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Antioxidant enzymes and physiological 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 contribution of ROS scavenging enzymes and other physiological traits towards heat tolerance in potato. Data on activity of antioxidant enzymes *viz.* catalase, peroxidase and superoxide dismutase and physiological parameters *viz.* membrane stability index, chlorophyll stability index, leaf area index, net assimilation rate and harvest index were analysed (correlation and path analysis) to find out the direct and indirect contribution of these traits toward adaptation of potato to high temperatures. Yield plant^{-1} had significant positive correlation, both at genotypic and phenotypic levels with catalase activity (0.5815 & 0.3491), peroxidase activity (0.4861 & 0.4131), SOD activity (0.5684 & 0.5362), CSI (0.6535 &0.6065), MSI (0.5208 & 0.4933), LAI (0.3129 & 0.2900), NAR (0.9098 & 0.8475) and harvest index (0.9323 & 0.8760). These findings will help in breeding of heat tolerant potato varieties for tropical areas.

Keywords: heat tolerance, tuberization, ROS scavengening, correlation, path analysis

Introduction
Potato (*Solanum tuberosum* L., family Solanaceae) is the fourth most important food crop in the world after rice, wheat and maize. However, it's 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) [11]. 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) [3]. 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) [12, 3].
Excepting 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 hills of Idukki district of Kerala, 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. High temperature stress adversely affect physiological and other cellular processes, retard the growth and development (Wahid *et al.* 2007) [20] and consequently yields. Plants have evolved an elaborate system of antioxidants and enzymatic scavenging systems to detoxify the harmful levels of reactive oxygen species (ROS) produced in the cytosol during high temperature and other abiotic stress like salinity. Many studies have established the active role of antioxidant enzymes in protecting plants against such harmful effects (Larkindale and Kinght 2002; Suzuki and Mittler 2006) [10, 19].
In potato, tuber yield is a complex polygenic trait (Killick 1977) [9] 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 selection of heat tolerant genotypes 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. YSR Horticultural University, Venkataramannagudem, West Godavari district, Andhra Pradesh (17.4° N, 78.48° 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.

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

Data were collected on activity of anti oxidant enzymes *viz.* catalase, peroxidase and super oxide dismutase from all the genotypes. Physiological parameters; Membrane Stability Index (MSI), Chlorophyll Stability Index (CSI) and growth parameters; Leaf Area Index (LAI), Net Assimilation Rate (NAR) and Harvest Index (HI) were also assessed besides other morphological traits. SOD activity was determined as suggested by Das *et al*., (2000) [5]. The method involved generation of superoxide radical of riboflavin and its detection by nitrite formation from hydroxylamine hydrochloride Catalase activity was estimated as per the procedure given by Gopalachari (1963) [8] in which sodium perborate acts as hydrogen donor. Peroxidase activity was assayed by following the method suggested by Nakano and Asada (1981) [15], by recording the decrease in absorbance at 290 nm, due to reduction in hydrogen peroxide content. LAI, NAR and HI were estimated by collecting data from three plants of each genotype from each replication. LAI was estimated by dividing the leaf area, measured by automatic leaf area meter at 60 DAP with ground area. To measure NAR, three plants from each genotype were taken out from the field at 30 DAP and 60 DAP and segmented into components like stem, leaf and tubers. The segmented parts were then oven dried at 70 °C to a constant weight and dry weights were recorded and summed up.

$$NAR = \frac{WT_2 - WT_1}{(T_2T_1)(LA_2 LA_1)} \quad mg\ m^{-2} day^{-1}$$

Where,
WT_1 = dry weight of plant at time T_1
WT_2 = dry weight of plant at time T_2
LA_1 = leaf area at time T_1
LA_2 = leaf area at time T_2

