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Research paper

Effect of high temperature on yield associated parameters and vascular bundle development in five potato cultivars

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ABSTRACT

High temperature is one of the major abiotic stresses affecting performance of crop plants including potato yield. To gain an insight into whether high temperature effects tuber yield and its relation to translocation of photoassimilates in potato, a comparative study was conducted using five (Kufri jyoti, Kufri megha, Kufri pokraj, Rangpuria, and Badami) potato cultivars for two consecutive years. These cultivars were sown early in the season (mid August–November) when the temperature was high and normal growing season (ambient condition) (mid October–mid January) in an open field along in a polyhouse where the temperature was high. Early season planting experienced highest temperature (30–35 °C) and temperature in the polyhouse was 2–4 °C higher than the ambient condition. Leaf net CO_2 assimilation rate, stem anatomy, xylem size, sugar-starch ratio, activity of sucrose phosphate synthase, tuber bulking rate and tuber yield were evaluated under all three conditions (early season, ambient condition and polyhouse conditions). Overall, compared to ambient conditions, under early season and polyhouse conditions, the net photosynthesis rate was significantly reduced but sugar starch ratio was significantly enhanced in all tested cultivars. Under both early planting and polyhouse conditions, the xylem cells were abnormally enlarged and deformed in all potato cultivars, however, the effects were minimal in case of cultivar Kufri megha (high yielding cultivar) and Rangpuria (local cultivar) which was correlated with the minimal yield reduction. Overall, the temperature induced abnormalities in vascular tissues appears to be critical for tuber bulking rate and tuber yield (42–55% in the high yielding cultivars and 44–54% in the local cultivars). The cultivars that could maintain xylem size and phloem structure tended to minimize the negative effects of high temperature on tuber yield.

1. Introduction

The global surface temperature is predicted to increase by 1.5–2 °C by the end of this century (IPCC, 2014). This increase in temperature is likely to affect every sphere of life causing large negative impacts on agricultural productivity thereby threatening global food production and security. In plants, higher temperature not only affects the basic physiological processes like photosynthesis, respiration, membrane stability etc. but also modulates endogenous hormones and primary and secondary metabolites (Wahid et al., 2007).

Under high temperature, alteration in enzyme activities associated with carbon metabolism, starch accumulation, and sucrose synthesis is caused by down-regulation of specific genes responsible for the same (Ruan et al., 2010). With reduced assimilate production, high temperature above 20 °C interferes with assimilate partitioning in potato resulting in lower tuber yield (Ahmad et al., 2011). For instance, in wheat, temperature above 30 °C reduced the transport of assimilates from the flag leaves to the developing grains (Farooq et al., 2011). Rate of assimilate translocation, from source leaves to the sink, depends on several factors including rate of photosynthesis, phloem loading/unloading and assimilate flow within the phloem (Lemoine et al., 2013). This indicates that the carbon translocation from the source leaves to the sink is regulated by the phloem transport system. This phloem transport system is also very vital in the maintenance of the sink

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strength.

Sucrose phosphate synthase (SPS) modulates the partitioning of photo-assimilates by catalysing the synthesis of sucrose contributing to the osmotic driving force for phloem translocation (mass flow) (Huber and Israel, 1982; Lalonde et al., 1999). The SPS activity is very sensitive to variation in temperature. For example, in soybean leaves SPS activity was reduced at less than optimum temperature (18/14 °C) (Rufty et al., 1985). While in potato, high temperature increased the SPS activity (Ahmad et al., 2011). Nonetheless, activity of SPS in anthers of tomato was suppressed by heat stress (> 40 °C/25 °C, day/night) (Kaur et al., 2015). Likewise, in mulberry leaves, SPS activity reduced at high temperature (Chaitanya et al., 2001).

High temperature also causes several anatomical aberrations and alternations. For example, high temperature caused poor development of vascular bundles and mesophyll in rice (Zhang et al., 2009). At temperature above 28 °C, substantial increase in spikelet sterility was observed in rice due to glume closure which is correlated with carbohydrates content and the pattern of vascular bundle in the lodicule (Yan et al., 2016). The phloem structure in the vascular bundle could have important implications for several processes from growth to yield (Savage et al., 2016). However, phloem transport is hampered by changes in the source and sink tissues, as these may alter the translocation process (Savage et al., 2013).

Potato, the world's fourth major food crop after maize, rice and wheat (Muthoni et al., 2011), grows well at temperature of 15–25 °C (Ahmad et al., 2011) and is quite sensitive to high temperature (Haverkort et al., 2008). The present decline in potato productivity due to rise in global temperature (Muthoni and Kabira, 2015) inflicts a through explanation of the cause and to develop strategies for sustainable improvement of tuber yield under high temperature. In previous studies, we described the impact of high temperature on morphology, physiology and biochemistry of potato crop (Paul et al., 2016a, 2016b, Paul and Gogoi, 2015, Paul et al., 2014); where it was reported that high temperature induced physiological and biochemical alterations in potato plant caused yield reduction. Nonetheless the impact of high temperature on vascular bundles and its association with the yield formation was rarely investigated. This study was, therefore, conducted, to evaluate the influence of high temperature on the conducting elements (xylem and phloem) and SPS activity (one of the rate limiting enzymes for sucrose synthesis) in both local and high yielding cultivars of potato.

