Response of Selected Potato Genotypes to Natural Virus Infection in the Field

Gidraf Onduru Okeyo*, Rama Devi Narla¹, Hillary Moses Omondi Otieno¹ and Elmar Schulte-Geldermann²

¹Department of Plant Science and Crop Protection, University of Nairobi, Nairobi, Kenya.
²CGIAR Research Program on Roots, Tubers and Bananas (RTB), International Potato Center, Regional Office Sub-Saharan Africa, ILRI Campus, Nairobi, Kenya.

Authors’ contributions

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

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ABSTRACT

Potato viruses are one of the major biotic factors causing high yield losses in potato production fields. In contrast to other disease causing pathogens, potato viruses’ lack well documented chemical control strategy and hence difficult to control once established in the field. The aim of the study was to assess the reaction of different potato genotypes to natural virus infection in the field. The present study was carried out on 12 potato genotypes (7 CIP clones and 5 commercial varieties) at the Field Station of the University of Nairobi, Upper Kabete campus Kenya in two potato growth seasons. A Randomized Complete Block Design (RCBD) of 4 replications was adopted with 12 treatments. Data was collected on percent crop emergence, disease incidence, growth and yield performance. At the end of season 2, tubers were sampled randomly per genotype and tested for presence of viruses using CIP DAS-ELISA kit. Analysis of variance on different parameters revealed varied response of each genotype to virus infection in the field in both seasons. Four potato viruses: PVS (67%), PVY (20%), PLRV (12%) and PVM (7%), were detected infecting tested potato tubers.

*Corresponding author: E-mail: ogidraf@gmail.com;
1. INTRODUCTION

Potato (Solanum tuberosum L.) is the second most grown food crop in Kenya after maize [1]. The crop plays an important role in maintaining the country’s food security, poverty alleviation through creation of employment and income generation to both farmers and people in the potato value chain [2]. The sector is however facing numerous production challenges mainly low yields and poor quality tubers. Average potato yields in Kenya have been reported at 7.7 tons/ha which is much less than the average 40 tons/ha produced in developed countries. However, this figure has fluctuated in the recent years, from 9.5 to less than 3 tons/ha in 2010 [3]. Low yields are due to low soil fertility, infected seed potato tubers, unfavorable climatic conditions during crop growth, pests and diseases [4].

Among pests and diseases, potato viruses have been reported a major constraint in potato production fields [5,6]. Infection of seed potato tubers with viruses has led to high yield losses by up to 68% in potato fields free from bacterial and fungal diseases [3]. Yield loss following virus infection is variety specific. Each potato variety reacts with different degree of loss in tuber yield depending on the type of virus, growth stage, type of infection, and period of field exposure to that specific pathogen [7,8]. Various management options have been proposed to help reduce virus infections of potato crops in the field. These options include use of certified seed potato tubers, Positive Selection of healthy looking mother plants during plant growth to act as seed source and adoption of aeroponics technology in seed production [9-11]. Other methods of potato virus control include use of virus and vector resistant potato varieties, use of mineral oils and borders crops [3,12-14]. However, adoption of these management strategies especially use of certified seeds and positive selection has been a challenge to most farmers in Kenya [9,15].

Six types of potato resistances to viruses namely resistance to infection (Field Resistance), resistance to virus accumulation, resistance to virus movement, mature plant resistance, tolerance, and resistance to virus vectors have been reported [14]. These are further subdivided into two namely; Extreme Resistance (ER) where there is little or no virus accumulation at the infection site and reduced movement to non-infected tissues and Hypersensitive Resistance (HR) where a necrotic lesion develops around the infected tissue preventing spread to surrounding tissues [16]. Extreme Resistance (ER) and Hypersensitive Resistance (HR) genes of major potato viruses such as PVY, PVA, PLRV, PVX, PVS and PVM have been identified and incorporated into different potato lines to help reduce yield loss [14]. Most potato varieties that are grown by small scale farmers in Kenya have demonstrated low levels of resistance and tolerance to potato viruses and other disease causing pathogens due to their genetic inability to withstand physiological disorders caused by these pathogens. Breeders have repeatedly bred new varieties which are resistant and or tolerant to potato viruses, higher yields, better storability and processing qualities in order to reduce this problem (17). However, these varieties lose their resistance and or desired traits with time due to increased virus pressure in potato production fields and also due to potato seed degeneration resulting from continuous recycling of farm saved seed potato tubers (11). Therefore new potato varieties should be screened for resistance and or tolerance to potato viruses before their release for adoption by farmers. Thus, the aim of this study was to assess the reaction of different potato genotypes to potato virus to natural virus infection in the field.

