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ASSESSMENT OF FOUR COMMERCIAL WATERMELON CULTIVARS AND ONE LOCAL LANDRACE FOR THEIR RESPONSE TO NATURALLY OCCURRING DISEASES PESTS AND NON-PATHOGENIC DISORDERS IN SUB-HUMID TROPICAL CONDITIONS

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ABSTRACT

Four commercial watermelon cultivars available in Kenya and one local landrace were evaluated for their susceptibility/resistance to naturally occurring diseases, pests and non-pathogenic disorders. The accessions included three most common commercial watermelon cultivars in Kenya namely 'Sugarbaby', 'Crimson Sweet' and 'Charleston Gray'; one newly introduced cultivar from United States namely 'Yellow Crimson'; and one local landrace (GBK-043014) from Kakamega district in Western Kenya.

No inoculation was done because the study targeted naturally occurring diseases, pests and non-pathogenic disorders. Disease rating was done when the most susceptible accession(s) was severely diseased. Data collected was subjected to analysis of variance (ANOVA) using SAS version 9.1 and differences declared significant at 5% level. The SAS procedure PRINCOMP was then used to perform a principle component (PC) analysis using severity scores and accessions plotted on two dimensions using the first two principle components (PC1 and PC2). Results demonstrated significant variation among accessions in susceptibility/resistance to various diseases, pests and non-pathogenic disorders that were observed.

Keywords: watermelon, cultivars, landrace, disease, pests, non-pathogenic disorders, Kenya.

INTRODUCTION

Watermelons [Citrullus lanatus(Thunb.) Matsum. & Nakai] are susceptible to several diseases that attack the roots, foliage, and fruit resulting in reduced yields. These include Fusarium wilt, anthracnose, damping off, gummy stem blight, bacterial fruit blotch, yellow vine, bacterial rind necrosis, cercospora leaf spot, angular leaf spot, alternaria leaf spot, Phytophthora blight, powdery mildew, downey mildew and viral diseases (Roberts and Kucharek, 2006; Sikora, 1997). Disease control is essential in the production of high quality watermelons. A control program that combines the use of cultural practices, genetic resistance, and chemical application as needed usually provides the best results. The use of disease-resistant varieties is an economical means of controlling diseases (Warren *et al*., 1990). Levi *et al*. (2001) reported the need for watermelon improvement, for increased disease and pest resistance to better meet market demands. Plant breeders need sources of resistance that can be incorporated into adapted breeding lines to help control various problems of watermelon (Gusmini *et al*., 2005). Owing to their different genetic composition, different varieties of watermelon will respond differently to various stresses. In order to come up with the best variety for a given agro-ecological zone, it is essential to assess the inherent resistance in various accessions available in the area.

There are over 1,200 varieties of watermelon worldwide (Miles, 2004) and a wide variety of watermelons have been cultivated in Africa (Zohary and Hopf, 2000) but there is little information regarding their ancestries (Levi *et al*., 2001). In Kenya, for example, some watermelon landraces have been identified in different parts of the country but have not been exploited. On the other hand, Tindall (1983) recommended several inbred cultivars to Kenyan growers but only a few have gained popularity in the country. These include 'Sugarbaby', 'Crimson Sweet', and 'Charleston Gray' which are all old cultivars that were developed half a century ago and are therefore more vulnerable to new threats such as diseases and pests, pollution, climate change, among others. There is scant data available comparing modern cultivars with local landraces and the factors which result in farmers preferring local landraces over modern varieties are not very well understood. The available information suggests that modern varieties often lack additional characters which farmers consider important (Hardon and Boef, 1993). A lot of watermelon breeding has been ongoing throughout the world especially in the United States and new cultivars are continuously being developed. However, Levi *et al*. (2001b) reported that many watermelon cultivars developed over the last two centuries have a narrow genetic background.

Levi *et al*. (2001) reported that resistance to anthracnose and watermelon mosaic virus exists among accessions of *C.* lanatus var. lanatus, and resistance to gummy stem blight and Fusarium wilt, may exist among accessions of *C.* lanatus var. citroides. Breeding for resistance to powdery and downy mildew, fusarium wilt, anthracnose and several viruses and insects that attack watermelon is a continuing challenge in watermelon production (Smartt and Simmonds, 1995; Davis *et al*., 2005). Watermelon improvement depends largely on identifying and introducing genes for resistance to diseases and pests and those that will improve yield, stress tolerance and other cultural responses (Smartt and

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Simmonds, 1995). There is therefore need to compare the inherent resistance of various watermelon accessions available in Kenya to various naturally occurring diseases, pests and non-pathogenic disorders affecting watermelon production. This data will be essential to validate some of the already suggested comparative advantages of landraces over modern cultivars or vice versa, and may provide new options for plant breeding. The objective of this study was therefore to assess the response of most popular commercial watermelon cultivars in Kenya and one local landrace to naturally occurring diseases, pests and non-pathogenic disorders of watermelon.

MATERIALS AND METHODS

The study was carried out at Maseno University Research fields. The site lies in Maseno Division, Nyanza Province, Kenya within the upper Midland 1 agro-ecological zone (Jaetzold and Schimidt, 1982) at latitude $0^{o}1$'N – $0^{0}12$'S, longitude $34^{o}25$'E – 47'E and an altitude of 1500m above the sea level (Mwai *et al.*, 2001). The area receives a bimodal mean annual rainfall of 1750mm with the first rainy season falling between March and July; and second season falling between September and early December. No month, however, is completely dry (Jaetzold and Schimidt, 1982). The mean annual temperature is 28.7^{o}C (Mwai *et al.*, 2001) with the hottest season occurring between January and April (Jaetzold and Schimidt, 1982). The soils are classified as dystric nitisols. They are well-drained, deep reddish brown, slightly friable clay with pH ranging between 4.5 and 5.4 (Mwai *et al.*, 2001).

