



Assessment of National Performance Trials of Potatoes in Mid-Altitude Regions of Kenya

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Abstract

Potato is the second most important food crop in Kenya after maize. It is a valuable cash and food crop mainly grown by small-scale farmers. Potato is cultivated mainly under rainfed production conditions at altitudes between 1500 and 3000 metre above sea level (masl). Consequently, National Performance Trials (NPTs) test sites are located in these highlands. Recently, potato production has spread to the mid-highlands (1200-1500masl) mostly due to high food demand occasioned by population increase, and migration of small scale farmers from the densely populated highlands to the more spacious midlands. Consequently, there is increased need to breed potato varieties that can grow profitably in the warmer mid-altitudes. This development called for identification of new conventional NPT test sites located in the mid-altitudes. Six mid-altitude sites were identified and client-managed conventional NPTs carried out. Twenty six potato genotypes were evaluated for two seasons. First season crop was planted in 2016 while the second season crop was planted in 2017. There was a significant ($p \leq 0.001$) effect of genotypes, environments and genotype x environment interaction in the first season. Trans-Nzoia was the highest yielding site. All genotypes yielded between 10 and 25 ton/ha. In the second season, only environments showed significant ($p \leq 0.001$) effects. Again, Trans-Nzoia was the highest yielding site. Across the two seasons, Trans-Nzoia gave an average yield of 26.96 ton/ha followed by Kabete at 18.21ton/ha. All the other four sites yielded less than 10 ton/ha. The high yields at Trans-Nzoia and Kabete could be due to higher altitudes in these two sites compared to the others. In order to develop potato varieties that can produce profitably in the warm mid-altitudes, breeding and early generation selections activities should be based in these areas.

Keywords: Kenya; Mid-altitude; National performance trials; Potato.

1. Introduction

In Kenya potato is an important food and cash crop, second after maize. Potatoes are grown twice annually (long and short rains) and it is estimated 1.5 million tons are produced by about 800,000 farmers on 161,000 ha per year. The average yields are about 7.7 ton/ha [1-3] although it is possible to raise the productivity to over 30 ton/ha through improved agronomic practices [4]. Potato production takes place mainly under rainfed conditions and is concentrated at altitudes between 1500 and 3000 meters above sea level [1]; over 70% of potato production is carried out at above 2,100 meters above sea level (masl) [5, 6]. Of all potato growers in Kenya, 98% are small-scale farmers, growing less than 0.4 ha of potatoes per year per farm (total of two planting seasons). They contribute 83% of the national production [5, 7, 8]. In a few counties such as Bomet, Nyandarua and Narok, a small number of large commercial growers cultivate potatoes on several hectares. In Kenya, release or introduction of new plant varieties is regulated by the Kenya Plant Health Inspectorate Service (KEPHIS). The new plant variety must pass the test for Distinctness, Uniformity and Stability (DUS Test) and National Performance Trial (NPT). The National Performance Trials (NPTs) are designed to test new candidate varieties for performance compared to varieties currently in the market. These trials, also known as Value for Cultivation and Use (VCU) trials are done across the country at specific agro-ecological zones where the full potential of the candidate variety can be expressed and where the variety is targeted to be grown once released. The purpose of NPTs is to determine the agronomic potential of a new variety before it is released for commercialization. During the NPT trials, candidate varieties are planted alongside existing varieties (checks) and performance gauged to ensure only superior varieties are released for commercialization. The tests are done for at least two growing seasons. Data is analysed after each season with combined analysis done after the second season of testing. After the combined analysis, KEPHIS prepares NPT report after which the National Performance Trials' Committee (NPTC) is convened to discuss the report. The NPTC recommends for release candidate plant varieties that meet the set criteria to the National Variety Release Committee

