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Evaluation of Bean Common Mosaic Disease and Associated Aphid Vector, *Aphis fabae* L., on Common Bean (*Phaseolus vulgaris* L.) Production in Lower Eastern Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Production of common bean in Kenya is constrained by pests and diseases and to improve bean yields amongst majority small-scale farmers, appropriate management strategies should be adopted. Bean common mosaic disease (BCMD) caused by bean common mosaic virus and vectored by bean aphids and infected seeds, substantially inhibit common bean production in Kenya. An extensive and diagnostic field survey was conducted in six agro ecological zones (AEZs) of lower eastern Kenya during the long and short rains of 2018 to determine BCMD incidence (BCMD-I), severity (BCMD-S), bean aphid abundance (BAA), bean aphid incidence (BAI) and the management strategies applied by farmers. Significant (*P≤0.001*) variations observed for these traits between bean varieties, rainy seasons and AEZs implied that farmers could select and grow a tolerant bean variety or grow a variety either in a season or an AEZ with low BCMD and bean aphid pressure. Such included AEZ-UMSA with least mean BCMD-I (42%), BCMD-S (1.9) and BAI (11%) compared to two AEZs (LHSH & LM4) that showed BCMD-I of >70%, BCMD-S >3.0 and BAI >50%. The AEZs differences could be attributed to variations in

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altitudes, temperature and humidity that influences vector (aphid) movement. Of the nine bean varieties identified during the survey, Selian 14 was the most preferred by farmers (at ~35%) with relatively lower BCMD-I (~49%) and BAI (~35%) compared to the least (<5%) farmer-preferred variety Wairimu that showed higher BCMD-I (56%) and BAI (~68%). Therefore variety Selian 14 was considered tolerant to BCMD and bean aphid. Significant (*P≤0.001*) and positive correlations (r = 0.67) between BAI and BCMD-I implied an effective control of bean aphids could reduce the impact of BCMD on bean production. On visual diagnostics, >75% of farmers could generally identify diseased or pest-infested bean crops and stage of growth of the crop most affected. None (0%) could however identify BCMD symptoms although ~40% identified the vector bean aphids with ~26% implementing some form of aphid or pest management strategy. On management, season-driven early planting and bean intercropping were the most applied strategies (>80%), crop rotation and weed control accounted for ~71%, certified seeds at 1% and non-chemical or pesticide applications (0%). Both low adoption of certified seeds and no chemical aphid control were attributed to high costs, despite the possibility the two factors could have contributed to higher incidences and severity of BCMD in the study area as the disease is both seed and vector-borne. In summary, lack of knowledge and training among farmers on diagnosis and management of aphid-pests and BCMD, were cited as the main constraints for low bean cultivation. This study therefore recommends provision of adequate extension services and farmer training in lower eastern Kenya for improved bean yield and subsequent better family livelihoods and income.

Keywords: Bean common mosaic disease; bean common mosaic virus; bean aphids; pests & disease management.

1. INTRODUCTION

Common bean, (*Phaseolus vulgaris* L) is a leguminous crop grown in several countries of eastern Africa particularly Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania and Uganda [1]. The diet of more than 300 million people worldwide comprise of common bean [2]. It is the main grain legume for direct human consumption and is preferred rich source of protein, vitamins, minerals and fiber [3]. Indeed the legume provides up to 57% of necessary dietary protein and 23% of energy to Africans [4]. Due to its low levels of fats or cholesterol free, common bean consumption reduces the risk of diseases like cancer, diabetes or coronary diseases [5]. The high consumption of the crop is mostly because it's relatively cheap compared to other protein sources [6].

Kenya is the leading bean producer in East Africa with 300, 000 to 500,000 hectares under cultivation yielding approximately 40,000–150,000 metric tons per year [7]. The legume is produced practically in every region of Kenya, with a high number of small-holdings of no more than one hectare per household, primarily for subsistence with around 40% of production for commercial purposes [7]. The crop is a major staple food in Kenya where it ranks second most important source of human dietary protein and third most important source of calories [8]. Kenya's highlands and midlands produce the majority of the country's common beans with Rift Valley, Nyanza, and Eastern Provinces accounting for 75% of annual cropping. Rift Valley leads with 33% of the national output, followed by Nyanza and western provinces each accounting for 22% [9]. Climate change has hampered production in Kenya's eastern regions and along the coast [10].

Despite two growing seasons in Kenya, many farmers only grow the crop once a year due to unfavorable weather conditions. For instance, in Rift Valley and Western regions, farmers allocate land to common beans once a year, during the March-May season (also known as the long rains), whereas farmers in the central and eastern regions grow it twice a year, with only 70% of farmers in the eastern region growing it during the long rains [9]. About 80 different seed types (bean varieties) have been identified in various parts of the country with six considered the most popular. These include Rosecoco, Nyayo, Wairimu, Kitui, Mwezi Moja and Mwitemania [11,12]. Over the last four years, the ASAL-based counties of Machakos, Kitui and Makueni have had the highest number of producers/growers in pulses [4]. These counties are found in the dry areas of Kenya and are largely considered food-vulnerable due to generally unsuitable climatic conditions. Additionally due to a variety of constraints, including irregular rainfall patterns, dryness, low soil fertility, insect pests and diseases, agronomic practices, low input use, intercropping with competitive crops, weed competition and lack of better bean varieties (Ng'ayu et al., 2013, [13]), production in these areas has fluctuated over time.

Among the most common insect pests which attack common beans in the field are black bean aphids (*Aphis fabae*) which cause the yield loss of about 37% [4,14], while among major common bean diseases include bean common mosaic disease (BCMD) [15,16]. Bean common mosaic virus (BCMV) which causes Bean common mosaic disease (BCMD) and or its related necrotic species Bean common mosaic necrotic virus (BCMNV) is the most widespread virus disease in Kenya [17]. Plant infection as high as 100% has been reportedly caused by BCMV and BCMNV with yield losses of 35-100% [18], Li et al., 2014; [19]). BCMV and BCMNV are both seed-borne and aphid-transmitted, with the latter in non-persistent manner [20,21] and are closely related and belong to the Family *Potyviridae*, genus *Potyvirus* [19].

Seed transmission rates vary from less than 1% to 50% depending on the common bean cultivar and stage of maturity [22]. As a result, the crop becomes infected during its early growth phases significantly reducing bean growth and yield. Diagnostic information of bcmd and mapping its temporal distribution in AGROECOLOGICAL ZONES (AEZS) has not been exhaustively done in lower eastern Kenya. This is an essential precursor for implementation of control measures [23]. Small-scale farmers grow food crops like beans, and their land sizes rarely surpass 1.0 ha, thus they don't rotate crops or allow for fallow times [24]. This leads to a build-up of pests and diseases. Amongst most important pests of beans is *Aphis fabae*, which directly account for yield losses ranging from 37 to 90 percent [25,26,27,24]. In addition, *Aphis fabae* indirectly reduce bean yield by transmitting BCMV and BCMNV that causes bcmd. There is insignificant data or information on the status of *Aphis fabae* and BCMD and associated management strategies in Aezs in lower eastern part of Kenya.

