Morphophysiological responses: criteria for screening heat tolerance in potato

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Increasing temperature has become an alarming issue, especially in the context of global food security. Potato, a cool-season crop, is characterized by specific temperature requirements and develops best at about 20°C. The present study was carried out to examine the morphophysiological responses of potato cultivars under high temperature in the experimental field of Tezpur University, Assam, India, consecutively for two years (2013–14 and 2014–15). Seeds of five popular potato cultivars of North East India, viz. Kufri jyoti, Kufri megha, Kufri pokraj (high-yielding cultivar) and Rangpuria, Badami (local cultivar) were sown under three temperature conditions: normal, inside polyhouse and in the early season. Plant height, leaf area index, membrane stability index, chlorophyll stability index and tuber yield were studied. We observed increase in plant height and leaf area index under high temperature environment with a decrease in membrane stability index, chlorophyll stability index and tuber yield. The cultivars Kufri megha and Rangpuria performed better under high temperature with respect to maintenance of morphological alterations leading to lower reduction in yield. Compared to high-yielding potato cultivars, local cultivars were more prone to high temperature. Thus, morphophysiological analysis can be considered as one of the rapid and efficient methods to screen potato cultivars for heat tolerance.

Keywords: Heat tolerance, high temperature, morphophysiology, potato.

INCREASED atmospheric temperature is one of the reasons for net decline in global food production. The expected rise in temperature is about 3–5°C by the end of this century[1]. This increased temperature is predicted to bring a net reduction in global potato production[2], which requires an optimum temperature of 15–25°C (ref. 3). India is ranked third in potato production, with 10% of the potato-growing areas being from North East India[4]. Assam, situated in NE India, has recorded a rise in annual maximum mean temperatures at a rate of +0.11°C per decade (ref. 5). Potato is planted in Assam during mid-October to early November and is harvested in January. During this period, 17–28°C temperature has been recorded in the region[6], which is projected to severely affect potato cultivation in Assam. Though Central Potato Research Institute (CPRI), India had released many potato cultivars based on their resistance against various diseases and phytopathogens, they have diverse adaptability to heat stress (http://cpri.ernet.in/varieties.htm). Therefore, focus should be made to screen the high temperature-tolerant potato cultivars.

High temperature resulted in taller plants with high stem dry weight and smaller leaves[7], and reduced tuber production for most potato cultivars[8]. It also extended the period of leaf growth, which presumably reduces net translocation of carbohydrates to the tubers[9]. In the case of rice, reduction of 6.7% in yield was observed, which is attributed to an average rise in temperature during the growing period[10]. Physiological leaf ageing also increases under high temperature[11], accelerating leaf senescence. Significant increase in leaf numbers was recorded due to blockage in reproductive development in wheat under high temperature[12].

Thus, the impacts caused by high temperature stress on morphophysiological characteristics of crops prompted us to study the effect of high temperature on some commonly grown potato cultivars of this region. The aim of this work was to find out the efficacy of morphophysiological traits as a selection criterion to screen potato cultivars for high temperature tolerance.

The seeds of three high-yielding potato cultivars – Kufri megha, Kufri jyoti and Kufri pokraj – were collected from Central Potato Research Station (CPRS), Shillong, India. Two local potato cultivars ‘Rangpuria’ and ‘Badami’ were obtained from Gingia, Bishwanath Chariali district, Assam. Potato cultivars were grown in the experimental field of Tezpur University campus, Assam, consecutively for two years in a randomized block design with four replications. Potato tubers were sown under three conditions: (a) normal growing season (October 2013, 2014–February 2014, 2015); (b) a polyhouse chamber (October 2013, 2014–February 2014, 2015) and (c) early sowing (August 2013, 2014–November 2013, 2015). The polyhouse was a wooden structure of size 9 m × 8 m × 8 m built and covered with PVC (polyvinyl chloride) film (of about 0.15 mm thickness and 85% of transmittance), and properly ventilated to avoid upsurge of CO_2. The dimensions of the plots were 2.6 × 2 m^2 with four rows (65 and 25 cm from row to row and plant to plant respectively). Climatological data for normal and early season were obtained from meteorological tower of Krishi Vigyan Kendra, Napaam, Tezpur (situated near the experimental field). In polyhouse, thermo hygrometers were placed for continuous checking of air temperature and relative humidity. Soil thermometers were used to record soil temperature. Soil water was monitored with the help of tensiometers and maintained above –30 kPa (at 20 cm below the soil surface) to ensure that the plant did not suffer water stress.

