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Research

Field and Forage Crops

Earliness and Crop Morphological Traits Modulate Field Pest Infestation in Green Gram

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Abstract

Breeding has significantly improved drought tolerance in green gram but marked yield losses continue due to damage by insect pests. Important pests of green gram are pod borers, *Maruca vitrata* (F.), aphids, *Aphis gossypii* Glover and whiteflies, *Trialeurodes vaporariorum* (Westwood). Management of these pests has partly been constrained by the limited understanding of crop traits that modulate their infestation. Field experiments were conducted in southeastern Kenya to evaluate a collection of old and new green gram varieties for tolerance to field pests, and to identify traits that confer resistance. The old varieties were KS20 and N26, both released in 1990s whereas the modern counterparts were Biashara, Karembo, and Ndengu-Tosha. Results showed significant differences among the varieties in maturity, leaf area, leaf hair density, leaf moisture content, and pod wall thickness. Earliness significantly reduced pest infestation, whereby KS20 matured early while N26 was late, and the new varieties were intermediate. On average, across the three environments, leaf area ($R^2 \geq 0.32$) and leaf moisture content ($R^2 \geq 0.18$) positively correlated with pest infestation while leaf hair density ($R^2 \geq 0.30$), and pod wall thickness ($R^2 \geq 0.54$) showed a negative association with pod borer and aphid counts. However, results did not reveal any particular traits that associated with the varieties, which implied that breeding of green gram in Kenya has not selected for tolerance to field pests. Nonetheless, green gram field pest management practices could select for varieties with early maturity, open plant canopy, pubescent leaves, and thicker pod walls.

Key words: modern variety, leaf hair, maturity, pod borer, sucking pest

Green gram, also known as mung bean, *Vigna radiata* (L.) R. Wilczek is a legume crop that is grown for its edible dry seeds and a source of low flatulence proteins. Green gram originated from India and has since spread to other continents, including Africa (Mbeyagala et al. 2017). The crop has a short life cycle and adapts well to drought due to its elaborate root system which enhances exploration for water and nutrients (Kumar and Sharma 2009). Globally, the annual production of green gram is about 3 million tons from more than 6 million hectares under cultivation (Nair et al. 2013). In Kenya, green gram is predominantly grown in the climatically marginal areas of eastern Kenya as food staple and cash crop (Kilimo Trust 2017, Karimi et al. 2019).

In southeastern Kenya, farmers often obtain about 0.5 t/ha against a yield potential of 4.5 t/ha. Yield potential is the yield of a crop when it is grown in its adapted environment with adequate supply of water and nutrients, and through sufficient elimination of yield-limiting factors such as pests, diseases, and weeds (Morita et al. 2007). This large yield gap could be attributed to drought, pests, diseases, and poor agronomic practices. However, significant advances have been made to adapt green gram to drought through the development of early maturity varieties (Karimi et al. 2019), and closely coupled with consumer-preferred traits such as seed color and taste (Amjad et al. 2009). Nonetheless, significant yield losses continue to accrue from field pests, particularly pod borers, *Maruca vitrata* (F.), aphids, *Aphis gossypii* Glover and whiteflies, *Trialeurodes vaporariorum* (Westwood) (Machocho et al. 2012).

In Kenya, and despite limited data, yield loss in green gram due to field pests could range from 50 to 90% depending on type of pest and pressure of infestation (Kilimo Trust 2017). In India, about 40% yield loss is attributed to field pests (Prabhaker et al. 2005). These pests cause chewing, piercing, and sucking damage on leaves, flowers, and young pods (Panneerselvam and Lakshmanan 2009). The adult pod