2. MATERIALS AND METHODS

2.1 Survey Sites

Two-seasonal diagnostic surveys were carried out in the six agro-ecological zones (AEZs) in 2018 to determine BCMD infections, occurrence of bean aphids and associated management practices. The six AEZs (LM4, LM5, LHSH/LH2, UM4, UMSA/UM5 and UMSH/UM2) (were distributed across the three counties (Machakos, Makueni & Kitui) in lower eastern Kenya (Table 1a). Descriptions and characteristics of the AEZs were sourced from literature reviews [28,29].

2.2 Sampling Design and Size

Using Cochran's sampling technique; the study adopted a simple random sampling technique to determine the sample sizes. Based on KPHC [30], the total population of the six targeted AEZs was 146,174. From this population, a total sample size of 342 (Table 1b) was obtained using Slovin's formulae as indicated (Watson, 2001): $N = \{Z^2 \; P\,(1\text{-}P) + E^2\}/\,\{E^2 + [Z^2P(1\text{-}P)/N]\}$, where: N = target population; Z = 1.96; P = expected proportion in the population based on previous studies and E = marginal error (4%).

Sampling was done by stopping at regular predetermined distances of about 2 to 5 kilometers (km) (to allow for wide coverage of the survey area, between farmers' fields along major accessible roads traversing each sampling location [31]. Agricultural fields sampled were approximately 1 ha or more in size. The farmers who participated in the study were chosen by random sampling with questionnaires and face to face interviews used to collect data. Sampling was timed at minimum of four weeks after emergence when aphid infestation and virus symptoms could be easily observed.

Table 1a. Description of the various agro-ecological zones (AEZs) under study

AEZs	GPS	Average Altitude (meters asl)	Annual Mean temp (ºC)	Annual Av. rainfall (mm)
LM4	0°45'S; 36°45'E	1219	22.0-17.9	700-850
LM5	1.37°S; 38.02°E	1204	24.0-21.6	600-800
LHSH/LH2	1º35'S; 37°10´E	1829	17.9-16.0	1000-1300
UM4	1°31'S; 37°45'E	1340	20.9-17.9	700-809
UMSA/UM5	3°00´S; 38°30´E	1853	20.2-18.6	550-600
UMSH/UM2	0º30'S; 37°27'E	1981	20.5-18.1	980-1200

Source: Amukono, [28]; Mariara and Karanja [29]; asl = above sea level

Table 1b. Sample size from each AEZ based on Slovin's formulae

AEZs	Number of farmers
LM4	80
LM5	61
LHSH/LH2	59
UM4	97
UMSA/UM5	22
UMSH/UM2	23
Total	**243**

2.3 Bean Aphid Abundance and Incidence

Bean aphid abundance (BAA) was determined by sampling 30 plants randomly selected in a field. The number of bean aphid per plant were counted and BAA scored using a visual rating scale of 0 – 3 as described by Ochilo and Nyamasyo [14], where: 0 = No Aphids present; 1 = < 50 aphids/plant; 2 = 51 – 100 aphids/plant and 3 = >100 aphids/plant. Bean aphid incidence (BAI) was calculated as percent number of infested plants over total number of plants assessed [32].

2.4 BCMD Incidence and Severity

Symptoms associated with leaf mosaic, plant stunting and leaf malformations were the main criteria for identification of BCMD in the field [33]. A total of 30 plants were assessed along diagonals in each farmer's fields. From these plants, BCMD-I was calculated as a proportion or percent of clearly symptomatic plants expressed as a percentage of the total number (30) of plants sampled [34]. The BCMD severity (BCMD-S) was estimated by scoring the leaf symptoms using a scoring scale as described by Manandhar et al. [35] where: 1 = No symptom; 2 = mild symptom; 3 = moderate symptom; 4 = severe and widespread symptom and 5 = severe symptom with likely loss in yield.

2.5 Management of BCMD and Bean Aphids

Data on methods or practices applied by farmers to manage BCMD and bean aphids were collected through interviews and questionnaire. The questionnaires sought to establish the main common bean varieties grown, cropping systems, source of seeds, and time of planting, bean growth stages, weeding, intercropping, and knowledge on identification of insect-pests and disease symptoms by farmers and control methods they applied.

2.6 Data Analysis

Using Gensat software ver. 18, data on BCMD-I, BCMD-S, BAA and BAI were subjected to analysis of variances (ANOVA) with variations determined at the seasonal, AEZs and bean variety levels (independent variables). The means were separated by the least significant difference (LSD) test at P≤0.05) and standard deviations. Data on diagnostics and management of BCMD and aphids were analyzed by Microsoft Excel. Results were presented in tables and graphs.

3. RESULTS

3.1 Foliar BCMD Symptoms and Bean Aphids

Compared to healthy bean plant or leaf (Fig. 1a), typical BCMD symptoms were observed during the survey. This included a light green or yellow mosaic pattern on the leaves (Fig. 1b & 1c) as well as accompanying puckering or distortion and rolling of the leaves (Fig. 1d). Some of the severely infected plants were also stunted. Black bean aphid infestations were also observed on the bean stems (Fig. 1e) as well on the leaves and bean pods (Fig. 1f & 1g).

3.2 Seasonal Variations for BCMD and Bean Aphids

Parameters used to measure BCMD and bean aphids generally varied between seasons. Although the differences were non-significant (P>0.05), relatively higher BCMD-I was observed in season 1 of October-November-December (OND) compared to season 2 of March-April-May (MAM) (Fig. 2a). For aphid infestation, significantly (P≤0.05) higher aphid incidence (BAI) was observed in season 1 (OND) than in season 2 (MAM) (Fig. 2a). Similar results were observed for symptom severity scores (BCMD-S) and aphid abundance (BAA) (Fig. 2b). In summary, more BCMD infections or symptoms and bean aphid infestations was observed in season 1 (OND) compared to season 2 (MAM) (Fig. 2a & 2b).

3.3 Variations for BCMD and Bean Aphids across AEZs

ANOVA showed significant (P≤0.001) differences between AEZs for BCMD-I and BCMD-S as well as bean aphid incidence (BAI) (P≤0.002) with only non-significant (P>0.05) variations analyzed for bean aphid abundance (BAA) between AEZs (Table 2). Three AEZs (LHSH, UMSH & LM 4) had significantly higher BCMD-I (~67 – 73%) compared to two AEZs (UMSA & LM 5) with the least BCMD-I (~42%) (Fig. 3a). Almost similar trends were recorded for BAI where UMSA and LM 5 had the least BAI (~11 – 19%) compared to the other four (LHSH, UM 4, UMSH & LM 4) AEZs with higher BAI (~37 – 53%) (Fig. 3b). The least mean BCMD-S score of ~1.9 – 2.4 (mild symptoms) were observed in UMSA, LM5 and UM4; moderate symptoms (severity of ~2.8 – 3.1) were recorded in LHSH and UMSH and the highest significant mean BCMD-S of 3.6 (severe and widespread symptom) was recorded at LM4 (Fig. 4a). Non-significant variations were also observed for bean aphid abundance (BAA), the lower BAA score of 1.23 (<50 aphids $plant^{-1}$) was recorded in UMSA compared to relatively higher BAA score of 1.55 – 1.99 (50 - 100 aphids $plant^{-1}$) showed by the remaining five (LM 5, UM 4, UMSH, LM 4 & LHSH) AEZs (Fig. 4b).