2. MATERIALS AND METHODS

2.1 Description of the Study Area and Source of Starting Materials

The field experiment was conducted at the Field Station of the University of Nairobi, Upper Kabete campus in two potato growth seasons long rains (March to July 2015) and short rains (October,
alternately to prevent potato late blight infection and spread in the field. Cultural practices such as weeding and earthing-up were conducted regularly until plant maturity. During plant growth data was collected on parameters like percent plant emergence, disease incidence and plant height during crop growth until maturity. At harvested in FG3, Medium sized and apparently healthy looking tubers were selected from each genotype and sprouted in insect proof diffused light store for two months. These tubers were used as planting materials in FG4. These tubers were planted in the field to produce FG4 and the whole cycle repeated as was done in FG3.

2.3 Detection of Viruses in Seed Potato Tubers from Field Generation Four (FG4)

During the final harvest of FG4, 100 medium (30-60 mm diameter) size and apparently healthy looking tubers were randomly selected from each genotype and sprouted in an insect proof diffused light store for two months to break dormancy. The sprouted tubers were tested for presence of viruses. Due to uneven sprouting among the twelve genotypes, sub-samples of thirty tubers per genotype were selected from each stock of the sprouted tubers per genotype. One sprout was cored out from each tuber using sterilized knife and planted in a tray of sterilized sand medium in an insect proof greenhouse. Thirty sprouts of each genotype were planted per tray. As a result of varied emergence rates among the genotypes, five seedlings at three leaves stages were selected randomly from each genotype from which three leaves were sampled per seedling from top, middle and bottom and tested for presence of the six main potato viruses namely; Potato leaf roll virus (PLRV), Potato virus A (PVA), Potato Virus M (PVM), Potato Virus S (PVS), Potato Virus X (PVX), and Potato Virus Y (PVY) using DAS-ELISA kit sourced from International Potato Center, Lima, Peru following descriptions by descriptions by Clark and Adams [19]. Threshold values were read from ELISA reader at 405 nm and positive samples determined using the formula \( x = \frac{\text{Threshold value} - \bar{x}}{h} \times 2 \), where \( x = \) Threshold value and \( \bar{x} \) is average value of healthy controls as outlined in the kit.

2.4 Data Collection and Analysis

Data on percentage emergence was collected randomly from the whole plot on a weekly basis from the 30th day after planting for three weeks. Data on virus disease incidence was scored by examining plants showing different virus disease
symptoms like leaf roll, crinkling, stunted growth and mosaic in each plot. This was done weekly from the eighth week after planting, where data on disease incidence was scored for four weeks. Disease incidence was determined using the following formula:

\[
\text{Virus incidence (\%)} = \frac{\text{Number of symptomatic plants}}{\text{Total number of plants}} \times 100
\]

At flowering, twenty potato plants were sampled randomly from each plot and data on plant height was collected using a string and a tape measure. At harvest, 40 plants were randomly sampled per plot from which data on number of tubers and yield in grams per hill was collected. Threshold values for each of the six viruses were recorded per sample from the ELISA reader and a comparison was made between these values and that of calculated average value of healthy controls as outlined in the kit. Samples which displayed threshold values equal to or greater than twice the average values of healthy controls were recorded as negative samples for each virus. Virus positive tuber samples were checked for multiples infections.

All the collected data was analyzed using Genstat 15th version. Fisher’s protected Test was used to separate treatment means and Least Significant Differences (LSD) at 5% probability level. Correlation analyses were conducted to establish the relationship between disease incidence, plants height, number of tubers and yield (t/ha) both in FG3 and FG4.

### 3. RESULTS

#### 3.1 Effect of Viruses on Emergence of Seed Potato Tubers

Percent sprout emergence varied significantly with genotypes at 30, 37, 44 and 58 days after planting in both seasons. In FG3, Shangi displayed high percentage of emerged seedlings by 90% while Sherekea had the lowest emerged seedlings with 0% at 30 days after planting. At 58 days after planting, Asante had the highest number of emerged plants at 98% unlike Sherekea which had the least at 61% (Table 1). In FG4; Asante, Tigoni, and Shangi showed high percent emergence in the range of 78% to 81% unlike Kenya Mpya, 398098.65, and Sherekea which had low numbers of emerged plants in the range of 0 to 7% within 30 days of planting. Fifty-eight days after planting; genotypes 392797.22, 398190.200, Asante and 393371.157 achieved high numbers of emerged plants in the range of 92% to 93% while Kenya Mpya, Sherekea and 398098.65 attained the lowest numbers of emerged plants in the range of 50 to 61% respectively (Table 2).