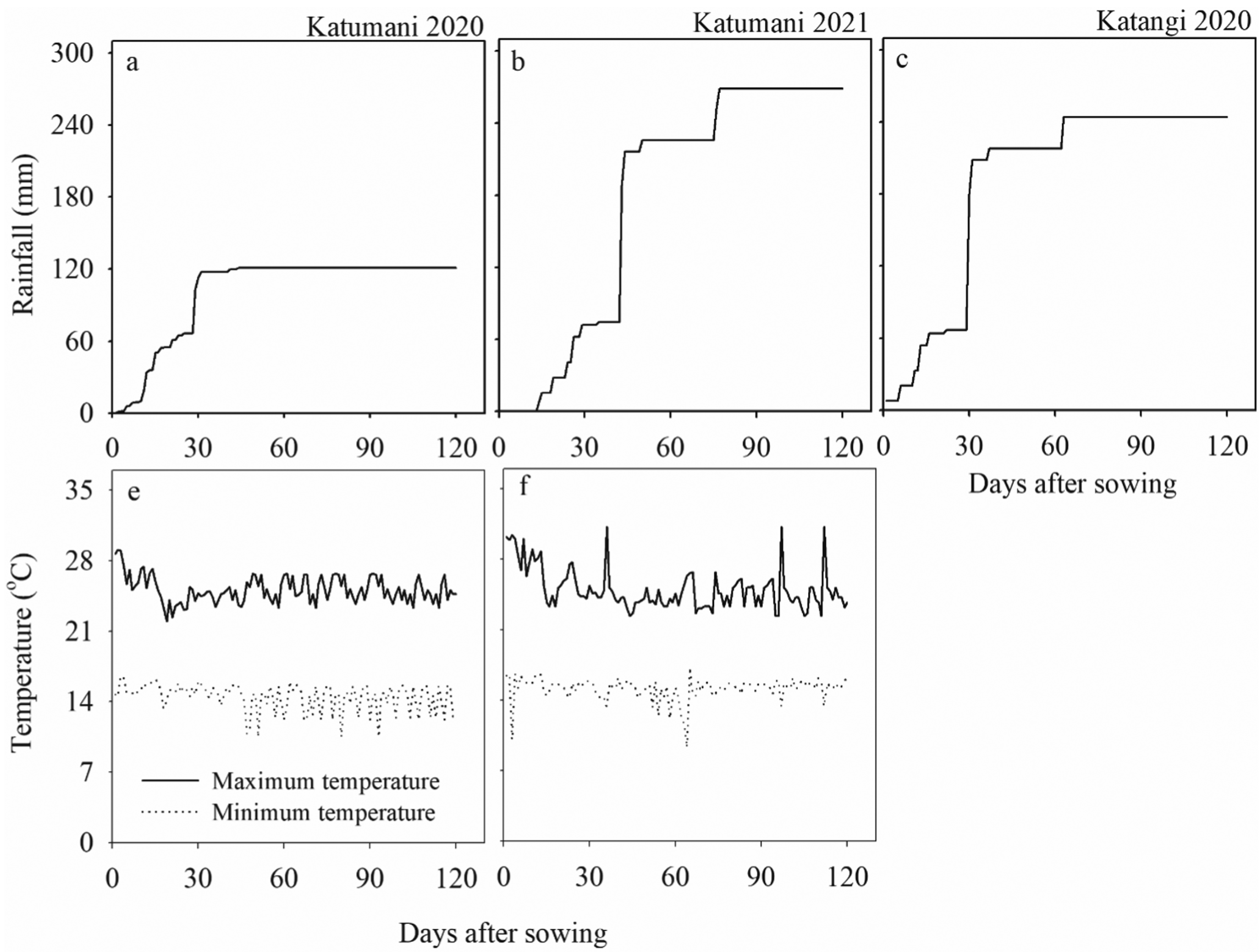

Fig. 1. Growing conditions for green gram including cumulative rainfall (a, b, c) and estimated daily maximum and minimum temperatures (d, e) in Katumani 2020 short rains, Katumani 2021 long rains, and Katangi 2020 short rains in Machakos County, Kenya.

Table 1. Days to 50% branching, flowering and physiological maturity (±SE of mean) of five green gram varieties grown in Katumani and Katangi in Machakos County of Kenya during 2020 short rains and 2021 long rains

	Katumani 2020			Katangi 2020			Katumani 2021		
Variety	Branching	Flowering	Maturity	Branching	Flowering	Maturity	Branching	Flowering	Maturity
N26	46 ± 0.7d	61 ± 0.6e	103 ± 1.0d	42 ± 0.6c	62 ± 0.7d	84 ± 1.0d	50 ± 0.9d	69 ± 0.9d	125 ± 0.9c
KS20	31 ± 1.0a	46 ± 0.6a	82 ± 0.7a	28 ± 0.7a	41 ± 1.0a	71 ± 0.3a	39 ± 0.9a	53 ± 1.0a	90 ± 0.6a
Karembo	42 ± 0.7b	55 ± 0.7c	91 ± 0.9c	40 ± 0.9b	49 ± 0.3b	76 ± 0.6c	45 ± 0.3c	65 ± 1.4c	108 ± 1.2b
Biashara	42 ± 0.7b	54 ± 0.3b	87 ± 0.9b	40 ± 0.9b	50 ± 1.3b	71 ± 0.3a	52 ± 1.2d	64 ± 0.9bc	109 ± 2.2b
Ndengu-Tosha	43 ± 0.3c	57 ± 0.3d	87 ± 0.8b	42 ± 1.3c	56 ± 0.6c	73 ± 0.5b	42 ± 0.5b	61 ± 0.8b	94 ± 2.1a
F statistic	21.7	38.4	28.9	14.9	26.2	24.9	14.5	11.2	38.1
P value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LSD	0.8	0.8	1.6	2.3	2.5	1.5	2.1	3.2	4.3
% CV	1.0	0.8	0.9	3.2	2.6	1.0	2.7	2.7	2.2

Means compared and separated by Fisher's least significant difference (LSD). Means ± SEM followed by the letter within a column are not significantly different at $P \leq 0.05$, df = 2 for replication and df = 4 for variety.

borer lays eggs on flowers or immature pods while young caterpillars bore into the pod (Ganapathy and Durairaj 2000). They feed from inside the pod and reach a length of 12–17 mm before making exit holes (Banu et al. 2007). Infested crops wilt and stunt, and the damaged tissues form entry points by secondary pathogens (Bayoumy et al. 2017). Aphids and whiteflies have piercing and sucking mouth parts whose damage leads to deformation, discoloration, stunting, and the formation of black sooty mold due to production of honey dew, as well as the transmission of viral diseases (Morita et al. 2007).

Several sources of pest escape, avoidance, and resistance to insects have been identified in grain legumes, often controlled by crop developmental rate, morphology, and biochemical traits (Fekri et al. 2013, Hasanuzzaman et al. 2016). However, Kenyan green gram varieties have rarely been characterized for these traits. Early maturity varieties escape pest attack by maturing before the pest population multiplies (Halder and Srinivasan 2011). Crop morphology and biochemical traits significantly alter the pest habitat and behavior (Gomez et al. 2008). Dense crop canopies offer excellent habitat for pests compared with more open structure (Bach 1980). On the other hand, morphological traits such as leaf pubescence and pod wall thickness modify pest behavior (Girija et al. 2008). Leaf hairs impair movement and feeding of aphids and the larvae of pod borers, while thick pod walls resist mechanical penetration by insects (Sakala et al. 2000).

Table 2. Leaf area (cm^2) at vegetative and flowering stage (±SE of mean) of five green gram varieties grown in Katumani and Katangi in Machakos County of Kenya during 2020 short rains and 2021 long rains

Variety	Katumani 2020	Katangi 2020	Katumani 2021
N26	56 ± 0.5c	79 ± 1.2a	98 ± 1.3b
KS20	43 ± 0.8b	40 ± 1.2c	84 ± 2.5a
Karembo	38 ± 1.4a	47 ± 1.8c	81 ± 2.8a
Biashara	36 ± 1.7a	63 ± 0.9b	75 ± 5.1a
Ndengu-Tosha	39 ± 0.7a	47 ± 0.3c	84 ± 2.1a
F statistic	17.8	58.8	2.6
P value	0.001	0.001	0.006
LSD	4.0	3.9	9.7
% CV	5.0	3.8	6.1

Means compared and separated by Fisher's least significant difference (LSD). Means ± SEM followed by the letter within a column are not significantly different at $P \leq 0.05$, df = 2 for replication and df = 4 for variety.

Table 3. Leaf hair density per cm^2 at vegetative and flowering (±SE of mean) of five green gram varieties grown in Katumani and Katangi in Machakos County of Kenya during 2020 short rains and 2021 long rains

Variety	Katumani 2020	Katangi 2020	Katumani 2021
N26	48 ± 0.9a	38 ± 0.9a	55 ± 0.7ab
KS20	101 ± 0.7e	99 ± 0.5e	82 ± 3.1c
Karembo	71 ± 0.6d	58 ± 0.4d	53 ± 0.9a
Biashara	55 ± 0.1b	44 ± 0.3b	59 ± 2.2b
Ndengu-Tosha	66 ± 0.6c	54 ± 0.2c	57 ± 0.5ab
F statistic	341.9	685.6	14.9
P value	0.001	0.001	0.001
LSD	2.2	1.9	4.9
% CV	1.7	1.7	4.3

Means compared and separated by Fisher's least significant difference (LSD). Means ± SEM followed by the letter within a column are not significantly different at $P \leq 0.05$, df = 2 for replication and df = 4 for variety.