Fig. 1a. Healthy bean plant / leaf observed during the survey of the study area

Fig. 1b–1d. Symptoms of BCMD recorded on bean plants during the survey

Fig. 1e – 1g. Black bean aphids observed on bean plants during the survey of the study area

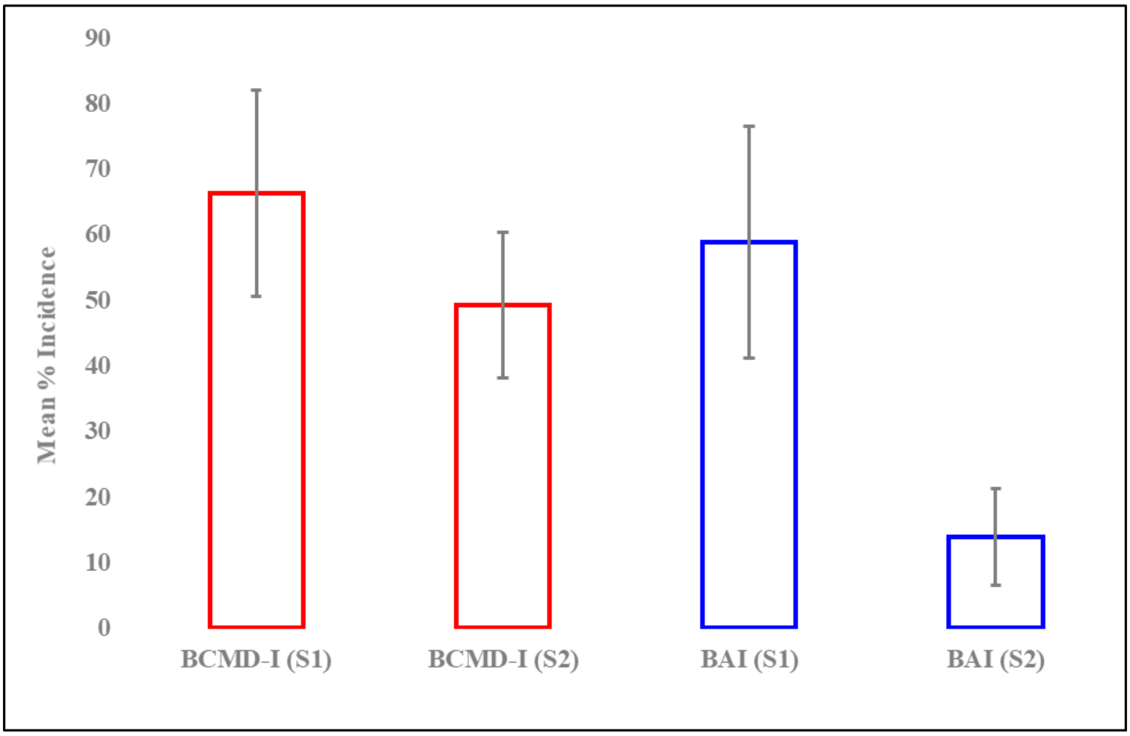

Fig. 2a. Seasonal variations for BCMD-I and BAI. S1 = season 1 / OND (October, November & December); S2 = season 2 / MAM (March-April-May); *error bars = standard deviation*

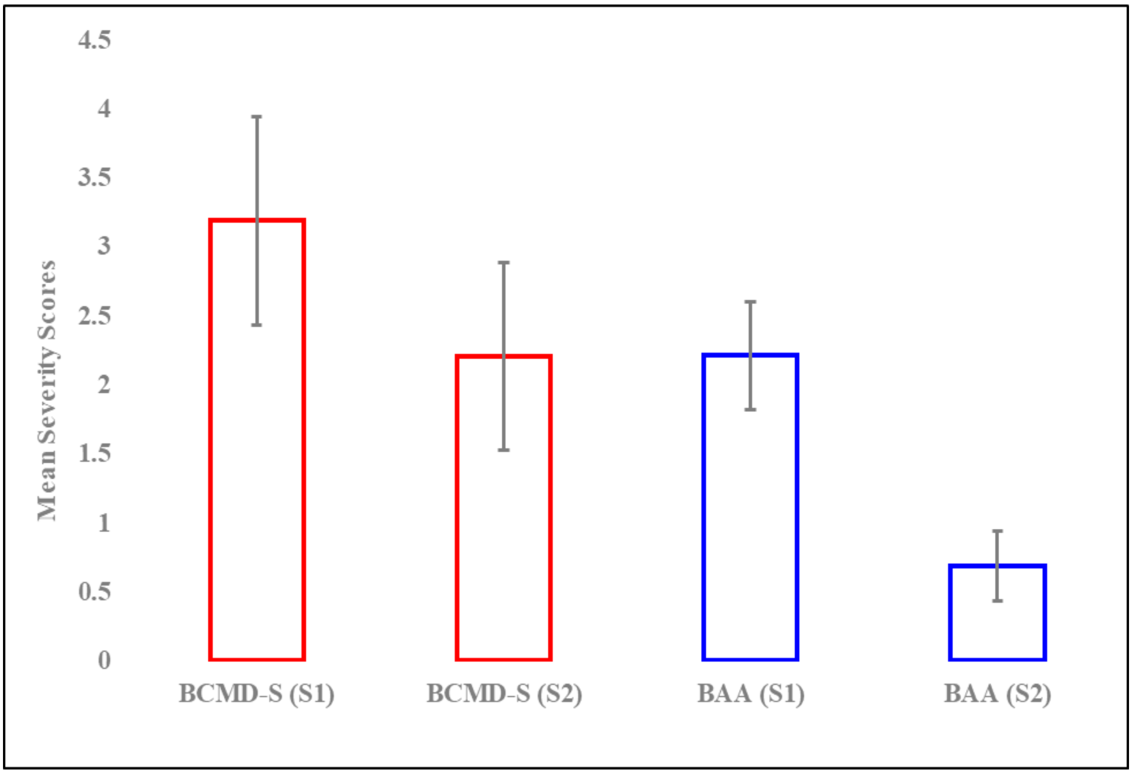

Fig. 2b. Seasonal variations for BCMD-S and BAA. S1 = season 1 / OND (October, November & December); S2 = season 2 / MAM (March-April-May); *error bars = standard deviation*

Table 2. ANOVA for BCMD-I, BAI, BCMD-S and BAA analyzed from AEZs

BCMD-I						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	96497.31	5	19299.46	96.376	0.00122	2.23
within Groups	114944.4	574	200.252			
BAI						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	95231.45	5	19046.29	26.925	0.00166	2.23
within Groups	408157.8	574	707.379			
BCMD-S						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	198.304	5	39.661	31.853	0.00114	2.23
within Groups	714.689	574	1.245			
BAA						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	30.953	5	6.191	8.514	0.0861	2.23
within Groups	421.729	574	0.727			

