Estimation of Heterosis Among Potato (S*olanum tuberosum* L.) Crosses in Ethiopia

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Abstract

Determination of heterosis in tetraploid potato crosses is necessary for identification of superior genotypes for variety development or breeding program. However, producing heterotic potato genotypes through local crossing is not a common practice in Ethiopia. Hence, this study was conducted to estimate the magnitude of better, and standard check heteroses in potato clones that are produced from local crossing. This will help identify potential of hybrid for future breeding schemes. Heterosis of 75 clones were evaluated using a 9 x 9 Simple Lattice design. Results of the analysis of variance showed significant differences for all the growth characters, except medium-sized tubers and specific gravity of tuber. These results indicate the presence of genetic variability among the samples. The clones exhibited as high as 55.62 and 58.31 t.ha^{-1} marketable and total tuber yield, respectively. These clones also displayed mid, better parent and standard heterosis of 118.8%, 90.5% and 239.1%, respectively, for marketable tuber yield. This result indicates the presence of high magnitude heterosis which could be used to exploit the hybrid vigor. In addition, mid, better parent, and standard check heterosis were estimated at 79.36%, 61.04% and 209.17% for total tuber yield, respectively. Our results show the highest chance of getting heterotic offspring than parental and standard check varieties to developing new potato varieties. The information generated from this study would be valuable for researchers who intend to develop high-yielding varieties of potato.

Keywords: clone, heterosis, tuber yield

Introduction

The cultivated potato (*Solanum tuberosum* L.) is a highly heterozygous autotetraploid crop (2n = 4x = 48), with a genome size of 844 Mb (Muthoni et al., 2012). The complexities of tetrasomic inheritance in cultivated potato arise due to diploid gametes in which diallelic interactions can be transmitted to the next generation, sister chromatids can occur because of double reduction and two alleles be identical by descent (Baptiste, 2014). Understanding the complexities of tetrasomic inheritance in the potato and their implications in potato breeding will go a long way in enhancing efficiency in a conventional breeding program (Bradshaw, 2006).

Heterosis is a phenomenon whereby there is increased vigor, size, fruitfulness and speed of development, resistance to disease and insect pests in plants. It is also the opposite of inbreeding depression (Shull,1952). Autotetraploid potato can be severe by inbreeding depression when self-crossing occurs (Park et al., 2009). The parents involved in the successful crosses, which are moderately distant parents, can dispose the hybrid to higher heterosis (Manosh et al. 2008). Hence, heterosis breeding based on the identification of the parents and their cross combinations can produce the highest level of transgressive segregates (Falconer, 1960).

Heterosis can be quantified in terms of the mid-parent, the high or better-parent and standard check heterosis. Exploitation of heterosis in potato can allow the identification of better progenies that will produce high yield and are resistant to abiotic and biotic stress. This happens by reducing inbreeding within mutually heterotic gene pools. Heterosis is better for the yield and yield stability in potato and is a key feature in the success of producing hybrid cultivars. It has also been used as an important phenomenon in cultivar improvement because it is a major yield factor in plant breeding and can change in agriculture by improving agronomic traits of crops to meet the world's food needs (Duvick, 1999).

In Ethiopia generating heterotic clones through local crossing is little effort due to too much dependence

on materials from international potato center (CIP) (Getachew et al., 2016). Despite this, heterosis for yield and its component traits have not extensively studied in potato genotypes that are created by local crossing. Therefore, producing heterotic potato hybrids can help to supply food for burgeoning populations and improve environmental health of food production system in a country. Hence, investigating the magnitude of heterosis that exists among clones generated through hybridization is vital to develop better potato varieties and to guide the choice of desirable parents for developing superior hybrids or future breeding programs (Faizaan et al., 2016). This study was conducted to estimate the magnitude of heterosis for different traits in potato clones that are obtained from local crossing.

Materials and Methods

Study Site

The experiment was conducted at Adet Agricultural Research Station, during the main growing season in 2018. Adet Agricultural Research Center is located at longitudes ranging from 37° 28' 38'' to 37° 29' 50'' E and latitudes ranging from 11° 16' 19'' to 11° 17' 28'' N in northern highlands of Ethiopia, with an average altitude of 2240 meters above sea level (Andualem et al., 2013). The mean annual total rainfall during the growing season was 1432 mm with the average minimum and maximum temperatures of 10.81 to 25.55.

Sampling

A total of 81 genotypes of potato were used in the study (Figure 1, 2, 3). Seventy-five of these genotypes were progenies produced from biparental crossing of Ethiopian potato varieties by Adet Agricultural Research Center in 2015. In addition, five high yielding parent varieties, Belete, "Ater Ababa" , Gera, "Shenkola" **,** "Jalene" and "Dagim" , were used as the standard check varieties due to their high yielding and improved traits for comparison in this experiment (Table 1).

The experiment was laid out as a 9 x 9 simple lattice

Table 1. Clones and parents of potato used in the experiment during rainy season in 2018.

Trt	Clone	Trt	Clone	Trt	Clone	Trt	Clones
1	J x A.277	22	J x A.42	43	J x A.27	64	B x A.248
2	B x A.153	23	B x A.15	44	Ge xSh.186	65	J x A.18
3	J xA.296	24	J x A.49	45	J x A.130	66	J x A.123
4	B x A.174	25	B x A.60	46	B x A.163	67	B x A.207
5	J x A.94	26	J x A.77	47	J x A.67	68	J x A.186
6	B x A.225	27	"Gera" (F)	48	"Shenkola" (M)	69	B x A.129
7	Ge x Sh.65	28	J x A.31	49	Ge x Sh.206	70	J x A.122
8	"Belete" (F)	29	Ge x Sh.101	50	J x A.146	71	J x A.243
9	J x A.140	30	J x A.333	51	B x A.8	72	Ge x Sh.90
10	B x A.74	31	B x A.228	52	J x A.102	73	Ge x Sh.317
11	J x A.170	32	J xA.266	53	B x A.213	74	J x A.196
12	B x A.112	33	J x A.143	54	J x A.245	75	J x A.250
13	J x A.21	34	J x A.326	55	J x A.345	76	J x A.119
14	B x A.184	35	"Dagim" (S)	56	B x A.201	77	J x A.246
15	B x A.164	36	J x A.188	57	"Ater Ababa" (M)	78	J x A.165
16	J x A.120	37	J xA.60	58	J x A.135	79	"Jalene" (F)
17	J x A.187	38	B x J.16	59	B x A.603	80	B x A.97
18	B x A.44	39	J x A.34	60	J x A.201	81	Ge x Sh.96
19	J x A.39	40	Ge x Sh.319	61	B x A.55		
20	B x A.198	41	B x A.140	62	J x A.9		
21	Ge x Sh.29	42	J x A.23	63	Ge x Sh.100		