High-yielding and local potato cultivars grown under normal growing condition were harvested 90 DAS (14

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January 2014, 2015) and 100 DAS (24 January 2014, 2015) respectively, whereas inside the polyhouse and in early sowing, cultivars from both the groups matured early and were harvested 80 DAS (4 November 2013, 2014).

The parameters were studied at 15, 55 and 75 DAS, which correspond to the vegetative, tuberization and maturity stage of the crop under normal condition. For morphological measurements three central plants of each block were selected and labelled.

Plant height (cm) was measured using a meter ruler by assessing the distance from soil level to the top fully opened leaf of the main shoot.

Leaf area index (LAI) was calculated as the ratio of leaf area per plant to the ground surface area occupied by the plant canopy[13]

$$\text{LAI} = \frac{\text{Leaf area/plant}}{\text{Ground surface/plant}}.$$

For analysis of various biochemical parameters, the third and fifth leaves from the top of the potato plants were collected.

Total chlorophyll contents were determined following the method of Anderson and Broadman[14]. Fresh leaf material (500 mg) was ground with 10 ml of 80% acetone at 4°C and centrifuged at 2500 *g* for 10 min. This procedure was repeated until the residue became colourless. The extract was transferred to a graduated tube to make the volume up to 50 ml with 80% acetone. Aliquots of the extract (3 ml) were transferred to a cuvette and absorbance was read at 645 and 663 nm with a spectrophotometer (UV 1700 Pharma Spec, Japan).

Chlorophyll stability index (SI) was calculated using the formula[15]

$$\text{CSI} = \frac{\text{Chlorophyll of the treatment}}{\text{Chlorophyll of the control}}.$$

Membrane stability index (MSI) was estimated by assessing the electrical conductivity of leaf discs in double-distilled water at 40°C and 100°C respectively. Leaf samples (100 mg, third and fifth leaves from the top) were cut into discs of uniform size and taken in test tubes containing 10 ml of double-distilled water in two sets. One set was kept at 40°C for 30 min and another at 100°C for 15 min in a boiling water bath. Next their respective electrical conductivities $C1$ and $C2$ were measured using conductivity meter (Labotech Precision Instruments, Model ME 885) and MSI was taken as a ratio of $C1$ and $C2$ in percentage

$$\text{MSI (\%)} = \left[1 - \left(\frac{C1}{C2}\right)\right] \times 100.$$

On dying of vines, potato tubers under normal condition were harvested on 27 January and 5 February for high-yielding cultivars (HYCs) and local cultivars respectively, in both the years. Whereas crop inside the polyhouse and from early season sowing was harvested on 5 and 10 January for HYCs and local cultivars respectively, in both the years. In each replication, harvesting was done from 1 sq. m area, tubers were cleaned, and after weighing the tuber yield was expressed in quintals per hectare.

Data were statistically analysed within sampling dates using two-way analysis of variance (ANOVA) by SPSS (version 16.0) to determine the significance between treatments, cultivars and treatment × cultivar interactions. Morphophysiological data showed homogeneity between the years, whereas we noted significant differences in the yield. Therefore, pooled data of morphophysiological parameters for two years are presented here and yield data for both the years are shown separately. Correlation matrix was developed taking the average of all the sampling dates for each parameter with crop yield at harvest.