(NVRC). The varieties could be released if either of the following criteria were satisfied: (1) Varieties yielded statistically better ($P \leq 0.05$) than the mean yield of the checks in the two seasons' combined analysis; (2) Varieties yielded statistically similar ($P \leq 0.05$) to mean yield of checks in the two seasons' combined analysis but there was at least a 5% numerical yield advantage over the mean of checks in two seasons' combined analysis and any declared and confirmed special attributes [4]. Thereafter, Distinctness, Uniformity and Stability (DUS) tests are conducted on successful candidate varieties following procedures provided in the International Union for the Protection of New Varieties of Plants (UPOV) test guidelines (TG) for the specific crop [4]. The DUS testing is a way of determining whether a newly bred variety differs from existing varieties within the same species (Distinctness), whether the characteristics used to establish distinctness are expressed uniformly (Uniformity) and that these characteristics do not change over subsequent generations (Stability). The NVRC deliberates on the recommended varieties with consideration of DUS report and makes decision on varieties to be released for commercialization. Once released, new varieties are then gazetted and listed in the National Crop Variety list after which the breeder can multiply and sell the new variety. The NPTs can be managed by KEPHIS or the client. In KEPHIS-managed NPTs, the client delivers the seed of the candidate varieties to KEPHIS. Then KEPHIS does the rest; this costs the client 1200 US dollars per variety per season. In the client-managed NPT, the client facilitates KEPHIS official during data collection. For potatoes in Kenya, there are conventional NPTs and intensive NPTs. Conventional NPTs are rain-fed and involve conventional agronomic practices. The trials are conducted on varieties that are meant for production by small-scale farmers using the normally recommended cultural practices. Intensive NPTs require the use of high input management under irrigation with intensive control of pests and diseases. They are conducted on varieties meant for production using an intensive agronomic package e.g. more intensive irrigation, frequent pest and disease protection schedules or higher fertilizer doses than normal, among others [4]. Intensive NPTs targets varieties for large-scale farmers with mechanized systems. These intensive practices are costly and are rarely practised by small scale potato farmers who are often resource constrained.

Because most potatoes in Kenya are grown in the high altitude areas, test sites for conventional NPTs are located in these highlands. In recent times, however, potato production has spread to the mid-altitude areas (1200-1500 masl) mostly due to the high demand for food occasioned by population increase and, migration of small scale farmers from the densely populated highlands to the more spacious midlands. As a result, there developed a need to breed potato varieties that can grow profitably in the warmer midlands. This new development called for identification of a new set of conventional NPT test sites located in the mid-altitudes. Six mid-altitude sites were identified and client-managed conventional NPTs carried out on potatoes for the first time. Reported here is the performance of the candidate varieties in these sites.

2. Materials and Methods

2.1. Test Sites

The client-managed NPTs for medium altitude potatoes (medium altitude kit) were planted out in six sites for two seasons resulting in 12 environments (Table 1).

Table-1. Test environments for the mid-altitude client- managed conventional NPTs for potatoes

Year(Season)	Environment	Site
2016	ENV 1	Embu
2016	ENV 2	Trans-Nzoia
2016	ENV 3	Mabanga
2016	ENV 4	Maragua
2016	ENV 5	Kianjai
2016	ENV 6	Kabete
2017	ENV 1	Embu
2017	ENV 2	Kabete
2017	ENV 3	Kianjai
2017	ENV 4	Mabanga
2017	ENV 5	Maragua
2017	ENV 6	Trans-Nzoia

The 2016 crop was planted on various dates from 16th March to 13th April 2016 and harvested from 2nd to 11th August 2016. The 2017 crop was planted on various dates from 18th October to 8th November 2017 and harvested from 13th to 22nd February 2018. The sites are generally mid altitude (Table 2).