Note: Trt = treatment number; J x A="Jalene" x "Ater Ababa"; B x A= "Belete" x "Ater Ababa"; Ge x Sh = "Gera" x "Shenkola"; (F) = Female parent; (M) = male parent; (S) = standard check variety; numbers followed crosses indicated the codes of clone.

design. Each clone was planted in plot size of 4.5 m^2 (net) which contained two rows in plot with twenty plants per plot. Medium-sized and well-sprouted potato tubers were planted at the spacing of 75 cm between rows and 30 cm between plants. The recommended dose of fertilizer was applied at a rate of 81/69 N/P$_2$O$_5$ per hectare. The whole phosphorus fertilizer was applied during planting, but N source (Urea) was applied at planting, 2 weeks after emergence and at flowering at an equal 1/3 rates. Earthing up was executed two times throughout the entire growing period, one at 30 days and another one at 60 days after planting. Fungicide (Ridomil®, a.i. mancozeb and metalaxyl-M) was applied once when symptom occurred on experiment to control potato late blight disease.

Data Collection

Morphological, phenological, and agronomical data were collected during the growth period of the crop, following Huaman et al. (1977). The data of days to emergence(DE), days to flowering (DF), days to maturity (DMA), main stem number (SN), plant height (PH), tuber number per plant (TNP), tuber yield per plant (TYP), very small tuber numbers (VSN), medium sized tubers (MDN), large sized tubers (LTN), tuber dry matter content (DM), tuber starch content (SC), tuber specific gravity (SG), average tuber weight (AW), marketable tuber number (MTN), marketable tuber yield (MY), unmarketable yield (UMY) and total tuber yield (TY) were collected from sixteen plants per plots.

Data Analysis

The quantitative data was subjected to analysis of variance (ANOVA) using SAS statistical software 9.0 (SAS, 2000). Means for significant treatments were compared by Fisher's least significant differences (LSD) at 5% (P<0.05).

Estimation of Heterosis

Heterosis were computed using the Excel Microsoft Program 2019. Quantitative traits of potato progenies were used to estimate mid-parent, better parent heterosis and standard heterosis according to the procedures suggested by Fehr (1987), Bitzer and Fu (1972) and by Falconer and Mackay (1996) respectively. The value of the clones was computed for trait using the following formula:

Mid-parent heterosis (MPH) (%) = $(\frac{\bar{F}-MP}{MP})$x100

where

MP = mid parent value for the crosses

$\bar{F}$ = mean value cross (clones)

Heterobeltiosis or better parent heterosis (%) = $(\frac{\bar{F}-BP}{BP})$ X100

where

BP = mean of better parent (desirable one) of the respective cross.

Economic heterosis or standard check heterosis (%) = $(\frac{\bar{F}-SC}{SC})$ X100

where

SC = mean value of standard check variety

$\bar{F}$ = is the mean performance of hybrids over replications.

MP (t) = $\frac{F1-MP}{\sqrt{\frac{3}{2r}(EMS)}}$, BP (t) = $\frac{F1-BP}{\sqrt{\frac{2}{r}(EMS)}}$ and SC (t) = $\frac{F1-SC}{\sqrt{\frac{2}{r}(EMS)}}$

where

F$_1$ = Mean of the hybrid for a specific trait

BP = Mean of better parent in the cross

R = number of replications

EMS = error mean square.

The significance of heterosis was carried out by adopting student 't' test according to Wynne et al. (1970). Heterobeltiosis was tested by 't' test according to Sarawgi and Shrivastava (1988). The t values obtained were tested against the tabular t-value at error degree of freedom.

Results and Discussion

Our results demonstrated that the analysis of variance due to clones and its components (parents and standard check) were highly significant for all the traits except medium sized tubers (%) and tuber specific gravity (g.cm^3). The significant differences among clones obtained from crossing indicates that there is a chance of obtaining clones that are better performing than their parents and standard check variety for different traits. The clones are expected to be highly heterozygous in which additive and non-additive gene actions and in most case, both operate (Ross, 1986; Arndt, 1990).

Estimation of Heterosis

The result of heterosis for 75 clones are presented in Table 3. 4 and 5. Many of the clones showed positive and negative significance of heteroses for phenology, quality, yield and yield-related traits in the current study.

Heterosis (%) Over Mid-Parent

Both positive as well as negative heterosis of 75 potato offspring was observed (Table 3). Mid parent (average) heterosis was significant by some clones for phenological, yield and yield component traits suggesting the presence of directional dominance for the expression of these traits. A total of 5 clones out of 75 showed desirable negative significant heterosis

Table 2. Family mean-values of evaluated clones for quantitative traits

Clones	Value	DMA	Ph	TN/P	TYP	AVW	MKY	TTY	DM	SC
J x A (41)	Min	88	33.1	7	0.23	16.61	6.58	10.8	14.13	8.59
	Max	101	66.0	25	0.97	71.38	43.8	44.1	27.68	20.67
	Mean	95	49.2	14	0.59	42.27	23.3	27.0	21.18	14.88
"Jalene" (F)	Mean	93	50.2	15	0.60	40.96	23.0	27.4	18.15	12.18
"Ater Ababa" (M)	Mean	91	48.1	13	0.49	39.32	17.1	22.4	22.18	15.76
B x A (24)	Min	88	32.3	6	0.27	26.45	8.73	11.7	15.63	9.93
	Max	102	73.3	23	1.03	78.10	55.6	58.3	29.00	21.84
	Mean	95	46.6	12	0.62	53.55	26.9	30.3	21.73	15.36
Belete	Mean	99	52.9	8	0.88	106.80	41.0	42.6	24.3	17.66
Ge x Sh (10)	Min	90	41.3	8	0.30	35.11	2.51	16.8	13.78	8.28
	Max	99	71.6	17	1.03	103.30	33.9	45.7	25.48	18.70
	Mean	94	53.9	12	0.63	56.49	21.7	29.2	21.57	15.22
Gera(F)	Mean	99	65.8	13	0.89	72.87	37.1	39.3	20.98	14.69
"Shenkola" (M)	Mean	101	66.6	10	0.82	82.11	36.0	37.6	23.75	17.17
"Dagim" (C)	Mean	92	57.4	10	0.43	48.94	16.4	18.9	21.3	14.99
	G-mean	95	49.3	13	0.60	48.74	24.5	28.0	21.47	15.14