ANOVA = analysis of variance; SoV = source of variations. SS = sum of squares; df = degree of freedom; MS = mean squares

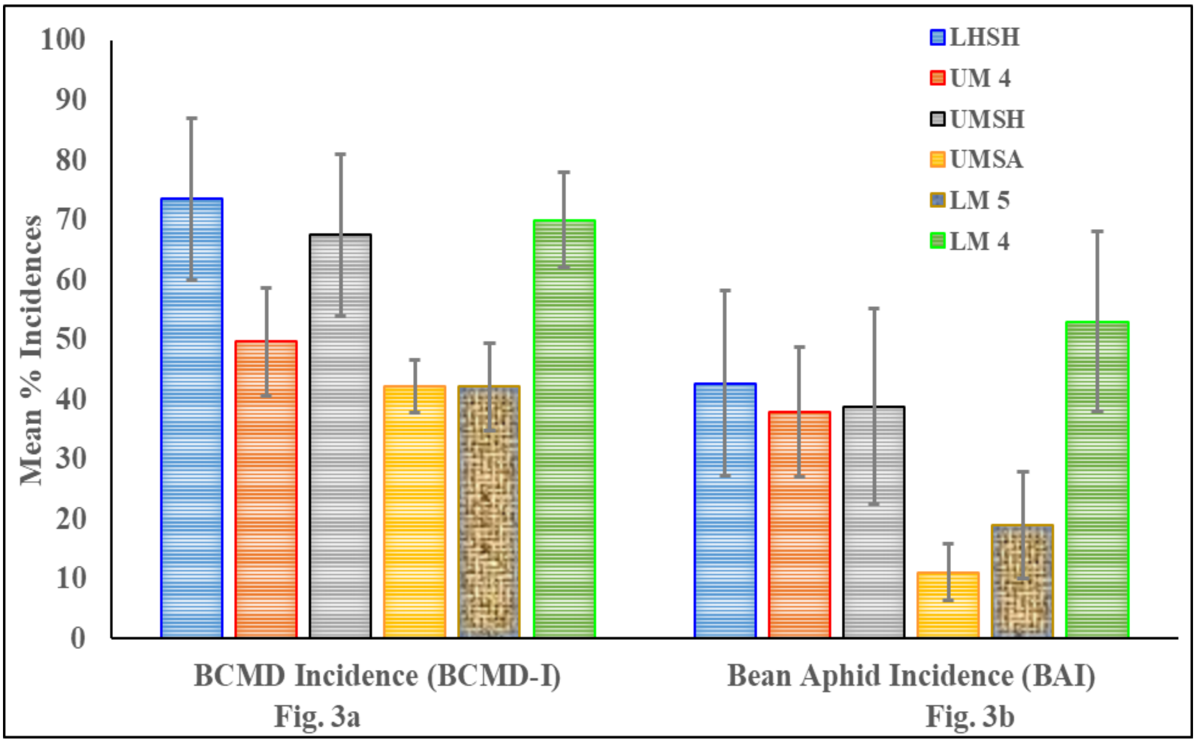

Fig. 3a. Variations for BCMD-I in different agro-ecological zones; Fig. 3b. Variations for BAI in different agro-ecological zones. *Error bars = standard deviation*

3.4 Bean Varietal Variation for BCMD and Bean Aphids

Nine (9) bean varieties were identified across AEZs during the survey (Fig. 5). Notable orders of preference were (in ascending order) Wairimu, Selian 27, Selian 15, Mwitemania, Canadian Wonder, Rosecoco, Selian 12, Selian 13 and Selian 14 (Fig. 5). Wairimu and Selian 14 respectively represented the least and the most common cultivated bean varieties in the study area. These bean varieties showed differences in BCMD infections and infestations by bean aphids (Table 3). For example ANOVA results indicated significant (P≤0.001) variations between bean varieties for BCMD-I, BAI and BCMD-S (Table

3). Bean varietal variation for BAA was insignificant (P>0.05) (Table 3). The highest BCMD-S score of 3.58 (severe and widespread symptom) was recorded in Selian 15 compared to the least mean score of 2.18 (mild symptoms) in Wairimu (Table 4). In terms of BCMD-I, ~69% analyzed in Selian 15 was the highest compared to the least BCMD-I of ~50% in Selian 14 (Table 4). Two varieties (Canadian Wonder & Rosecoco) has mean bean aphid abundance (BAA) score of 1.5 – 1.70 (50 - 100 aphids plant^{-1}) compared to the remaining seven varieties with BAA score of 1.1 – 1.40 (<50 aphids plant^{-1}) (Table 4). A higher bean aphid incidence (BAI) of ~68% was recorded in variety Wairimu compared to least BAI of ~28% calculated in both Canadian Wonder and Selian 12 (Table 4).

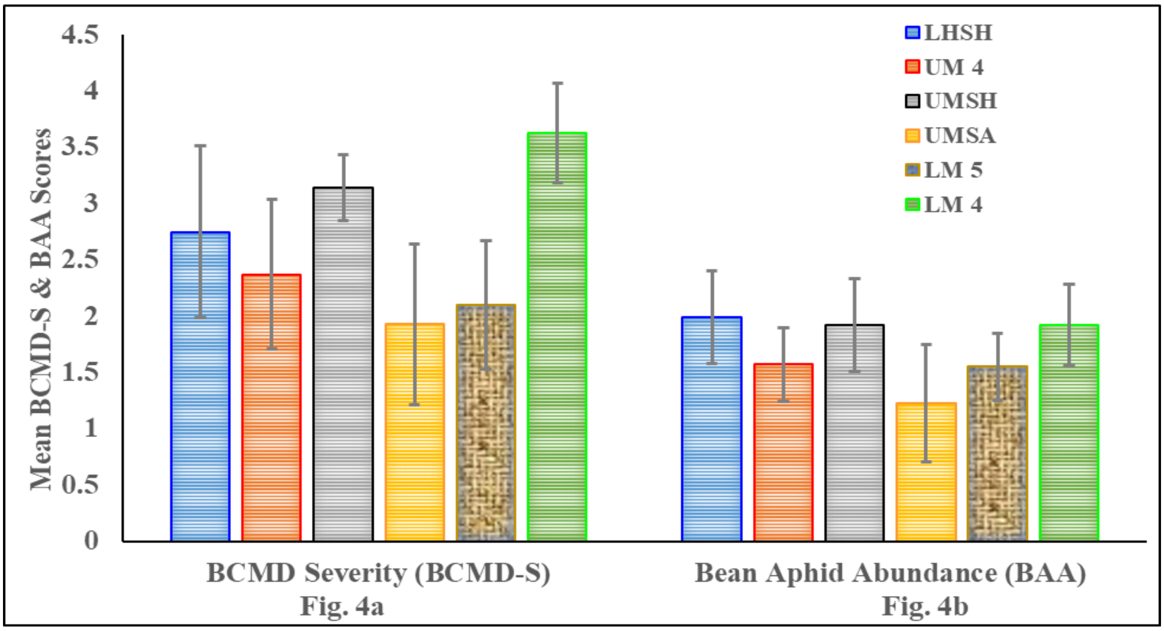

Fig. 4a. Variations for BCMD-S in different agro-ecological zones; Fig. 4b. Variations for BAA in different agro-ecological zones. *Error bars = standard deviation*

