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Morphological Traits Associated with Heat Tolerance in Potato

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ABSTRACT

Heat tolerant and susceptible genotypes of potato were grown in a non potato growing tropical region i.e. West Godavari district of Andhra Pradesh during *rabi* 2016-17 in order to find out the morphological traits that contribute to heat tolerance. Data on different yield and yield attributing characters were analysed (correlation and path analysis) to find out the direct and indirect contribution of important traits towards adaptation of potato to high temperatures. Yield plant^{-1} was found to have significant positive correlation at both genotypic and phenotypic levels with plant height (0.3115** and 0.2495*), number of nodes plant $^{-1}$ (0.2789* & 0.2543*), number of stolans plant^{-1} (0.5822** and 0.3360**), number of tubers plant^{-1} (0.4385** & 0.3751**) and average tuber wt. (0.6988** and 0.7021**). However it was negatively correlated with and leaflet size (-0.5180** and -0.4869**) at genotypic as well as phenotypic level. These studies help in breeding of heat tolerant potato varieties by exercising selection for such traits.

Introduction

Potato (*Solanum tuberosum* L., family Solanaceae) is the fourth most important food crop in the world after rice, wheat and maize. However, its cultivation is limited to relatively cooler areas and seasons throughout the world due to photo and thermo-sensitivity of the crop (Minhas *et al.,* 2011). In India, about 90% potatoes are grown in northern plains during short winter days. The yield and quality of potatoes are very sensitive to high temperatures (Bodlaender 1963; Ewing 1981). Minimum night temperature plays a crucial role during tuberisation which is reduced at night temperatures above 20°C with complete inhibition of tuberization above 25°C. Optimum temperatures for tuber formation are widely regarded as being in the range of 10-17°C (Bodlaender 1963; Moorby and Milthorpe 1975). Climate change is likely to lead to an overall temperature increase of 1-1.4 °C (Hijmans 2003) and development of potato cultivars with increased heat tolerance appears to be important to cope with climate change. Except Nilgiri hills of Tamil Nadu, few districts of Karnataka and a very limited area in Andhra Pradesh (some parts of Chittoor district and hills of Vizag district) and Kerala (hills of Idukki district), potato is not grown widely in the southern states of India, though it is consumed on par with other vegetables in these states. To expand the potato cultivation in non-traditional warmer areas, there is need to evolve varieties that could germinate, grow and tuberize well under high temperature. In potato, tuber yield is a complex polygenic trait (Killick, 1977) and is the product of interactions between various characters. Information on the nature and magnitude association among different characters is a pre-requisite for an efficient breeding strategy. The present investigation was, therefore, focused on character association in potato crop grown under high temperature stress conditions which will help in breeding of heat tolerant potato suitable for cultivation in non traditional areas with relatively higher temperature during crop growth period.

Materials and Methods

Twenty five potato genotypes supplied by Central Potato Research Institute Campus, Modipuram, Meerut comprising six released varieties, one germlasm accession and eighteen hybrids specifically bred for heat tolerance which are in advance stage of testing under All India Coordinated Research Project on Potato and were evaluated in the experimental farm of College of Horticulture, Dr. Y S R Horticultural University, Venkataramannagudem, West Godavari district, Andhra Pradesh (17.4^{o} N, 78.48^{o} E and 18 m above mean sea level) during *rabi*, 2016-17. The meteorological data recorded at the location is presented in table 1. The entries were planted during last week of October 2016, in RBD with three replications. Twenty tubers each were planted in rows with a spacing of 60 cm x 30cm. Data were collected on germination % (%), stem number, plant height (cm), number of nodes, inter nodal length (cm), leaflet size (cm^{2}), number of stolans plant^{-1}, number of tubers plant^{-1}, average tuber weight (g) and yield plant^{-1} (g) and other physiological and biochemicals traits from five random plants form each replication and the average was computed. Germination % was calculated by counting number tubers germinated on 30th day after planting and dividing the number with total number of tubers planted and multiplied by hundred. The height of the plant was measured in centimeters from ground level to the tip of the main shoot with the help of a meter ruler on 60th day after planting. Number nodes of the main shoot were counted and inter nodal length was computed by dividing plant height with number of nodes. Leaf let size was measured with a leaf area meter. The data recorded on various characters were subjected statistical analysis using Windostat Version 9.2 software. Analysis of variance was carried out as per Panse and Sukhatme (1985). Phenotypic and genotypic correlations were worked out by using the formulae suggested by Falconer (1964). Path co-efficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959) was used to calculate the direct and indirect contribution of various traits towards potato yield.