Harvest Index was measured by dividing the tuber yield with total biomass produced at 80 DAP. Membrane stability index (MSI) was determined following the modified method of potato by Nagarajan and Bansal (1986) [14] where the total inorganic ions (mainly K^+) leaked are measured in terms of electrical conductivity of the bathing medium before and after heat treatment using an electrical conductivity meter. 100.0 mg of fresh leaf samples were incubated in 20.0 ml deionized water at 52°C for 30 minutes. Initial electrical conductivity (IC) was measured using conductivity meter. Same tubes were boiled at 100°C for 10 minutes and final conductivity (FC) was measured. Membrane stability index was calculated using the formula:

$$MSI = [1 - (IC/FC)] \times 100.$$

Chlorophyll stability index was estimated by measuring the chlorophyll content of the leaf samples exposed to high temperature (treated) and control according to the procedure given by Murthy and Majumdar (1962) [13]. Two leaf samples of 250 mg each were weighed, cut into 8-10 bits and transferred to two test tubes containing 20 ml distilled water. One tube kept at room temperature (control) and the other in water bath at 50° C (treated) for 30 minutes. The leaf bits were then transferred to pistil and mortar and macerated in 10 ml of 80% acetone. The contents were centrifuged at 3000 rpm for 10 minutes. The supernatant was collected in a 25 ml volumetric flask and made up to the volume with 80% acetone and O. D. was taken in a spectrophotometer at 652nm. Chlorophyll stability index was calculated as below.

$$\text{Chlorophyll stability index} = \frac{\text{Total chlorophyll content (treated)} \times 100}{\text{Total chlorophyll content (control)}}$$

$$\text{Total chlorophyll content} = \frac{\text{O.D at 652} \times V}{34.5 \times W} \quad (mg/g)$$

Where V = volume (25 ml)
W= wt. of the leaf sample taken in grams

Tuber yield is the weight of all the tubers (g) harvested from five random plants of each genotype from each replication.

Results and Discussion

The data on mean performance of the 25 genotypes for different yield attributing characters are furnished in table no.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.

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

No.	Entry	Catalase activity	Peroxidase activity	SOD activity	MSI	CSI	LAI	NAR	HI	Tuber yield
1	HT/7-620	66.3	202.3	12.3	24.4	36.1	2.8	4.2	0.7	213.0
2	HT/7-1105	54.6	140.0	10.2	28.6	33.2	3.1	2.3	0.3	138.0
3	HT/7-1329	69.3	210.0	14.6	58.3	57.8	3.8	6.2	0.8	281.0
4	HT/10-1554	62.3	162.3	9.5	44.3	45.3	2.3	5.6	0.8	219.7
5	HT/10-1559	63.5	156.0	8.6	50.1	43.0	2.5	5.4	0.8	232.3
6	HT/10-2002	44.4	95.0	6.5	42.3	28.4	2.8	2.5	0.4	163.0
7	HT/10-2816	32.3	174.0	6.5	62.0	54.6	2.5	2.3	0.4	164.0
8	HT/11-3	45.6	140.0	5.6	44.5	30.5	2.6	2.5	0.4	136.0
9	HT/11-2912	49.0	157.3	8.6	49.1	49.5	5.1	3.2	0.4	109.0
10	HT/12-43	52.3	168.7	5.3	29.4	25.3	2.7	2.3	0.4	151.3
11	HT/12-116	56.4	174.0	5.4	32.3	20.3	2.5	2.5	0.4	149.7
12	HT/12-664	58.4	152.0	9.8	40.2	19.3	2.3	4.3	0.3	146.0
13	HT/12-725	64.9	156.7	9.8	52.3	87.3	3.2	5.3	0.7	239.7
14	HT/12-751	58.6	240.0	8.9	43.9	76.3	2.8	3.5	0.4	182.3
15	HT/12-830	70.9	210.0	8.4	45.6	83.0	4.5	6.1	0.7	244.3
16	HT/12-834	67.0	250.7	15.5	53.1	88.4	4.8	6.5	0.8	254.3
17	HT/12-881	52.5	105.0	6.7	32.3	20.4	3.2	3.2	0.3	150.7
18	HT/12-908	55.4	240.0	8.8	49.8	39.6	2.1	3.6	0.5	180.7
19	MS/6-1947	55.3	160.3	9.2	52.3	33.6	3.2	2.5	0.5	207.7
20	Kufri Khyati	60.0	146.7	8.8	42.3	26.3	2.3	1.2	0.4	105.0
21	Kufri Pukhraj	61.2	196.0	6.4	39.3	38.6	2.3	2.0	0.3	108.3
22	Kufri Garima	59.8	105.0	6.5	26.3	25.7	2.6	1.4	0.4	116.0
23	Kufri Mohan	60.1	132.3	8.2	32.3	22.4	3.1	1.8	0.3	112.7
24	Kufri Surya	58.9	220.0	15.6	52.3	52.3	3.3	2.6	0.4	159.0
25	Kufri Jyothi	61.6	179.3	6.8	25.6	45.3	3.1	1.6	0.4	118.0
	Mean	57.6	170.9	8.9	42.1	43.3	3.0	3.4	0.5	171.3
	CV	12.2	11.2	6.4	3.6	8.0	7.2	5.9	9.8	9.9
	SE	4.0	11.0	0.4	0.9	2.0	0.1	0.1	0.0	0.2
	CD 5%	11.6	31.3	0.9	2.5	5.7	0.4	0.3	0.1	0.5
	CD 1%	15.4	41.7	1.2	3.3	7.6	0.5	0.4	0.1	0.7