Note: J x A = "Jalene" cross with "Ater Ababa" ; B x A = "Belete" cross with "Ater Ababa"; Ge x Sh= "Gera" cross with "Shenkola" ; "Dagim" (C) = standard check variety; Min= minimum, Max = maximum; G mean = grand mean, DMA = days to 90% maturity; Ph (cm) = plant height, TN/P = tuber number per plant; TYP (g) = tuber yield per plant; AVW (g) = average tuber weight; MKY = marketable yield (t.ha^{-1}); TTY = total yield (t.ha^{-1}); DM = tuber dry matter content (%); SC = tuber starch content (%)

Figure 1. Mature and harvested potato berries from local crossing

Figure 2. Potato seedlings produced from local crossing

Figure 2. Potato seedlings produced from local crossing

for days to maturity and ranged from -10 to -9.2% by J x A.266 and Ge x Sh.100 clones, respectively.

In the case of plant height (cm), it is evident that only 10 offspring showed desirable positive significant heterosis ranging from -37.6 to 45.2% for clones Ge x Sh.186 and B x A.164, respectively. With respect to heterosis for plant height, positive heterosis of hybrids is considered desirable (Biswas et al., 2005). Potato clones that manifested positively significant heterosis had tallest plant height which can produce heterotic tuber yield due to over dominance or epistatic gene interaction that involve dominance and additive gene effect (Shawn, 2012).

The heterosis over mid parent for tuber number per plant and average tuber weight ranged between -50 to109% and -64.4 to 77.5%. From a total of 75 clones, 15 exhibited positively significant heterosis for tuber number per plant and eight (8) clones observed positively significance for average tuber weight. Most populations showed positively significant heterosis for tuber number per plant than heterosis of average tuber weight due to negative correlation between these two traits (Maris,1989). Instead of marketable and total tuber yield, mid parent heterosis ranged from -93.1 to 118.8% and -64.1 to 79.4%, respectively. This result is higher than Biswas (2010) who found mid parent heterosis to range from -63.5 to 61.7% for tuber yield. Among 75 clones only 18% of genetic materials showed above 50% mid parent heterosis by tuber yield in this study, and a total of 19 clones were expressed positively significant mid parent heterosis for this trait. The high correlation between heterozygosity and yield on tetraploid potato due to overdominance was explained by Mendoza and Haynes (1974).

The maximum and minimum mid parent heterosis for dry matter and starch content ranged between -38.4 to 37.2 and -48.0 to 47.9%, respectively. Only four clones recorded positively significant mid parent heterosis but none of them showed negative significance by these two traits. Most of the clones had not shown any significance for tuber dry matter and starch content that could be attributed to internal cancellation of positive and negative effects and the dominance not being of unidirectional in nature (Mather, 1982).

Heterosis (%) Over Better-Parent

The analysis of better parent heterosis in 75 clones are presented in Table 4. The better heterosis for days to maturity and plant height ranged from -11.6 (B x A.97) to 8.2% and -39 to 38.7% (B x A.164) accordingly. Negatively significant better parent heterosis were observed for seven clones for days to maturity indicating earliness of clones than the best parent. In case of plant height only three clones manifested positively significant better parent heterosis but 24 were exhibited negatively significant heterosis.

The better parent heterosis for tuber number per plant and average tuber weight ranged from -56.7 to 73.1% (B x A.44) and -75.7 to 73.2% (J x A.102), respectively. Among 75 clones only six (6) were expressing positively significant heterosis for tuber number per plant whereas 16 clones exhibited negatively significant heterosis. The highest and lowest heterosis for marketable and total tuber yield ranged from -93.2 to 90.5% (J x A.119) and -72.6 to 61.0% (J x A.119), respectively, but the minimum and maximum positively significant better heterosis for marketable tuber yield ranged between 35.7 to 90.5% by 10 clones due to over-dominance or intra-allelic interaction at one or multiple loci that can be the base of heterosis (Shawn, 2012). This indicated the presence of higher variability for tuber yield in the progeny than parental varieties. This could be because offspring were represented by a segregating population from the cross between highly heterozygous parents.

On the other hand, heterosis for dry matter and starch content ranged between -42 to 24.8% and -51.8 to 31.1% accordingly. Only two clones namely J x

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Table 3. Mid parent heterosis in 75 potato clones