Results and Discussion

The data on mean performance of the 25 genotypes for different yield attributing characters are furnished in table 2. The analysis of variance on 25 potato genotypes revealed significant differences among the genotypes for all the characters indicating prevalence of genetic variability under high temperature stress conditions of tropical plains. The phenotypic and genotypic correlation coefficients between tuber yield and its component characters and among themselves were worked and are presented below (Table 3).

Yield plant^{-1} was found to have significant positive correlation, at genotypic as well as phenotypic level with plant height (0.3115** and 0.2495*), number of nodes plant $^{-1}$ (0.2789* and 0.2543*), number of stolans plant^{-1} (0.5822** and 0.3360**), number of tubers plant^{-1} (0.4385** and 0.3751**) and average tuber wt. (0.6988** and 0.7021**). However it showed significant negative correlation with leaflet size (-0.5180** and -0.4869**) at genotypic as well as phenotypic level. Germination % was found to have significant positive association with plant height at both genotypic and phenotypic levels (0.2759* and 0.2611*), and with inter nodal length (0.2669*), only at genotypic level. It has negative association with leaflet size at genotypic as well as phenotypic levels (-0.2591* and -0.2327*). Stem number was found to have significant positive correlation with number of tubers plant^{-1} at both genotypic and phenotypic levels (0.2629* and 0.3096**), with plant height (0.2885*), number of nodes (0.3771**), number of stolans plant^{-1} (0.2666*) at phenotypic level only. However, it recorded significant negative correlation with leaflet size at both genotypic and phenotypic levels (-0.3554** and -0.5515**). Plant height exhibited significant positive correlation both at genotypic and phenotypic levels with number of nodes plant^{-1} (0.6903** and 0.5129**), inter nodal length (0.2544* and 0.4620**), number of stolans plant^{-1} (0.4743** and 0.3543**), and number of tubers plant^{-1} (0.4465** and 0.3627**) and with stem number (0.2885*) at genotypic level. It has significant negative association with leaflet size (-0.2822*).

Number of nodes plant^{-1} has significant positive correlation with average tuber wt. (0.3166** and 0.2857*) at both genotypic and phenotypic level, stem number (0.3771**) at phenotypic level, while negative correlation with inter nodal length both at genotypic and phenotypic level (-0.5106** and -0.5021**). Inter nodal length showed significant positive correlation with number of stolans plant^{-1} (0.4096** and 0.2872*) and number of tubers plant^{-1} (0.3738** and 0.2659*) at both genotypic and phenotypic levels but significant negative association with average tuber wt.(-0.2287*) at genotypic level. Leaflet size showed significant negative association with number of stolans plant^{-1} (-0.2787* and -0.2587*), number of tubers plant^{-1} (-0.3250** and -0.2972**), average tuber wt (-0.3103** and -0.2775*), at genotypic and phenotypic levels.

Number of stolans plant^{-1} showed significant positive association with no of tubers plant^{-1} (0.9862** and 0.9506**), but negative association with average tuber wt.(-0.3471** and -0.3340**) at both genotypic and phenotypic levels. Number of tubers plant^{-1} showed significant negative association with average tuber wt. (-0.3154** and -0.3586**) at both genotypic and phenotypic levels.