Character association

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. The phenotypic and genotypic correlation coefficients between tuber yield and its component characters and among themselves were worked and are furnished in the Table 3.

Table 3: Correlation coefficients amoung different yield attributing characters of potato

Character	Catalase	Peroxidase	SOD	CSI	MSI	LAI	NAR	HI
Catalase		0.4815**	0.5730**	0.4038**	-0.1431	0.2764*	0.6166**	0.6097**
Peroxidase	0.2919*		0.5722**	0.6554**	0.3860**	0.2524*	0.4593**	0.4266**
SOD	0.4443**	0.4971**		0.4837**	0.3893**	0.4413**	0.5572**	0.4982**
CSI	0.3193**	0.5761**	0.4662**		0.5604**	0.5683**	0.6466**	0.6122**
MSI	-0.0965	0.3464**	0.3835**	0.5427**		0.2600*	0.4628**	0.4242**
LAI	0.2046	0.2183	0.4145**	0.5385**	0.2484*		0.4197**	0.2672*
NAR	0.4522**	0.4129**	0.5394**	0.6326**	0.4558**	0.3985**		0.8655**
HI	0.4330**	0.3621**	0.4762**	0.5777**	0.4039**	0.2447*	0.8330**	
Yield/Plant (G/P)	0.5815**	0.4861**	0.5684**	0.6535**	0.5208**	0.3129**	0.9098**	0.9323**
	0.3491**	0.4131**	0.5362**	0.6065**	0.4933**	0.2900**	0.8475**	0.8760**

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

Yield plant^{-1} had significant positive correlation, both at genotypic and phenotypic levels with catalase activity (0.5815** & 0.3491**), peroxidase activity (0.4861** & 0.4131**), SOD activity (0.5684** & 0.5362**), CSI (0.6535**&0.6065**), MSI (0.5208**& 0.4933**), LAI (0.3129** & 0.2900**), NAR (0.9098** & 0.8475**), and

harvest index (0.9323** & 0.8760**). Thus all the three antioxidant enzymes studied were found to have positive influence on yield under tropical conditions. Amoung these, SOD was found to exert more influence. CSI and MSI were highly correlated with yield levels under elevated temperatures. The impact of LAI is comparatively less indicating that it is the biochemical and physiological mechanisms associated with abiotic stress rather than the total canopy area that influences performance of a genotype under stress conditions. The inter relationships amoung these traits were also worked. Catalase activity showed significant positive association at genotypic as well as phenotypic level with peroxidase activity (0.4815** and 0.2919*), SOD activity (0.5730** and 0.4443**), CSI (0.4038** and 0.3193**), NAR (0.6166** and 0.4522**) and harvest index (0.6097** and 0.4330**). However it exhibited non significant negative association with membrane stability index both at genotypic and phenotypic levels (-0.1431 and-0.0965). It showed significant positive association with LAI (0.2764*) only at genotypic level. Peroxidase activity showed significant positive association, both at genotypic and phenotypic levels with catalase activity (0.4815** & 0.2919*), SOD activity (0.5722** & 0.4971**), CSI (0.6554** & 0.5761**), MSI (0.3860** & 0.3464**), NAR (0.4593** & 0.4129**) and harvest index (0.4266** & 0.3621**). It showed significant positive association with LAI (0.2524*) only at genotypic level. SOD activity showed significant positive association with LAI (0.4413** & 0.4145**), NAR (0.5572** & 0.5394**), catalase activity (0.5730** & 0.4443**), peroxidase activity (0.5722** & 0.4971**), CSI (0.4837** & 0.4662**), MSI (0.3893** & 0.3835**) and harvest index (0.4982** & 0.4762**). Leaf Area Index showed significant positive association both at genotypic and phenotypic levels with SOD activity (0.4413** & 0.4145**), CSI (0.5683** & 0.5385**), MSI (0.2600* & 0.2484*), NAR (0.4197** & 0.3985**), harvest index (0.2672* & 0.2447 *). It showed significant positive association only at genotypic level with catalase activity (0.2764*) and peroxidase activity (0.2524*). Net Assimilation Rate exhibited significant positive association with catalase activity (0.6166 ** & 0.4522**), peroxidase activity (0.4593** & 0.4129**), SOD activity (0.5572** & 0.5394**), CSI (0.6466** & 0.6326**), MSI (0.4628** & 0.4558**), LAI (0.4197** & 0.3985**) and harvest index (0.8655** & 0.8330**) both at genotypic and phenotypic levels. Harvest Index showed significant positive association with catalase activity (0.6097** & 0.4330**), peroxidase activity (0.4266** & 0.3621**), SOD activity (0.4982** & 0.4762**), CSI (0.6122** &0.5777**), MSI (0.4242** & 0.4039**), LAI (0.2672* & 0.2447*) and NAR (0.8655** & 0.8330**) both at genotypic and phenotypic levels.