Table 3. ANOVA for BCMD-I, BAI, BCMD-S and BAA analyzed from bean varieties

BCMD-I						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	24326.47	9	2702.941	7.016	0.00113	1.895
within Groups	236931.2	639	385.254			
BAI						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	37589.1	9	4176.566	3.93	0.00704	1.895
within Groups	653530	639	1062.65			
BCMD-S						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	83.815	9	9.313	6.357	0.0017	1.895
within Groups	936.152	639	1.465			
BAA						
SoV	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
btw Groups	16.726	9	1.858	1.586	0.115	1.895
within Groups	748.623	639	1.172			

ANOVA = analysis of variance; SoV = source of variations. SS = sum of squares; df = degree of freedom; MS = mean squares

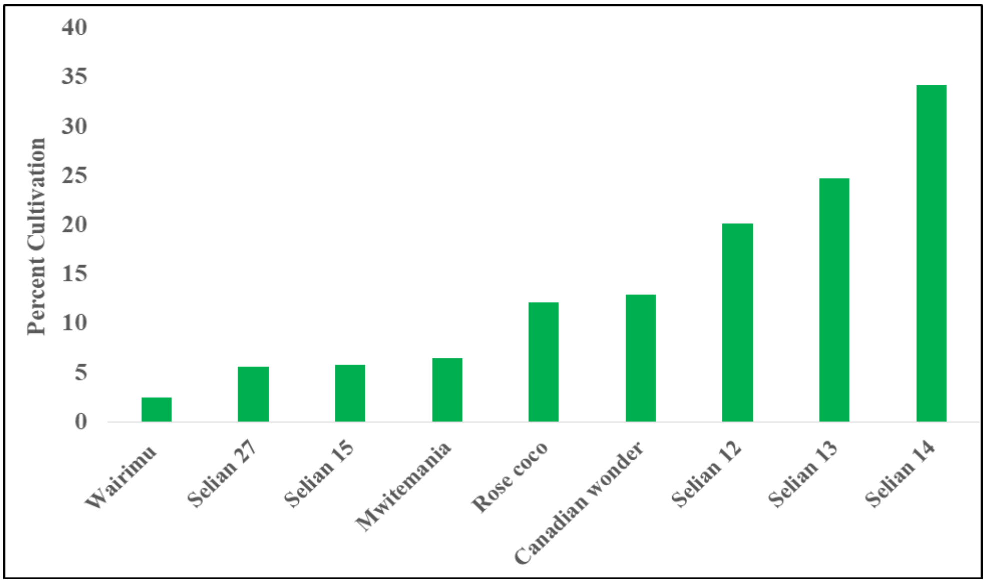

Fig. 5. Diversity and preferences for bean varieties in study area

Table 4. Mean (±SE) BCMD-I (%), BCMD-S, BAA and BAI (%) for different bean varieties

Bean Variety	BCMD-S	BCMD-I (%)	BAA	BAI (%)
C. Wonder	2.61^{ab} ±1.21	53.27^{cd} ±18.76	1.51^{e} ±0.41	28.22^{g} ±11.60
Rosecoco	2.63^{ab} ±1.23	61.02^{cd} ±18.96	1.69^{e} ±0.45	37.73^{fg} ±11.19
Selian 12	2.56^{ab} ±1.26	56.32^{cd} ±20.49	1.14^{e} ±0.48	27.65^{g} ±14.00
Selian 13	2.66^{ab} ±1.18	60.07^{cd} ±20.41	1.36^{e} ±0.45	30.54^{fg} ±15.97
Selian 14	2.77^{ab} ±1.31	49.67^{d} ±5.62	1.35^{e} ±0.35	35.49^{fg} ±19.32
Selian 15	3.58^{a} ±0.85	68.51^{c} ±10.38	1.40^{e} ±0.40	50.43^{gh} ±17.14
Selian 27	2.58^{ab} ±0.52	52.33^{cd} ±10.78	1.33^{e} ±0.37	58.00^{gh} ±12.29
Wairimu	2.18^{b} ±0.32	56.00^{cd} ±15.30	1.40^{e} ±0.22	67.67^{h} ±9.30
Mwitemania	2.37^{ab} ±0.48	52.00^{d} ±6.89	1.40^{e} ±0.22	51.67^{gh} ±17.44

Means within each column for each parameter that are not followed by the same letter(s) are significantly different (P≤0.001), while those followed by the same letter(s) are not significantly different (P>0.05)

Table 5. Correlations between BCMD-S and BAA and between BCMD-I and BAI in AEZs (5a) varieties (5b)

5a) based on data from AEZs			5b) based on data from bean varieties		
	BAA	BAI		BAA	BAI
BCMD-S	0.399^{aa}		BCMD-S	0.404^{b}	
BCMD-I		0.673^{a}	BCMD-I		0.418^{bb}

^{a} = P≤0.001; ^{aa} = P≤0.003 (2-tailed; df = 1178); *^{b} = P≤0.005); ^{bb} = P≤0.008 (2-tailed; df = 1274)*

Correlation coefficients between disease symptoms and aphid infestation were positive and significant irrespective of whether data correlated was obtained from identified bean varieties or from different AEZs (Table 5). For AEZs, correlations between BCMD-S and BAA were significant at P≤0.001 while between BCMD-I and BAI was significant at P≤0.003 (Table 5a). Similarly for bean varieties, correlations between BCMD-S and BAA was significant at P≤0.008 and between BCMD-I and BAI was significant at P≤0.005 (Table 5b).

3.5 Diagnosis and Management of BCMD and Bean Aphids

About 79% of the farmers in the study area could identify their diseased or pest-infested bean crops with more (~90%) of the same respondents able to identify the stage of growth of the crop most affected (Fig. 6). However, no single farmer, (0%), in the study area could identify symptoms specifically associated with BCMD compared to approximately 40% that were able to identify the vector bean aphids (Fig.

6). Approximately 26% of the farmers implemented some form of aphid or pest management strategy (Fig. 6). Cultural methods of controlling pests (aphids) and by extension BCMD were the most applied (Fig. 7). For instance, ~82% of the respondents planted their crops early at the onset of rainfall; ~80% intercropped their beans with other crops; equal number (~71%) carried out crop rotation and weed control and the least 1% cultural control was noted on sourcing of certified bean seeds (Fig. 7). None of the farmers (0%) applied pesticides or chemicals.