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
J x A.277	-1.1	2.8	35.7**	0.0	53.5**	35.3*	18.4	23.7
J x A.296	7.1*	9.8	14.3	22.5	61.6**	40.6**	35.9**	46.2**
J x A.94	2.7	-31**	-50**	0.0	-45.7*	-49**	11.5	14.8
J x A.140	0.0	1.1	-14.3	-12.5	-30.9	-28.4*	0.1	0.0
J x A.170	8.2*	6.4	78.6**	-5.0	75.3**	72.1**	24.2*	31.2*
J x A.21	6.0	21.7*	50.0**	-5.0	50.4**	42.7**	14.9	19.2
J x A.120	3.8	12.5	57.0**	-22.5	5.5	16.6	13.2	17.0
J x A.187	1.6	34.3**	7.1	25.0	51.7**	34.6*	-12.4	-15.9
J x A.39	1.1	9.8	-21.4	47.5**	28.9	16.5	1.0	1.4
J x A.42	0.5	3.4	14.0	5.0	40.9*	29.1*	15.8	20.3
J x A.49	0.5	15.3	14.3	35.0*	76.4**	53.3**	13.8	17.8
J x A.77	3.3	22.5**	28.6*	12.5	78.9**	47.8**	16.5	21.3
J x A.31	-2.7	-5.1	28.6*	-5.0	38.1*	32.8*	21.3*	27.3*
J x A.333	7.6*	-31.6**	0.0	-58**	-67.1**	-56.5**	-30	-38.5
J x A.266	9.2**	24.6**	-21.4	67.5**	57.1**	37.2**	37.2**	47.9**
J x A.143	8.7**	-4.1	-7.1	-32.5	-53.5**	-38.5**	-18.6	-23.8
J x A.326	-2.7	18.8*	14.0	2.5	50.7**	32.5*	20.3	26.1
J x A.188	8.7	-23.9*	-36**	12.5	-6.7	-21.7	-23.3	-29.9
J x A.60	1.1	-32.7**	-28.6*	-27.5	-44.2*	-45.5**	6.5	8.4
J x A.34	-0.5	4.7	7.0	22.5	37.4*	27.4*	14.0	17.9
J x A.23	-4.9	-8.3	-36**	40.0*	-13.2	-13.8	-16.1	-20.7
J x A.27	4.4	-10.6	-21.4	10.0	1.8	-5.0	-11.11	-14.3
J x A.130	-4.9	-22.8**	0.0	0.0	14.8	-1.1	-0.8	-1.0
J x A.67	-0.5	1.6	21.43	-25.0	-14.7	-3.5	19.4	25.0
J x A.146	2.7	-12.0	-50**	2.5	-52.2**	-51.4**	0.2	0.2
J x A.102	3.8	21.1*	-7.1	77.5**	92.4**	66.7**	-15.3	-20.0
J x A.245	1.1	14.2	0.0	72.5**	104.5**	72.2**	14.1	18.1
J x A.345	2.7	7.6	-7.1	0.0	-8.9	-8.7	17.8	22.9
J x A.135	0.5	0.4	-21.4	-22.5	-46.5*	-39.8**	-17.6	-22.6
J x A.201	-1.1	18.3*	50.0**	7.5	63.1**	64.0**	19.0	24.5
J x A.9	7.6*	-9.6	29.0*	-10	16.0	16.3	6.3	8.1
J x A.18	1.1	2.4	36.0**	-32.5	11.9	-6.8	16.2	20.8
J x A.123	-0.5	-10.7	7.0	-12.5	-7.9	-10.6	11.3	14.6
J x A.186	6.0	-6.8	-28.6*	-7.5	-19.4	-30.8*	-11.6	-14.9
J x A.122	8.7**	-20.3*	-21.4	12.5	-9.3	-13.5	-1.6	-2.0
J x A.243	1.6	-17.0	14.0	-12.5	9.3	6.5	11.8	15.3
J x A.196	-2.7	-14.0	14.0	-48**	-51.6**	-40**	-19.5	-25.1
J x A.250	1.6	-11.8	-21.4	2.5	-14.6	-19.4	-7.3	-9.3
J x A.119	1.1	23.1**	7.0	55.0**	118.8**	77.2**	18.0	23.2
J x A.246	2.2	-0.7	-21.4	25.0	11.3	0.3	-18.2	-23.4
J x A.165	5.4	-4.8	-21.4	-5.0	-6.3	-8.4	13.8	17.8

Table 3. Mid parent heterosis in 75 potato clones (continued)

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
B x A.153	5.8	-22.0*	27.3	-51**	-7.3	2.5	11.3	19.5
B x A.174	3.7	-11.9	-27.3	-38.4*	-40.6**	-39.8*	-24.2	-26.2
B x A.225	0.5	-7.9	0.0	-39.7*	-46.9**	-30**	-16.3	-16
B x A.74	-3.7	-2.3	27.3	-34**	-5.1	-1.6	-15.1	-14.5
B x A.112	-3.2	-28**	-9.1	-43**	-45.9**	-42**	-2.6	1.7
B x A.184	6.8**	-18.4	-9.1	-33**	-29.0*	-29.7*	-14.6	-13.8
B x A.164	5.3	45.2**	45.5**	-10.96	91.7**	79.4**	5.8	12.5
B x A.44	5.8	4.2	109**	-43**	25.8*	26.9*	3.3	9.3
B x A.198	-3.2	7.0	9.1	-5.48	39.6**	32.8*	-13.3	-12.1
B x A.15	0.5	-4.3	27.3	-34**	17.8	21.8*	-9.1	-6.7
B x A.60	-6.3	12.3	-45.5*	6.9	-23.6	-28.6*	-16.9	-16.7
B x A.228	-6.3	6.0	0.0	-6.9	12.6	8.9	-14.2	-13.3
B x J.16	3.7	-19.5*	0.0	-1.4	24.8	17.1	-3.5	0.5
B x A.140	-5.3	-36.1	-45.5*	4.1	-34.1**	-37**	-35.4	-40.6
B x A.163	4.7	10.4	54.6**	-37.0*	-0.5	12.3	-18.5	-18.9
B x A.8	0.0	-31**	-9.1	-62**	-61.9**	-57**	-27.1	-29.9
B x A.213	-4.2	-12.8	-9.1	4.1	9.8	3.3	-7.0	-4.0
B x A.201	2.1	-21.1*	9.1	-39.7*	-29.4*	-27.9*	-17.7	-17.8
B x A.603	-3.7	-15.7	9.1	-5.5	14.7	7.6	-5.1	-1.5
B x A.55	1.6	25.2**	18.2	-8.2	20.9	19.5	11.3	19.5
B x A.248	7.4**	-36**	-9.1	-64**	-69.9**	-64**	-33.6	-38.3
B x A.207	-3.2	-20.6*	-18.2	-8.2	-11.9	-18	-7.0	-3.9
B x A.129	-2.1	-25.9*	45.4**	-57.5*	-44.5**	-34**	-19.2	-19.7
B x A.97	-7.9	-3.8	0.0	-28.8	-19.4	-24.6*	19.9	30.7*
Ge x Sh.65	-1.0	-27.6*	-25.0	-29.5	-43.9**	-41.6*	3.0	3.7
Ge x Sh.29	-3.0	-23.6*	-25.0	-7.7	-93.1**	-28.7*	-2.9	-3.6
Ge x Sh.101	-8.5*	-32.0**	0.0	-47**	-49.4**	-44.7*	-6.9	-8.6
Ge x Sh.319	-9.5*	8.15	33.3*	-32.1	-7.4	-6.6	-0.2	-0.2
Ge x Sh.186	-3.5	-37.6*	-33.3*	-53**	-55.6**	-56**	-38.4	-48.0
Ge x Sh.206	-2.5	-6.5	-8.33	32.1*	-12.1	18.9*	5.0	6.2
Ge x Sh.100	-10.0**	-19.8	42.0*	-46**	-28.9**	-21.4	13.9	17.4
Ge x Sh.90	-9.0**	-20.7	8.0	-39.7*	-23.6*	-17.9	10.0	12.1
Ge x Sh.317	-9.0**	-24.1*	0.0	-55**	-61.5**	-42**	-1.2	-1.5
Ge x Sh.96	-4.0	-10.4	25.0	-32.1	-12.0	-9.1	-0.4	-0.5
"Belete"	99.0	52.9	8.0	106.8	40.98	42.63	24.2	17.7
"Atera Ababa"	91.0	50.2	13.0	39.4	17.05	22.4	22.2	15.8
"Jalene"	93.0	50.2	15.0	41.0	23.0	27.4	18.2	12.2
"Gera"	99.0	65.8	13.0	72.9	37.1	39.3	21.0	14.7
"Shenkola"	101.0	66.6	10.0	82.1	36.0	37.6	23.8	17.2
Maximum	9.2	45.2	109.0	77.5	118.8	79.4	37.2	47.9
Minimum	-10.0	-37.6	-50.0	-64.4	-93.1	-64.1	-38.4	-48.0