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>30 DAP</th>
<th>37 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shangi</td>
<td>89.5 j</td>
<td>92.0 j</td>
<td>94.9 h</td>
<td>96.3 ab</td>
</tr>
<tr>
<td>Tigoni</td>
<td>85.2 i</td>
<td>89.1 i</td>
<td>90.5 g</td>
<td>91.7 d</td>
</tr>
<tr>
<td>Asante</td>
<td>83.8 h</td>
<td>96.4 k</td>
<td>97.5 i</td>
<td>97.7 a</td>
</tr>
<tr>
<td>392797.22</td>
<td>54.8 g</td>
<td>91.3 j</td>
<td>94.5 h</td>
<td>96.0 ab</td>
</tr>
<tr>
<td>393077.159</td>
<td>53.2 f</td>
<td>75.7 g</td>
<td>88.3 f</td>
<td>94.7 bc</td>
</tr>
<tr>
<td>300046.22</td>
<td>43.7 e</td>
<td>79.4 h</td>
<td>86.2 e</td>
<td>91.0 d</td>
</tr>
<tr>
<td>397073.7</td>
<td>24.5 d</td>
<td>60.5 e</td>
<td>85.3 e</td>
<td>95.3 abc</td>
</tr>
<tr>
<td>398190.200</td>
<td>24.3 d</td>
<td>70.2 f</td>
<td>86.5 e</td>
<td>95.3 abc</td>
</tr>
<tr>
<td>393371.157</td>
<td>18.2 c</td>
<td>51.2 d</td>
<td>80.7 d</td>
<td>93.3 cd</td>
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<td>398098.65</td>
<td>9.2 b</td>
<td>28.8 b</td>
<td>49.5 a</td>
<td>67.3 e</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>9.0 b</td>
<td>25.0 a</td>
<td>59.7 c</td>
<td>66.3 e</td>
</tr>
<tr>
<td>Sherekea</td>
<td>0.0 a</td>
<td>48.3 c</td>
<td>57.4 b</td>
<td>60.7 f</td>
</tr>
<tr>
<td>Mean</td>
<td>41.3</td>
<td>67.3</td>
<td>80.9</td>
<td>87.1</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.5</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>LSD P≤0.05</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*Means within the same column having a common letter(s) do not differ significantly at P ≤0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, DAP= Days after Planting*
Table 2. Percent emergence of potato seed tubers at different days after planting (DAP) in field generation four (FG4)

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>30 DAP</th>
<th>37 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asante</td>
<td>81.0 j</td>
<td>86.1 h</td>
<td>89.2 gh</td>
<td>91.8 gh</td>
</tr>
<tr>
<td>Tigoni</td>
<td>79.4 i</td>
<td>86.1 h</td>
<td>88.0 g</td>
<td>90.3 g</td>
</tr>
<tr>
<td>Shangi</td>
<td>78.4 i</td>
<td>820.0 g</td>
<td>85.3 f</td>
<td>87.1 f</td>
</tr>
<tr>
<td>392797.22</td>
<td>53.2 h</td>
<td>85.5 t</td>
<td>90.1 h</td>
<td>92.9 t</td>
</tr>
<tr>
<td>393077.159</td>
<td>50.0 g</td>
<td>72.3 f</td>
<td>84.5 f</td>
<td>90.5 g</td>
</tr>
<tr>
<td>300046.22</td>
<td>40.1 f</td>
<td>73.0 f</td>
<td>78.3 e</td>
<td>81.6 e</td>
</tr>
<tr>
<td>397073.7</td>
<td>22.7 e</td>
<td>55.0 d</td>
<td>67.8 d</td>
<td>75.4 d</td>
</tr>
<tr>
<td>398190.200</td>
<td>20.7 d</td>
<td>70.0 e</td>
<td>84.8 f</td>
<td>92.0 g</td>
</tr>
<tr>
<td>393371.157</td>
<td>16.9 c</td>
<td>49.8 c</td>
<td>78.6 e</td>
<td>91.7 g</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>7.3 b</td>
<td>24.4 a</td>
<td>58.5 c</td>
<td>60.6 c</td>
</tr>
<tr>
<td>393077.159</td>
<td>3.0 e</td>
<td>53.7 b</td>
<td>78.6 e</td>
<td>91.7 g</td>
</tr>
<tr>
<td>Shangi</td>
<td>0.0 a</td>
<td>41.7 b</td>
<td>53.3 b</td>
<td>54.8 b</td>
</tr>
<tr>
<td>Mean</td>
<td>38.1</td>
<td>62.6</td>
<td>74.8</td>
<td>79.9</td>
</tr>
<tr>
<td>CV (%)</td>
<td>2.5</td>
<td>1.8</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>LSD (P≤0.05)</td>
<td>1.4</td>
<td>1.6</td>
<td>1.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Means within the same column having a common letter(s) do not differ significantly at P≤0.05. LSD=Least Significant Difference, CV (%) =Coefficient of Variation, DAP= Days after Planting.