Three most popular commercial cultivars of watermelon in Kenya namely; 'Sugarbaby', 'Charleston Grey', and 'Crimson Sweet', one newly introduced commercial cultivar from United States namely; 'Yellow Crimson', and one local landrace (GBK-043014) from Kakamega district (altitude 1250-1500m ASL) in Western Kenya, were used in this study. Seeds of the landrace were obtained from National Genebank of Kenya (Muguga) in March 2007 and were grown at Maseno University Horticultural Fields for seed bulking before proceeding to the main study. Commercial cultivars were obtained from local shops except 'Yellow Crimson' which was obtained from Rispern Seeds, INC. Beecher, Illinois. 'Sugarbaby', 'Charleston Grey' and 'Crimson Sweet' were from East Africa Seeds, Kenya.

The seeds were directly sown in the field at a spacing of 1.5m x 1.5m. Since watermelon is reported to have poor germination, five to ten seeds were planted per hole but were thinned to one seedling three-four weeks after planting. Organic manure and NPK fertilizer were applied in the planting holes before sowing at the recommended rate of thirty (30) t/ha and 200 kg/ha, respectively.

Two rows of 'sugarbaby' were used as guard rows around the experimental field. Other agronomic practices including irrigation, weeding and top dressing were conducted uniformly and as required in all plots. No chemicals or any other method of pest and disease control were employed.

The first season experiment was conducted between September and December, 2007 followed by the second season experiment between January and May, 2008. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications.

Typical symptoms and severity index were used during evaluation of diseases, non-pathogenic disorders and pests. A scale of 1-5 whereby 1 = 0-20%; 2 = 21-40%; 3 = 41-60%; 4 = 61-80%; and 5 = 81-100% was adopted from Ssekyewa (2006) and was used to score the severity of diseases, pests, and non-pathogenic disorders, based on percentage number of leaves/fruits showing symptoms and extent of leaf/fruit damage. Disease rating was done when the most susceptible accession(s) was severely diseased as suggested by Gusmini *et al.*, 2005.

For example, for anthracnose, plants were rated for disease severity when symptoms progressed to stems and fruits of the most susceptible accession(s). The data was subjected to analysis of variance (ANOVA) using SAS version 9.1 (SAS Institute, 2005) and differences declared significant at 5% level.

Least Significant Difference ($LSD_{5\%}$) was used to separate the means. The SAS procedure PRINCOMP was then used to perform a principle component (PC) analysis using severity scores and accessions plotted on two dimensions using the first two principle components (PC1 and PC2). Descriptive statistics (mean, standard deviation, and coefficient of variation), were generated using the SAS procedure,

RESULTS

Disease severity

Four diseases that were easily identifiable using their typical symptoms were observed during the study. These were yellow vine disease, anthracnose, cercospora leaf-spot and rind necrosis (Table-1). Highly significant variation ($p<0.001$) in resistance/susceptibility to anthracnose was observed among accessions in both seasons. In the first season, only 'Sugar baby' and the Kaka mega landrace were found to be susceptible to this disease unlike in the second season when 'Charleston Gray' was also susceptible (average score 1.72). 'Sugar baby' had a higher susceptibility scoring an average of 4.17 and 4.33 in first and second season respectively, compared to the Kaka mega landrace which scored an average of 2.56 and 2.44 in first and second season respectively. All other accessions remained free from this disease. Combined season scores were 4.25, 2.45, and 1.36 for 'Sugar baby', Kaka mega landrace and 'Charleston Gray', respectively. Seasonal variations in susceptibility to anthracnose were not significant ($p>0.05$) while accession x season interactions were significant ($p<0.05$).

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Table-1. Disease rating per accession.

Diseases	**Yellow Vine**			**C. Leaf Spot**			**Anthracnose**			**Rind Necrosis**		
Accession	**Sn 1**	**Sn 2**	**Mean**	**Sn 1**	**Sn 2**	**Mean**	**Sn 1**	**Sn 2**	**Mean**	**Sn 1**	**Sn 2**	**Mean**
Sugarbaby	1.44^{b}	1.22^{c}	1.33^{b}	2.72^{a}	2.33^{a}	2.53^{a}	4.17^{a}	4.33^{a}	4.25^{a}	2.67^{b}	2.00^{b}	2.33^{b}
Y. Crimson	2.11^{b}	1.33^{c}	1.72^{b}	1.67^{bc}	1.56^{b}	1.61^{bc}	1.00^{c}	1.00^{d}	1.00^{d}	1.00^{c}	1.00^{c}	1.00^{c}
C. Sweet	3.11^{a}	2.56^{a}	2.83^{a}	2.11^{b}	1.22^{b}	1.67^{b}	1.00^{c}	1.00^{d}	1.00^{d}	1.00^{c}	1.00^{c}	1.00^{c}
C. Gray	3.11^{a}	1.83^{b}	2.47^{a}	1.22^{c}	1.11^{b}	1.17^{c}	1.00^{c}	1.72^{c}	1.36^{c}	3.67^{a}	3.33^{a}	3.50^{a}
Landrace	1.44^{b}	1.33^{c}	1.39^{b}	2.11^{b}	1.44^{b}	1.78^{b}	2.56^{b}	2.44^{b}	2.50^{b}	1.00^{c}	1.00^{c}	1.00^{c}
$LSD_{5\%}$	0.8548	0.4857	0.6513	0.5885	0.6065	0.484	0.4286	0.3822	0.3233	0.3720	0.3700	0.3043
F Test	***	***	***	***	***	***	***	***	***	***	***	***
CV (%)	20.24	15.59	27.98	15.90	21.02	23.17	11.71	9.77	13.45	10.58	11.79	14.42
SD	0.8772	0.5662	0.79932	0.5845	0.5171	0.5851	1.3209	1.2924	1.2858	1.1586	0.9677	1.0537

Means followed by the same letter are not significantly different
*** = Highly Significant
Sn = Season