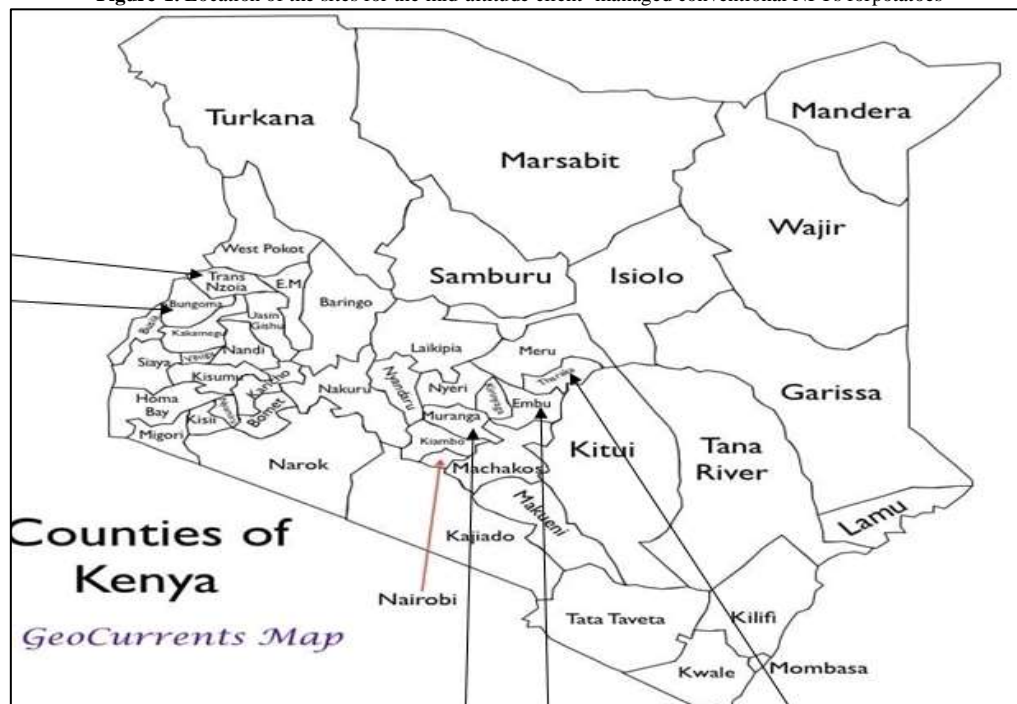
Table-2. Trial sites for the mid-altitude client-managed conventional NPTs for potatoes

Site	County	Altitude (masl)	Longitude	Latitude
Maragua	Murang'a	1375	E 037 ⁰ 27. 480'	S 00 ⁰ 30. 316'
Embu-KALRO	Embu	1514	E 037 ⁰ 27. 549'	S 00 ⁰ 30. 168'
Kianjai	Meru	1424	E 037 ⁰ 46. 091'	S 00 ⁰ 10. 000'
Trans-Nzoia	Trans-Nzoia	1801	E 035 ⁰ 01. 538'	N 00 ⁰ 54. 230'
Mabanga	Bungoma	1510	E 034 ⁰ 37. 501'	N 00 ⁰ 36. 180'
Kabete-Campus	Nairobi	1807	E 036 ⁰ 44.880'	S 01 ⁰ 14.706'

masl=meters above sea level, KALRO=Kenya Agriculture and Livestock Research Organisation

Murang'a, Embu, Meru and Nairobi counties are located in central Kenya generally while Bungoma and Trans-Nzoia are located in the western side (Figure 1).

Figure-1. Location of the sites for the mid-altitude client- managed conventional NPTs for potatoes



2.2. Test Materials

The experimental materials consisted of 26 genotypes of which four were checks and the rest were candidates. Eighteen genotypes were evaluated in season 1 (2016) and seventeen were evaluated in season 2 (2017). Only nine genotypes were common in both seasons (Table 3).

Table-3. Potato genotypes tested in the mid-altitude client- managed conventional NPTs

Genotype	Source	Test status	Season 1 (2016)	Season 2 (2017)
IHG	KALRO TIGONI	CANDIDATE	X	X
3C22	KALRO TIGONI	CANDIDATE	X	X
ASANTE	KALRO TIGONI	CHECK	X	X
CIP300056.33	CIP	CANDIDATE	X	
CIP388676.1	CIP	CANDIDATE	X	
CIP395193.6	CIP	CANDIDATE	X	
CIP395434.1	CIP	CANDIDATE	X	
CIP397196.3	CIP	CANDIDATE	X	
CIP398190.404	CIP	CANDIDATE	X	X
CIP398190.605	CIP	CANDIDATE	X	
CIP398190.89	CIP	CANDIDATE	X	X
CIP398193.511	CIP	CANDIDATE	X	
CIP398193.553	CIP	CANDIDATE	X	
CIP398208.505	CIP	CANDIDATE	X	X
CIP398208.620	CIP	CANDIDATE	X	
DUTCH ROBYJN	KALRO TIGONI	CHECK	X	X
SHANGI	KALRO TIGONI	CHECK	X	X
TIGONI	KALRO TIGONI	CHECK	X	X
CIP398180.292	CIP	CANDIDATE		X
CIP313002.4	CIP	CANDIDATE		X
CIP312084.731	CIP	CANDIDATE		X
CIP398201.510	CIP	CANDIDATE		X
CIP313010.15	CIP	CANDIDATE		X
CIP398190.735	CIP	CANDIDATE		X
CIP312010.759	CIP	CANDIDATE		X
CIP313009.84	CIP	CANDIDATE		X