The direct and indirect effects of different yield contributing traits (morphological, physiological and biochemical) on tuber yield plant^{-1} were estimated through path analysis at phenotypic and genotypic levels. The data on effects of morphological traits on yield at genotypic and phenotypic levels are presented in table 4 and 5 respectively. The direct effect of germination % on yield plant^{-1} at genotypic level is negative and high (-0.2419). Its indirect effect through inter nodal length (-0.5617) is high and negative, through number of nodes plant^{-1} (-0.0113), number of tubers plant^{-1} (-0.0002), average tuber wt. (-0.0057), stem number (-0.0029), is low and negative. Its indirect effect through plant height (0.7024) is high and positive, through leaflet size (0.0131), number of stolans plant^{-1} (0.0089) is low and positive. At phenotypic level also the direct effect of germination % is negative and high (-0.374). Its indirect effect through plant height (-0.0004), number of nodes plant^{-1} (-0.0008), inter nodal length (-0.0080), number of stolans plant^{-1} (-0.0052), number of tubers plant^{-1} (-0.0162), stem number (-0.0007) is low and negative. While its indirect effect through average tuber wt. (0.0233), leaflet size (0.0024) is low and positive.

The direct effect of stem number on yield plant^{-1} is low and negative at genotypic level (-0.0536) and its indirect effect through number of nodes plant^{-1} (-1.1091) is high and negative, through germination % (-0.0131), number of tubers plant^{-1} (-0.0033), average tuber wt. (-0.0656) is low and negative; through plant height (0.7344) and inter nodal length (0.2096) is high and positive; through leaflet size (0.0278) and number of stolans plant^{-1} (0.0988) is low and positive. The direct effect of stem number on yield plant^{-1} is low and negative at phenotypic level (-0.0678). Its indirect effect through germination % (-0.004), plant height (-0.0002), number of nodes plant^{-1} (-0.0053), number of stolans plant^{-1} (-0.0552), average tuber wt. (-0.0630) is low and negative; through number of tubers plant^{-1} (0.2416) is high and positive and through inter nodal length (0.0028) and leaflet size (0.0037) is low and positive.

The direct effect of plant height on yield plant^{-1} is high and positive at genotypic level (2.5459), and its indirect effect through number of stolans plant^{-1} (0.1757) is high and positive, through leaflet size (0.0142), average tuber wt. (0.0949), is low and positive. While its indirect effect through number of nodes plant^{-1} (-2.0303), inter nodal length (-0.5353) is high and negative; through germination % (-0.0667), number of tubers plant^{-1} (-0.0048), stem number (-0.0155), is low and negative. At phenotypic level the direct effect of plant height on yield plant^{-1} is negative (-0.0014) and its indirect effect is through germination % (-0.0098), number of nodes plant-1 (-0.0149), inter nodal length (-0.0170), number of stolans plant^{-1} (-0.0994), stem number (-0.0087), is low and negative, through number of tubers plant^{-1} (0.3334), average tuber wt. (0.0561), leaflet size (0.0023), is low and positive. The direct effect of number of nodes plant^{-1} on plant yields is negative and high at genotypic level (-2.9412); while its indirect effect through average tuber wt. (0.2822), plant height (1.7574), inter nodal length (1.0745) is high and positive, through number of stolans plant^{-1} (0.0099) is low and positive, through germination % (-0.0009), tuber no plant^{-1} (-0.0004) is low and negative. At phenotypic level the direct effect of this trait on yield plant^{-1} is low and negative (-0.0291). Its indirect effect through germination % (-0.0010), plant height (-0.0007), number of stolans plant^{-1} (-0.0017), stem number (-0.0124) is low and negative; while through inter nodal length (0.0185), leaflet size (0.0011), number of tubers plant^{-1} (0.0206) and average tuber wt. (0.2509) is low and positive.