3.2 Response of Potato Genotypes to Virus Disease Incidence in the Field

Disease incidence varied significantly among the two cropping seasons ranging from 8% to 85% in FG3 (Table 3) and from 26% to 88% in FG4 (Table 4). Disease incidence differed significantly at (P≤0.05) among seasons. All genotypes expressed varied levels of susceptibility to virus infection based on percentage disease incidence in the two seasons. Disease incidence increased in FG4 and this varied among genotypes with Shangi showing the highest increase by 37% and 393077.159 showing the least increase by 3%.

3.3 Effect of Potato Viruses on Plant Heights of Different Potato Genotypes

Plant height varied significantly per genotype ranging from 40cm to 107cm in FG3 and 37 to 83cm in FG4. In both seasons, plant height differed significantly at (P≤0.05). Decline in plant height was observed in FG4 and the average percent decrease varied among the genotypes.
### Table 4. Percent virus disease incidences at different weeks after planting (WAP) in field generation four (FG4)

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>8 weeks</th>
<th>9 weeks</th>
<th>10 weeks</th>
<th>11 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asante</td>
<td>53.3 j</td>
<td>71.7 h</td>
<td>77.2 j</td>
<td>81.8 j</td>
</tr>
<tr>
<td>393077.159</td>
<td>49.5 e</td>
<td>70.4 h</td>
<td>81.7 k</td>
<td>87.5 k</td>
</tr>
<tr>
<td>Tigoni</td>
<td>28.8 h</td>
<td>49.7 g</td>
<td>63.4 h</td>
<td>70.7 h</td>
</tr>
<tr>
<td>398098.65</td>
<td>23.7 g</td>
<td>44.7 f</td>
<td>65.9 i</td>
<td>79.7 i</td>
</tr>
<tr>
<td>300046.22</td>
<td>17.7 f</td>
<td>29.7 e</td>
<td>49.0 g</td>
<td>55.2 g</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>13.9 e</td>
<td>21.1 c</td>
<td>33.7 d</td>
<td>44.9 e</td>
</tr>
<tr>
<td>393371.157</td>
<td>12.5 d</td>
<td>22.9 d</td>
<td>30.6 c</td>
<td>37.0 c</td>
</tr>
<tr>
<td>Shangi</td>
<td>10.4 c</td>
<td>24.4 d</td>
<td>39.8 f</td>
<td>48.5 f</td>
</tr>
<tr>
<td>Sherekea</td>
<td>9.7 bc</td>
<td>18.5 b</td>
<td>27.8 b</td>
<td>39.8 d</td>
</tr>
<tr>
<td>398190.200</td>
<td>9.5 bc</td>
<td>28.4 e</td>
<td>36.6 e</td>
<td>45.3 e</td>
</tr>
<tr>
<td>392797.22</td>
<td>8.5 b</td>
<td>19.2 b</td>
<td>27.9 b</td>
<td>35.7 b</td>
</tr>
<tr>
<td>397073.7</td>
<td>7.0 a</td>
<td>13.3 a</td>
<td>19.9 a</td>
<td>26.3 a</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>20.4</td>
<td>34.5</td>
<td>46.1</td>
<td>54.4</td>
</tr>
<tr>
<td><strong>CV (%)</strong></td>
<td>4.7</td>
<td>3.4</td>
<td>2.8</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>LSD (P ≤ 0.05)</strong></td>
<td>1.4</td>
<td>1.7</td>
<td>1.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Means within the same column having a common letter(s) do not differ significantly at P ≤ 0.05, LSD = Least Significant Difference, CV (%) = Coefficient of Variation, WAP = Weeks after Planting

with Shangi showing the highest decrease at 27% while Asante and 397073.7 recorded the least decrease at 4%. The remaining genotypes displayed a decline in plant heights ranging from 5% to 12% (Table 5).