Owing to climate change and the consequent increase in pest epidemics, new green gram varieties in Kenya such as Karembo, Biashara, and Ndengu-Tosha were developed under high insect pressure compared with older counterparts like KS20 and N26. In this regard, the newer varieties could have inadvertently acquired resistance through selection for yield. Thus, the identification of sources of resistance in green gram varieties could open opportunities for the deployment of insect tolerant varieties in Kenya. Studies on host plant tolerance to insect pests in legume crops are restricted to few historically important crops like common bean, *Phaseolus vulgaris* (L.) and pigeon pea, *Cajanus cajan* (L.). The present study examines two old and three new varieties of green gram to identify traits that influence varietal resistance to infestation by pod borers, aphids, and whiteflies. The study hypothesized that selection for drought tolerance and yield in Kenyan green gram varieties concomitantly improved resistance to pest infestation, albeit unintended.

Materials and Methods

Experiment Sites

Field experiments were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) station in Katumani, and in a farmer's field in Katangi, both in Machakos County. This involved two seasons in Katumani during 2020 short rains and 2021 long rains seasons, and one season in Katangi in the course of 2020 short rains. KALRO Katumani is located 1°34′ 58″ S, 37°14′ 43″ E, and 1,600 m elevation. The mean maximum and minimum temperature in Katumani are 25°C and 14°C, respectively. Soils of this site are well drained dark red to clay with pH 7.0. The farmers' field in Katangi is located 1° 40′ 93″ S, 37° 68′ 92″ E and 1,051 m above sea level. Katangi is hotter than Katumani with mean maximum temperature of 35°C and minimum 17°C. Soils of Katangi are well drained red brown to clay soils with pH 6.5. Rainfall in both sites has a bimodal distribution pattern, with a long rains season from March to June and a short season from October to December. Long term data show the two sites receive 382 mm during the long rains season, and 274 in the short season.

Table 4. Leaf moisture content and pod wall thickness (±SE of mean) of five green gram varieties grown in Katumani and Katangi in Machakos County of Kenya during 2020 short rains and 2021 long rains

	Leaf moisture content (%)			Pod wall thickness (mm)		
Variety	Katumani 2020	Katangi 2020	Katumani 2021	Katumani 2020	Katangi 2020	Katumani 2021
N26	85 ± 0.9a	99 ± 0.9a	82 ± 2.7a	8.6 ± 0.7a	9.7 ± 1.4a	0.6 ± 0.03a
KS20	48 ± 4.5e	38 ± 0.5e	80 ± 4.1a	10.2 ± 0.6b	13.0 ± 0.2b	0.7 ± 0.01a
Karembo	71 ± 0.6d	58 ± 0.4d	80 ± 1.8a	8.2 ± 0.4a	10.9 ± 0.5a	0.6 ± 0.04a
Biashara	55 ± 0.1b	44 ± 0.3b	80 ± 1.7a	7.2 ± 0.2a	11.7 ± 0.5a	0.7 ± 0.04a
Ndengu-Tosha	66 ± 0.6c	54 ± 0.2c	79 ± 2.2a	7.4 ± 0.5a	10.1 ± 0.8a	0.7 ± 0.04a
F statistic	15.5	705.2	0.1	1.7	0.9	0.5
P value	0.001	0.001	0.911	0.011	0.015	0.312
LSD	2.2	1.9	8.1	1.5	1.7	0.1
% CV	1.7	1.7	5.4	9.6	8.3	9.8

Means compared and separated by Fisher's least significant difference (LSD). Means ± SEM followed by the letter within a column are not significantly different at $P \leq 0.05$, df = 2 for replication and df = 4 for variety.

Treatments and Experiment Design

Treatments comprised five green gram varieties that have contrasting growth rate, morphology, and yield attributes. The varieties were two old releases (KS20 and N26) and three new selections which consisted of Biashara, Karembo, and Ndengu-Tosha. Varieties KS20 and N26 were released in 1990s while Karembo and Biashara were released in 2017, and Ndengu-Tosha is in the final stages of release to the market. Treatments were laid out in a randomized complete block design and replicated in three blocks. To account for spatial variation in the experimental fields, the five green gram varieties were randomly allocated within each of the three blocks of the experiment.

Experiment Management

In each season, land was tilled prior to onset of rains with a disc plough and harrowed to fine tilth. Crops of green gram were sown at the onset of rains at a spacing of 50 cm between rows and 10 cm between plants. Plots measured 5 m by 5 m with 1 m alleys between them, and 1.5 m between replications. When the crops emerged, cutworms and bean fly were controlled with a single dose of Thunder