Path coefficient analysis

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) [21] and utilized by Dewey and Lu (1959) [6] 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) [14]. The direct and indirect effects of different yield contributing and quality traits on tuber yield plant^{-1} were estimated through path analysis at phenotypic and genotypic levels and are presented in Tables 4 and 5 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	Catalase activity	Paroxidase activity	SOD activity	CSI	MSI	LAI	NAR	Harvest Index
Catalase activity	-0.1593	-0.0767	-0.0913	-0.0643	0.0228	-0.044	-0.0982	-0.0971
Paroxidase activity	-0.0359	-0.0746	-0.0427	-0.0489	-0.0288	-0.0188	-0.0343	-0.0318
SOD activity	0.0268	0.0268	0.0468	0.0226	0.0182	0.0206	0.026	0.0233
CSI	0.0271	0.044	0.0324	0.0671	0.0376	0.0381	0.0434	0.0411
MSI	0.0169	-0.0457	-0.0461	-0.0663	-0.1183	-0.0308	-0.0548	-0.0502
LAI	-0.0077	-0.007	-0.0123	-0.0158	-0.0072	-0.0278	-0.0117	-0.0074
NAR	-0.3115	-0.2321	-0.2815	-0.3267	-0.2338	-0.2121	-0.5052	-0.4373
HI	0.4942	0.3458	0.4038	0.4963	0.3439	0.2166	0.7015	0.8106
Yield plant^{-1}	0.5815	0.4861	0.5684	0.6535	0.5208	0.3129	0.9098	0.9323

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	Catalase activity	Paroxidase activity	SOD activity	CSI	MSI	LAI	NAR	Harvest Index
Catalase activity	0.0157	0.0046	0.007	0.005	-0.0015	0.0032	0.0071	0.0068
Paroxidase activity	-0.0053	-0.018	-0.009	-0.0104	-0.0063	-0.0039	-0.0075	-0.0065
SOD activity	-0.0317	-0.0354	-0.0713	-0.0332	-0.0273	-0.0295	-0.0384	-0.0339
CSI	0.0148	0.0268	0.0217	0.0465	0.0252	0.025	0.0294	0.0269
MSI	-0.0011	0.0038	0.0042	0.006	0.011	0.0027	0.005	0.0044
LAI	-0.013	-0.0139	-0.0263	-0.0342	-0.0158	-0.0636	-0.0253	-0.0156
NAR	-0.0271	-0.0248	-0.0323	-0.0379	-0.0273	-0.0239	-0.0599	-0.0499

HI	0.0813	0.068	0.0894	0.1085	0.0758	0.0459	0.1564	0.1877
Yield plant^{-1}	0.3491	0.4131	0.5362	0.6065	0.4933	0.29	0.8475	0.876