2.3. Field Layout Crop Management and Data Collection

The trials were laid out in augmented design replicated three times. Each plot measured 3m x 3m and consisted of four rows. Each row had eleven plants resulting in 44 plants per plot. Plant spacing was 0.75m x 0.3m. Well-sprouted egg-sized potato seed tubers were planted. At planting, diammonium phosphate (DAP) (18% N: 46% P₂O₅) was applied at the recommended rate of 500 kg/ha. Weeding, ridging and pests and disease control were carried out as per recommendations for potato production in Kenya [9]. Data collected include stand count at harvest, days to 50% flowering, days to physiological maturity and incidences of late blight, bacterial wilt and viruses. When most genotypes matured, the crop was harvested. From each plot, yield data was collected from the two inner rows i.e. from 22 plants.

2.4. Data Analysis

Data for 2016 and 2017 were analysed separately because only 9 genotypes were common to both seasons (Table 3). After harvesting, yield data was analysed using AMMIsoft [10] into a single model analysis of variance (ANOVA) for genotype (G) and environment (E) main effects and Genotype x Environment Interaction (GxE). The Additive Main effects and Multiplicative Interaction (AMMI) first applies ANOVA to partition the variation into G, E, and GxE and then it applies principal components analysis (PCA) to the GxE model. Three numbers from the ANOVA table provide a preliminary indication whether AMMI analysis will be worthwhile: the sum of squares (SS) for genotypes (G), GxE signal (GE_S), and GxE noise (GE_N). The SS values for G and GxE are direct outputs from ANOVA [10]. To estimate the SS for GE_N, multiply the error mean square (from replication) by the number of degrees of freedom (df) for GE [11]. Then obtain GE_S by subtracting GE_N from GxE. The AMMI analysis is appropriate for datasets having substantial G and substantial GE_S. When the SS for GE_S is at least as large as that for G, AMMI analysis will probably be worthwhile. On the other hand, if the SS for GE_N is approximately equal to that for GxE, the GxE is buried in noise. In that case, GxE should be ignored and AMMI analysis is inappropriate [10]. Early interaction principal components (IPCs) selectively capture GE_S signal while late ones GE_N noise.

3. Results and Discussion

3.1. Season1 (2016)

The AMMI analysis of variance showed significant ($p \leq 0.001$) effects of genotypes, environments and genotype x environment interaction (Table 4). The SS for G was 2447.39, GE_N was $32.34 \times 85 = 2748.9$ while the GE_S was $7127.90 - 2748.9 = 4379$. Since GE_S is almost twice as large as G, AMMI analysis is likely to be worthwhile. In the GxE interaction, only IPC 1 and 2 were significant at $p \leq 0.001$. Both accounted for 66.92% of the GxE interaction. Consequently, AMMI 2 was used to describe the GxE interaction. The AMMI 2 utilizes the genotypic and environmental main effects to describe additive variation and two interaction principal component axes (IPC 1 and IPC 2) for the non-additive variation.