### Table 5. Plant height (cm) of different potato genotypes in field generation three (FG3) and field generation four (FG4) and percent decrease in FG4

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>FG3</th>
<th>FG4</th>
<th>Percent decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shangi</td>
<td>106.6 g</td>
<td>78.1 c</td>
<td>26.8</td>
</tr>
<tr>
<td>398190.200</td>
<td>91.3 f</td>
<td>83.4 a</td>
<td>8.7</td>
</tr>
<tr>
<td>393371.157</td>
<td>86.4 f</td>
<td>81.1 b</td>
<td>6.2</td>
</tr>
<tr>
<td>Tigoni</td>
<td>75.9 e</td>
<td>71.1 d</td>
<td>6.4</td>
</tr>
<tr>
<td>392797.22</td>
<td>72.8 de</td>
<td>64.1 e</td>
<td>11.9</td>
</tr>
<tr>
<td>397073.7</td>
<td>66.6 cd</td>
<td>64.3e</td>
<td>3.5</td>
</tr>
<tr>
<td>393077.159</td>
<td>61.3 bc</td>
<td>56.8 g</td>
<td>7.3</td>
</tr>
<tr>
<td>Asante</td>
<td>60.7 bc</td>
<td>58.6 f</td>
<td>3.6</td>
</tr>
<tr>
<td>Sherekea</td>
<td>55.7 b</td>
<td>53.1 h</td>
<td>4.7</td>
</tr>
<tr>
<td>398098.65</td>
<td>46.2 a</td>
<td>41.4 i</td>
<td>10.3</td>
</tr>
<tr>
<td>300046.22</td>
<td>44.5 a</td>
<td>40.9 i</td>
<td>8.0</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>40.4 a</td>
<td>36.6 j</td>
<td>9.4</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>67.4</td>
<td>60.8</td>
<td></td>
</tr>
<tr>
<td><strong>CV (%)</strong></td>
<td>5.4</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td><strong>LSD (P ≤ 0.05)</strong></td>
<td>6.2</td>
<td>1.6</td>
<td></td>
</tr>
</tbody>
</table>

Means within the same column having a common letter(s) do not differ significantly at P ≤ 0.05, LSD = Least Significant Difference, CV (%) = Coefficient of Variation
Table 6. Number of potato tubers per hill of different genotypes in field generation three (FG3) and field generation four (FG4) and percent decrease in FG4

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>FG3</th>
<th>FG4</th>
<th>Percent decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shangi</td>
<td>12.6 a</td>
<td>9.8 a</td>
<td>22.6</td>
</tr>
<tr>
<td>Tigoni</td>
<td>10.5 ab</td>
<td>5.8 de</td>
<td>46.5</td>
</tr>
<tr>
<td>397073.7</td>
<td>10.3 bc</td>
<td>7.0 bc</td>
<td>33.8</td>
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<td>392797.22</td>
<td>9.0 bc</td>
<td>6.6 bcd</td>
<td>27.1</td>
</tr>
<tr>
<td>Sherekea</td>
<td>8.3 bc</td>
<td>5.1 e</td>
<td>39.1</td>
</tr>
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<td>300046.22</td>
<td>8.3 bc</td>
<td>5.1 e</td>
<td>42.9</td>
</tr>
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<td>Asante</td>
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<td>7.5 b</td>
<td>4.0</td>
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<td>7.4 bcd</td>
<td>7.0 bc</td>
<td>5.9</td>
</tr>
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<td>393077.159</td>
<td>6.2 cde</td>
<td>6.0 cd</td>
<td>2.7</td>
</tr>
<tr>
<td>398098.65</td>
<td>4.7 de</td>
<td>3.4 f</td>
<td>27.1</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>3.8 e</td>
<td>3.2 f</td>
<td>14.9</td>
</tr>
</tbody>
</table>

Mean          | 8.3  | 6.2  |
CV (%)        | 22   | 10.8 |
LSD (P ≤ 0.05)| 3.1  | 1.0  |

Means within the same column having a common letter(s) do not differ significantly at P ≤ 0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation

Reduction in number of tubers was observed in all the twelve genotype in FG4. Percentage decline in number of tubers varied among the genotypes. Highest levels of decline were recorded in 397073.7 by 47% and lowest in 393077.159 by 3% (Table 6).

3.5 Effects of Potato Viruses Total Yield

High yields were recorded in FG3 ranging from 10-49 t/ha compared to FG4 in which yields ranged 5-25 t/ha. Yield differed significantly at P ≤ 0.05 across the genotypes in both seasons. In FG3, 392797.22 had the highest yield at 49.2 t/ha and 398098.65 the least at 10.2 t/ha. In FG4; 392797.22 had the highest yield of 25.0 t/ha and Sherekea the least yield of 5 t/ha. All the genotypes displayed low yields in FG4. The yield drop varied between the genotypes with each showing different percentage decrease. Sherekea had highest percent decrease in yield with 68% while 398098.65 displayed the lowest by 48% decrease (Table 7).