The direct effect of catalase activity on yield plant^{-1} at genotypic level is medium and negative (-0.1593). It's indirect effect through NAR (-0.3115) is high and negative, through LAI (-0.0077), peroxidase activity (-0.0359), is low and negative. While it's indirect effect through, harvest index (0.4942) is high an positive, through SOD activity (0.0268), CSI (0.0271), MSI (0.0169), is low and positive. The direct effect of this trait at phenotypic level is low and positive (0.0157). It's indirect effect through CSI (0.0148), harvest index (0.0813), is low and positive; through LAI (-0.0130), NAR (-0.0271), peroxidase activity (-0.0053), SOD activity (-0.0317), MSI (-0.0011), is low and negative. The direct effect of peroxidase activity on yield plant^{-1} at genotypic level is low and negative (-0.0746). It's indirect effect through LAI (-0.0070), NAR (-0.2321), catalase activity (-0.0767), MSI (-0.0457) is low and negative. Where as it's indirect effect through harvest index (0.3458) is high and positive; through SOD activity (0.0268) and CSI (0.0440) is low and positive. The direct effect of peroxidase activity on yield plant^{-1} at phenotypic level is low and negative (-0.0180). It's indirect effect through LAI (-0.0139), NAR (-0.0248), catalase activity (0.0046), SOD activity (-0.0354), is low and negative; through harvest index (0.0680), CSI (0.0268), MSI and (0.0038) is low and positive.

The direct effect of SOD activity on yield plant^{-1} at genotypic level is low and positive (0.0468). It's indirect effect through harvest index (0.4038) is high and positive; through CSI (0.0324) is low and positive; through LAI (-0.0123), NAR (-0.2815), catalase activity (-0.0913), peroxidase activity (-0.0427) and MSI (-0.0461) is low and negative.The direct effect of this trait on yield plant^{-1} at phenotypic level is low and negative (-0.0713). It's indirect effect through LAI (-0.0263), NAR (-0.0323) and peroxidase activity (-0.0090) is low and negative; while through CSI (0.0217), MSI (0.0042), catalase activity (0.0070), (0.0079) and harvest index (0.0894) is low and positive. The direct effect of LAI at genotypic level is low and negative (-0.0278). The indirect negative effect through NAR (-0.2121), catalase activity (-0.0440), MSI (-0.0308), peroxidase activity (-0.0188) is low and negative; where as it's indirect effect through SOD activity (0.0206), CSI (0.0381) is low and positive and through harvest index (0.2166) is high and positive. At phenotypic level also, the direct effect of LAI is positive but low (0.0056) and it's indirect positive effect through other traits is; catalase activity (0.0032), CSI (0.0250), MSI (0.0027), harvest index (0.0459), and it's indirect effect is through LAI (-0.0636), NAR (-0.0239), peroxidase activity (-0.0039) and SOD activity (-0.0295) is low and negative. The direct effect of NAR at genotypic level is high and negative (-0.5052). It's indirect effect through LAI (-0.011), MSI (-0.0548), catalase activity (-0.0982) and peroxidase activity (-0.0343) is low and negative. While it's indirect effect through harvest index (0.7015) is high and positive; through SOD activity (0.0260), CSI (0.0434) is low and positive. The direct effect of this trait at phenotypic level is low and negative (-0.0599). While it's indirect effect through catalase activity (0.0071), CSI (0.0294) and MSI (0.0050) is low and positive; through LAI (-0.0253), peroxidase activity (-0.0075) and SOD activity (-0.0384) is low and negative.The direct effect of harvest index on yield plant^{-1} is high and positive at phenotypic level (0.8106). It's indirect effect through SOD activity (0.0233), CSI (0.0411), is low and positive; through NAR (-0.4373) is high and negative, through LAI (-0.0074), catalase activity (-0.0971), peroxidase activity (-0.0318), MSI (-0.0502), is low and negative.

Thus the association amoung antioxidant enzymes and the physiological parameters, as seen above reveal the concerted and coordinated action of these systems to impart tolerance of potato genotypes to high temperatures. Increased activities of antioxidant enzymes *viz*. superoxidase dismutase, catalase and ascorbate peroxidase in the heat tolerant potato variety Kufri Surya compared to the sensitive variety Chipsona 3 was reported by Aien *et al*., (2011) [1] as well as in other crops; sweet potato (Rui *et al.* 1990) [16], wheat (Sairam *et al.* 2000 [17]; Almeselmani *et al.* 2006 [2]) and mulberry (Chaitanya *et al.* 2002) [4].

Conclusion

Elevated temperatures produce reactive oxygen species (ROS) in plant systems. Tolerant genotypes cope up with such situations and protect the cells and organelles like chloroplast, mitochondria, cell membranes etc by employing antioxidant defense system, comprising mainly of superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (CAT) enzymes. The present study helps in breeding of potato varieties for suitable for high temperature areas by incorporating selection indices for ROS scavenging enzymes.

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