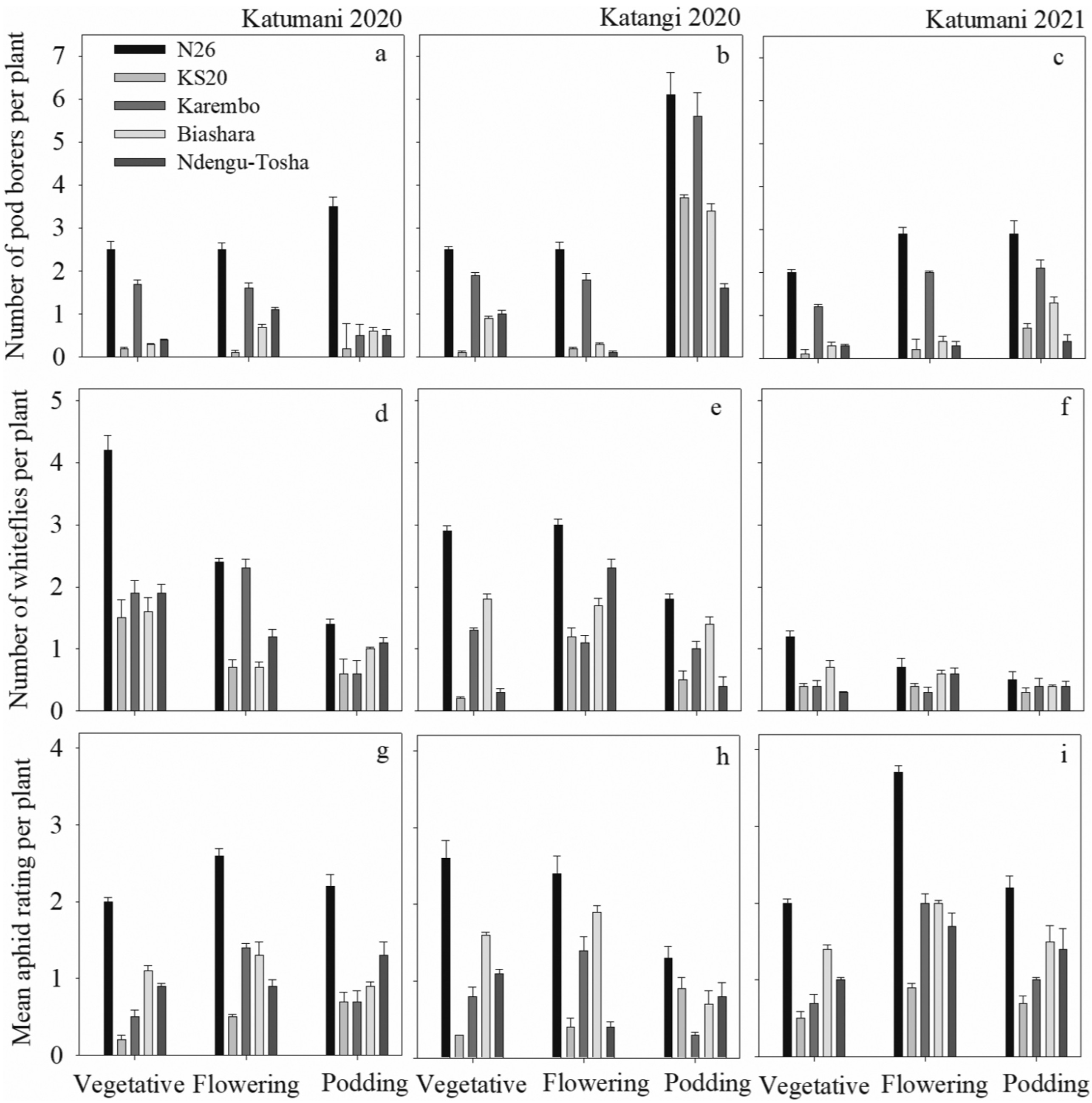

Fig. 2. Number of pod borers (a, b, c), whiteflies (d, e, f), and aphids (g, h, i) at vegetative, flowering and podding stage in five green gram varieties grown in Katumani and Katangi during 2020 short rains and 2021 long rains in Machakos County, Kenya. Aphid numbers were scored using a 1–5 scale, where; 0 denoted absence of the pest, 1—a few scattered individuals, 2—a few isolated colonies, 3—several isolated colonies, 4—large isolated colonies, and 5—large continuous colonies.

(imidacloprid 10 ml/10L water, Bayer Crop Science AG, Germany). The preharvest interval of imidacloprid is 14 d, and data collection started from 40 d after emergence, hence the chemical did not impact crop infestation by pod borers, whiteflies, and aphids. Bacterial and fungal diseases were controlled with regular sprays of Ridomil (mancozeb 50 g/20 L water, Syngenta Limited, India). A foliar fertilizer of nitrogen, phosphorus, and potassium, and trace elements was applied at 50% branching to correct for nutrient deficiencies. Plots were kept weed-free by hand weeding.

Data Collection

Weather data during the growing season was obtained from Kenya Meteorological Department's weather stations near the experiment sites, and included daily rainfall, as well as daily maximum and minimum temperate (https://meteo.go.ke/). Crop phenology was scored periodically but with emphasis on days to 50% branching, flowering, and physiological maturity. Crop growth rates varied among the varieties, thus phenological stage was recorded when 50% of plant populations in each plot reached the respective growth stage.

Five plants per plot were randomly selected for data collection, and sampling was done early in the morning when the temperature was coolest, and before the pests become active. Pod borer, aphid, and whitefly infestation was scored at vegetative, 50% flowering, and 50% podding stages. Pod borers and whiteflies were sampled by counting pest numbers on the lower, middle, and upper section of the plant canopy, and means computed. Aphid numbers were scored with the use of a 1–5 scale, where; 0 denoted absence of the pest, 1 meant a few scattered individuals, 2 designated a few isolated colonies, 3 represented several isolated colonies, 4 was large isolated colonies, and 5 signified large continuous colonies (Mkindi et al. 2017).

Crop morphological traits such as leaf area, leaf hair density, and pod wall thickness were measured from 10 randomly selected plants at vegetative, flowering, and podding stages. Leaf length and width were measured using a ruler and leaf area was computed and corrected with the use of coefficient 1.46 at vegetative and 1.59 at flowering stage. Leaf hair density was determined per cm^2 on the abaxial leaf surface by counting leaf hairs under a dissecting microscope.

At 50% flowering, ten plants were randomly sampled per plot, and nine fully developed leaves removed per plant for moisture determination. Three leaf samples were collected from upper, middle, and lower portions of the plant, and bulked for fresh weight determination per plot. Leaves were dried in an oven at 60°C until no further loss in mass, and dry weight determined with a weighing balance. Leaf moisture content (%) was calculated as the ratio between the difference in wet and dry weight, and dry weight.

At physiological maturity, thickness of the pod wall was measured by the use of a vernier calipers in ten randomly selected pods per plot. Collection of seed yield was done differently among the five green gram varieties. For KS20 and Karembo, harvesting was done when pods turned brown while N26, Biashara, and Ndengu-Tosha yield was collected when pods turned black. Ten plants were randomly sampled per plot for the determination of number of pods per plant and seeds per pod. Entire plots were harvested but with the exception of guard rows, and seed yield expressed in t/ha.

Data Analysis

Data were subjected to analysis of variance (ANOVA) to assess the experimental sources of variation using GenStat 15th Edition (Payne et al. 2011). A two way ANOVA routine was used, with replicate (block) and variety as factors, while variables consisted of the collected measurements. Prior to analysis, data was tested for normality and conformed to requirements of ANOVA. Residuals were checked for normal distribution, and no transformations were required. Treatment means were compared and separated using Fisher's least significant difference (LSD) at 5% probability level. Relationships between crop traits and pest numbers were explored by simple linear regression analysis. Linear regression slopes were tested for significant differences from zero by Sigma Plot version 10.0 (Systat Software, Inc, San Jose California USA, www.systatsoftware.com) (Kitonyo et al. 2018).

Results

Figure 1 shows temperature and rainfall data during 2020 short rains and 2021 long rains. In this study, the two experiment seasons in Katumani and one season in Katangi are referred to as three distinct environments. In 2020 growing season, Katumani received 121 mm while Katangi recorded 244 mm of rainfall. In 2021, Katumani received 268 mm. Rainfall and temperature during the experiment season in the three environments were typical of the two sites.