During the first year of experiment, the recorded mean air temperature ranged from 15°C to 23°C under normal condition; however, we obtained 1–2°C higher mean air temperature in the second year. Regardless of years, 2–4°C rise in additional temperature was noted inside the polyhouse. The documented mean air temperature in early season ranged from 21°C to 35°C and 23°C to 36°C during the first and second year of the experiment respectively. On the other hand, recorded relative humidity in normal condition was 62–70% and 65–72% throughout the first and second year of experimentation respectively. Inside the polyhouse, relative humidity was invariably 8–10% higher than the normal condition. During early season, the recorded relative humidity was in the range 68–82% in both the years (Table 1).

Except a non-significant ($P \leq 0.01$) interaction of year (Y) × cultivar (C) at vegetative and tuberization stage and year (Y), treatment (T) and Y × T at maturity stage on plant height, other interactions were highly significant ($P \leq 0.01$) at all three growth stages of the crop (Table 2). Irrespective of temperature conditions, increase in plant height was recorded from vegetative to tuberization and then seized during maturity. Significant ($P \leq 0.01$) rise in plant height was documented under high temperature compared to normal condition and this was found to be more pronounced inside the polyhouse. Among the HYCs, Kufri jyoti recorded maximum increase in plant height followed by Kufri pokraj and Kufri megha in all the growth stages, whereas local cultivar Badami recorded maximum plant height compared to Rangpuria (Table 3). We obtained significant negative correlation of plant height with tuber yield under all three experimental conditions (Table 4).

Irrespective of growth stage, all the factors and their interactions were highly significant ($P \leq 0.01$) on LAI,

Table 1. Variation in temperature and relative humidity (monthly average) in the normal season, polyhouse and early season sown crop over the sampling period during 2013–14 and 2014–15

	In season		Polyhouse		Early season	
Period	Air temperature (°C)	Relative humidity (%)	Air temperature (°C)	Relative humidity (%)	Air temperature (°C)	Relative humidity (%)
2013–2014						
August	–	–	–	–	34	80.2
September	–	–	–	–	34.9	81.1
October	23.7	68.6	26.4	78.9	23.7	68.6
November	21.5	65.3	24.2	73.4	–	–
December	15.4	62	17.4	70.4	–	–
January	17.9	64.5	21.8	74.3	–	–
February	21.2	69.3	25.8	80.1	–	–
2014–2015						
August	–	–	–	–	35.5	82
September	–	–	–	–	34.1	80.8
October	25.8	69.4	29.4	80.2	25.8	69.4
November	22.4	67.9	25.7	78.3	–	–
December	16.8	64.4	19.4	82.1	–	–
January	18.7	67.6	23.1	81.4	–	–
February	23.4	71.3	29.4	83.5	–	–

Table 2. Mean square and leaf significant difference (l.s.d.) values for plant height, leaf area index (LAI) and membrane stability index (MSI) in potato cultivars during three different growth stages

Growth stage		Plant height (cm)	LAI	MSI (%)
Vegetative	Year	77.22**	10.60**	239.67**
	Treatment	974.63**	133.51**	3,211.92**
	Cultivar	122.75**	8.33**	214.09**
	Y * T	13.04**	1.15**	19.71**
	Y * C	0.695^{ns}	0.08*	39.27**
	T * C	5.75**	1.11^{ns}	67.92**
	Y * T * C	4.49**	0.15**	18.94**
	Error	0.612	0.26	0.699
	l.s.d$_{0.05}$	0.202	0.132	0.216
Tuberization	Year	68.92**	14.43**	3.53^{ns}
	Treatment	30,041.15**	130.18**	7,500.16**
	Cultivar	2,982.91**	211.98**	194.82**
	Y * T	8.565**	1.44**	1.01^{ns}
	Y * C	1.070^{ns}	0.76^{ns}	2.36^{ns}
	T * C	413.51**	5.09^{ns}	26.43**
	Y * T * C	0.919**	0.24**	1.38
	Error	1.645	0.69	1.21
	l.s.d$_{0.05}$	0.33	0.216	0.285
Maturity	Year	3.41^{ns}	210.13**	79.26^{ns}
	Treatment	38,289.8 ^{ns}	101.06**	8,938.89**
	Cultivar	1,669.29**	6.28**	114.60**
	Y * T	1.16^{ns}	358.28**	5.51^{ns}
	Y * C	5.77**	135.92**	4.21^{ns}
	T * C	384.63**	144.57**	26.35**
	Y * T * C	6.78**	142.32**	2.50^{ns}
	Error	1.24	0.64	2.54
	l.s.d$_{0.05}$	0.28	0.20	0.412

T, Treatment; C, Cultivar; Y, Year; ns, Non-significant; *$P < 0.05$; **$P < 0.01$.