Note: values with *and ** are significantly different at at P≤ 0.05 and P≤0.01 probability levels, respectively. DMA = days to maturity; Ph = plant height; TN/P = tuber number per plant; AVW= average tuber weight; MKY = marketable tuber yield; TTY = total tuber yield; DM = tuber dry matter; SC = tuber starch content.

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Table 4. Better parent heterosis in 75 potato clones

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
J x A.277	-2.2	0.7	27.0	-2.4	33.7	22.9	7.6	9.6
J x A.296	5.9	7.6	7.0	19.5	40.7**	27.7	23.5*	29.6*
J x A.94	1.6	-33**	-53*	-2.4	-52.7*	-53.4*	1.3	1.7
J x A.170	7.0*	4.3	67.0**	-7.3	52.6**	56.3**	12.9	16.3
J x A.21	4.8	19.2	40.0**	-7.3	31.0	29.7*	4.5	5.7
J x A.120	2.7	10.2	43.0**	-24.4	-8.1	5.9	2.9	3.7
J x A.187	0.5	31.6*	0.0	22	32.1	22.3	-20.3	-25.4
J x A.39	0.0	7.6	-30.0*	43.9**	12.2	5.8	-8.1	-10.2
J x A.42	-0.5	1.3	3.0	2.4	22.7	17.3	5.3	6.6
J x A.49	-0.5	13.0	7.0	31.7	53.6**	39.3**	3.5	4.4
J x A.77	2.2	20.0	20.0	9.8	55.8**	34.3*	6.0	7.5
J x A.31	-3.8	-7.0	20.0	-7.3	20.2	20.7	10.2	12.9
J x A.333	6.5	-33**	-7.0	-59**	-71**	-61**	-36.3	-45.5
J x A.266	8.1*	22.1*	-27.0	63.4**	36.9*	24.7	24.8*	31.1*
J x A.143	7.5*	-6.0	-17.0	-34.2	-60**	-44**	-26.0	-32.5
J x A.326	-3.8	16.5	3.0	0.0	31.3	20.4	9.3	11.7
J x A.188	7.5*	-25**	-40*	9.8	-18.7	-28.9	-30.2	-37.9
J x A.60	0.0	-34**	-37*	-29.3	-51.4*	-51**	-3.2	-3.9
J x A.34	-1.6	2.6	-3.0	19.5	19.6	15.8	3.6	4.5
J x A.23	-5.9	-10.2	-43.0*	36.6	-24.4	-21.7	-23.7	-29.7
J x A.27	3.2	-12.4	-27.0	7.3	-11.4	-13.7	-19.2	-24
J x A.130	-5.9	-24.4*	-7.0	-2.4	0.0	-10.1	-9.8	-12.3
J x A.67	-1.6	-0.4	13.0	-26.8	-25.7	-12.3	8.5	10.8
J x A.146	1.6	-13.7	-57.0*	0.0	-58**	-56**	-8.9	-11.2
J x A.102	2.7	18.7	-13.0	73.2**	67.6**	51.5**	-23.0	-28.8
J x A.245	0.0	11.9	-7.0	68.3**	78.1**	56.5**	3.7	4.7
J x A.345	1.6	5.4	-17.0	-2.4	-20.7	-17.0	7.1	8.9
J x A.135	-0.5	-1.6	-30.0*	-24.4	-53**	-45**	-25.1	-31.4
J x A.201	-2.2	16.0	4.00**	4.9	42.0*	49.0**	8.2	10.3
J x A.9	6.5	-11.4	17.0	-12.2	1.0	5.7	-3.4	-4.2
J x A.18	0.0	0.3	23.0	-34.2	-2.6	-15.3	5.6	7.1
J x A.123	-1.6	-12.5	-3.0	-14.6	-19.8	-18.8	1.2	1.6
J x A.186	4.8	-8.6	-33.0*	-9.8	-29.8	-37.1*	-19.6	-24.6
J x A.122	7.5*	-21.9*	-27.0	9.8	-21.0	-21.4	-10.5	-13.1
J x A.243	0.5	-18.7	3.0	-14.6	-4.8	-3.2	1.7	2.2
J x A.196	-3.8	-15.7	3.0	-48.8*	-58**	-46**	-26.9	-33.6
J x A.250	0.5	-13.5	-27.0	0.0	-25.7	-26.8	-15.7	-19.6
J x A.119	0.0	20.6	-3.0	51.2*	90.5**	61.0**	7.3	9.2
J x A.246	1.1	-2.7	-30.0*	22.0	-3.1	-8.9	-25.6	-32.1
J x A.165	4.3	-6.7	-27.0	-7.3	-18.4	-16.8	3.5	4.4
B x A.153	1.5	-25.5*	8.0	-66**	-34**	-21.8	10.7	13.1
B x A.174	-0.5	-15.9	-38.0*	-58**	-58**	-54**	-24.6	-30.2