The direct effect of inter nodal length on yield plant^{-1} is high and negative at genotypic level (-2.1045). Its indirect effect through germination % (-0.0646), tuber no plant^{-1} (-0.0040), average tuber wt (-0.2038) is low and negative and through plant height (0.6476), number of nodes plant^{-1} (1.5017) is high and positive, through number of stolans plant^{-1} (0.1517), stem number (0.0053), is low and positive. At phenotypic level the direct effect of this trait on yield plant^{-1} is low and negative (-0.0369). Its indirect effect through germination % (-0.0081), plant height (-0.0006), average tuber wt. (-01577), number of stolans plant^{-1} (-0.0806), is low and negative. While its indirect effect through number of nodes plant^{-1} (0.0146), leaflet size (0.0016), number of tubers plant^{-1} (0.2444), stem number (0.0051), is low and positive. The direct effect of leaflet size on yield plant^{-1} is low and negative at genotypic level (-

0.0504). Its indirect effect through plant height (-0.7185), average tuber wt. (-0.2765) is high and negative, while through number of stolans plant^{-1} (-0.1032), is low and negative. Where as its indirect effect through number of nodes^{-1} (0.2996), inter nodal length (0.4719) is high and positive, through germination % (0.0627), tuber no plant^{-1} (0.0035), stem no (0.0296), is low and positive. At phenotypic level, the direct effect of leaflet size on yield plant^{-1} is low and negative (-0.0105). Its indirect effect through number of tubers plant^{-1} (-0.2732), average tuber wt. (-0.2437), is high and negative; through germination % (0.0087), plant height (0.0003), number of nodes plant^{-1} (0.0030), inter nodal length (0.0055), number of stolans plant^{-1} (0.0726), stem number (0.0241) is positive but low. The direct effect of number of stolans plant^{-1} on yield plant^{-1} at genotypic level is high and positive (0.3704). Its indirect effect through plant height 0.2074) is high and positive; through leaflet size (0.0141) is low and positive; while through inter nodal length (-0.8619) and average tuber wt. (-0.3093) is high and negative; through germination % (-0.0058), number of nodes plant^{-1} (-0.0785), number of tubers plant-1 (-0.0108), stem number (-0.0143), is low and negative. The direct effect of this trait on yield plant^{-1} at phenotypic level is high and negative (-0.2805). Its indirect effect through average tuber wt. (-0.2933) is high and negative; through germination % (-0.0007), plant height (-0.0005), number of nodes plant^{-1} (-0.0002), inter nodal length (-0.0106), stem number (-0.0133) is low and negative; through leaflet size (0.0027), number of tubers plant-1 (0.8736), is low and positive.

Table.1 Weekly meteorological data recorded at college farm, College of Horticulture, Venkataramannagudem, from October 2016 to Febraury 2017

Standard Week No.	Week	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)
		Max.	**Min.**	**Max.**	**Min.**	
44	30th Oct-4th Nov	38.03	23.34	91.0	82.0	0
45	5th Nov-11th Nov	37.52	23.09	92.9	87.5	35.4
46	12th Nov-18th Nov	35.71	21.15	92.3	92.7	0
47	19th Nov-25th Nov	33.25	20.46	93.3	92.4	17.2
48	26th Nov-02nd Dec	31.13	20.72	91.8	92.5	0
49	03rd Dec-09th Dec	31.10	21.54	92.0	92.8	0
50	10th Dec-16th Dec	31.00	20.59	91.4	89.0	0
51	17th Dec-23rd Dec	30.35	19.85	92.1	92.8	0
52	24th Dec-30th Dec	29.73	19.13	91.6	92.7	0
01	31st Dec-06th Jan	30.38	19.19	91.3	92.8	0
02	07th Jan-13th Jan	31.63	19.42	91.8	91.0	0
03	14th Jan-20th Jan	32.69	18.70	91.0	93.0	0
04	21st Jan-27th Jan	33.12	20.12	91.7	89.0	0
05	28th Jan-03rd Feb	33.74	21.57	91.4	92.8	0
06	04th Feb-05th Feb	34.70	22.72	91.6	92.0	0