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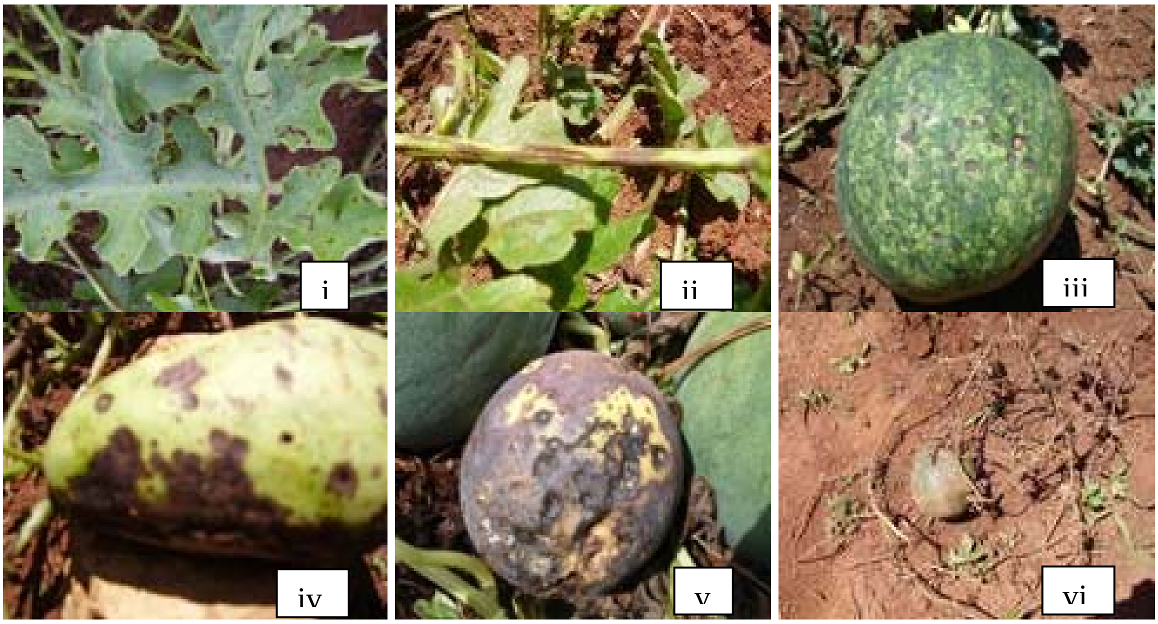

Plate-1. Anthracnose lesions on: (i) Sugarbaby leaf, (ii) Kakamega landrace stem, (iii) Sugarbaby fruit, (iv) Charleston gray fruit, (v) Kakamega landrace fruit, (vi) Dead Sugarbaby fruit that succumbed to anthracnose disease.

Yellow vine disease [Plate-2(i)] was most prominent in the first season than in the second season and was mostly affecting the commercial cultivars especially ‘Crimson Sweet’ and ‘Charleston Grey’. Highly significant ($p<0.001$) variation was observed in both seasons among accessions in susceptibility/resistance to this disease. In the first season, ‘Crimson Sweet’ and ‘Charleston Gray’ were not significantly ($p>0.05$) different in susceptibility to yellow vine, both scoring an average of 3.11. Their susceptibility, however, not only declined but was also significantly ($p<0.05$) different in the second season (2.56 and 1.83 respectively). ‘Yellow Crimson’, ‘Sugar baby’ and Kakamega landrace appeared to contain appreciable resistance to this disease. In the first season, ‘Yellow Crimson’ scored an average of 2.11 and was not significantly ($p>0.05$) different from ‘Sugar baby’ and Kakamega landrace, both of which scored an average of 1.44. Their susceptibility, however declined in the second season with ‘Sugarbaby’ scoring an average of 1.22 and was not significantly ($p>0.05$) different from ‘Yellow Crimson’ and Kakamega landrace, both of which scored an average of 1.33. Combined season scores were 2.83, 2.47, 1.72, 1.39, and 1.33 for ‘Crimson Sweet Charleston Gray Yellow Crimson Kakamega landrace and ‘Sugarbaby’ respectively. Seasonal variations in susceptibility to yellow vine disease were highly significant ($p<0.001$) while accession x season interactions were not significant ($p>0.05$).

Typical symptoms of Cercospora [Plate-2(ii)] leaf spot were observed in both seasons in all accessions except on the wild accession. However, a highly significant ($p<0.001$ and $p<0.01$ in first and second season respectively) variation was observed among accessions in resistance/susceptibility to this disease. ‘Sugar baby’ was found to be significantly ($p<0.05$) the most susceptible with average scores of 2.72 and 2.33 in first and second season respectively. ‘Charleston Grey’, ‘Yellow Crimson’, ‘Crimson Sweet’ and Kakamega landrace appeared to possess some considerable resistance against the disease scoring an average of 1.22, 1.67, 2.11 and 2.11 in the first season and 1.11, 1.56, 1.22 and 1.44 in the second season respectively. Combined season scores were 2.53, 1.78, 1.67, 1.61 and 1.17 for Sugarbaby Kakamega landrace, ‘Crimson Sweet Yellow Crimson and ‘Charleston Gray respectively. Seasonal variations in susceptibility to Cercospora leaf spot were highly significant ($p<0.001$) while accession x season interactions were not ($p>0.05$).

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Plate-2. (i) Yellow vine disease symptoms on Charleston Gray and (ii) Cercospora leaf spot symptoms at an advanced stage on a Sugarbaby leaf.

Rind necrosis was found to be a major problem in Charleston Gray' (Plate-3) and 'Sugarbaby'. In both seasons, a highly significant variation ($p<0.001$) in resistance/susceptibility to rind necrosis was observed among accessions. 'Charleston Gray' was significantly ($p<0.05$) the most susceptible with average scores of 3.67 and 3.33 in first and second season respectively, compared to Sugarbaby which scored an average of 2.67 and 2.00 in first and second season respectively. Combined season scores were 3.50 for 'Charleston Gray' and 2.33 for 'Sugarbaby'. Seasonal variations in susceptibility to rind necrosis were significant ($p<0.01$) as well as accession x season interactions ($p<0.05$).