The five green gram varieties showed significant differences ($P < 0.001$) in phenology (Table 1). Across the three environments, variety KS20 matured earlier than the rest of the varieties while N26 was late. Varieties Biashara, Karembo, and Ndengu-Tosha were

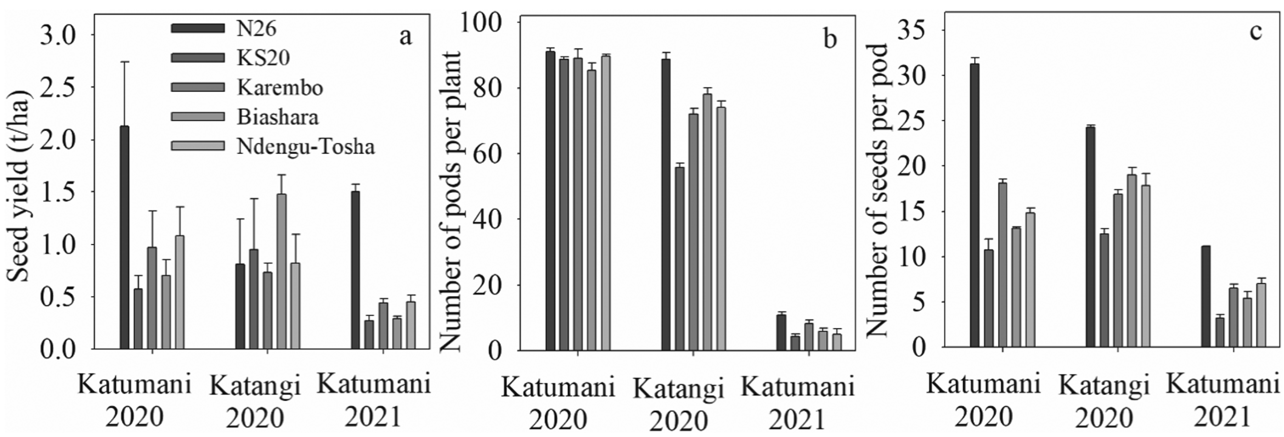

Fig. 3. Seed yield (a), number of pods per plant (b), and number of seeds per pod (c) of five green gram varieties grown in Katumani and Katangi during 2020 short rains and 2021 long rains in Machakos County, Kenya.

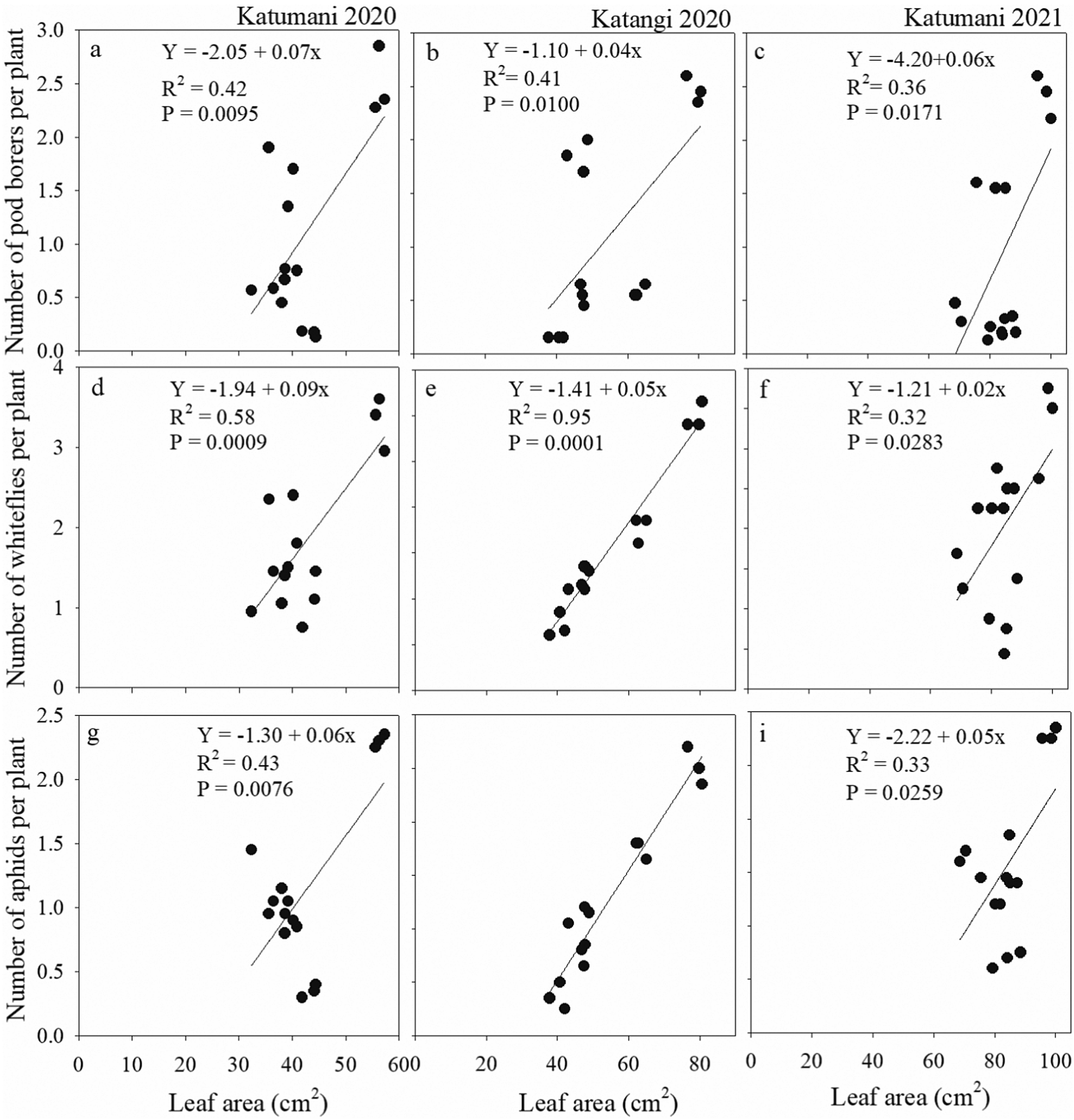

Fig. 4. Relationship between leaf area (cm²) and number of pod borers (a, b, c), whiteflies (d, e, f), and aphids (g, h, i) in five green gram varieties grown in Katumani and Katangi during 2020 short and 2021 long rains. Data were pooled across vegetative and flowering stage. *n* = 15 in Machakos County, Kenya Aphid numbers were scored using a 1–5 scale, where; 0 denoted absence of the pest, 1—a few scattered individuals, 2—a few isolated colonies, 3—several isolated colonies, 4—large isolated colonies, and 5—large continuous colonies.

intermediate in maturity. On average in the cooler Katumani site, KS20 attained 50% branching in 35 d, 50% flowering in 49 d, and matured in 89 d while in Katangi, the same variety took 28 d, 42 d, and 72 d to branch, flower, and mature, respectively. On the other hand, the late maturing N26 attained 50% branching in 44 d and flowered in 61 d in both Katumani and Katangi but matured in 83 d in Katangi, and took 114 d in Katumani. In Katumani, the intermediate varieties (Karembo, Biashara, and Ndengu-Tosha) branched in 42 d, flowered in 56 d, and matured in 88 d while in Katangi the varieties took 39, 51, and 74 d to reach 50% branching, flowering, and physiological maturity, respectively.