Table.2 Mean performance of different yield attributing characters in potato

S No.	Entry	Germination %	stem number	Plant height (cm)	No of nodes plant^{-1}	Inter nodal length (cm)	Leaflet size (cm^{2})	Number of stolans plant^{-1}	Number of tubers plant^{-1}	Average tuber weight (g)	Tuber yield plant^{-1} (g)
1	HT/7-620	86.7	8.4	55.8	14.3	3.9	15.4	6.1	5.5	40.5	213.0
2	HT/7-1105	100.0	6.6	50.2	13.3	3.8	19.2	4.8	4.2	33.0	138.0
3	HT/7-1329	80.0	6.8	47.0	12.3	3.8	18.6	6.0	5.1	55.1	281.0
4	HT/10-1554	68.3	10.2	42.6	13.7	3.1	16.2	6.2	5.6	39.4	219.7
5	HT/10-1559	86.7	9.0	42.0	13.0	3.3	16.3	8.6	7.5	31.0	232.3
6	HT/10-2002	93.3	6.4	46.6	10.0	4.7	23.5	7.9	7.2	22.7	163.0
7	HT/10-2816	75.0	8.4	50.6	13.0	3.9	12.3	5.8	5.1	32.2	164.0
8	HT/11-3	95.0	7.2	59.0	13.7	4.3	30.2	7.0	6.2	21.9	136.0
9	HT/11-2912	85.0	7.5	45.5	10.0	4.6	12.6	7.1	5.9	18.5	109.0
10	HT/12-43	85.0	6.2	43.8	12.0	3.7	25.8	7.1	5.8	26.0	151.3
11	HT/12-116	100.0	7.8	45.0	11.3	4.0	26.8	6.3	5.2	28.8	149.7
12	HT/12-664	85.0	5.3	39.0	10.0	3.9	32.5	7.2	5.7	25.8	146.0
13	HT/12-725	46.7	6.4	41.0	9.0	4.6	24.8	9.1	7.9	30.4	239.7
14	HT/12-751	83.3	6.7	51.0	12.0	4.3	28.0	6.2	4.9	37.3	182.3
15	HT/12-830	76.7	7.1	46.0	12.7	3.6	12.3	8.2	7.5	33.2	244.3
16	HT/12-834	91.7	9.6	69.6	13.7	5.1	11.2	16.2	13.8	18.7	254.3
17	HT/12-881	65.0	7.5	53.0	13.7	3.9	33.0	6.0	5.1	30.0	150.7
18	HT/12-908	78.3	7.0	38.8	11.0	3.5	25.9	6.6	6.1	30.0	180.7
19	MS/6-1947	76.7	8.2	57.2	15.3	3.7	17.1	6.5	5.7	36.6	207.7
20	Kufri Khyati	86.7	8.4	45.8	12.7	3.6	28.3	6.6	5.5	19.2	105.0
21	Kufri Pukhraj	70.0	8.5	35.5	10.0	3.6	25.6	6.7	5.9	18.5	108.3
22	Kufri Garima	56.7	8.5	49.0	13.7	3.6	32.5	7.1	6.3	18.4	116.0
23	Kufri Mohan	56.7	6.1	43.0	11.7	3.7	29.7	7.1	5.9	19.1	112.7
24	Kufri Surya	90.0	8.0	47.8	8.0	6.0	16.1	6.4	5.4	29.8	159.0
25	Kufri Jyothi	86.7	9.5	38.5	9.3	4.1	19.6	7.0	6.4	18.6	118.0
	Mean	80.2	7.7	47.3	12.0	4.0	22.1	7.2	6.2	28.6	171.3
	CV	8.0	14.2	9.4	6.3	12.5	6.7	9.9	9.4	14.5	9.9
	SE	3.7	0.6	2.6	0.4	0.3	0.9	0.4	0.4	2.4	0.2
	CD 5%	10.5	1.8	7.3	1.2	0.8	2.4	1.2	1.0	6.8	0.5
	CD 1%	14.0	2.4	9.8	1.7	1.1	3.3	1.6	1.3	9.1	0.7

Table.3 Correlation coefficients among different yield attributing characters in potato