2. Materials and methods

2.1. Experimental site and soil

The experiment was conducted in the experimental field of Tezpur University (26°14′N and 92°50′E) at Tezpur, Assam, India. This area falls in the subtropical climatic zone and experiences monsoon type of climate. The experimental soil was silt loam in texture with soil organic carbon 1.41%, available nitrogen, phosphorus, potassium 275.97, 36 and 279.59 kg ha^{-1} respectively, bulk density 1.1 Mg m^{-3}, water holding capacity 44.4% with slightly acidic pH (5.93).

2.2. Plant material and growth conditions

The seeds of three high yielding potato cultivars Kufri megha, Kufri jyoti and Kufri pokraj were collected from the Central Potato Research Station, Shillong, India. Two local potato cultivars 'Rangpuria' and 'Badami' were obtained from Gingia, district Biswanath Chariali, Assam, India. These cultivars are popularly grown in northeast India. The characteristics of the cultivars are detailed below:

2.2.1. Kufri jyoti

Tubers are medium to large in size, oval in shape with whitish skin and fleet eyes. The sprouts are blue-purple. They are moderately resistant to late and early blight and grows well both in hills and plains.In hills, the crop matures in 110–130 days while in the plains maturation takes place in 90–100 days. Yield potential is around 10–16 t/ ha.

2.2.2. Kufri megha

Tubers are whitish, smooth surfaced and oval in shape with shallow eyes. The sprouts are dull green. They are highly resistant to late blight, are grown in the hilly areas and mature in 100–120 days. Yield potential is around 19–22 t/ ha.

2.2.3. Kufri pokraj

Tubers are white, large, oval, slightly tapered smooth skin, fleet eyes, and yellow flesh. The sprouts are blue-purple. They are resistant to early blight and moderately resistant to late blight. Maturation takes place in 70–90 days and yield potential is 30 t/ ha.

2.2.4. Local cultivars (Rangpuria and Badami)

Tubers are very small and dark red in colour. Rangpuria is round shaped while Badami is nut-shaped. The average yield of these cultivars has not been documented yet.

Potato cultivars were grown in a randomized complete block design in factorial arrangement with three replications. The potato cultivars were raised under three temperature conditions managed by planting (a) in normal growing season (ambient condition); October to February, (b) in polyhouse chamber; October to February, and (c) in early season; August to November during the years 2014–2015 and 2015–2016. The polyhouse was a wooden structure of size (11 m × 10 m × 10 m) built and covered with polyvinyl chloride film (of about 0.15 mm thickness and 85% of transmittance) properly ventilated to avoid upsurge of CO_2. The dimensions of the plots were (2.6 m × 2 m) with four rows (65 cm and 25 cm from row to row and plant to plant spacing, respectively).

Weather data for ambient condition and early season were collected from meteorological tower of Krishi Vigyan Kendra, Napaam, Tezpur (situated near the experimental field). Inside polyhouse, thermo hygrometers were positioned for constant checking of air temperature and relative humidity. Soil thermometers were used to record the soil temperature. Soil moisture status was monitored with tensiometers and was maintained above −30 kPa (at 20 cm below the soil surface) to ensure that the plant did not suffer water stress. Fertilizers were applied at 60-50–50 kg nitrogen (as urea), phosphorus (as single superphosphate) and potassium (as muriate of potash) ha^{-1} as basal dose. Three irrigations were applied at 15, 35 and 55 days after sowing (DAS) in all the temperature treatments during the entire crop cycle.

Under ambient condition and inside polyhouse, the seeds were sown on 17 October (2014 and 2015). However, under ambient condition, high yielding potato cultivars showed symptoms of maturity (yellowing of leaves) 90 DAS while the local cultivars matured 95 DAS and both the groups were harvested 100 DAS (24 January 2015 and 2016). Inside the polyhouse, both high yielding and local cultivars matured at 75 DAS and were harvested 80 DAS (4 January 2015 and 2016). In early season, seeds were planted on 17 August 2014 and 2015) and both the groups of cultivars matured at 60 DAS and were harvested at 70 DAS (25 October 2014 and 2015).

During first year, the recorded mean air temperature ranged between 16 and 28 °C during the normal growing season (ambient condition) whereas inside the polyhouse the temperature was 2–4 °C higher than the outside (Fig. 1A). On the other hand, the mean air temperature in early season ranged between 23 and 36 °C in the first year. However, temperature was higher (1–2 °C) under all the conditions during the second year of the study. The earth's temperature is predicted to increase by 2–4 °C by the end of this century (IPCC, 2014). Our polyhouse conditions mimicked exactly these predictions as the temperature inside the polyhouse was 2–4 °C higher than the ambient condition grown plants in both the years. Although the comparison between early season grown plants with control (ambient condition) plants was not done