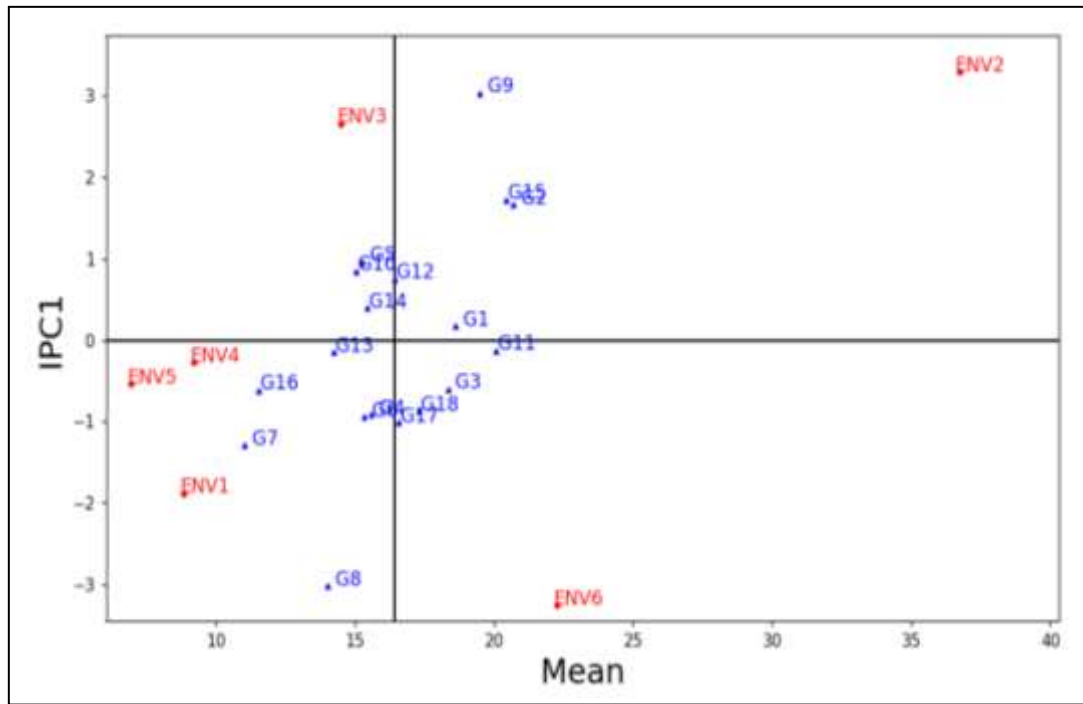
Table-4. Analysis of variance for Season 1(2016)

Source	df	ss	ms	% treatment SS explained	% of G x E interaction SS explained
Total	323	51796.75	160.36		
Treatment	107	44706.07	417.81 ***		
Genotypes (G)	17	2447.39	143.96***	5.47	
Environments (E)	5	35130.78	7026.16***	78.58	
G x E	85	7127.90	83.86 ***	15.94	
IPC 1	21	3157.85	150.37***		44.30
IPC 2	19	1612.55	84.87***		22.62
IPC 3	17	1236.86	72.76		17.35
IPC 4	15	734.46	48.96		10.3
Residual	13	386.17	29.71		5.42
Error	216	7090.68	32.83		
Blocks within Environments	12	493.11	41.09		
Pure Error	204	6597.57	32.34		

df = Degrees of freedom; *** = Significant at $p \leq 0.001$; SS = Sum of Squares, MS = Mean Squares.