Table 4. Better parent heterosis in 75 potato clones (continued)

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
B x A.225	-3.5	-12.0	-15.0	-59**	-62**	-47**	-16.7	-20.5
B x A.74	-7.6	-6.7	8.0	-55**	-33**	-25.0	-15.5	-19.1
B x A.112	-7.1	-32**	-27.0	-61**	-62**	-56**	-3.1	-3.8
B x A.184	2.5	-22.0*	-23.0	-54**	-50**	-46**	-15	-18.5
B x A.164	1.0	38.7*	23.0	-39**	35.7**	36.8**	5.3	6.4
B x A.44	1.5	-0.5	73**	-61**	-10.9	-3.2	2.8	3.4
B x A.198	-7.1	2.2	-8.0	-36**	-1.2	1.3	-13.7	-16.8
B x A.15	-3.5	-8.6	8.0	-55**	-16.6*	-7.1	-9.6	-11.8
B x A.60	-10.0**	7.3	-54.0**	-27.1	-45.9*	-45.5**	-17.3	-21.2
B x A.228	-10.0**	1.3	-15.0	-36.5**	-20.3*	-16.9	-14.6	-17.9
B x J.16	-0.5	-23.1*	-15.0	-32.7**	-11.6	-10.7	-4.0	-5.0
B x A.140	-9.1*	-39**	-54.0**	-29.0**	-53.4**	-52.0**	-35.7	-43.8
B x A.163	0.5	5.5	31.0*	-57.0**	-29.6**	-14.3	-18.9	-23.2
B x A.8	-4.0	-34**	-27.0	-73.8**	-73.0**	-67.5**	-27.5	-33.7
B x A.213	-8.1	-16.7	-23.0	-29.0**	-22.3*	-21.3	-7.4	-9.1
B x A.201	-2.0	-24.7*	-8.0	-58.9**	-50.0*	-45.0**	-18.1	-22.2
B x A.603	-7.6	-19.5*	-8.0	-35.5**	-18.8	-18.0	-5.6	-6.8
B x A.55	-2.5	19.6	0.0	-37.4**	-14.4	-8.9	10.7	13.1
B x A.248	3.0	-39.0**	-23.0	-75.7**	-78.7**	-72.6**	-34.0	-41.7
B x A.207	-7.1	-24.1*	-31.0*	-37.4**	-37.6**	-37.4*	-7.4	-9.1
B x A.129	-6.1	-29.2*	19.0	-71.0**	-60.7**	-49.7**	-19.6	-24.0
B x A.97	-12.0**	-8.2	-15.0	-51.4**	-42.9**	-42.5**	19.3	23.7
Ge x Sh.65	-2.0	-28.0**	-31.0*	-32.9**	-44.7**	-42.9**	-3.1	-3.8
Ge x Sh.29	-4.0	-24.0**	-35.0*	-12.2	-93.2**	-30.3*	-8.5	-10.5
Ge x Sh.101	-9.0**	-32.0**	-12.0	-50.0**	-50.2**	-45.9**	-12.3	-15.2
Ge x Sh.319	-10.0**	7.5	19.0	-35.4**	-8.7	-8.6	-6.0	-7.4
Ge x Sh.186	-4.5	-38.0**	-38.0*	-54.9**	-56.3**	-57.3**	-42.0	-51.8
Ge x Sh.206	-3.5	-7.0	-19	25.6	-13.4	16.3	-1.2	-1.5
Ge x Sh.100	-11.0**	-20.0*	27.0	-48.8**	-30.0*	-23.1	7.3	8.9
Ge x Sh.90	-9.0**	-21.0*	-4.0	-42.7**	-24.7*	-19.7	3.3	4.0
Ge x Sh.317	-10.0**	-25**	-8.0	-57.3**	-62.0**	-43.7**	-7.0	-8.6
Ge x Sh.96	-5.0	-10.9	15.0	-35.4**	-13.3	-11.1	-6.2	-7.7
"Belete"	99.0	52.9	8.0	106.8	41.0	42.6	24.2	17.7
"Ater Ababa"	91.0	50.2	13.0	39.4	17.1	22.4	22.2	15.8
"Jalene"	93.0	50.2	15.0	41.0	23.0	27.4	18.2	12.2
"Gera"	99.0	65.8	13.0	72.9	37.1	39.3	21.0	14.7
"Shenkola"	101.0	66.6	10.0	82.1	36.0	37.6	23.8	17.2
Maximum	8.1	38.7	73.1	73.2	90.5	61.0	24.8	31.1
Minimum	-11.6	-39.0	-56.7	-75.7	-93.2	-72.6	-42.0	-51.8

Note: values with *and ** showed significant differences at P≤ 0.05 and P≤0.01 probability levels, respectively. Values in "Belete", "Jalene" and "Gera" = mean of female parents, whereas in "Ater Ababa" and "Shenkola" = mean of male parents. DMA= days to maturity, Ph= plant height; TN/P= tuber number per plant; AVW= average tuber weight; MKY= marketable tuber yield; TTY= total tuber yield; DM= tuber dry matter; SC= tuber starch content.

A.266 and J x A.296 manifested positively significant better parent heterosis for quality traits. Most of the potato progenies in the three families expressed low or equal amount of tuber dry matter and starch content with parents due to the parents involved in these crosses were very closely related by this trait, or distantly related and the incompatibility of allele's combinations can result on low heterosis Manosh et al. (2008).

Heterosis % Over Standard Check Variety

The maximum positively significant and negatively non-significant economic heterosis ranged between 10.9 to -4.9% for days to maturity (Table 5). In the case of plant height, the economic heterosis was between -43.8 to 27.7%. Only clone B x A.164 manifested positively significant standard check heterosis but 31 clones were negatively significant.

The highest and lowest economic heterosis for tuber number per plant and average tuber weight ranged from -40 to 150% and -65.3 to 110.2%, respectively. A total of 23 clones exhibited positively significant heterosis by tuber number per plant. Only 14 clones expressed positive significance for average tuber weight. In terms of marketability and total tuber yield, economic heterosis ranged between -84.7 to 239.1% and -42.6 to 209.2% respectively. A total of 35 clones exhibited positively significant heterosis for marketable and total tuber yield in tested clones. The number of clones that recorded above 50 percent of heterosis in the current study for total tuber yield were 10 (mid parent), 7 (better parent) and 35 (standard heterosis). Luthra (2005) reported above 50% heterosis with significantly positive heterosis for 18 crosses out of 120 by tuber yield. Analysis of economic heterosis for quality traits (dry matter and starch content) were between -35.3 to 36.2% and -44.8 to 45.7%, respectively (Table 4). From a total of 75 clones, only five exhibited positively significant heterosis, but no clones showed negatively significant for these quality traits.