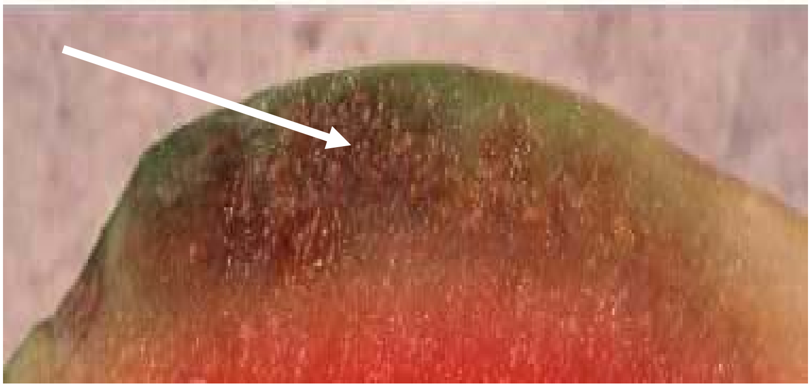

Plate-3. Typical symptoms of rind necrosis on Charleston Gray fruit.

Pest severity

Although Kakamega landrace portrayed resistance to many pests that attacked commercial cultivars, it appeared the most susceptible to cucumber beetles which significantly destroyed (score 3) the leaves and flower petals of this accession particularly in the first season of this study. The accession, however, portrayed great tolerance to the pest and appeared to suffer no economic yield loss. The pest did not even affect fruit development even after damaging the petals of this accession. 'Yellow Crimson' was also partially attractive (score 2.11) to this beetle but the rest of the accessions were not preferred. In the second season there was dramatic reduction of cucumber beetle infestation with the few beetles being limited to Kakamega landrace and 'Yellow Crimson' (Table-2.)

A highly significant ($p<0.001$) variation in susceptibility to melon fly was observed in both seasons among accessions. In both seasons, the Kakamega landrace remained completely resistant (score 1) to melon fly with no signs of the dreaded fly being noted not even in a single fruit. 'Yellow Crimson' also portrayed appreciable resistance with an average score of 1.78 and 1.89 in first and second season, respectively. 'Crimson Sweet', 'Sugarbaby' and 'Charleston Gray' were the most susceptible to this pest recording averages of 2.78, 3.44 and 3.56, respectively in the first season, and 2.78, 3.00 and 3.33, respectively in the second season. Combined season scores were 3.45, 3.22, 2.78, 1.84 and 1.00 for 'Charleston Gray', 'Sugarbaby', 'Crimson Sweet', 'Yellow Crimson' and Kakamega landrace, respectively (Table-2). Seasonal variations as well as accession x season interactions in susceptibility to melon fly were not significant ($p>0.05$).

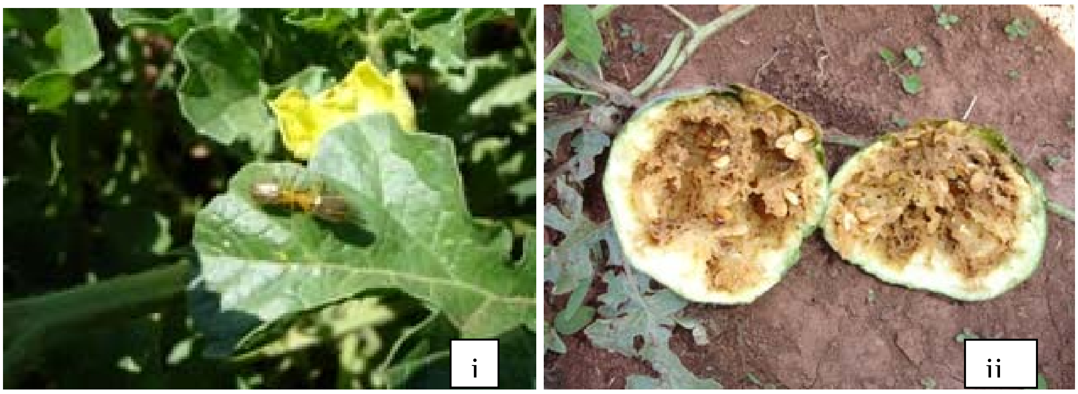

Plate-4. (i) Cucumber beetles on the landrace and (ii) Melon fly damage in Sugarbaby fruit.

Table-2. Assessment of pest damage per accession.

Pest	**Cucumber beetles**			**Melon fly**		
Accession	Sn 1	Sn2	Mean	Sn 1	Sn 2	Mean
Sugarbaby	1.50[c]	1.00[c]	1.25[c]	3.44[a]	3.00[ab]	3.22[a]
Yellow Crimson	2.11[b]	1.67[b]	1.89[b]	1.78[c]	1.89[c]	1.84[c]
Crimson Sweet	1.61[c]	1.00[c]	1.31[c]	2.78[b]	2.78[b]	2.78[b]
Charleston Gray	1.67[bc]	1.00[c]	1.34[c]	3.56[a]	3.33[a]	3.45[a]
Landrace	3.00[a]	2.44[a]	2.72[a]	1.00[d]	1.00[d]	1.00[d]
$LSD_{5\%}$	0.4677	0.3566	0.4434	0.4925	0.5487	0.3079
F Test	***	***	***	***	***	***
CV (%)	12.56	13.32	21.84	10.41	12.14	11.46
SD	0.6074	0.6102	0.6616	1.0454	0.9100	0.9647

Means followed by the same letter are not significantly different *** = Highly significant

There was a highly significant ($p<0.001$) and strong but negative ($R = -0.952$, $R^2 = 0.906$) correlation between melon fly and Cucumber beetles infestation as shown in Figure-1 below.