Leaf area varied significantly ($P < 0.05$) among the varieties (Table 2). On average, variety N26 had larger leaf area compared with rest of the varieties in all environments. Variety KS20 had the smallest leaf area while that of Biashara, Karembo, and Ndengu-Tosha was intermediate. However, a large variation in leaf area was recorded across the three environments, usually with higher dimensions in wetter seasons.

Table 3 presents leaf hair density per cm² at vegetative and flowering stages among the collection of green gram varieties. Variety KS20 had significantly higher number of leaf hairs compared with the rest of varieties while N26 had the least hairs. The three new

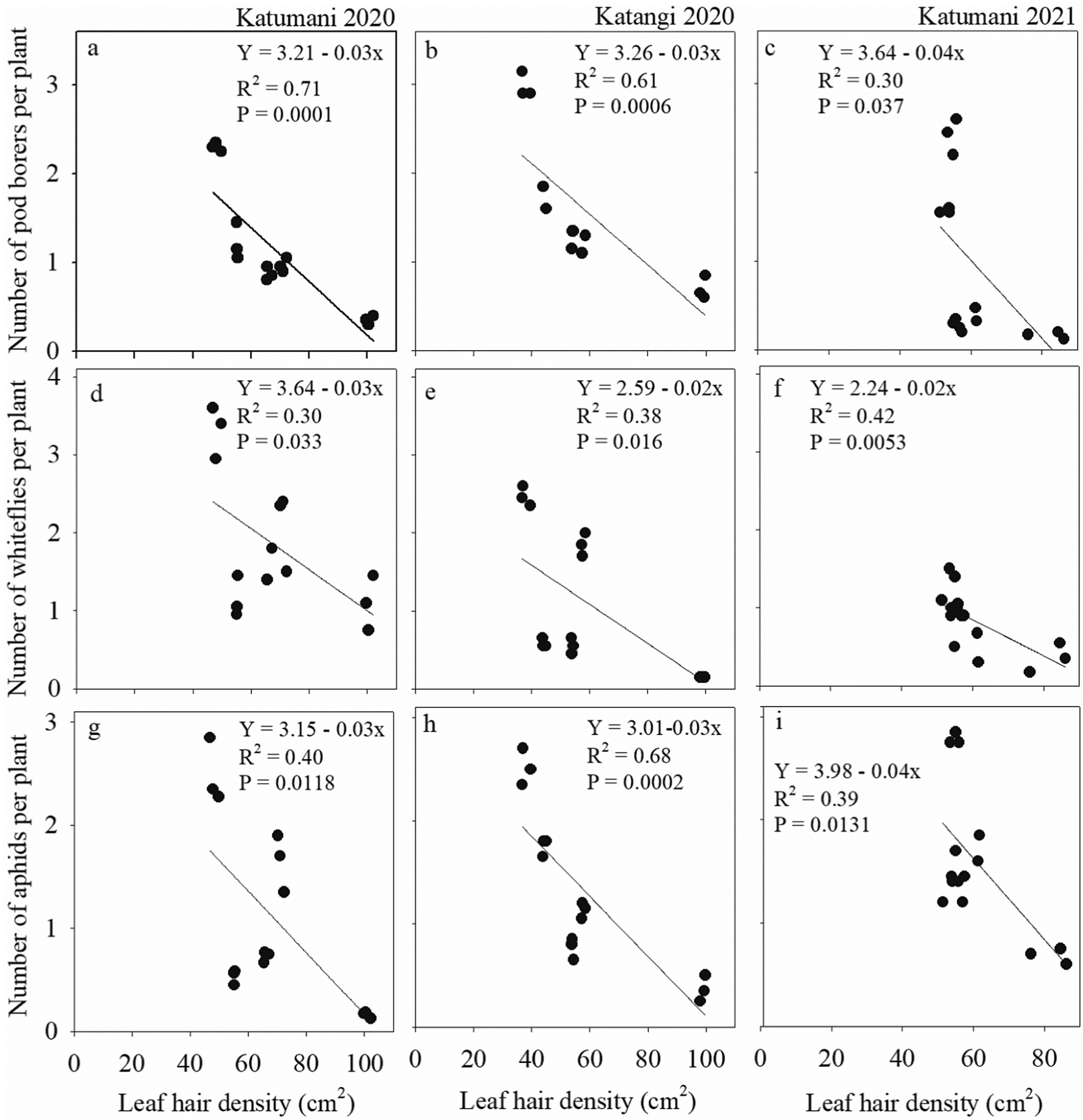

Fig. 5. Relationship between leaf hair density per cm² and number of pod borers (a, b, c), whiteflies (d, e, f), and aphids (g, h, i) in five green gram varieties grown in Katumani and Katangi during 2020 short and 2021 long rains. Data were pooled across vegetative and flowering stage. *n* = 15 in Machakos County, Kenya. Aphid numbers were scored using a 1–5 scale, where; 0 denoted absence of the pest, 1—a few scattered individuals, 2—a few isolated colonies, 3—several isolated colonies, 4—large isolated colonies, and 5—large continuous colonies.

varieties had intermediate leaf hair density compared with their older counterparts. However, Karembo consistently recorded a higher number of leaf hairs among the new releases.

The varieties showed significant differences in leaf moisture content in Katumani and Katangi during the 2020 short rains except in Katumani in 2021 long rains. Variety N26 had significantly higher leaf moisture content while KS20 had the lowest. Varieties Biashara, Karembo, and Ndengu-Tosha were in the intermediary (Table 4). Differences in pod wall thickness were measured during the 2020 season but without differences in the 2021 season. Variety N26 had thicker pod walls of 10–13 mm compared with the rest of varieties. However, Karembo recorded thicker pod walls among the four varieties with thinner husks compared (Table 4).