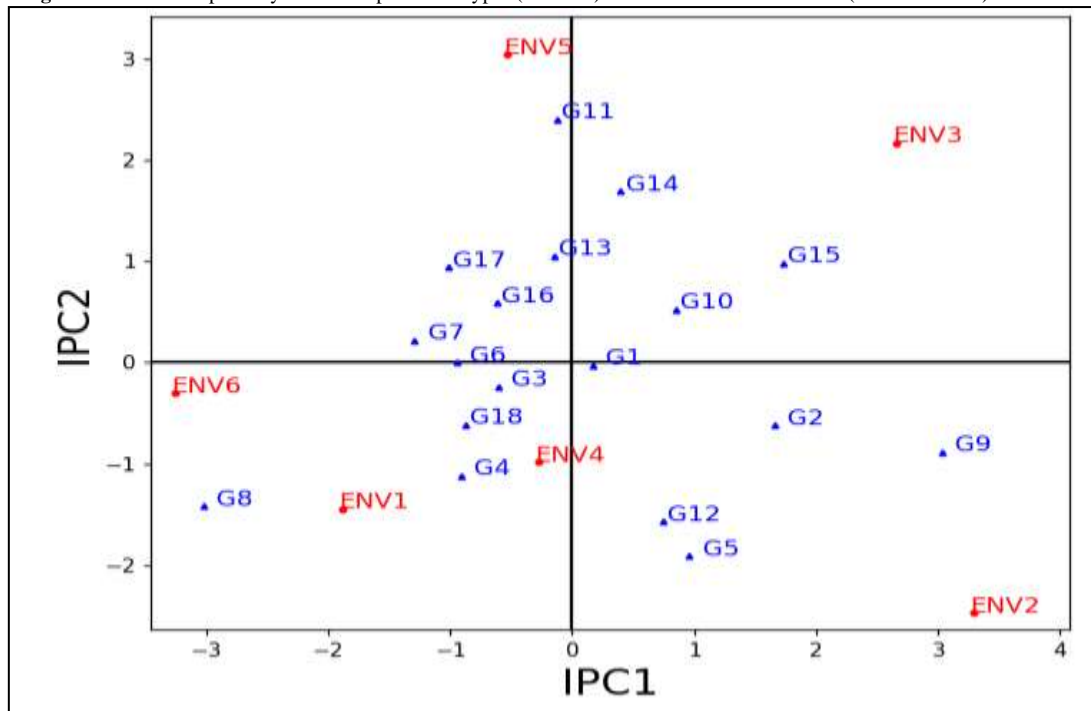
The genotypes with IPC1 scores close to zero expressed general adaptation across the environments whereas the larger scores depicted more specific adaptation to environments with IPC1 scores of the same sign [12]. Consequently, G9 (CIP398190.404) was better adapted to ENV 2 (Trans-Nzoia) while G8 (CIP397196.3) was better adapted to ENV 6 (Kabete). The ENV 2 (Trans-Nzoia) was the highest yielding while ENV 1 (Embu), ENV 3 (Mabanga), ENV 4 (Maragua) and ENV 5 (Kianjai) were the lowest yielding in 2016 (Figure 2). All the genotypes yielded low (less than 25 ton/ha) across all the sites; possibly due to higher temperatures in mid-altitudes compared to the highlands. A common approach for genotype selection pursues both high yield and stability; the best genotype should combine high yield and stable performance across the range of production environments [10]. Consequently, G11 showed high yields and stable performance (Figure 2). Genotypes G8 and G9 were the most unstable.

Figure-2. AMMI biplot of the main and first interaction principal component (IPC1) effects of both genotypes and environments on potato tuber yields in season 1



Genotype G8 (CIP397196.3) showed a high and positive interaction with ENV 1 (Embu) and ENV 6 (Kabete) whereas G11 (CIP398190.89) interacted positively with ENV 5 (Figure 3). Genotype G8 was the winner in ENV 1, 4 and 6 while G9 was the winner in ENV 2 (Figure 3). The ENV 4 (Maragua) had the least interactive behaviour.

Figure-3. AMMI 2 biplot of yields of 18 potato entotypes (G1-G18) across the six environments (ENV 1-ENV 6) in season 1



3.2. Season 2(2017)

The analysis of variance showed significant ($p \leq 0.001$) effects of environments and significant ($p \leq 0.01$) effects of the treatments (Table 5). However, the GxE interaction was not significant.

Table-5. Analysis of variance for Season 2 (2017)

Source	df	ss	ms	% treatment SS explained
Total	323	59067.92	182.87	
Treatment	107	26148.56	244.38**	
Genotypes (G)	17	3062.73	180.16 ^{ns}	11.71
Environments (E)	5	9806.22	1961.24 ***	37.5
G x E	85	13279.62	156.231 ^{ns}	50.79
IPC 1	21	11842.52	563.93 ^{ns}	
IPC 2	19	886.56	46.66 ^{ns}	
IPC 3	17	456.33	26.84 ^{ns}	
IPC 4	15	56.93	3.80 ^{ns}	
Residual	13	37.28	2.87	
Error	216	32919.36	152.40	
Blocks within Environments	12	1112.55	92.71	
Pure Error	204	31806.81	155.92	