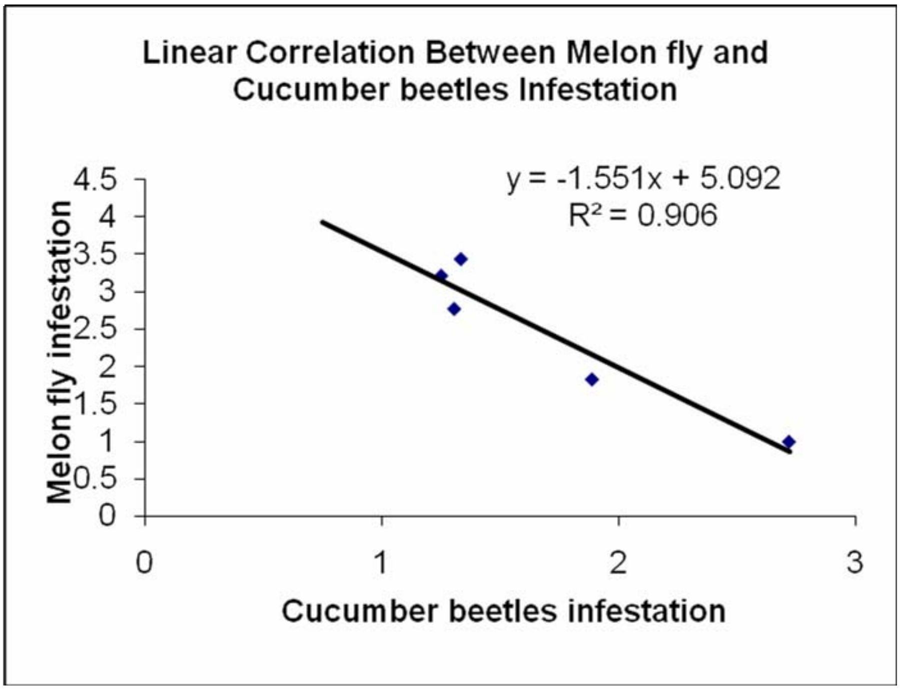

Figure-1. Linear correlation between melon fly and cucumber beetles infestation.

Other pests that were observed included ladybirds, aphids, white flies and rind worms but their levels of infestation were of no economic importance.

Non-pathogenic disorders

A highly significant (p<0.001) variation in susceptibility to bursting [Plate-5(i)] was observed among accessions in both seasons. 'Sugarbaby' was the most susceptible to the disorder recording an average score of 3.27 and 3.34 in first and second season respectively (Table-3). The disorder was also noted on 'Yellow Crimson' and 'Crimson Sweet' which recorded an average score of 2.67 and 2.61 respectively in the first season and 2.89 and 2.67 respectively in the second season. Combined season scores were 3.30, 2.78 and 2.64 for 'Sugarbaby', 'Yellow Crimson' and 'Crimson Sweet' respectively. Charleston Gray' and Kakamega landrace remained free (score 1) from this disorder in both seasons. Most fruits were found to burst as they approached maturity. The bursting would start with a small superficial crack increasing in length and depth to expose the juicy flesh and seeds. The intensity of the crack increased during sunny days. Seasonal variations as well as accession x season interactions in susceptibility to bursting were not significant (p>0.05).

Blossom-end rot disorder [Plate-5(ii)] was observed on 'Charleston Gray' and to a lesser extent on 'Sugarbaby'. A highly significant (p<0.001) variation in susceptibility to blossom-end rot was observed among accessions in both seasons. 'Charleston Gray' scored an average of 3.33 and 2.72 in first and second season, respectively while 'Sugarbaby' scored an average of 1.50 and 1.22 in first and second season, respectively (Table-3). Combined season scores were 3.03 and 1.36 for 'Charleston Gray' and 'Sugarbaby' respectively. No other accession suffered from this disorder. Seasonal variations in susceptibility to blossom-end rot as well as accession x season interactions were significant (p<0.01).

Plate-5. (i) Bursting disorder on Sugarbaby fruit and (ii) blossom end-rot disorder on Charleston gray fruit.

Table-3. Assessment of non-pathogenic disorders in watermelon accessions.

Disorder	**Bursting**			**Blossom-end rot**		
Accession	**Sn 1**	**Sn 2**	**Mean**	**Sn 1**	**Sn 2**	**Mean**
Sugarbaby	3.28^{a}	3.33^{a}	3.31^{a}	1.50^{b}	1.22^{b}	1.36^{b}
Yellow Crimson	2.67^{b}	2.89^{a}	2.78^{b}	1.00^{c}	1.00^{b}	1.00^{c}
Crimson Sweet	2.61^{b}	2.67^{a}	2.64^{b}	1.00^{c}	1.00^{b}	1.00^{c}
Charleston Gray	1.00^{c}	1.00^{b}	1.00^{c}	3.33^{a}	2.72^{a}	3.03^{a}
Landrace	1.00^{c}	1.00^{b}	1.00^{c}	1.00^{c}	1.00^{b}	1.00^{c}
$LSD_{5\%}$	0.3977	0.7621	0.3477	0.2997	0.3451	0.1844
F Test	***	***	***	***	***	***
CV (%)	10.01	18.57	13.12	10.16	13.19	15.17
SD	0.9911	1.0841	1.0211	0.9468	0.7178	0.8304

Means followed by the same letter are not significantly different. *** = Highly Significant

Results of the principle component analyses for severity scores of diseases, pests and non-pathogenic disorders indicated that the first three PCs explained 39%, 29% and 18% (a total of 86%) of the total diversity (Table-4). The two-dimensional presentation of all accessions grouped by seasons (1 and 2) is presented in Figure-2. 'Charleston Gray' (CG) separated clearly from the rest and was located on the upper part of the PCA graph (Figure-2). On the lower part of the PCA graph where other accessions were located, 'Sugarbaby' (SB), separated from the rest and was located on the right hand side of the graph. 'Crimson Sweet' (CS), 'Yellow Crimson' (YC) and the landrace (LR) were grouped close together with the landrace being at the bottom, 'Yellow Crimson' at the middle and 'Crimson Sweet' at the top.