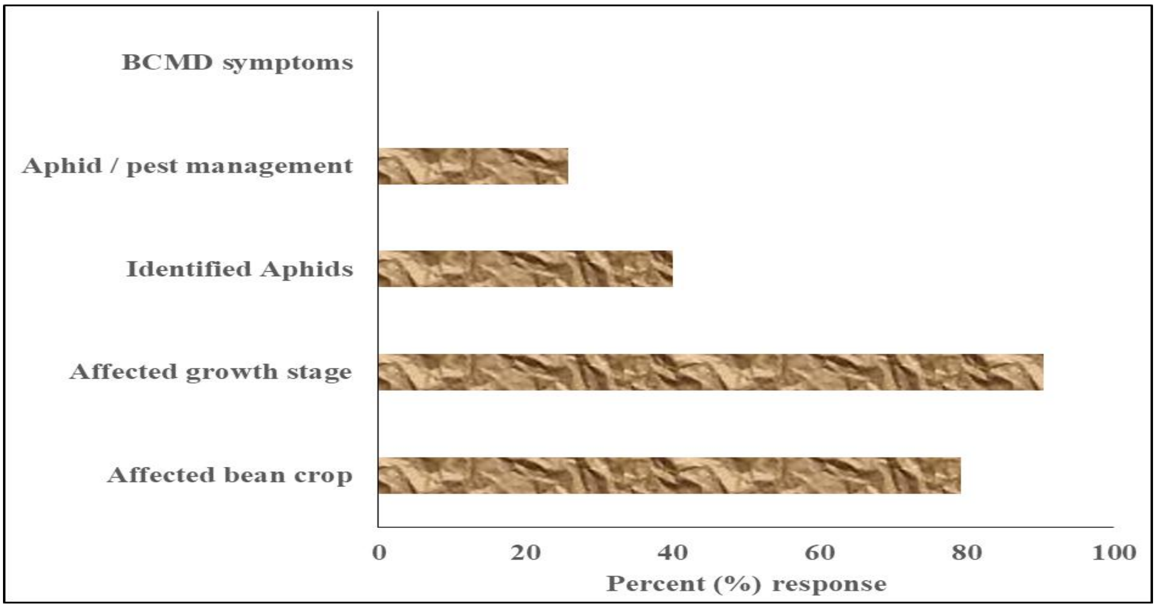

Fig. 6. Farmer knowledge on BCMD and bean aphids on affecting their bean crops

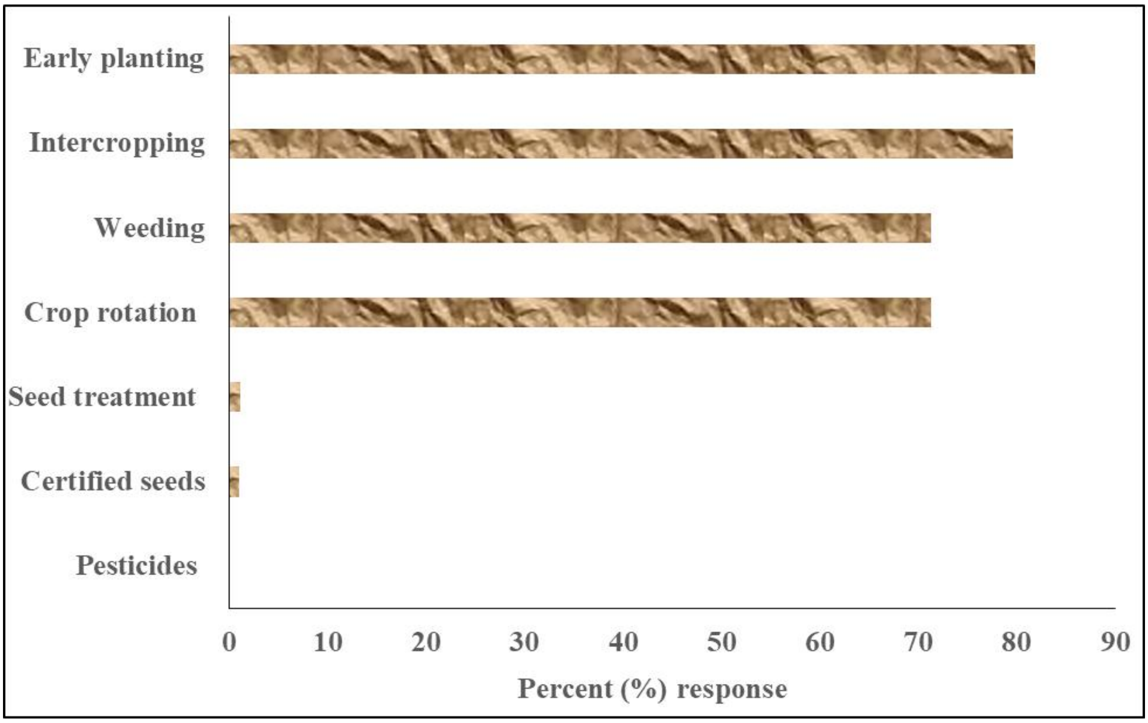

Fig. 7. Management methods for BCMD and bean aphid applied by farmers in study area

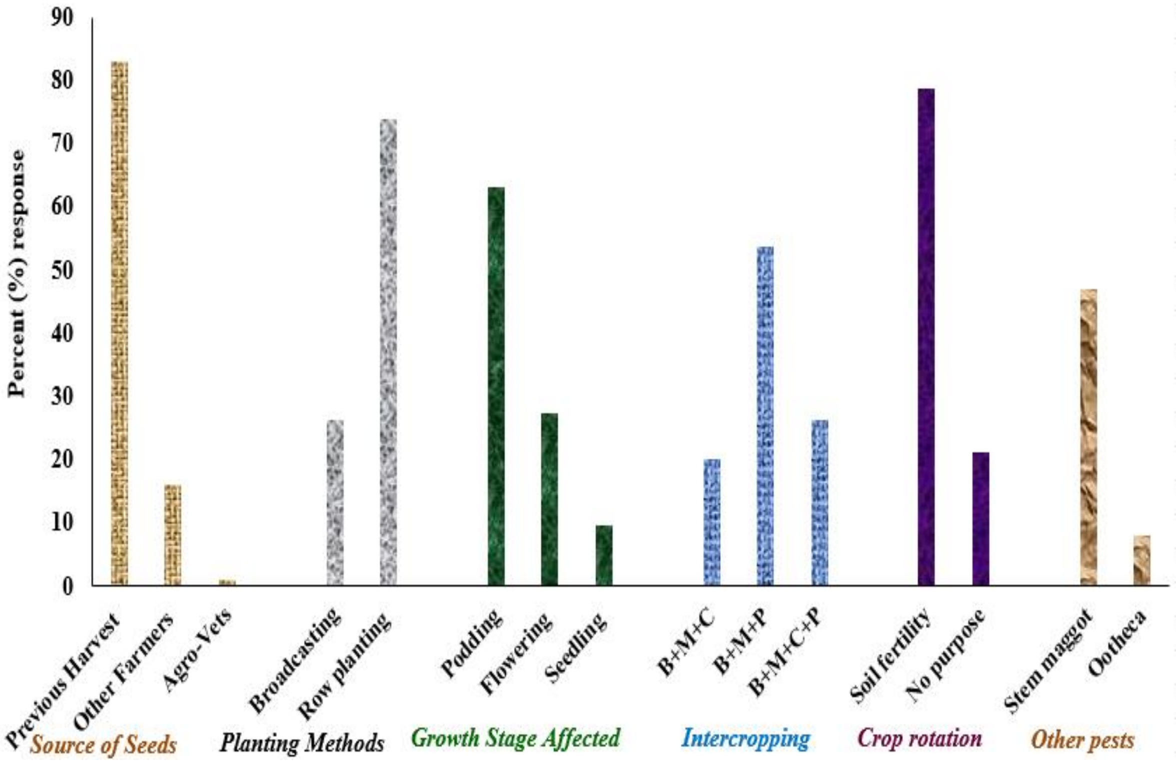

Fig. 8. Supporting results on BCMD and bean aphid control strategies applied by farmers (B = beans; M = maize; C = cowpeas; P = pigeon peas)