Table 3. Effect of high temperature on plant height, leaf area index, membrane stability index and chlorophyll stability index (CSI) of potato cultivars

	Vegetative			Tuberization			Maturity		
Cultivar	In season	Polyhouse	Early season	In season	Polyhouse	Early season	In season	Polyhouse	Early season
Plant height (cm)									
Kufri jyoti	10.83f	23.91a	16.93bc	25.88fg	101.02a	74.79bc	26.29h	103.67a	75.99cd
Kufri megha	7.93g	17.74b	13.03e	20.37fg	89.10ab	67.2cd	21.80i	96.33b	68.34d
Kufri pokraj	9.77f	22.99a	15.37d	22.95de	96.93a	70.53abc	24.99h	100.67a	72.99d
Rangpuria	5.98h	16.26cd	10.33f	16.00g	63.14cd	36.34efg	18.87i	88.68b	38.24g
Badami	7.25g	17.71b	12.55e	19.14fg	68.83bc	40.17g	21.52i	81.03c	42.92f
LAI									
Kufri jyoti	5.97cd	8.93a	6.25bc	11.49de	17.47a	14.78bc	10.95c	14.97a	13.84a
Kufri megha	3.22g	7.77ab	5.35cde	9.79fg	14.29c	12.08de	9.70d	14.28a	11.71bc
Kufri pokraj	4.18efg	8.64a	5.87cd	11.14ef	15.98b	13.65c	12.4b	14.84a	12.25b
Rangpuria	3.01g	6.60bcd	5.15def	4.78j	7.87hi	7.35i	5.90g	8.15ef	7.20f
Badami	3.68fg	6.69bcd	5.38cde	7.18i	9.27gh	8.20hi	7.03fg	9.12de	7.88ef
MSI (%)									
Kufri jyoti	74.58a	52.52ef	51.11f	80.16a	48.91cd	47.45cd	55.60bc	40.37ef	39.05f
Kufri megha	77.28a	60.12cd	58.14cde	82.07a	53.22c	53.21c	70.20a	45.74de	41.86ef
Kufri pokraj	68.23b	53.32ef	51.73ef	79.90a	48.44cd	50.65cd	65.27a	42.91ef	40.07ef
Rangpuria	68.12b	58.75cde	52.48ef	76.13a	49.80cd	48.25cd	58.93b	50.29cd	44.06ef
Badami	63.16bc	53.69def	49.52f	68.58b	47.40cd	44.83d	54.80bc	44.92def	40.62ef
CSI									
Kufri jyoti	–	0.64c	0.56c	–	0.71abc	0.61bcd	–	0.50ab	0.48ab
Kufri megha	–	0.84a	0.69abc	–	0.82ab	0.73abc	–	0.56a	0.47b
Kufri pokraj	–	0.71abc	0.62bc	–	0.77abc	0.71abc	–	0.51ab	0.48ab
Rangpuria	–	0.73ab	0.73ab	–	0.88a	0.56cd	–	0.50ab	0.46b
Badami	–	0.72ab	0.61bc	–	0.64bcd	0.46d	–	0.49ab	0.37c

except for treatment (T) × cultivar (C) in the vegetative stage; year (Y) and treatment (T) with cultivar (C) in tuberization stage (Table 2).