In this study the most promising clones with high yield were found in biparental crosses of "Jalene" with "Ater Ababa" followed "Ater Ababa" with "Belete" (Table 2). But low yielding and inferior genotypes were found in crosses of "Gera" with "Shenkola" varieties due to the same origin of pedigree (KP- 90134) for parental varieties or far linked parents (Manosh et al., 2008) that attributed non-allelic interaction with the large number of decreasing alleles (Mather,1982). Clones such as J x A.119, J x A.170, J x A.245, J x A.102 and B x A.164 showed the highest heterosis for tuber yield among tested materials. Offspring (clones) derived from crossing "Belete" with "Ater Ababa" and "Gera" with "Shenkola"   did not manifest positively

or negatively significant heterosis on mid and better parent for quality traits. This indicates equality or inferiority of progenies than their parents for these traits or because of crossing with a homozygote parent by this trait which might have generated homozygote hybrids. These results agree with reports of Kumar (2008) and Manivel (2010) who found non-significant or low heterosis for tuber dry matter and starch content.

Accordingly, many authors reported the three heteroses on potato populations. Parmar et al. (2015) reported the range of -28.62 to 51.11%, -35.91 to 48.44% and -40.44 to 0.66% for mid parent, better parent heterosis and standard heterosis for plant height, respectively. Baptiste (2014) reported the highest mid parent heterosis of 36.05 and highest best parent heterosis of 34.44 for tuber yield among one family progenies. Baptiste (2014) also reported mid parent heterosis ranging from -42.03 to 160.08% and better parent heterosis of -47.04 to125.00% among 41 clonal progenies by tuber yield. Biswas (2010) noted mid parent heterosis (-63.5 to 61.7%), better parent heterosis (-68.6 to 21.4%) and standard heterosis (-72.4 to 13.9%) for tuber yield from 30 clones. Luthra (2006) reported 120 hybrids and 29 parents of potato based on progeny mean and heterosis, with only 4 offsprings exhibiting significant positive heterosis for tuber yield.

Conclusion

Heterosis by cross pollination between tetraploid potato varieties would help to develop better hybrids with high yield potential acceptable to the consumers. In this study, most clones that showed positively significant heterosis (mid, better parent and standard check) for tuber number per plant, average tuber weight and tuber yield were found in biparental crosses of "Jalene" with "Ater Ababa", followed by "Ater Ababa"   with "Belete". Low yielding clones were found in progenies of "Gera" and "Shenkola" due to same origin of pedigree. These findings would help researchers find the critical areas for the development of new potato varieties that some of the investigators were not able to explore. A new theory could be handy for many researchers to develop better hybrids through conventional crossing. Finally, the study results indicate that the highest chance of getting heterotic potato offspring were generated from local crossing relatively with high yield than parent and standard check varieties. Besides, further investigation can be done to exploit hybrid vigor for effective improvement in yield potential of the traits of the best crosses.

Table 5. Standard check heterosis for different traits in potato clones.

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
J x A.277	-1.1	-12.0	90**	-18.4	87.4**	78.6**	12.1	15.2
J x A.296	7.1*	-6.0	60**	0.0	97.3**	85.6**	28.6*	36.2*
J x A.94	2.7	-41.0**	-30	-18.4	-33.8	-32.3	5.5	6.9
J x A.140	0.0	-13.5	15	-28.6	-15.6	-5.5	-5.3	-6.8
J x A.170	8.2*	-8.9	150.0**	-22.5	113.9**	127.1**	17.6	22.3
J x A.21	6.0	4.2	110.0**	-22.5	83.6**	88.4**	8.8	11.1
J x A.120	3.8	-3.7	115.0**	-36.7*	28.8	53.9*	7.2	9.0
J x A.187	1.6	15.0	50.0*	2.0	85.2**	77.7**	-17.0	-21.6
J x A.39	1.1	-6.0	5.0	20.4	57.3*	53.8*	-4.3	-5.5
J x A.42	0.5	-11.5	55.0*	-14.3	72.0**	70.5**	9.6	12.1
J x A.49	0.5	-1.3	60.0**	10.2	115.3**	102.4**	7.8	9.7
J x A.77	3.3	4.9	80.0**	-8.2	118.4**	95.1**	10.3	13.0
J x A.31	-2.7	-18.7*	80.0**	-22.5	68.5**	75.3**	14.8	18.7
J x A.333	7.6*	-41.0**	40.0	-65**	-59.9*	-42.6**	-33.7	-42.7
J x A.266	9**	6.7	10	36.7*	91.7**	81.1**	29.9**	37.9*
J x A.143	8.7*	-17.9	25	-44.9*	-43.2	-18.8	-22.9	-29.0
J x A.326	-2.7	1.7	55.0*	-16.3	84.0**	74.9**	13.9	17.5
J x A.188	8.7*	-34.8*	-10.0	-8.2	13.9	3.3	-27.4	-34.7
J x A.60	1.1	-42.0**	-5.0	-40.8*	-31.9	-28.0	0.8	1.0
J x A.34	-0.5	-10.4	45.0	0.0	67.7**	68.2**	7.9	9.9
J x A.23	-4.9	-21.5*	-15	14.3	6.0	13.8	-20.5	-26.1
J x A.27	4.4	-24.0**	10.0	-10.2	24.3	25.4	-15.9	-20.1
J x A.130	-4.9	-34.0**	40.0	-18.4	40.2	30.6	-6.1	-7.8
J x A.67	-0.5	-13.0	70.0**	-38.8*	4.2	27.4	13.0	16.4
J x A.146	2.7	-25.0**	-35.0	-16.3	-41.6	-35.8	-5.2	-6.6
J x A.102	3.8	3.7	30.0	44.9*	134.9**	120.0**	-19.8	-25.2
J x A.245	1.1	-2.2	40.0	40.8*	149.7**	127.4**	8.0	10.0
J x A.345	2.7	-7.9	25.0	-18.4	11.2	20.6	11.5	14.5
J x A.135	0.5	-14.1	5.0	-36.7*	-34.6	-20.6	-22.0	-27.9
J x A.201	-1.1	1.3	110.0**	-12.2	99.1**	116.5**	12.7	16.0
J x A.9	7.6*	-23.0**	75.0	-26.5	41.6	53.5*	0.6	0.7
J x A.18	1.1	-12.4	85.0**	-44.9*	36.6	23.1	10.0	12.6
J x A.123	-0.5	-24.0**	45.0	-28.6	12.4	18.0	5.4	6.8
J x A.186	6.0	-20.2	0.0	-24.5	-1.6	-8.6	-16.3	-20.7
J x A.122	8.7*	-32.0**	10.0	-8.2	10.7	14.2	-6.8	-8.7
J x A.243	1.6	-29.0**	55.0*	-28.6	33.4	40.6	5.9	7.4
J x A.196	-2.7	-26.0**	55.0*	-57**	-40.9	-21.0	-23.8	-30.2
J x A.250	1.6	-25.0**	10.0	-16.3	4.2	6.4	-12.2	-15.5
J x A.119	1.1	5.4	45.0	26.5	167.1**	134.0**	11.7	14.8
J x A.246	2.2	-15.0	5.0	2.0	35.9	32.4	-22.5	-28.6
J x A.165	5.4	-18.48	10.0	-22.5	14.3	20.9	7.8	7.8