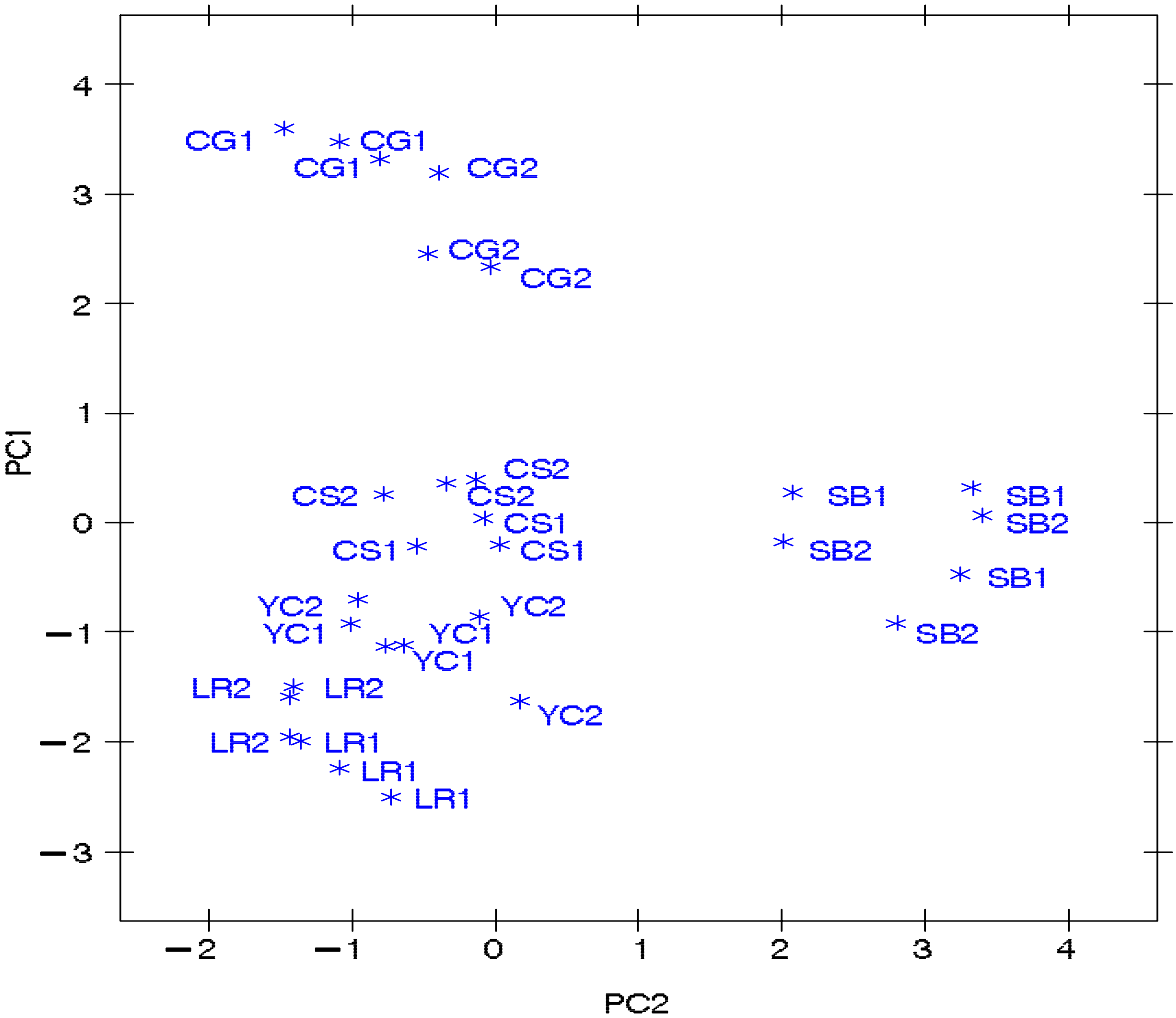

Figure-2. Principle component (PC) analysis plot of first two principle components, depicting diversity among watermelon accessions based on resistance to pests, diseases and disorders.

Table-4. The first three principle components (PC) of the eight resistance variables.

Variable	PC1	PC2	PC3
Cercospora leaf spot	-0.243394	0.465237	0.100438
Anthracnose	-0.121458	0.513675	0.417950
Yellow vine	0.297718	-0.241633	-0.415464
Rind necrosis	0.484607	0.167221	0.357425
Melon fly	0.458527	0.334444	-0.156594
Cucumber beetles	-0.334643	-0.317489	0.391923
Blossom endrot	0.509788	-0.051708	0.311257
Bursting	-0.142870	0.466924	-0.489756
Eigen value	**3.125**	**2.328**	**1.417**
Proportion	**0.39**	**0.29**	**0.18**
Cumulative	**0.39**	**0.68**	**0.86**

DISCUSSIONS

Disease resistance

Generally, disease and pest severity was found to be high in commercial cultivars than in the landrace, especially the three old and most popular commercial cultivars, namely; 'Sugarbaby', 'Crimson Sweet' and 'Charleston Gray'. Landraces and wild progenitors are reportedly useful sources of resistance as they contain a great genetic diversity. Progenitors of many crops still occur in the wild, while landraces have been cultivated for a long period of time, usually under rather primitive cultural practices. The natural enemy and the host species usually have co-existed side by side for ages and co-evolution and natural selection may have taken place (Niks and Lindhout, 2006).

Yellow vine disease which is reportedly a relatively new disease of watermelon, caused by an unknown, phloem-limited bacterium (Wehner *et al.,* 2001) was a major problem especially in the first season and was mostly affecting commercial cultivars. 'Crimson Sweet' and 'Charleston Gray' were the most susceptible, while 'Yellow Crimson' portrayed moderate resistance. 'Sugarbaby' and the Kakamega landrace demonstrated good resistance and could be potential sources of resistance against yellow vine disease. Wehner *et al.* (2001) called for research to identify good sources of resistance against this disease.