Table 7. Yield (t/ha) of potato genotypes recorded in field generation three (FG3) and field generation four (FG4) and percent decrease in FG4

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>FG3</th>
<th>FG4</th>
<th>Percent decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>392797.22</td>
<td>49.2 a</td>
<td>25.0 a</td>
<td>49.09</td>
</tr>
<tr>
<td>398190.200</td>
<td>46.7 ab</td>
<td>19.8 c</td>
<td>57.56</td>
</tr>
<tr>
<td>397073.7</td>
<td>39.1 bc</td>
<td>18.7 d</td>
<td>52.27</td>
</tr>
<tr>
<td>393371.157</td>
<td>37.2 bc</td>
<td>22.2 b</td>
<td>40.35</td>
</tr>
<tr>
<td>Shangi</td>
<td>34.5 cd</td>
<td>14.4 f</td>
<td>58.43</td>
</tr>
<tr>
<td>Asante</td>
<td>33.1 cd</td>
<td>17.5 e</td>
<td>47.31</td>
</tr>
<tr>
<td>Tigoni</td>
<td>30.3 cd</td>
<td>11.8 i</td>
<td>61.09</td>
</tr>
<tr>
<td>300046.22</td>
<td>29.0 cd</td>
<td>12.9 h</td>
<td>55.34</td>
</tr>
<tr>
<td>393077.159</td>
<td>25.6 d</td>
<td>13.2 g</td>
<td>48.28</td>
</tr>
<tr>
<td>Sherekea</td>
<td>15.9 e</td>
<td>5.0 l</td>
<td>68.22</td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>11.1 e</td>
<td>5.6 k</td>
<td>49.34</td>
</tr>
<tr>
<td>398098.65</td>
<td>10.2 e</td>
<td>6.3 j</td>
<td>38.04</td>
</tr>
</tbody>
</table>

Mean          | 30.2  | 14.4  |
CV (%)        | 18.6  | 1.1   |
LSD (P ≤ 0.05)| 5.5   | 0.2   |

Means within the same column having a common letter(s) do not differ significantly at P ≤ 0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation
3.6 Correlation among Disease Incidence, Plant Height, Number of Tubers per Hill and Yield in FG3 and FG4

Disease incidence displayed week negative correlation with plant height, number of tubers per hill and yield (t/ha) \( (r = -0.38, r = -0.38 \) and \( r = -0.42 \) at \( P \leq 0.05 \)), plant heights correlated positively to number of tubers and yield \( (r = 0.71 \) and \( r = 0.64 \) at \( P \leq 0.05 \)) and number of tubers correlated positively to yield \( (r = 0.51 \) at \( P \leq 0.05 \)) in FG3 (Table 8). Disease incidence correlated negatively to plant height, number of tubers and yield \( (r = -0.28, r = -0.20 \) and \( r = -0.33 \) at \( P \leq 0.05 \)), plant heights correlated positively to number of tubers and yield \( (r = 0.72 \) and \( r = 0.67 \) at \( P \leq 0.05 \)) and number of tubers per hill correlated positively to yield in grams \( (r = 0.66 \) at \( P \leq 0.05 \)) in FG4.

3.7 Virus Infection Status of Seed Tubers from Field Generation Four (FG4)

Results of tested tubers revealed PVS as the most dominant virus \( (67\%) \) followed by PVY \( (20\%) \), PLRV \( (12\%) \) and PVM \( (7\%) \). PVA and PVX were not found in the tested tubers. All potato genotypes tested positive for PVS; four genotypes for PVY and PLRV while only two genotypes tested positive for PVM. Two genotypes showed double infections by PVS + PVY, one genotype by PVS + PLRV, one genotype by PVY + PVM; one genotype showed triple infection by PLRV + PVM + PVS and finally three genotypes showed single infections by PVS, PVY and PLRV.

Table 8. Correlation coefficients among disease incidence, plant height, number of tubers per hill and total yield of different potato genotypes in FG3 and FG4

<table>
<thead>
<tr>
<th></th>
<th>Field generation 3 (FG3)</th>
<th></th>
<th>Field Generation4 (FG4)</th>
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<tbody>
<tr>
<td></td>
<td>Disease incidence</td>
<td>Plant heights</td>
<td>Number of tubers</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>-0.38*</td>
<td>0.71**</td>
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</table>

Coefficients denoted by * indicate no significant correlations while coefficients denoted by ** indicate significant correlations at \( p \leq 0.05 \)

Table 9. Incidences of potato viruses detected in seed tubers from field generation four (FG4)

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Percent ELISA-positive samples</th>
<th>PLRV</th>
<th>PVA</th>
<th>PVM</th>
<th>PVS</th>
<th>PVX</th>
<th>PVY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shangi</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Asante</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tigoni</td>
<td>20</td>
<td>40</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sherekea</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>100</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kenya Mpya</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>60</td>
<td></td>
<td></td>
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<tr>
<td>397073.7</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>300046.22</td>
<td>20</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>392797.22</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>398098.65</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>393371.157</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>393077.159</td>
<td>20</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>398190.200</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent incidence (%)</td>
<td>11.67</td>
<td>6.67</td>
<td>66.67</td>
<td>20.0</td>
<td></td>
<td></td>
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</tbody>
</table>

*Negative results, PLRV-Potato Leaf Roll Virus, PVA-Potato Virus A, PVM-Potato Virus M, PVS-Potato Virus S, PVX-Potato Virus X, PVY-Potato Virus Y*
two genotypes by PLRV + PVS + PVY in tested tubers (Table 9).