Alterations in pod borer, whitefly, and aphid infestation among the five varieties across the three environments were recorded (Fig. 2). In detail, variety N26 had the highest pest infestation while KS20 had the lowest population. Biashara, Karembo, and Ndengu-Tosha were intermediary compared with the old varieties but Karembo harbored comparatively a higher number of pests. On the other hand, except in Katangi during 2020, N26 consistently had the largest yield components while KS20 recorded the least, and new varieties were intermediate (Fig. 3a–c).

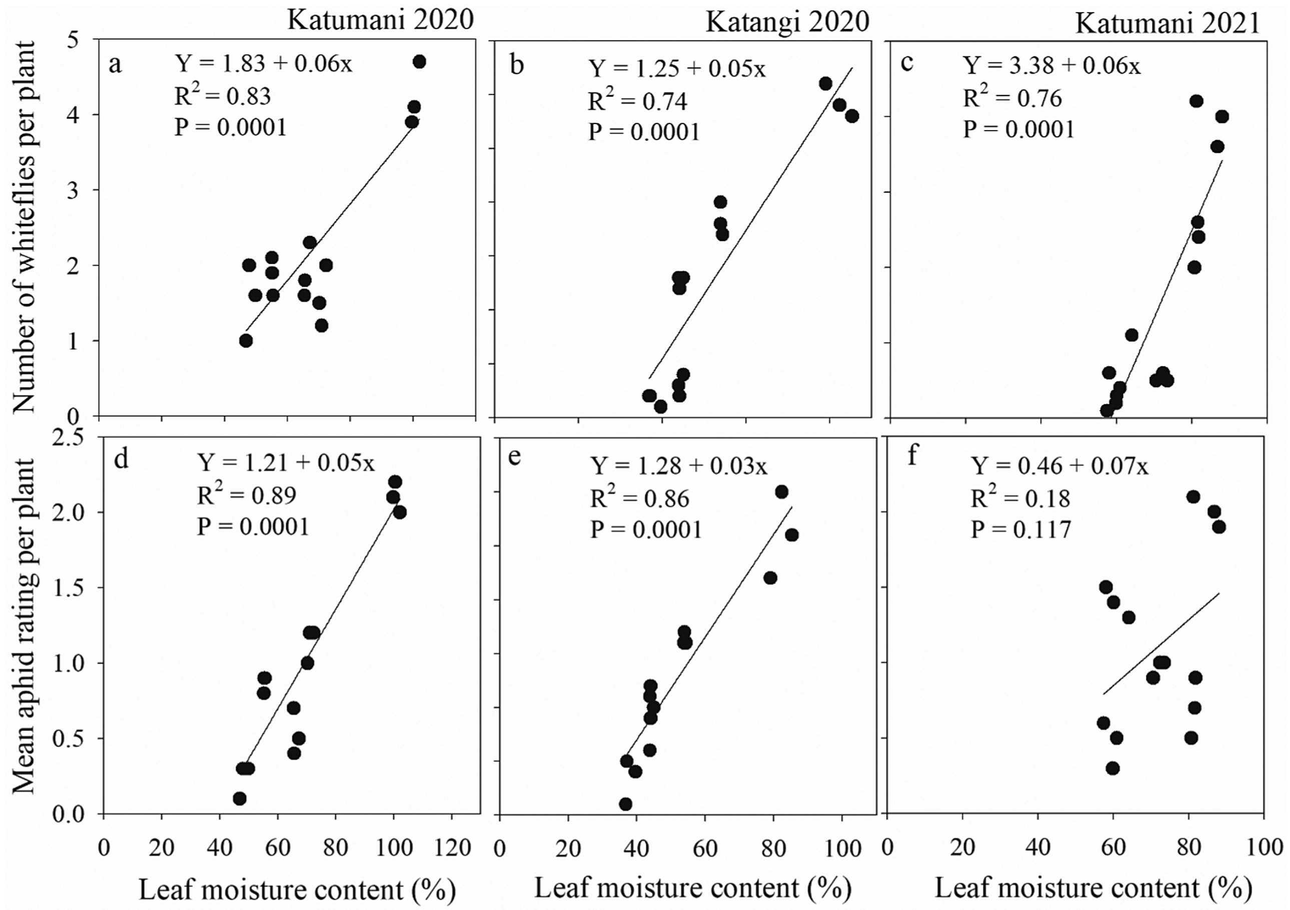

Fig. 6. Relationship between leaf moisture content (%) and number of whiteflies (a, b, c) and aphids (d, e, f) in five green gram varieties grown in Katumani and Katangi during 2020 short and 2021 long rains. Data were pooled across vegetative and flowering stage. *n* = 15 in Machakos County, Kenya. Aphid numbers were scored using a 1–5 scale, where; 0 denoted absence of the pest, 1—a few scattered individuals, 2—a few isolated colonies, 3—several isolated colonies, 4—large isolated colonies, and 5—large continuous colonies.

Data revealed strong associations between pest numbers and crop traits, chiefly leaf area, leaf hair density, leaf moisture content, and pod wall thickness. Across the three environments, leaf area positively ($R^2 \geq 0.36$; Fig. 4a–c) associated with pod borer infestation, where varieties with large canopies harbored more pests. Similarly, a higher number of more whiteflies per plant were recorded in crops with large leaf area ($R^2 \geq 0.32$; Fig. 4d–f). Strong associations ($R^2 \geq 0.33$) were also measured between leaf area and aphid population (Fig. 4g–i). However, relationships between crop traits and pest population were stronger in wetter environments as shown in Fig. 1

Negative but strong associations were measured between leaf hair density and pest infestation. Varieties with higher leaf hair density recorded a lower number of pest numbers while those with lesser leaf hairs recorded larger pest numbers (Fig. 5). Across the three environments, number of pod borers per plant reduced as leaf pubescence increased ($R^2 \geq 0.30$; Fig. 5a–c). Similar trends were observed for whiteflies ($R^2 \geq 0.30$; Fig. 5d–f) and aphid numbers ($R^2 \geq 0.39$; Fig. 5g–i). Additionally, pest numbers were modulated by leaf moisture content (Fig. 6). In this regard, strong and positive associations between leaf moisture content and whiteflies were measured ($R^2 = 0.83$, 0.74, 0.76; Fig. 6a–c). Similar associations were measured between aphid rating and leaf moisture ($R^2 = 0.89$, 0.86; Fig. 6d and e), except in Katumani during 2021 season ($P = 0.117$; Fig. 6f). Further, strong associations between pod borer numbers and pod wall thickness ($R^2 = 0.54$, 0.62, 0.57) were recorded across the three environments (Fig. 7a–c).