Anthracnose, which is a fungal disease, caused by Colletotrichum lagenarium (Sikora, 1997) was the most troublesome disease especially in 'Sugarbaby' and the Kakamega landrace. 'Charleston Gray' which is reportedly resistant to most races of anthracnose (Wehner and Barrett, 2005) escaped infection in the first season but succumbed in the second season. In general, anthracnose severity was high in the second season compared to the first season.

The seasonal differences may have been caused by high rainfall that was received in the second season as compared to the first season. Sikora (1997) reported that warm (24°C) and wet (frequent rains, poor drainage) conditions favour rapid development and spread of this disease. Symptoms were found to appear at the onset of rainfall which in the second season coincided with the start of reproductive phase and lasted up to maturity. Sikora (1997) reported that anthracnose can appear anytime during the season, but most damage occurs late in the season after the fruit is set. Anthracnose is the only disease that was important to the Kakamega landrace. Probably the causal agent of anthracnose never existed in the region of origin of this landrace and hence natural selection for its resistance did not take place. However, unlike in the first season when the symptoms spread to the fruits of the landrace, the fruits managed to escape infection in the second season. Anthracnose is qualitatively inherited and probably a wider collection of this landrace could portray resistance. 'Yellow Crimson' and 'Crimson Sweet' appeared to have good resistance to anthracnose.

According to Wehner and Barrett (2005), most commercial watermelon cultivars including 'Crimson Sweet' have some resistance against anthracnose. Seven races of anthracnose pathogen have been reported. Races 4, 5, and 6 are virulent in watermelon and are more important. Races 1 and 3 are not virulent and many varieties are resistant to them, while resistance to other races is being sought (Wehner *et al.,* 2001). Unfortunately, it was not possible to extract and identify specific race(s) of anthracnose pathogen that were present in the field during this study.

Cercospora leaf spot was another important disease that was observed in this study and its severity was higher on the inbred cultivar 'Sugarbaby'. The fungus Cercospora citrullina causes this disease (Roberts and Kucharek, 2006). Its symptoms were also noted on the leaves of 'Yellow Crimson', 'Crimson Sweet' and the Kakamega landrace but the three showed moderate resistance against the disease. 'Charleston Gray' and the

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wild accession demonstrated good resistance to this disease.

This disease was more troublesome in the first than second season, and this may be attributed to the different rainfall patterns that were observed in the two seasons. It was found to be more severe in the early stages of plant development when the leaves were tender and more succulent. Roberts and Kucharek (2006) reported that cercospora leaf spot is favored by wet conditions and warm temperatures of 27-32°C, and that the spores are readily wind-borne and rain splashed.

The first season received more rainfall during the vegetative phase of the plants thus creating more conducive conditions for growth and spread of the causal pathogen at an early stage. On the other hand, the second season received more rainfall during the reproductive phase running through to maturity hence low disease severity in this season. There is no documented information regarding any developed cultivars that are resistant to Cercospora leaf spot.

The fourth disease, rind necrosis, was observed in only two accessions namely 'Charleston Gray' and 'Sugarbaby'.The disease was limited to fruits only and was found to develop inside the fruit with no external symptoms. It could only be detected after harvesting and when the fruits were cut open. Breeding for resistance against this disease is highly desired on susceptible accessions because the disease is difficult to control by other means. The specific causal agent of this disease is not yet known (Wehner *et al.,* 2001) but it is thought to be caused by some bacteria that are naturally present in fruit (Roberts and Kucharek, 2006). Drought stress is also reported to predispose melons to rind necrosis (Warren *et al*., 1990). Some varieties resistant to this disease have been identified (Wehner *et al.,* 2001) but there are no other control measures (Roberts and Kucharek, 2006).

Pest Resistance

Only two pests were of economic importance during this study; melon fly and cucumber beetles. Melon fly (Bactrocera cucurbitae) was a menace especially on commercial cultivars probably because of the soft rinds of their immature fruits. The pest reportedly prefers to infest young, green, soft-skinned fruits. It lays the eggs 2 to 4 mm deep in the fruit tissues, and the maggots feed inside the fruit (Dhillon *et al*., 2005). 'Yellow Crimson', however, portrayed good resistance (score 2) against the pest probably because of its hard rind.

The Kakamega landrace was completely resistant (score 1) to melon fly with no signs of infestation being noted not even on a single fruit. The hairy ovary and fruitlets of the Kakamega landrace which deter the adult fly from laying its eggs in the fruitlets, along with its hard rind that inhibits penetration of the melon fly could be the main factors responsible for its resistance against melon fly. In addition, some resistance may be attributed to the high level of cucurbitacin in this accession. Robinson (1992) reported that hard rind and biochemical components, possibly including high cucurbitacin and phenol content and low concentration of sugars, organic acids, and minerals are some of the factors contributing to resistance against melon fly.

Growing fruit fly-resistant genotypes is the best control strategy since the maggots damage the fruits internally and is therefore difficult to control this pest with insecticides (Dhillon *et al*., 2005). Melon fly resistance is controlled by a single dominant gene *Fwr* (Guner and Wehner, 2004).

Significant cucumber beetle infestation was experienced in the first season, declining dramatically in the second season. This was attributed to the fact that the maize crop in the neighboring field which acted as an alternate host of these beetles in the first season was not grown in the second season. According to Martin and Blackburn (2003) immature stages (larvae) of certain species of cucumber beetles also feed on corn where it is referred to as, corn rootworm. The first season crop was planted as the maize in the neighboring field was maturing and it therefore coincided with a high population of cucumber beetles which were probably searching for an alternate host. Cucumber beetles may be attracted from a considerable distance to cucurbit plants with high cucurbitacin content. Cucurbitacins are stable compounds without appreciable volatility or odour and their attractiveness to beetles is evidently not olfactory. However, it has been speculated that feeding of cucumber beetles on high cucurbitacin plants releases an unidentifiable volatile aggregation pheromone of high potency (Robinson, 1992). Cucumber beetles infestation was therefore high on Kakamega landrace (score 4) perhaps because this accession has not been selected for low cucurbitacin content. Bisognin (2002) reported that cucurbitacin is attractive to diabrotica beetles and resistance is achieved by selecting for reduced cucurbitacin content. Cucurbitacins are feeding stimulants for several species of diabrotica beetles (Martin and Blackburn, 2003) and varieties with less cucurbitacin show less damage (Hoffmann and Zitter, 1994). 'Yellow Crimson' also appeared partially attractive to cucumber beetles but other commercial cultivars were not preferred probably because they have been selected for low cucubitacin content during selection for sweet taste.

