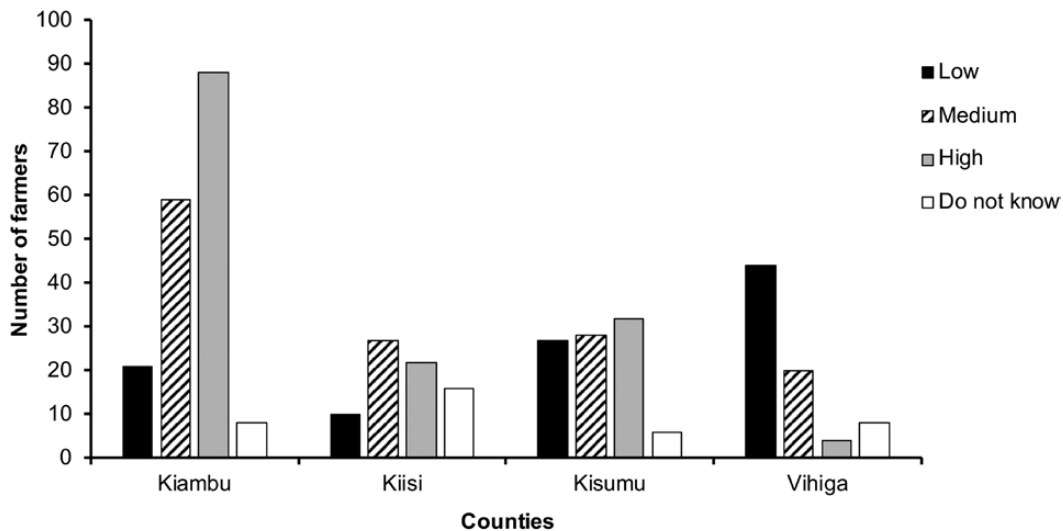


Fig. 5. Number of farmers in four counties in Kenya who stated the effectiveness of using insecticides to control aphids in leafy amaranth production. Survey included 600 farmers.

when located in peri-urban areas of the transition zone from rural to cities (Otieno et al. 2009). Ngugi et al. (2007) found that Kiambu farmer groups in central Kenya successfully enter high-value market segments for leafy indigenous vegetables due to the county's close proximity to the city of Nairobi. Most farmers saved seed from the previous harvest to use as planting material, indicating that the seed system is underdeveloped for LA (Abukutsa-Onyango 2007, Achigan-Dako et al. 2014). An informal seed saving and trading system for domestic production of indigenous leafy vegetables has been reported by Ayieko and Tschirley (2006).

Insect infestation causes low yields and quality in amaranth (Aderolu et al. 2013, Kagali et al. 2013). Species diversity and abundance of insect pests associated with amaranth species vary by location and season (Aderolu et al. 2013). Earlier work by Muyonga et al. (2010) found that aphids were a major field pest of grain

amaranth in Uganda. Aphids are one of the major insect pests that damage LA, causing leaves to curl and become unsalable to customers (World Vegetable Center 2003). Among aphid species, the green peach aphid, *Myzus persicae* Sulzer (Hemiptera: Aphididae), is recognized as one of the most destructive insect pests of LA (Mureithi et al. 2017). The female participants in focus group discussion in Vihiga county described symptoms of aphids on LA: 'The infested plants infect other clean plants, which leads to low output and lack of enough vegetables for home consumption and sale, low income due to loss of money that was used to buy pesticides, and no market caused by low quality and quantity of leafy amaranth vegetables produced.' A principal option for growers to protect their crops from aphids is to use synthetic insecticides. Without proper application, insecticides may have deleterious effects on beneficial insects and lead to the development of insecticide resistance, secondary



pest outbreaks, excessive pesticide residues, and soil and water pollution (Macharia et al. 2013). Different mechanisms of resistance to insecticides have been identified in *M. persicae* (Sulzer) that enable this species to withstand many insecticides (Bass et al. 2014). Some insecticides are lethal to ladybird beetles, lace wings, and earwigs (Garzon et al. 2015, Malagnoux et al. 2015). The spider communities also are affected by the use of insecticides (Gaelle et al. 2016).

Other LA pests were mentioned by the study participants. Six percent of the farmers mentioned red spider mite (*Tetranychus urticae*) as one of the major pests. It is unknown if predatory mites are present in the four counties on LA, which could help with the control of red spider mite. Effective predatory mites, such as those described by Furtado et al. (2007) could be used. The pea leafminer *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae) has been reported in Kenya and Tanzania, which attacks cultivated and wild amaranth, and burrows irregular white mines on the leaves (Foba et al. 2015). Leaf holes were mentioned as one of the symptoms of aphids by the survey respondents. However, aphids do not cause this symptom and amaranth is attacked by other herbivorous arthropod pests that feed on various plant parts, including roots, stems, flowers, seeds and leaves (Mureithi et al. 2017).