Planting accounted for the most common planting method (~74%) compared to ~26% of the farmers that did broadcasting (Fig. 8). Farmers identified, (in descending order), podding (~63%), flowering (~27%) and seedling (~10%) as crop growth stages affected by pests. An intercrop of beans (B) + Maize (M) + Pigeon peas (P) was the most popular (~54%) followed by B + M + P + cowpeas (C) at ~26% and B + M + C at 20% (Fig. 8). About 79% of the farmers carried out crop rotation for purposes of improving soil fertility while 21% did not know why they rotated their crops. In addition to aphids, 47% of the farmers identified bean stem maggots and foliar beetle or Ootheca (8%) as other significant bean pests (Fig.8).

4. DISCUSSION

4.1 Occurrence of BCMD and Bean Aphids in Lower Eastern Kenya

BCMD is caused by Bean common mosaic virus (BCMV) and Bean common mosaic necrosis virus (BCMNV) both transmitted via seeds and bean aphids, producing varied symptoms on infected bean plants [36,37]. In comparison to healthy bean plant, typical symptoms associated with BCMD such as yellowing, a light green or yellow and dark green mosaic pattern on leaves, puckered or distorted and rolled leaves were visually diagnosed in the present study. These symptoms were previously observed by Mukeshimana et al. [36] and Buruchara et al. [18]. Bean aphids were found colonizing the stems, leaves and pods. This corroborates findings by Buruchara et al. [18] who also observed colonies of black bean aphid formed around bean stems, growing points and leaves. The aphids may eventually cover the whole plant, suck the sap, young plants may wither and die and older plants may become stunted and bear distorted leaves [18]. Variations for BCMD infections and aphid infestations between seasons, agro-ecological zones and commonly cultivated bean varieties observed in this study have also been reported. For instance BCMD infections vary with environments, type of infection (seed-borne or vector-transmitted), type of virus, bean variety or cultivar, time of infection and stage of growth or the age of the plant when infected [38,39]. Ochilo and Nyamasyo [14] also observed that variations in bean aphid incidences were mostly determined by location, with low rainfall and high temperatures having a higher prevalence of black bean aphid than those with high rainfall and low temperatures.

Seasonality of symptoms has also been in reported previous studies [40] with such seasonal variations attributed to virus, their hosts and vectors dynamics. For instance, Honjo et al. [41] reported that within-host virus accumulation may widely change with seasons depending on virus replication and host growth. Seasonality of virus infections or symptoms is also attributed to vector / aphid activities and host susceptibility or host populations [41,42]. Differences between S1 / OND and S2 / MAM might have also contributed to BCMD and aphid differences. S1 / OND is regarded as short-rainy season that is more reliable for farming compared to unreliable rainfall of S2 / MAM (KMD, 2017). More farmers could have cultivated or grown beans on their farms thereby providing high host population and subsequently higher incidences of aphids and BCMD in S1 / OND compared to S2 / MAM with less host population and low aphid infestation and low BCMD severity. Insects such as aphids spread the virus from some source, which if absent there will be no virus [43]. In concurrence to these results, Mangeni et al. [19] also scored higher incidence of virus disease symptoms in short rainy season than in the long rainy season in western Kenya.

Differences between AEZs for BCMD and aphid infestations as shown in this study were corroborated by Manadhar et al. (2016) who also found differences in disease severity between AEZS. Such BCMD severities and incidences varied from mild, moderate and severe symptoms in Nepal [35] as well as in AEZs in western Kenya (Masheti, 2019; [44,45]). Differences in temperature and humidity exist between AEZS with altitudes in lower altitude recording higher temperatures than AEZS in higher altitude [46,47]. The observed differences in AEZS for BCMD and aphid infestations could probably be attributed to differences in environmental or climatic factors such as altitudes, temperature and rainfall or humidity among others. Literature reviews revealed differences in response to altitudes and temperature between the two-virus species (BCMV & BCMNV) that cause BCMD. For instance, higher altitudes and concomitant lower temperature respectively enhanced incidence of BCMV on bean plants and favored activities of the vectors (aphids) in transmission of BCMV into the host plant [48,44].

The mean annual temperature of the surveyed AEZs ranged from 16ºC to 24ºC. Generally, for plant viruses to replicate, they require an optimal temperature ranging between 15°C and 30°C [49,50,51,52]. All the AEZs under study portrayed some level of bean aphid incidence. This can be attributed to the average temperatures (18ºC) which are associated with a high aphid incidence as described by Kumar et al., [53]. The low altitude AEZs, which also have high temperatures in the areas like UMSA and LM5 have shown low aphid abundance. This was corroborated by Makila et al [54] who found that, a high population of the aphid colonies can be disrupted by high temperatures that cause their deaths especially in low altitude areas. Fluctuation in environmental temperature regime during the course of infection process leads to symptom variation due to viral infection [55]. These findings are consistent with previous research that has shown the impact of various weather conditions, such as temperature, rainfall, and humidity on arthropod vector reproduction and development, distribution, and feeding behavior, as well as the impact on virus replication and transmission [56].

Variations among the bean varieties for BCMD incidences or severity were observed in the current study. This agrees with the study by Mulumba et al. [57] which showed that in the case of common beans (*Phaseolus vulgaris*), higher diversity of crop types, as assessed by number of varieties (richness) and evenness of distribution, corresponds to a reduction in average disease damage levels and a reduction in disease variance. Increasing variety (intra-specic) diversity can be used as a risk-minimizing strategy to reduce pest and disease damage [57,58]. Related studies previously reported differences for BCMD incidences or severities between bean varieties in western Kenya [19,44], Masheti, 2019. In western Kenya, Mangeni et al. [19] reported lower BCMD-I in Rosecoco and Wairimu varieties. These results imply that response to BCMD is variety or cultivar dependent. This potentially allows for selection and breeding of varieties tolerant or resistant to BCMD [43] for improved yield. Both Selian 14 and Selian 15 bean varieties were previously classified as resistant or tolerant to diseases such as anthracnose, bacterial blight and BCMV in Tanzania [59]. In the current study, Selian 14 was also considered tolerant to BCMD while Selian 15 was susceptible due to high BCMD incidence. Mangeni et al. [43] also identified bean varieties that were susceptible, tolerant and resistant to BCMV in western Kenya.