4. DISCUSSION

Percent crop emergence was low in FG4 compared to FG3. This may be attributed to infections of the seed potato tubers by seed borne viruses in the field during seed multiplication process in FG1 and FG2 in addition to new infections during FG3 growth period [20]. Singh et al. [21] also reported decline in percent crop emergence between seasons. The observed decline varied among the twelve potato genotypes in which 397073.7 showed the highest percent decline and Tigoni the least. This phenomenon may have occurred as a result of variation in tolerance of potato genotypes to virus infections in the field [8]. Recent studies have also documented a varied decline in plant emergence among different potato varieties in experiment due to seed degeneration. In comparison to commercial varieties, clones like 393077.159, 398190.200, 392797.22 and 393371.157 had the lowest levels of percent decrease in plant emergence signifying high tolerance of these genotypes to potato viruses.

Duration to attain maximum emergence also varied among the twelve genotypes in both seasons. This may have resulted from several factors like difference in dormancy periods among the genotypes which is dependent on cultivar, tuber ripening, growth conditions, storage conditions and size of tubers used in propagation [22-24]. All the commercial varieties used in the study namely Asante, Tigoni, Kenya Mpya and Shangi are reported to have short dormancy under diffused light storage except Sherekea which has long dormancy ranging between four to five months [25] while CIP clones have different dormancy periods under diffused light storage; 397073.7 at 112 days, 398098.65 not reported, 300046.22 at 74 days, 393077.159 at 90 to ≥ 120 days, 398190.200 not reported, 392797.22 at 109 days and 393371.157 at 90 to ≥ 120 days [26].

High virus disease incidence which varied among the twelve genotypes was recorded in FG4. High virus incidences in FG4 might have occurred due to absence of insect vector (aphid) control strategies in the experimental field [27] and abiotic factors like water stress [28]. All the twelve genotypes expressed varied levels of susceptibility to potato viruses based on percentage disease incidence in the two growth seasons. This variation may have resulted from difference in levels of resistance of potato genotypes to infection by prevalent viruses in the field [16]. Ali et al. [8] and Islam et al. [29] also revealed varied virus disease incidences in different potato varieties. Similar results were reported by [5,8,30]. The increase in disease incidence was genotype dependent and was high in Shangi and 398190.200 and least in 393077.159 in FG4. Among the commercial varieties, Sherekea is reported to be resistant to PLRV and PVS while Kenya Mpya has extreme resistance to PVX [25]. Among the seven clones used in the study, 392797.22 and 393077.159 are reported to be resistant to PLRV, all the seven clones except 398190.200 are resistant PVX while 397073.7, 30046.22, 392797.22 and 393077.159 are resistant to PVY [26]. Genotypes 393077.159, Asante and 398098.65 which showed high disease incidences in FG3, had low percent increase in disease incidence in FG4. This may be because these genotypes had almost reached their optimal virus infection levels in FG3 compared to other genotypes used in the study [31].

Plant height in all the twelve potato genotypes were significantly high in FG3 compared to FG4. Low plant height in FG4 may have been as a result of high disease incidences recorded in FG4 and due to seed potato tuber infections in previous seasons [7]. Similarly, Salazar [32] and Kumar, [33] also documented dwarfism and stunted growth as the major symptoms of potato virus infections in production fields as confirmed by this study. Rahman et al., [7] and Islam et al., [29] also reported decrease in plant height due to Potato Leaf Roll Virus (PLRV) and Potato Virus Y infections in their experiments. Decline in plant height varied between the twelve genotypes with Shangi showing the highest decline and 397073.7 the least in FG4. This variation in decline of plant height observed in different genotypes was also reported in studies by Hossain [34] and Islam et al. [29] who revealed varied reductions of plant heights in different varieties due to PVY infections. The variability in decline of plants heights can be attributed to difference in tolerance of these genotypes to infection by predominant potato viruses in the field [29,35].

