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Transformation of Sucrose to Starch and Protein in Rice Leaves and Grains under Two Establishment Methods

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Abstract: Six rice varieties, PR120, PR116, FengAiZan, PR115, PAU201 and Punjab Mehak 1 were raised under aerobic and transplanting conditions to assess the effects of planting conditions on sucrose metabolising enzymes in relation to the transformation of free sugars to starch and protein in flag leaves and grains. Activities of sucrose synthase, sucrose phosphate synthase and acid invertase increased till flowering stage in leaves and mid-milky stage (14 d after flowering) in grains and thereafter declined in concomitant with the contents of reducing sugar. Under aerobic conditions, the activities of acid invertase and sucrose synthase (cleavage) significantly decreased in conjunction with the decrease in non-reducing sugars and starch content in all the varieties. Disruption of starch biosynthesis under the influence of aerobic conditions in both leaves and grains and the higher build up of sugars possibly resulted in their favoured utilization in nitrogen metabolism. FengAiZan, PR115 and PR120 maintained higher levels of sucrose synthase enzymes in grains and leaves and contents of metabolites (amino acid, protein and non-reducing sugar) under aerobic conditions, while PR116, Punjab Mehak 1 and PAU201 performed better under transplanting conditions, thus showing their adaptation to environmental stress. Yield gap between aerobic and transplanting rice is attributed primarily to the difference in sink activity and strength. Overall, it appear that up-regulation of sucrose synthase (synthesis) and sucrose phosphate synthase under aerobic conditions might be responsible in enhancing growth and productivity of rice varieties.

Key words: aerobic; rice; acid invertase; protein; amino acid; starch; sucrose synthase; sucrose phosphate synthase; water soluble carbohydrate; sugar

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. Almost half of the world's population depend on rice as their staple diet, so demand for rice production is still rising because of the continuous increase in population. To sustain present food self-sufficiency and meet future food requirements, rice productivity has to be increased by 3% per annum (Ke et al, 2009; Pyngrope et al, 2013). Rice system consumes 4×10^{11} L water which results in sharp decline in fresh water resources in the world (Tuong and Bouman, 2003). Owing to increased water scarcity and labour cost, a shifting trend towards less water demanding rice i.e aerobic cultivation is the need of the hour. Alternatively, aerobic rice which is established directly from seeds without up-holding of water offers a promising approach for higher water conservation with reasonable crop productivity (Bernier et al, 2008; Farooq et al, 2011).

Water soluble carbohydrates (WSC) mobilises from the leaf during grain filling stages can become an important source of assimilate for grain yield in rice under water deficit conditions (Li et al, 2006). Leaf WSC accumulation is influenced by environmental factors (Winder et al, 1998; Heidary et al, 2007). However, considerable genotypic variation in leaf WSC concentration has been documented and positive relationships between leaf WSC concentration at flowering and wheat grain weight under certain water-limited environmental conditions, have been observed (Xue et al, 2008). Therefore, high WSC concentration

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is considered to be a potentially useful trait for improving grain weight and yield in water limited environments. Apparently, senescence induced by water deficits shortens grain-filling period and can result in reductions in grain weight and grain yield (Saeedipour, 2011). Protein content is known to be influenced by many factors, including the genotype and fertilizers, but is mainly influenced by the planting conditions (Meena et al, 2012). Proteins accumulated under stress conditions may provide a storage form of nitrogen that is re-utilized in post-stress recovery and also play a role in osmotic adjustments (Danai-Tambhale et al, 2011).

Sucrose metabolism plays pivotal roles in development, stress response and yield formation, mainly by generating a range of sugars as metabolites to fuel growth and synthesize essential compounds (Li et al, 2006; Tang et al, 2009). Although sucrose is produced primarily in mature leaves, it can be resynthesized in sink tissues. Sucrose synthesis and breakdown are central to energy sustainability. Sucrose is enzymatically degraded into hexoses to power and support the growth of sinks. There is a compelling evidence that sucrose metabolism is among the key regulatory systems conferring tolerance to abiotic stress (Bala et al, 2010; Ruan et al, 2010). Upon translocation through the phloem to sinks, sucrose is degraded by either invertase or sucrose synthase into hexoses or their derivatives, which are then used in diverse ways. Invertase hydrolyzes sucrose into glucose and fructose whereas sucrose synthase degrades sucrose in the presence of uridine diphosphate (UDP) into UDP-glucose and fructose (Ruan et al, 2014).

Although several studies were carried out on aerobic rice system, work regarding the comparative role of carbohydrate metabolism at different developmental stages under both planting conditions was lacking. So biochemical consequences of aerobic conditions mediated by changes in carbohydrate mechanism are worthy of investigation. Therefore, this study aimed to evaluate the changes of sucrose metabolising enzymes in six rice varieties under both aerobic and transplanting conditions.

MATERIALS AND METHODS

Rice materials, cultivation and sampling procedure

A field study was conducted at the Punjab Agricultural University (PAU), Ludhiana, India (30°56′ N, 75°52′ E, 247 m above the sea level). The climate is characterised by hot summers and very cold winters. The crop was raised in triplicates under two cropping/water management systems i.e. dry direct-seeded aerobic (aerobic) and conventional puddled transplanted (transplanting) rice in puddled soils followed by flood irrigations with alternate wetting and drying (flooded) in loamy soil (pH 7.7), which is low in organic carbon and available N, medium in available P and K in plot area of 1 m × 1 m (random block design). Six rice varieties, PR120, PR116, FengAiZan, PR115, PAU201 and Punjab Mehak 1, were raised under two different conditions, i.e. aerobic and transplanting conditions. PAU201 and PR120 have wider adaptability in the region with respect to high yield potential, while PR115, FengAiZan and Punjab Mehak 1 are early vigor and short duration varieties. PR115, PR116, PR120, PAU201 and Punjab Mehak 1 are pure lines developed by PAU whereas FengAiZan is a Chinese line. For aerobic rice, land was prepared with two plowings with a disc harrow and one planking. The aerobic rice was seeded directly at 2–3 cm depth in moist seed bed using 50 kg/hm^2 in rows spaced at 20 cm. The aerobic condition was maintained by applying flash irrigation (5 cm) every time when the soil moisture reaches -15 kPa at 15 cm depth. The sowing of transplanted crop was done at 7 d before the direct sowing and 30-day old nursery was transplanted which ensured the same climatic conditions for both the planting systems. Land preparation for conventional transplanted rice consisted of one dry plowing, followed by irrigation and two harrowings to puddle the soil. Transplanting was done in the puddled field in rows with space of 20 cm × 15 cm. The field was ponded for the first 15 d and thereafter, it was repeatedly flood irrigated 2 d after the water infiltrated in the soil until two weeks before harvesting. During the reproductive stage, the irrigation was applied between -10 kPa soil moisture tension. Nitrogen at 120 kg/hm^2 (260 kg urea) was applied in three equal splits i.e. 40 kg/hm^2 each at puddling, 21 d and 42 d after transplanting. All aerobic direct seeded rice treatments were sprayed twice with 1% ferrous sulfate (250 L/hm^2) at 35 and 42 d after transplanting. For the control of annual weeds, Butachlor 50 EC at 3.0 L/hm^2 was applied 2 d after transplanting. All other management practices were done as per the recommendations of the Package and Practices of PAU. All enzymatic and non-enzymatic determinations were performed on flag leaf at tillering, flowering, 7, 15 and 30 d after flowering