Cucurbitacins are tetracyclic triterpenoid compounds occurring very often in species of the Cucurbitaceae (hence their name) but also occurring in some other plants. These bitter very toxic compounds evidently were favoured by natural selection as a means of protecting plants against herbivore attack.

Over the course of co-evolution, however, cucumber beetles acquired means to tolerate cucurbitacins and developed preference for these compounds. Cucumber beetles are able to detoxify or excrete cucurbitacin compounds and they also sequester sufficient cucurbitacin in their bodies to provide deterrence to predators. Attractant-baited traps and attracticidal baits made of mixtures of cucurbitacins as a feeding stimulant and a small amount of insecticide are promising for control of cucumber beetles (Hoffmann and Zitter, 1994). Since melon flies are deterred by high cucurbitacin content in some watermelon accessions, while cucumber beetles are highly attracted to such accessions, a highly significant ($p<0.001$) and strong but negative correlation ($R=-0.952$, $R^2=0.906$) was observed between melon fly and cucumber beetles infestation in the first season Figure-1.

Although cucumber beetles reportedly cause losses to cucurbits by directly feeding on young plants, blossoms, and fruit (Martin and Blackburn, 2003; Hoffmann and Zitter, 1994), no fruit, damage was observed in this study but the beetles concentrated on leaves and flower petals. Interestingly, the pest did not appear to affect fruit development in any significant manner even after damaging the petals. Apparently, the beetles also played a major role as pollination agents. In addition to damaging the crop, the adult beetles transmit bacterial wilt and viral diseases (Martin and Blackburn, 2003; Hoffmann and Zitter, 1994). Bacterial wilt, caused by Erwinia tracheiphila, is a particularly important disease of cucumbers and melons (Hoffmann and Zitter, 1994).

Resistance to non-pathogenic disorders

Bursting and blossom-end rot were the only non-pathogenic disorders that were observed in this study. ‘Sugarbaby’ was the most susceptible to bursting while ‘Charleston Gray’ and Kakamega landrace were completely resistant.

The disorder was also noted on ‘Crimson Sweet’ and ‘Yellow Crimson’. Bursting may result from mechanical damage or injury from rodents when the fruits are young (Roberts and Kucharek, 2006). The disorder may also result from uneven growth rate, which is particularly associated with heavy rainfall or irrigation when fruits are maturing (Warren *et al*., 1990). This could be the main reason why this disorder was more severe in the second season due to high rainfall that was experienced as the fruits matured.

The problem can also be genetic (Guner and Wehner, 2004) and probably this is why some accessions remained free from this disorder. According to Warren *et al*. (1990), melon types with round fruit are more susceptible to bursting. Resistance of ‘Charleston Gray’ to the disorder was therefore attributed to its elliptical shape. However, the Kakamega landrace with its good round shape remained free from this disorder.

Therefore, rind thickness and hardness apparently play important roles in preventing bursting in watermelon. Blossom-end rot was noted on ‘Charleston Gray’ and to a lesser extent on ‘Sugarbaby’. No other accession suffered from this disorder. Although poor calcium nutrition and moisture stress are reportedly the major causes of blossom-end rot (Warren *et al*., 1990), the problem can also be said to be genetic because all the accessions were subjected to similar agronomic practices.

Resistance diversity

The results of principle component analysis demonstrated significant diversity between accessions. Since all accessions were evaluated under same conditions, it can therefore be reported that they contained different resistance genes. ‘Charleston Gray’ was located on the uppermost side of the PCA graph probably because it was the most susceptible to blossom-end rot, melon fly and rind necrosis.

These three had the highest contribution to PC1 (Table-4). The landrace and ‘Yellow Crimson’ were located at the bottom of the PCA graph. The two demonstrated good resistance to most of the problems including those that had the highest contribution to PC1 (blossom-end rot, melon fly, rind necrosis and yellow vine). They were also the most susceptible to cucumber beetles which had the least contribution to both PC1 and PC2.

The two could be potential sources of resistance to various watermelon problems but they should be selected for reduced cucurbitacin content to make them less attractive to cucumber beetles. ‘Sugarbaby’ and ‘Crimson Sweet’ were located side by side near the middle of the PCA graph indicating that the two suffered almost equal damage but with some inverse extremes. For example, ‘Sugarbaby’ was resistant to yellow vine which proved to be a major disease of ‘Crimson Sweet’. Likewise, ‘Crimson Sweet’ showed resistance to anthracnose to which ‘Sugarbaby’ was highly susceptible. In addition, anthracnose had the highest contribution to PC2 while yellow vine had the second lowest contribution (after cucumber beetles) to PC2 (Table-4). ‘Sugarbaby’ and ‘Crimson Sweet’ can exchange some vital resistance genes.

CONCLUSIONS

In general, Kakamega landrace and the newly introduced commercial cultivar, ‘Yellow Crimson’, portrayed good resistance against melon fly and most of watermelon diseases that appeared in the study period. The two can therefore serve as good sources of resistance against melon fly and various diseases of watermelon.

The landrace should, however, be improved for resistance against anthracnose and for reduced cucurbitacin content in order to reduce its attractiveness to cucumber beetles. Other commercial cultivars were susceptible to melon fly and to some of the diseases that appeared in this study. Apparently, there is reduced genetic variability among these accessions making them more vulnerable to new threats such as diseases and pests, climate change, among others. It can therefore be concluded that there is need to broaden the genetic variability of these old cultivars.

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