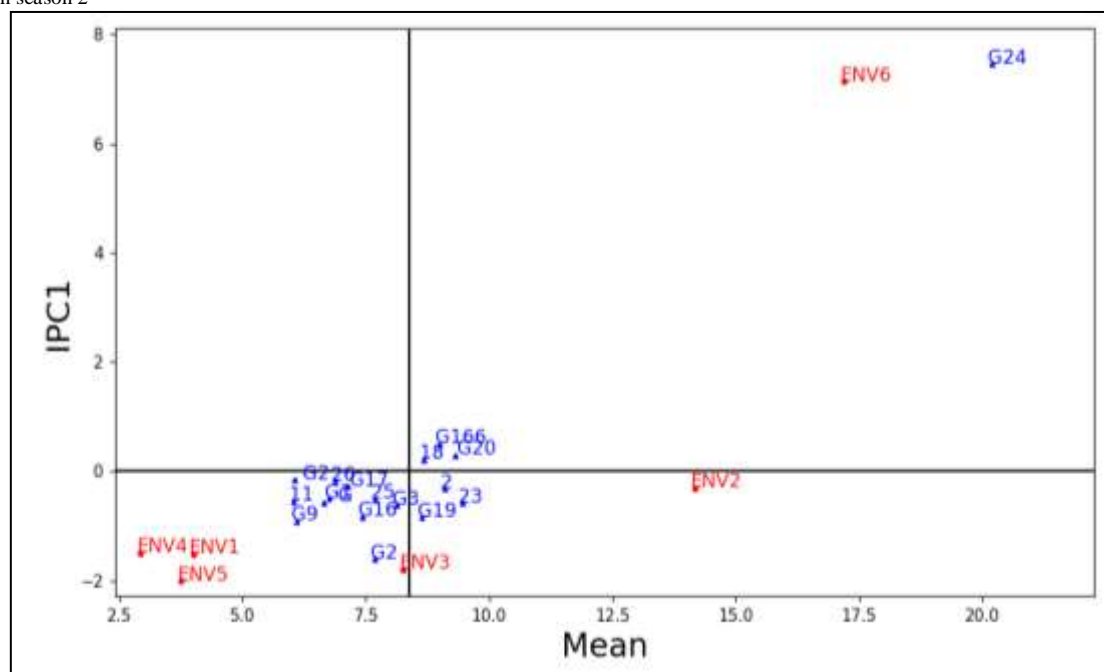
df = Degrees of freedom; SS = Sum of Squares; MS = Mean Squares; *** = Significant at $p \leq 0.001$; ** = Significant at $p \leq 0.01$; ns = not significant

The GxE interaction is mostly noise and AMMI analysis is inappropriate (Table 6).

Table-6. Estimated sums of squares for GxE signal and noise

G x E total	13279.62	
G x E noise	12954.38	97.55% of G x E total
G x E signal	325.24	2.45% of G x E total

Even though AMMI analysis is inappropriate because GxE is mainly noise, ENV 6 (Trans-Nzoia) was the highest yielding site in the second season followed by ENV 2 (Kabete) (Figure 4). Genotype G24 (CIP398180.292) was the highest yielding and showed specific adaptation to ENV 6 (Trans-Nzoia). All the other genotypes had average performance and showed general adaptation to the test environments.

Figure-4. AMMI biplot of the main and first interaction principal component (IPC1) effects of both genotypes and environments on potato tuber yields in season 2

Generally, performance was better in the first season than the second season across all the sites (Table 7). This could be due to less rainfall in 2017 compared to 2016. Trans-Nzoia was the best performing site in both seasons (Table 7) while Embu, Maragua, Mabanga and Kianjai had the lowest yields. This could be due to the lower altitude of these four sites compared to the others (Table 2).

Table-7. Mean performance of the test sites

	Kabete	Embu	Maragua	Mabanga	Kianjai	Trans-Nzoia	Average
Season 1	22.27	8.82	9.18	14.49	6.92	36.73	16.40
Season 2	14.16	4.00	3.75	2.93	8.25	17.20	8.38
Average	18.21	6.37	6.47	8.71	7.59	26.96	

The low yields observed in this study (16.40 ton/ha in season 1 and 8.38 ton/ha in season 2) are far below the potential yield of 40 ton/ha [13] possibly due to lower altitude. Low altitude means higher temperature and with potato being a cool season crop, its yields are likely to be lowered by high temperature. Potato is a cool season crop and grows best between 15 and 18 °C; temperatures above 21 °C have adverse effects on its growth [14]. The optimal yield for most commercial potato varieties is produced in average day time temperatures of 14-22 °C; above this, yield declines drastically [15, 16]. It is probable that most potato genotypes used in the current study were not bred specifically for the mid-altitude; this could also contribute to low yields. In order to develop potato varieties that can produce profitably in the warm mid-altitudes, breeding activities should be based in these areas or early generation selections carried out in these areas. Maybe other better performing mid-altitudes sites can be identified to replace the poor ones.