Character	Germination %	Stem number	Plant height	Node number	Inter nodal length	Leaflet size	Stolan number	Tuber number	Tuber weight
Germination %		0.0543	0.2759*	0.0038	0.2669*	-0.2591*	0.024	0.0156	-0.0063
Stem number	0.0099		0.2885*	0.3771**	-0.0996	-0.5515**	0.2666*	0.3096**	-0.0736
Plant height	0.2611*	0.1289		0.6903**	0.2544*	-0.2822*	0.4743**	0.4465**	0.1065
Node number	0.028	0.1826	0.5129**		-0.5106**	-0.1019	0.0267	0.0405	0.3166**
Inter nodal length	0.2162	-0.0746	0.4620**	-0.5021**		-0.2242	0.4096**	0.3738**	-0.2287*
Leaflet size	-0.2337*	-0.3554**	-0.2233	-0.1026	-0.1503		-0.2787*	-0.3250**	-0.3103**
Stolan number	0.0186	0.1969	0.3543**	0.0059	0.2872*	-0.2587*		0.9862**	-0.3471**
Tuber number	-0.0177	0.2629*	0.3627**	0.0224	0.2659*	-0.2972**	0.9506**		-0.3154**
Tuber weight	0.0265	-0.0717	0.0639	0.2857*	-0.1796	-0.2775*	-0.3340**	-0.3586**	
Yield/Plant (G/P)	-0.0652	0.124	0.3115**	0.2789*	0.0032	-0.5180**	0.5822**	0.4385**	0.6988**
	-0.0647	0.0993	0.2495*	0.2543*	-0.0125	-0.4869**	0.3360**	0.3751**	0.7021**

Correlation- above diagonal: genotypic, below diagonal: phenotypic
*, **: significant at 5% and 1% levels respectively.

Table.4 Direct and indirect effects of different yield attributing traits on tuber yield in potato at genotypic level. (data on only morphological traits are presented)

Character	Germination %	Stem number	Plant height	Number of nodes	Inter nodal length	Leaflet size	Number of stolans	Number of tubers	Av. tuber weight
Germination %	**-0.2419**	-0.0131	-0.0667	-0.0009	-0.0646	0.0627	-0.0058	-0.0038	0.0015
Stem number	-0.0029	**-0.0536**	-0.0155	-0.0202	0.0053	0.0296	-0.0143	-0.0166	0.0039
Plant height	0.7024	0.7344	**2.5459**	1.7574	0.6476	-0.7185	0.2074	0.1368	0.2711
Number of nodes	-0.0113	-1.1091	-2.0303	**-2.9412**	1.5017	0.2996	-0.0785	-0.1192	-0.9313
Inter nodal length	-0.5617	0.2096	-0.5353	1.0745	**-2.1045**	0.4719	-0.8619	-0.7866	0.4813
Leaflet size	0.0131	0.0278	0.0142	0.0051	0.0113	**-0.0504**	0.0141	0.0164	0.0156
Number of stolans	0.0089	0.0988	0.1757	0.0099	0.1517	-0.1032	**0.3704**	0.3745	-0.1286
Number of tubers	-0.0002	-0.0033	-0.0048	-0.0004	-0.004	0.0035	-0.0108	**-0.0107**	0.0034
Av. tuber weight	-0.0057	-0.0656	0.0949	0.2822	-0.2038	-0.2765	-0.3093	-0.2811	**0.8913**
Yield plant^{-1}	**-0.0652**	**0.124**	**0.3115****	**0.2789***	**0.0032**	**-0.5180****	**0.5822****	**0.4385****	**0.6988****

Table.5 Direct and indirect effects of different yield attributing traits on tuber yield in potato at phenotypic level. (data on only morphological traits are presented)