Compared to normal condition, significant ($P \leq 0.01$) increase of LAI was recorded under high temperature environments, with highest value inside the polyhouse. However, in maturity stage, non-significant decrease of LAI was noted from all three experimental conditions. Regardless of temperature conditions and growth stages, highest LAI was recorded in cultivar Kufri jyoti followed by Kufri pokraj and Kufri megha. Among the local cultivars, Badami showed higher value of LAI than Rangpuria (Table 3). Irrespective of temperature conditions, LAI was negatively correlated with tuber yield (Table 4).

Effect of year (Y) and its interaction with treatment (T) and cultivar (C) on MSI was found to be non-significant for both tuberization and maturity stages. ANOVA showed highly significant ($P \leq 0.01$) differences for the rest (Table 2).

Substantial decline in MSI was noted under high temperature environments compared to normal condition with higher reduction inside polyhouse. Among the HYCs, Kufri megha documented lowest decrease during vegetative and tuberization stage under both the high temperature conditions, whereas in case of local cultivars, higher reduction was found in Badami. However, in the maturity stage Kufri megha and Badami showed highest reduction in MSI (Table 3). Positive correlation was obtained between MSI and tuber yield.

Irrespective of growth stages, crops grown inside the polyhouse recorded significantly higher ($P \leq 0.01$) CSI compared to early season crop. Among the HYCs, Kufri megha maintained better CSI throughout the growth period in both high temperature conditions, followed by Kufri pokraj and Kufri jyoti. Nonetheless, in case of local cultivars Rangpuria recorded more CSI compared to Badami (Table 3). CSI was positively correlated with tuber yield (Table 4).

Yield reduction was observed under normal condition between both years. In the HYCs a reduction of 4–5% was recorded, while the local cultivar Badami showed a maximum of 12%. Again, significant ($P \leq 0.01$) decrease in tuber yield was documented under high temperature conditions compared to the control, with maximum reduction from early season sowing. Irrespective of high temperature conditions, cultivar Kufri megha recorded minimum yield reduction followed by cultivars Kufri pokraj and Kufri jyoti, whereas local cultivar Rangpuria restored better yield than Badami (Table 5).

Elevated levels of CO_2 enhance photosynthesis in C_3 plants (like potato)[16], which results in increased shoot biomass. However, the associated increase in temperature

Table 4. Correlation coefficients (r) of various parameters with tuber yield under in-season, polyhouse and early season

Treatment	Plant height	LAI	MSI	CSI
In season	–0.719^{ns}	–0.885*	0.919**	–
Polyhouse	–0.815*	–0.890**	0.028^{ns}	0.383^{ns}
Early season	–0.887*	–0.830*	0.049^{ns}	0.723^{ns}

ns, Non-significant; **Significant at $P = 0.01$; *Significant at $P = 0.05$.

Table 5. Effect of high temperature on tuber yield (q ha^{-1}) of potato cultivars during 2013–14 and 2014–15

Cultivar	In season	Polyhouse	Early season	Reduction inside polyhouse (%)	Reduction in early season (%)
2013–14					
Kufri jyoti	75.43 ± 1.7b	36.18 ± 2.5e	29.58 ± 2.1f	52.78	60.79
Kufri megha	89.79 ± 2.1a	52.54 ± 2.2c	48.23 ± 2.1cd	41.71	46.86
Kufri pokraj	83.031 ± 2.3b	43.23 ± 2.1d	34.5 ± 1.6f	48.67	58.70
Rangpuria	16.87 ± 1.5g	7.3 ± 1.3h	7.26 ± 1.1h	54.65	54.59
Badami	14.43 ± 1.8g	6.23 ± 1.1h	6.60 ± 0.9h	60.79	54.95
2014–15					
Kufri megha	86.93 ± 1.1a	50.87 ± 1.6d	32.67 ± 2.5fg	40.70	59.33
Kufri pokraj	80.40 ± 2.3b	39.2 ± 2.2e	30.67 ± 2.2fg	51.12	61.38
Rangpuria	15.6 ± 0.8h	6.67 ± 1.0i	6.00 ± 1.4i	56.89	60.56
Badami	13.26 ± 1.2h	5.83 ± 1.1i	5.20 ± 0.8i	61.42	59.37

shortens the life cycle of the crop, hastening the rate of organ development and finally reducting yield[17].