Low number of tubers per hill was recorded in FG4 compared to FG3 in all the genotypes. However, these phenomena varied among the twelve genotypes suggesting that different genotypes possess different resistance and
tolerance levels to potato viruses when exposed to natural virus infection in the field [29,35]. This variation can be attributed to difference in mechanisms supporting virus particle proliferation within the plant tissues of each genotype [32]. In addition, the decline in tuber numbers might have occurred due to increase in disease incidence observed in FG4 [8]. John et al. [36] and Islam et al. [29] also reported that different potato varieties displayed varied decline in number of tubers per hill due to infection by different potato viruses. In comparison to commercial varieties used in the study, genotypes 398190.200, 397073.7, 393371.157 and 392797.22 had high average number of tubers per hill in FG4 signifying high tolerance levels to natural virus infections in the field.

Low yields were observed in FG4 compared to FG3. These can be attributed to increase in disease incidence recorded in FG4 [8,29,30]. Salazar [32] reported that yield loss in potato fields increases with increasing symptom appearance on the foliage which was also confirmed by this study. Low yields might also have occurred as a result of low soil moisture availability during and after tuber initiation in FG4 (short rains). Potatoes are highly sensitive to water stress during tuber initiation and any alteration in optimal moisture availability in the soil during this growth period can lead to low number of tubers and reduced tuber expansion resulting to low yield [37,38]. Similar findings were also reported by many researchers [8, 29, 30, 36, 39] in their experiments.

Yield (t/ha) varied among the twelve genotypes in both FG3 and FG4. In FG3, 392797.22 displayed the highest yield and 398098.65 displayed the lowest yield. In FG4, 392797.22 displayed the highest yield while Sherekea had the lowest yield. This variation in yield might have occurred as a result of difference in levels of susceptibility to viruses [8,29], resistance and tolerance to potato viruses in the field. Yield loss also differed among the twelve genotypes in FG4. This variation can be attributed to differences in genotypes inherent reactions to virus infections at field conditions [32]. Genotypes 392797.22 393371.157, 398190.200 and 397073.7 displayed high yields in FG4 signifying high levels of tolerance to natural potato virus infections in the field when compared to other genotypes.

Disease incidence displayed weak negative correlation to plant height, number of tubers and yield in grams per hill in both FG3 and FG4. The weak correlation could be an indication that reduction in growth and yield parameters might also have occurred as a result of other biotic and a biotic factors such as water stress and insect pest infestation during crop growth [28,40]. Rahman et al. [30] and Islam et al. [29] also reported similar results in their experiments. Plant height, number of tubers per hill, and yield demonstrated strong positive correlations in both seasons. This was also reported by Tuncturk et al. [41] and Youisf et al. [42]. In their study, plant height, leaf number per plant, leaf area, dry weight, tubers number, tubers weight, and potato tuber yields displayed positive and significant correlations. Increased potato plant height increases leaf mosaic exposing the foliage thus improving partitioning and photosynthetic efficiency which leads to increased tuber number, size and higher yield.

Four potato viruses namely PLRV, PVM, PVS and PVY were found to infect tested seed potato tubers collected from FG4 either as single infection or as multiple infections. Potato Virus S was the most predominant followed by PVY, PLRV and PVM. Were et al. [43] also reported PVS as the most detected potato viral disease followed by PVY, PVX, and PLRV in samples collected from potato growing districts in Kenya. Similarly, Yardimci et al. [44] also reported PVS and PVY as the most prevalent viruses in potato tubers tested from different fields in Turkey detected using DAS-ELISA technique. In addition, Yardimci et al. [44] reported PVY+PVS (9.17%) as one of the most common multiple infections in potato (tubers) as revealed in this study. Serological results results revealed that all the twelve genotypes were infected by PVS. This may be attributed to ability of PVS to pass through tissue culture process which is usually adopted in production of certified seed [43] or because PVS is mainly transmitted mechanically, it can easily be spread by farmers during cultural activities when using infected tools [45].

Low incidences of PLVR and PVY and absence of PVM, PVA and PVX in the tested samples may be attributed to restricted spread of these viruses, due to low populations or absence of insect vectors and absence of alternate hosts in the experimental site [46]. Njukeng et al. [47] reported that some viruses especially PLRV, are more prevalent in leaves than tubers and this could also explain why some of these viruses were not detected in the tubers. The situation may also have occurred as a result of differences

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in levels of susceptibility of these genotypes to different potato viruses in the experimental field [48].

5. CONCLUSION

Potato genotypes reacted differently to natural virus infections in the field. Some new clones like 392797.22 393371.157, 398190.200 and 397073.7 had high levels of tolerance to virus infection compared to commercial cultivars. These varieties should be taken to National Performance Trials for further evaluation and officially released to farmers so as to curb seed degeneration arising from recycling of seed tubers across seasons. Farmers should also be sensitized on the importance of using potato varieties that are resistant to viruses so as to maximize yields.

ACKNOWLEDGEMENTS

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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