Character	Germination %	Stem umber	Plant height	Number of nodes	Inter nodal length	Leaflet size	Number of stolans	Number of tubers	Av. tuber weight
Germination %	**-0.0374**	-0.0004	-0.0098	-0.001	-0.0081	0.0087	-0.0007	0.0007	-0.001
Stem number	-0.0007	**-0.0678**	-0.0087	-0.0124	0.0051	0.0241	-0.0133	-0.0178	0.0049
Plant height	-0.0004	-0.0002	**-0.0014**	-0.0007	-0.0006	0.0003	-0.0005	-0.0005	-0.0001
Number of nodes	-0.0008	-0.0053	-0.0149	**-0.0291**	0.0146	0.003	-0.0002	-0.0007	-0.0083
Inter nodal length	-0.008	0.0028	-0.017	0.0185	**-0.0369**	0.0055	-0.0106	-0.0098	0.0066
Leaflet size	0.0024	0.0037	0.0023	0.0011	0.0016	**-0.0105**	0.0027	0.0031	0.0029
Number of stolans	-0.0052	-0.0552	-0.0994	-0.0017	-0.0806	0.0726	**-0.2805**	-0.2667	0.0937
Number of tubers	-0.0162	0.2416	0.3334	0.0206	0.2444	-0.2732	0.8736	**0.919**	-0.3296
Av. tuber weight	0.0233	-0.063	0.0561	0.2509	-0.1577	-0.2437	-0.2933	-0.3149	**0.8782**
Yield plant^{-1}	**-0.0647**	**0.0993**	**0.2495***	**0.2543***	**-0.0125**	**-0.4869****	**0.3360****	**0.3751****	**0.7021****

The direct effect of number of tubers plant^{-1} on yield plant^{-1} at genotypic level is low and negative (-0.0107). Its indirect effect through inter nodal length (-0.7866), average tuber wt. (-0.2811) is high and negative, through germination % (-0.0038), number of nodes plant^{-1} (-0.1192), stem number (-0.0166) is low and negative, through number of stolans plant^{-1} (0.3745) and plant height (1.1368) is high and positive; through leaflet size (0.0164) is low and positive. Its direct effect on yield is high and positive at phenotypic level (0.9190). Its indirect effect through germination % (0.0007), leaflet size (0.0031) is low and positive, through plant height (-0.0005), number of nodes plant-1 (-0.0007), inter nodal length (-0.0098), number of stolans plant-1 (-0.2667), average tuber wt. (-0.3149), stem number (-0.0178) is low and negative.

The direct effect of average tuber wt. on yield plant^{-1} at genotypic level is high and positive (0.8913); its indirect effect through plant height (0.2711), inter nodal length (0.4813) is high and positive; through germination % (0.0015), leaflet size (0.0156), number of tubers plant^{-1} (0.0034), stem number (0.0039) is low and positive; through number of stolans plant^{-1} (-0.1286), number of nodes plant^{-1} (-0.9313) is low and negative. At phenotypic level, the direct effect of this trait on yield is high and positive (0.8782), through inter nodal length (0.0066), leaflet size (0.0029), number of stolans plant-1 (0.0937), stem number (0.0049) is low and positive; through germination % (-0.0010), plant height (-0.0001), number of nodes plant-1 (-0.0083), number of tubers plant-1 (-0.3296) is low and negative.

Night temperature plays an important role during tuberization and optimum night temperatures for tuber formation are regarded in the range of 10-17^{o}C (Bodlaender, 1963; Moorby and Milthorpe, 1975). The weather data recorded at V R Gudem revealed prevailing mean night temperature of 20.5°C during tuber initiation (25 days after planting) and subsequent mean night temperature in the range of 19-21.5°C for about 30 days which are indicative of detrimental effect of high temperature on crop growth and tuberization. Potato tuber yield is a polygenically controlled complex character resulting from multiplicative interaction of yield components. The cumulative effects of such characters determine the dependent variable yield. These characters play an important role in modifying the system of yield as a whole in magnitude as well as in direction. Further, direct selection for tuber yield is not effective as it is a complex quantitative character and much influenced by the environment. The change in one character brings about a series of changes in other characters, since they are interrelated. Unfavourable associations between the desired attributes under selection may limit genetic advance. Hence, the study of correlation between yield and yield components are of considerable importance in selection programmes.