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References

- [1] FAO, 2013. *A policymakers' guide to crop diversification: The case of the potato in Kenya*. Rome, Italy: Food and Agriculture Organisation of the United Nations.
- [2] FAO, 2014. *The potato sector*. Rome, Italy: Food and Agriculture Organisation of the United Nations.
- [3] MoALF, 2016. *The national potato strategy*. Nairobi, Kenya: Ministry of Agriculture, Livestock and Fisheries.
- [4] Komen, S. K., Ngeny, J. M., and Osen, E., 2017. "Bridging the potato variety gap: a review of the Kenya - The Netherlands potato project (2012-2015): Its success, challenges and opportunities." *Open Agriculture*, vol. 2, pp. 267-273.
- [5] Janssens, S. R. M., Wiersema, S. G., Goos, H., and Wiersma, W., 2013. *The value chain for seed and ware potatoes in Kenya; Opportunities for development. LEI Memorandum 13-080*. The Netherlands: LEI Wageningen UR, Den Haag.
- [6] Wambugu, F. and Muriithi, L., 1982. *In vitro processing of germplasm*. In S. Nganga ed. *Potato development and Transfer of technology in Tropical Africa*. Nairobi: CIP pp. 117-18.
- [7] Gildemacher, P. R., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W. W., Wakahiu, M., Leeuwis, C., and Struik, P. C., 2009. "A description of seed potato systems in Kenya, Uganda and Ethiopia." *American Journal of Potato Research*, vol. 86, pp. 373-382.
- [8] Obare, G. A., Nyagaka, D. O., Nguyo, W., and Mwakubo, S. M., 2010. "Are Kenyan smallholders allocatively efficient? Evidence from Irish potato producers in Nyandarua North district." *Journal of Development and Agricultural Economics*, vol. 2, pp. 78-85.
- [9] KARI, 2008. *Production of food (ware) potatoes. KARI information brochure*. Nairobi, Kenya: Kenya Agricultural Research Institute.
- [10] Gauch, H. G., 2013. "A simple protocol for AMMI analysis of yield trials: Review and interpretation." *Crop Science*, vol. 53, pp. 1860-1869.
- [11] Gauch, H. G., 1992. *Statistical analysis of regional yield trials: AMMI analysis of factorial designs*, Elsevier, Amsterdam, the Netherlands. Hangzhou, China: Chinese, China National Rice Research Institute.
- [12] Ebdon, J. S. and Gauch, H. G., 2002. "Additive main effect and multiplicative interaction analysis of national turfgrass performance trials: I. Interpretation of genotype x environment interaction." *Crop Science*, vol. 42, pp. 489-496.
- [13] FAO, 2008. *International Year of the Potato*. Rome, Italy: Food and Agriculture Organization of the United Nations.
- [14] Muthoni, J. and Kabira, J. N., 2015. "Potato production in the hot tropical Africa: Progress made in breeding for heat tolerance." *Journal of Agricultural Science*, vol. 7, pp. 220-227.
- [15] Haverkort, A. J. and Verhagen, A., 2008. "Climate change and its repercussions for the potato supply chain." *Potato Research*, vol. 51, pp. 223-237.
- [16] Trapero-Mozos, A., Morris, W. L., Ducreux, L. J. M., McLean, K., Stephens, J., Torrance, L., Bryan, G. J., Hancock, R. D., and Taylor, M. A., 2018. "Engineering heat tolerance in potato by temperature-dependent expression of a specific allele of HEAT-SHOCK COGNATE 70." *Plant Biotechnology Journal*, vol. 16, pp. 197-207.