Likewise previous studies also showed that aphid infestations depended on bean variety or cultivar [60]. In addition to transmitting viruses, aphids damage bean crops by direct feeding and can significantly reduce bean yields sometimes by more than 50% [61,62,60,4]. All bean varieties identified in this study were infested by aphids (none showed resistance), implying that aphids could have also contributed to yield losses experienced by farmers. For effective bean aphid management, identification and screening for aphid resistant and tolerant cultivars was recommended [62,60]. It can be hypothesized that the relatively low BAI in Selian 14 perhaps contributed to its lower BCMD-I compared to Selian 15. The positive correlations between aphid population and disease incidence could further be attributed to the observed trends in BCMD infection on bean variety or cultivar. Previously, Omunyin et al., [33] correlated the incidence of BCMV with the presence of *A*. *fabae* on infected plants. Although this does not confirm that the virus was aphid-borne as it is also seed borne.

4.2 Management of BCMD and Bean Aphids in Lower Eastern Kenya

Several methods are often employed to manage pests and disease in crops for better yield for the farmer. These methods include cultural, chemical, biological and crop improvement through breeding for resistance. For an effective disease or pest control or management, a farmer's knowledge of available methods and their applications coupled with diagnosis of disease symptoms and pest identification is pre-requisite. Results of the current study indicated that only a few farmers implemented some form of aphid or pest and disease management strategy. Some underlying reasons include the high cost of the disease and pest management products that remains a barrier to achieving profitability even with higher bean yields [63,64]. Effective management of bean aphid includes timely planting of beans which is crucial and sowing should be done at the on-set of the rains after a minimum of 30mm of rainfall has been received [10,65]. Planting beans early in the season helps avoid or escape the high aphid population period [18,66]. Further, Plants infected early in the growing season or grown from infected seed may suffer a delay in maturity and have fewer pods and fewer seeds per pod than healthy plants [36]. The current study showed majority of the farmers' plant their beans in rows with recommended spacing. Row spacing had significant effect on planting, suggesting that yield can be optimized more by planting beans in rows. Such optimization needs to be carried out within specific variety for different responses. Although this may have contributed to reduce aphid incidences, it is noted that farmers planted their beans in rows for various reasons including additional yield from other food crops while others simply followed instructions for row planting with spacing from extension agents.

Most farmers in this study intercropped their beans with other crops with maize-bean intercrop dominating. The role intercropping beans with other crops to reduce aphid population (and by extension reduce incidences of BCMD) has also been reported and promoted. Ogecha et al. [47] observed reduced aphid incidences and severity in agro-ecological zones of western Kenya due to intercropping. Specifically reduction in incidence of black bean aphids or population has been reported in maize-bean intercrop (compared to bean monocrop) which was attributed to maize interference with aphid-finding host behaviour or colonization of the host plant as well as high population of natural enemies in the intercropped beans [67,68,47]. Nyirenda and Katende [69] also recommended intercropping beans with densely populated maize crop to prevent heavy aphid infestation. Further, beans grown in association with maize previously showed fewer incidences of pests and diseases including bean common mosaic [70]. For bean-maize intercrop, a stronger interaction effect (reduced aphids) was recorded on row spacing and maize growth [67].

Nyirenda and Katende [69] recommended removal of all weeds and volunteer plants especially if they are infested with aphids. This is corroborated by results of the current study where majority of the farmers practiced weeding and crop rotation as cultural control method for bean aphids. The control of weeds and other volunteer plants that could be potential hosts for the viruses have been shown favor the spread of BCMV [43,10]. In addition to reducing aphid populations, weeding also controls bean viruses such as BCMV that overwinters in infected weed hosts and in infected seed [71] providing initial source of BCMV inoculum for subsequent planting seasons. Destroying other legumes and weed hosts before planting and during life period of the bean crop has been recommended [18]. Thus, weeding of bean farms as observed in the current study ought to be encouraged. Rotating beans with non-host crops has been recommended for prevention of BCMV [66].

One of the most effective strategies for controlling BCMD is through sowing disease-free, clean and certified seeds. Literature sources also support use of healthy seeding material from certified sources to prevent BCMV [66,65]. Despite this, results of the current study indicated fewer farmers sourced certified seeds from licensed distributors compared to the farmers that sourced their seeds from previous harvest and from other farmers or their neighbors. Observations similar to these were made by Buruchara et al. [18] who indicated that most farmers use "farm-saved" seed or those produced by neighbors or informal farmer groups. In western Kenya, farmers plant their own seed not certified for virus freedom [43]. One reason attributed to this is that most rural farmers cannot afford the available certified bean seeds and are less accessible to them [18]. Potentially sowing of seeds from previous harvest and from neighbors contributed to incidences of BCMD observed in all AEZs in the study area. Most likely such seeds were infected and will carry on the infection to the bean planted from the same seed [54]. Over time, a build-up of seed-borne infection needs seed replacement with clean or healthy seed [18]. Seeds from aphid-infested plants should not be used as planting stock [36]. Planting certified seeds of varieties resistant to BCMV [72] or minimizing planting of susceptible varieties in areas known to have BCMV [18] has also been recommended

Use of chemicals has been shown to reduce chances of aphid infestations. For example, dressing seeds with chemicals such as Imidacloprid at planting protected seedling from early seedling pests and aphids infestation during early seedling stage [54]. According to Qureshi et al. [73] a systemic insecticide should be applied at planting to control aphids. In Kenya, several insecticides with different active ingredients such as Alphacypermethrin, Lambda-cyhalothrin and Acetamiprid are available [74] for aphid management. However, results of the current study demonstrated that there was minimal application of chemicals or pesticides as a management strategy against aphids. This may be attributed to the cost of pesticides, which are high, or lack of knowledge on the role of chemicals for pest management amongst farmers. Previous studies have reported the use of Biological Control (BC) in the management of aphids. For instance, a combination of natural enemies such as green lacewings, ladybird beetles, syrphid flies and parasitic wasps have been shown to keep aphids in check in the field [18]. Application of botanical pesticides such as neem and biocontrol products such as *Aphidius* spp. has also been recommended on Kenya [74]. Nevertheless, no biological control strategy was identified in the present study as being used in the management of aphids. In their study in Western Kenya, Mangeni et al. [43] established that farmers did not put in place comprehensive pest and disease management strategies. Overall, the current study established that farmers could not identify symptoms associated with BCMD and did not have a strategy in place for management of both bean aphids and BCMD.

5. CONCLUSIONS AND RECOMMENDATIONS

The disease, BCMD and *Aphis fabae* infested common beans in all AEZs of lower eastern Kenya. The degree of infestation and severity, on the other hand, varied from one AEZ to the next. AEZs with higher altitude had a higher incidence and severity of bean aphids than lower altitude areas. Intercropping maize and common beans reduced aphid infestation. Wairimu was the least preferred bean variety while Selian 14 was the bean variety most commonly cultivated in the study area. Majority of the farmers in the study area could identify diseased or pest-infested bean crops and the stage of growth of the crop most affected but none area could identify symptoms specifically associated with BCMD. A fair number of farmers were able to identify the vector- bean aphids. Only a few farmers implemented some forms of aphid or BCMD management strategies. In summary, the presence and variations of BCMD and associated vector, black bean aphids, in the study area requires management interventions including extension services and farmer training for purposes of improving yield for bean farmers in lower eastern Kenya.

CONSENT

As per international standard or university standard, Participants' written consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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