Data on correlation coefficients (Table 3) revealed that, genotypic correlations were in general higher than the phenotypic correlations which showed that though there was an inherent association among the characters, the phenotypic associations among them were adversely influenced by environment. A perusal of interrelation ships among yield and yield attributing characters indicate that, there was significant positive correlation, at genotypic as well as phenotypic level and plant height, number of nodes plant^{-1}, number of stolans plant^{-1}, number of tubers plant^{-1} and average tuber weight. However it showed significant negative correlation with leaflet size at genotypic as well as phenotypic level. It can also be observed that the traits that are positively associated with yield *viz.* plant height, number of nodes plant $^{-1}$, number of stolans plant^{-1} and number of tubers plant^{-1} are also positively associated with each other. The leaflet size which is negatively associated with yield is also negatively associated with the above traits, indicating simultaneous selection for the above characters coupled with smaller leaflet size would result in genetic gain in tuber yield. There were no significant association between yield plant^{-1} and germination %, stem number and inter nodal length.

The observed correlation between yield and a particular yield component character is the net result of the direct effect of that component and indirect effects through other yield attributes. The total correlation coefficient between yield and its component characters may sometimes be misleading, as it may be an over or under estimate of its association with other characters. Hence, direct selection by correlated response may not prove fruitful. When many characters are affecting a given trait, it is necessary to separate the correlation into direct and indirect effects of cause as devised by Wright (1921) and utilized by Dewey and Lu (1959) in selection programmes. If the correlation coefficients between causal factor and yield are equal to its direct effect, then the correlation explains the true relationship and direct selection of this trait will be effective. If the correlation coefficient is positive and its direct effect is negative or negligible, then the indirect effects seem to be the cause of correlations. Under such situations, the other factors have to be considered simultaneously. Sometimes correlations coefficient may be negative, but the direct effect is positive and high. Under these conditions, a restricted simultaneous selection model has to be followed *i.e.*, restrictions are to be imposed to nullify the undesirable indirect effects, in order to make use of the direct effect (Singh and Chaudhary, 1977).

The direct and indirect effects of different yield contributing traits (morphological, physiological and biochemical) on tuber yield plant^{-1} were estimated through path analysis at phenotypic and genotypic levels (Table 4 and 5). It can be seen that plant height which had significant positive correlation with yield at both genotypic and phenotypic levels (0.3115** and 0.2495*) also had high direct effect at genotypic level (2.5459) on yield, indicating direct selection for plant height is effective in improving the yields. Same is the case with number of stolans plant^{-1} which showed positive correlation with yield at both genotypic and phenotypic levels (0.5822** and 0.3360**) and also had high direct effect (0.3704). However, though number of tubers plant^{-1} was positively correlated with yield (0.4385** and 0.3751**), its direct effect is negative (-0.0107) at genotypic level indication direct selection of this trait is not effective in improving the yield, though indirect selection through number of stolans is effective as its impact is through this trait is high and positive (0.3745). The direct effect of average tuber weight is high at both genotypic and phenotypic levels (0.8913 and 0.8782) indicating selection for this trait would result in genetic gain in tuber yield. It is important to note that number of tubers plant^{-1} is negatively associated with average tuber weight. Thus, though tuber number and tuber weight are direct contributors of tuber yield, balance has to be maintained while exercising selection for these traits. Stem number and tuber number were positively associated with each other, but both had negative association with average tuber eight. These results support the findings of Desai and Jaimini (1998), Gopal (1999), Kumar and Kang (2000), Luthra (2001) and Luthra *et al* (2013). Mondal *et al.*, (2003) suggested that selection for higher number of tubers may be done by selecting for higher number of stems. Potato genotypes with many thin stems are known to produce numerous small sized tubers and such genotypes could be exploited in breeding for production of varieties suitable for baby potato (Luthra, 2001). For production of high yielding table potato varieties, a compromise needs to be made between tuber number and average tuber weight, as they are negatively correlated with each other and average tuber weight is positively correlated with tuber yield. To overcome this, Gopal *et al.*, (1994) and Luthra (2001) suggested that a standard may be fixed for the maximum number of tubers required in the selected genotype before employing selection for tuber yield and average tuber weight.

In conclusion, the ever increasing global temperature calls for breeding of food crops with heat tolerance. Development of heat tolerant varieties of potato, a highly sensitive crop for high temperatures needs thorough investigation of the traits that contribute to high tuber yields at elevated temperatures. Correlation and path analysis studies would help in identifying such traits whose selection results in genetic gain in tuber yield.

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