Discussion

Breeding of green gram in Kenya has significantly improved adaptation to moisture stress and yield but with limited attention to field pests, which continue to cause marked yield losses. The present study provides understanding into some of the mechanisms conferring the tolerance of green gram to pod borer, aphid, and whitefly infestation in semi-arid regions of Kenya. Among the selection of varieties, earliness contributed to the escape of pest attack while the crop morphological traits modulated pest infestation rate. Comparisons between the old and new varieties did not reveal particular associations between traits for tolerance to pest infestation and the year of variety release. Thus, however unintended, breeding has been not selected for specific traits of tolerance to pod borer, whitefly, and aphid infestation in Kenyan green gram varieties.

The new green gram varieties were intermediary in maturity compared with the early maturing KS20 and the late N26. Even though not reported in the present study, the seed traits of the intermediary Biashara, Karembo, and Ndengu-Tosha largely resemble those of the late maturing N26 (Karimi et al. 2019). This may perhaps suggest that breeding of the new varieties could have relied on particular traits of N26 but with the aim to reduce

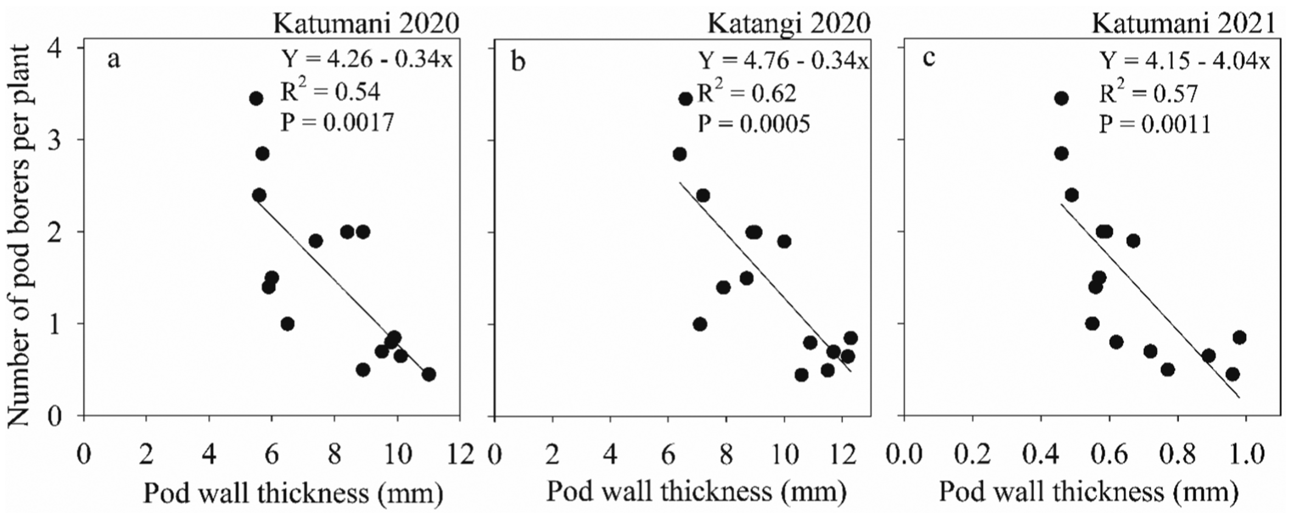

Fig. 7. Relationship between pod wall thickness (mm) and number of pod borers (a, b, c) in five green gram varieties grown in Katumani and Katangi during 2020 short and 2021 long rains, *n* = 15 in Machakos County Kenya.

growth duration. Green gram developmental rates mediated infestation by pod borer, aphids, and whitefly, principally through early maturity to escape economic thresholds of the pests. In addition, earliness associated with a more open canopy which could have created a less favorable habitat for pests. In India, Halder et al. (2006) observed that green gram varieties that had high pest infestation and damage had a large canopy, a high number of pod clusters, and matured late. Additionally, Nadeem et al. (2020) reported higher whitefly and aphid population in late maturity green gram varieties.

Crop morphological traits alter pest population through their physical interference with the mechanisms of host selection, feeding, ingestion, digestion, mating, and oviposition (Quandahor et al. 2019). These traits do not work in isolation but rather integrate to increase or decrease pest infestation rates. The present study measured significant and positive associations between pest numbers, leaf area, and leaf moisture content, hence these traits did not confer host plant resistance. These findings are in agreement with previous reports (Yamamura et al. 1999, Gomez et al. 2008, Dara 2019). Large leaves provide pests with a larger surface area for movement and feeding (Bayoumy et al. 2017). Often, leaf moisture content increases in tandem with leaf surface area (Yasir et al. 2011, Nahrung et al. 2012), and both traits complement each other to increase pest infestation.

Traits that conferred host plant resistance were mainly increased leaf hair density and thick pod walls. Remarkably the early maturity variety KS20 had significantly higher leaf hair density compared with the late N26, but there was no relationship between leaf area and pubescence. Similarly, Zia et al. (2012) reported a negative correlation between leaf hair density and pest population. In the present study, the effect of leaf pubescence was strong on pod borers, with an across-environment $R^2 \geq 0.30$, aphids ($R^2 \geq 0.39$), and whiteflies ($R^2 \geq 0.30$). Evidence shows that leaf pubescence interferes with pest behavior (Amjad et al. 2009, Ihsan-ul-Haq et al. 2003, Rustamani et al. 2014, Bayoumy et al. 2017, Quandahor et al. 2019). The low R^2 values reported in the present study could be attributed to difficulties in estimating pest population, especially with whiteflies. Although not measured in this study, biochemical substances such as semiochemicals and plant secondary metabolites like phenolic compounds could have significantly contributed to pest preference among the evaluated green gram varieties, and deserves further investigation.

Physical barriers such as increased pod wall thickness significantly differed among the test varieties. The early maturity KS20 had thicker pod walls compared to the susceptible N26 which had thinner husks. In the provision of a mechanical barrier, pod wall thickness correlated negatively with pod borer infestation. Halder and Srinivasan (2011) found lower pod borer damage in green gram varieties with thick pod walls. In addition to the physical obstruction rendered by thick pod walls, pods are reported to exude toxic chemicals that modify pest behavior (Warfield 1996, Girija et al. 2008, Sharma et al. 2015).

In conclusion, comparison between the old and new varieties did not reveal specific traits that could have been improved for tolerance to pest infestation in green gram. Comparative resistance to pod borer, aphid, and whitefly infestation among the tested green gram varieties was largely modulated by earliness, leaf hair density, and pod wall thickness. In addition to the potential deployment of these traits in breeding programs, earliness, and varietal resistance should be integrated in the management programs of economically important field pests of green gram.

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Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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