Both men and women used alternatives to control aphids in LA. Botanicals such as exotic garlic, neem oil, papaya leaves, and wood ash may reduce insect pest populations (Mochiah et al. 2011). The side effects of insecticides could be reduced by application of less toxic substances, such as insecticidal soap or botanicals, (Karagounis et al. 2006, Murray 2006). Companion plants (Refka et al. 2017) and plant extracts, including those from *Tagetes* species (Asteraceae) (Blagovesta et al. 2005, Gayatri and Sahu 2017, Salehi et al. 2018) and chili (*Capiscum annuum*) (Hussein and Abdul Samad 2008) may be alternative methods. Plant essential oils (Murray 2000, 2016) can act as feeding deterrents and repellents (Lee 2018); these products could be incorporated into an IPM program that offers a variety of control measures.

Respondents in Kiambu and Kisumu counties considered birds as a major constraint. Kiambu's landscape has forests, which provide habitat for wildlife, including birds. Lack of information on the general associations of birds living near or within the agricultural land of the four counties suggests further studies to determine the ecology of farm-related birds in agricultural landscapes of the two counties.

An IPM approach to aphid management was not employed by LA farmers in the study. A high percentage of respondents reported using only insecticides to control aphids although Muyonga et al. (2010) and Wekesa (2010) found low insecticide use for controlling aphids in grain amaranth in Uganda and the Kisumu County of Kenya. Grain amaranth differs from LA, in that marketable fresh leaves are the production goal of LA.

Most LA farmers relied on insecticides for aphid management, similar to Akotsen-Mensah et al. (2017) who found that most mango farmers use insecticides for insect pest control. Farmers in Kiambu reported applying insecticides once per week or more in the growing season and used higher application rates. They assumed that the only solutions to aphid infestations were to spray more frequently and use higher application rates, which they believed caused medium and highly effective insect control. De Bon et al. (2014) indicated that although insecticide use in Africa is the lowest in the world, vegetable growers often depend on insecticides to control pests due to the rapid control results obtained following application. Some farmers used nonsynthetic products of plant tea extracts and wood ash applications. Others noted aphid control methods included ash and a mixture of tobacco and ash applications (Sithanatham et al. 2004, Muyonga et al. 2010). Cultural practices used for aphid control by

two farmers included roguing of infested plants and intercropping, but other strategies such as exclusion by covering the plants or using resistant cultivars were not mentioned.

Our survey respondents could state insecticide trade names but not common names. Nyakundi et al. (2010) reported a lack of awareness about common names of insecticides in Kenya. Respondents used insecticides classified as class II by the World Health Organization, a class of insecticides considered moderately hazardous (Mutuku et al. 2014). Thirty-four percent of the farmers used insecticides to control aphids and the most commonly used insecticides reported by farmers surveyed were Cyclone 505EC (cypermethrin 10% and chlorpyrifos 35% w/v), Dizon 60EC (diazinon), and Duduthrin 5EC (lambda-cyhalothrin). Matthews et al. (2003) found cypermethrin, diazinon, and dimethoate insecticides commonly used on a wide range of vegetables in Cameroon. Other insecticides used by vegetable farmers in East Africa included Ambush 25DC (permethrin), dimethoate, and Karate 5EC (lambda-cyhalothrin) (Sithanatham et al. 2004). Key informants stated that insecticides used by farmers included Actara (thiamethoxam), Dizon (diazinon), Duduthrin (lambda-cyhalothrin), dimethoate, Karate (lambda-cyhalothrin), permethrin, and tetradifon. A county extension expert stated, 'Farmers use Karate (lambda-cyhalothrin) and dimethoate because they don't want insecticide residues and the vegetables can be harvested and sold within seven days.' Of concern is the use of dimethoate insecticide since its use was banned on fruits and vegetables by the Government of Kenya (Mutuku et al. 2014). Inappropriate use of insecticides can lead to insecticide resistance, residues, pest resurgence, secondary pest infestations and applicator safety and consumer health concerns (McKinney and Schoch 2003, Tiwari et al. 2011).