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Table 5. Standard check heterosis for different traits in potato clones (continued)

Clone	DMA	Ph	TN/P	AVW	MKY	TTY	DM	SC
B x A.153	9.0**	-31.0**	40.0	-26.5	64.0*	76.7*	26.3*	26.3*
B x A.174	7.1*	-22.5*	-20.0	-8.2	5.2	3.8	-14.0	-14.0
B x A.225	3.8	-19.0	10.0	-10.2	-6.0	20.4	-4.9	-4.9
B x A.74	-0.5	-14.1	40.0	-2.0	67.9*	69.6**	-3.6	-3.6
B x A.112	0.0	-37.0**	-5.0	-14.3	-4.2	0.4	10.6	10.6
B x A.184	10.0**	-28.0**	0.0	0.0	25.7	21.2	-3.1	-3.1
B x A.164	8.7*	27.7**	60**	32.7*	239.1**	209.2**	20.1	20.1
B x A.44	9.0**	-8.4	125.0**	-14.3	122.5**	118.8*	17.3	17.3
B x A.198	0.0	-5.9	20.0	40.8*	146.9**	129.0**	-1.5	-1.5
B x A.15	3.8	-15.8	40.0	-2.0	108.5**	110.0**	3.2	3.2
B x A.60	-3.3	-1.2	-40.0	59.2**	35.2	23.1	-5.6	-5.6
B x A.228	-3.3	-6.8	10.0	39.0	99.2**	87.8**	-2.6	-2.6
B x J.16	7.1*	-29.0**	10.0	46.9*	120.8**	101.9**	9.5	9.5
B x A.140	-2.2	-44.0**	-40.0	55.1**	16.5	8.5	-26.6	-26.6
B x A.163	8.2*	-2.86	70.0**	-6.1	76.0*	93.6**	-7.5	-7.5
B x A.8	3.3	-39.0**	-5.0	-42.9*	-32.6	-26.6	-17.3	-17.3
B x A.213	-1.1	-23.0**	0.0	55.1**	94.2**	78.0**	5.6	5.6
B x A.201	5.4	-30.6*	20.0	-10.2	24.9	24.3	-6.6	-6.6
B x A.603	-0.5	-26.0**	20.0	40.8*	102.8**	85.4**	7.8	7.8
B x A.55	4.9	10.12	30.0	36.7*	113.8**	105.9**	26.29*	26.3*
B x A.248	11.0**	-44.0**	0.0	-46.9*	-46.8	-38.0	-24.7	-24.7
B x A.207	0.0	-30.0**	-10.0	36.7*	56.0*	41.4	5.6	5.6
B x A.129	1.1	-35.0**	55.0*	-36.7*	-1.8	13.7	-8.2	-8.2
B x A.97	-4.9	-15.4	10.0	6.1	42.7	30.0	36.0**	36.0**
Ge x Sh.65	7.6*	-16.4	-10.0	12.2	25.0	19.1	8.1	8.1
Ge x Sh.29	5.4	-11.8	-15.0	46.9*	-84.7**	45.3	2.0	2.0
Ge x Sh.101	-0.5	-21.6*	15.0	-16.3	12.6	12.7	-2.2	-2.2
Ge x Sh.319	-1.6	24.8**	55.0*	8.2	106.4**	90.5**	4.8	4.8
Ge x Sh.186	4.9	-28.0**	-20.0	-24.5	-1.1	-11.0	-35.3	-35.3
Ge x Sh.206	6.0	7.9	5.0	110.0**	95.9**	142.4**	10.2	10.2
Ge x Sh.100	-2.2	-7.5	65.0**	-14.3	58.3*	60.3**	19.6	19.6
Ge x Sh.90	-0.5	-8.5	25.0	-4.1	70.3*	67.4**	15.1	15.1
Ge x Sh.317	-1.1	-12.4	20.0	-28.6	-14.2	17.3	3.8	3.8
Ge x Sh.96	4.4	3.4	50.0*	8.2	96.0**	85.3**	4.6	4.6
"Dagim" (S)	92.0	57.4	10.0	48.9	16.4	18.9	21.3	15.0
Maximum	10.9	27.7	150.0	110.2	239.1	209.2	36.2	45.7
Minimum	-4.9	-43.8	-40.0	-65.3	-84.7	-42.6	-35.3	-44.8
G-mean	0.5	-5.3	4.1	-9.7	0.7	-1.6	-0.7	0.6

Note: "Dagim" (S)= standard check variety; G-mean= grand mean; DMA= days to maturity, Ph= plant height; TN/P= tuber number per plant; AVW= average tuber weight; MKY= marketable tuber yield; TTY= total tuber yield; DM= tuber dry matter; SC= tuber starch content.

Acknowledgements

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