High temperature had a deleterious effect on growth and metabolism of all the studied potato cultivars. The recorded shoot elongation and LAI in the studied potato cultivars under high temperature environments might be due to the activity of certain growth-regulating substances. The optimum temperature required for foliage growth in potato is 20–25°C (ref. 18), with substantially high temperature inside the polyhouse (25–29°C) and in the early season (35°C) resulting in activation of endogenous plant growth hormone gibberellin[19], stimulating higher growth of the foliage (Table 3). Promotion of shoot growth in whole plant and leaf bud cutting due to exogenous application of gibberellin has already been documented in many crops by other researchers[20]. Gibberellin helps in extension of cell wall and elongation of internodes by enhanced loosening of cell wall, reduced wall cross linking or altered wall composition. Previous reports on pea suggest that gibberellin helps in shoot elongation by triggering solute transport into the expanding tissue. Therefore, cells would imbibe more water which subsequently increases their turgor pressure, and finally enhances the rate of wall growth and cell enlargement[21]. Irrespective of cultivars, the recorded decreased MSI under high temperature is due to the increased plasma membrane injury. This is confirmed by CSI results, where injury to thylakoid membrane enhances chlorophyll degradation under high temperature. Earlier report on orange plants showed that oxidative injury on cellular membrane, viz. thylakoid increased chlorophyll degradation and inhibition of its biosynthesis[22]. The recorded maximum decrease in MSI and CSI in cultivars Kufri jyoti and Badami (Table 3) might be due to increased fluidity of the membrane under high temperature (more under early season). Highest CSI value in cultivars Kufri megha and Rangpuria is due to greater chlorophyll conservation ability of both the cultivars.

Optimum temperature for tuberization in potato is 20°C (ref. 18) and the substantially higher temperature recorded inside the polyhouse (17–23°C) and in early season (35°C) hamper this. The documented significant reduction in tuber yield under high temperature may be due to improper partitioning of the assimilates from source to sink[7]. Thus, by restricting dry matter partitioning to the tuber, haulm growth is triggered under high temperature. Inhibitory effect of gibberellin in tuber formation of potato had been reported[23]. In the present experiment, the observed higher increment of plant height and LAI (Table 3) as well as reduction in tuber yield (Table 5) is presumably because of increased endogenous level of gibberellin under high temperature. However, the measured lower plant height, LAI and higher tuber yield (Table 5) in cultivars Kufri megha and Rangpuria compared to the other cultivars might be due to low gibberllic acid (GA)/abscisic acid (ABA) ratio that limits the overall plant growth and promotes tuber formation. Thus, it can be substantiated that down regulation of genes coding GA or induction of GA-antagonist compound like ABA under high temperature conditions might provide thermotolerance to potato crop. Therefore, cultivars Kufri megha and Rangpuria can be considered to have better tolerance to high temperature. Thus, morphophysiological characteristics can be efficiently used to screen potato cultivars for heat tolerance.

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Lab to land – factors driving adoption of dairy farming innovations among Indian farmers

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In India sustaining dairy farming as a rural livelihood and to meet the growing demand of milk, necessitates development and dissemination of technology for improving the farm's output. There is also a need to understand how far existing innovations are adopted by farmers and factors influencing adoption and/or rejection. Hence, the factors that influence adoption and the extent of adoption were consolidated from past research using meta analysis and other techniques. It was found that at large-level farmer's knowledge (true effect size *r* value +0.64) and at medium-level (true effect size *r* value ranging from +0.32 to +0.47) attitude, risk-taking behaviour and economic motivation, milk production and sales, education, extension agency contacts and mass media exposure influenced adoption of dairy innovation. Further, along with the above factors poor innovation attributes were limiting adoption to 55%.

Keywords: Dairying, diffusion and adoption, innovation, meta analysis, rural livelihood.

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