The primary supplier of insecticides was agricultural and veterinary shops. An agricultural extension officer as a key informant stated, 'Farmers receive advice on aphid management mainly from agro-veterinary shops where they buy insecticides. Other sources of advice include fellow farmers.' Epstein and Bassein (2003) similarly reported suppliers influencing the choice of insecticides used. Sithanatham et al. (2004) also reported that farmers purchase insecticides from local agricultural and veterinary suppliers. Insecticide containers ranged from factory-sealed and labeled to small quantities put into an unlabeled farmer-supplied container. A community leader serving as a key informant stated that some farmers use insecticides without knowing their chemical names.

The reported frequency of LA pesticide application ranged from once per week or every 2 wk, similar to other published reports (Abang et al. 2013, De Bon et al. 2014, Mutuku et al. 2014). High application frequency of insecticides may decrease farmer safety if reentry intervals are not followed and increase consumers' risk of insecticide exposure if preharvest intervals are not met (Park et al. 2016). Farmers reported application rates in ml or gm per 15 or 20 liters of water without referring to the land area being treated or recommended rates of application. De Bon (2014), citing Ajayi and Akinefesi (2007), reported the difficulty of calculating a correct application rate on very small areas as one of the causes of improper insecticide use. Several farmers stated using a fungicide to control aphids, further indicating the need for insecticide training and safety education programs. Small-landholder farmers in low and middle-income countries including Kenya, are at higher risk of negative health effects from insecticides since they experience higher rates of exposure (Ajayi et al. 2011), which could be reduced for LA farmers by using an integrated IPM system with proper product selection and rate of application, when warranted.

Biological controls also were not mentioned by those surveyed. Farmers did not discuss natural enemies of aphid or the possibilities that insecticide applications might eliminate natural enemies. Survey questions did not directly ask farmers about knowledge of biological control of insect pests in LA. General pest control questions preceded those which asked about specific insecticides and no farmers surveyed mentioned biological control. Insecticides are detrimental to arthropod biocontrol (Croft 1990, Stark and Banks 2003, Desneux et al. 2007). Ladybird beetles (Coleoptera: Coccinellidae) are common predators of aphids in natural field settings (Long and Finke 2014). Lack of information about natural enemies indicates that further research is needed to determine biological and cultural control practices that may be effective in LA production system.

Host-plant resistance can be used to manage aphids (Pierson et al. 2010). Respondents did not mention the use of host-plant resistance or an LA cultivar that was resistant to aphids for aphid control method. They only mentioned an aphid-susceptible cultivar of *A. dubius*, commonly called Terere, which is the most important and widely grown LA (Achigan-Dako et al. 2014). Germplasm of many crop species have shown resistance to aphids in forms of physical plant traits and allelochemicals that affect aphid behavior and survival (Smith and Clement 2012). Future research should evaluate the types of aphid resistance in LA species grown in Kenya.

Another consideration for IPM strategies is the production and harvest periods of LA plants. Because LA is a crop that is produced from seed to leaves in 45 d and uses repeated harvests, typically for an additional 2 mo and up to 3 mo, control measures need to be effective over the production and harvest seasons.

Developing an IPM-based program for LA aphid management offers several benefits, including identifying a working aphid threshold that would more accurately target a damaging aphid population, and reducing insecticide use and therefore also exposure and costs of production. Such an IPM program could incorporate biological and cultural control measures that are missing currently in LA production systems.

## Conclusions

Our three-part hypothesis that production constraints, pest management practices, and insect pests would be similar across the four counties had mixed results. Aphids were identified as the primary insect pest of LA production for surveyed farmers in the four counties and insect pest management practices used by farmers for aphid management were similar in the four counties. However, LA production constraints expressed by farmers varied by county. Birds were cited as constraint to LA production in Kiambu and Kisumu counties. In Vihiga and Kisii access to capital, markets, and land area were reported as significant constraints. Aphids were identified as the primary insect pest of LA production, but other insect pests reported by farmers, differed by county. LA farmers in all four counties perceived insecticides as effective in aphid management.

Additional research to develop and implement an IPM program for LA could benefit production by improving arthropod identification, reducing insecticide dependency and costs, utilizing additional alternative management strategies, and utilizing a treatment threshold. Development of an economic threshold for aphids, identifying tolerant or resistant LA cultivars and natural enemies of pests, and improved knowledge of cultural and biological controls could improve the sustainability of LA production in Kenya. Training Kenyan LA farmers about IPM practices, management options, correct selection and application procedures of labeled insecticides, and incorporating cultural and biological control of aphids in the LA production system will contribute to sustainability. IPM

strategies can reduce the cost and increase the efficacy of managing aphids in LA, enhance the livelihood of farmers, and supply nutritious food for small-landholder farmers and Kenyan consumers.

## Supplementary Data

Supplementary data are available at *Journal of Integrated Pest Management* online.

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