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Impact of sowing date on yield, dry matter and nitrogen accumulation, and nitrogen translocation in dry-seeded rice in North-West India

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ABSTRACT

The aims of the present study were to determine the optimum sowing time of newly developed rice genotypes for high crop water productivity in non-flooded dry-seeded rice (DSR) in north-west India, and to identify the factors underlying high yielding genotypes by comparing their sink production in DSR. We evaluated differences in dry matter, nitrogen accumulation, translocation, yield formation and evapo-transpiration requirement of the selected genotypes developed for DSR (two cultivars; PR-115 and PR-121, two recombinant inbred lines; RIL-367 and RIL-1649) under three sowing dates (1, 10, and 20 June), for two years in the rainy seasons of 2014 and 2015 in north-west India. RIL-1649 sown on 1 June had higher grain yield (9.4 t ha^{-1}) and similar or higher water productivity (1.3 kg m^{-3}) than the other sowing date x genotype combinations. Delaying sowing from 1 to 10 June reduced yield of all genotypes except PR-121, and there was no further decrease in yield with delay to 20 June of PR-115 and RIL-1649. The yield of RIL-1649 sown on 20 June (7.9 t ha^{-1}) was similar to that of PR-115 sown on 1 June.The high grain yield of RIL-1649 (7.9 t ha^{-1}) for the late sowing was due to high pre- and post-anthesis dry matter accumulation, coupled with greater contribution of dry matter translocation to grain yield. RIL-367 not only produced similar yield (8.5 t ha^{-1}) to the check variety PR-115 (8.3 t ha^{-1}) for the 1 June sowing, but also matured 13 days earlier than PR-115.These results suggest that RIL-367 could be useful for DSR-based intensive cropping systems in north-west India, and with higher crop water productivity (1.32 kg m^{-3}) than PR-115 (1.20 kg m^{-3}). In the late sown condition, grain yield had a positive relationship with harvest index, leaf area index at flowering, preanthesis dry-matter accumulation, and dry matter translocation. A greater amount of dry matter and nitrogen uptake at anthesis, in combination with an increased harvest index, resulted in a greater amount of translocated material during the grain filling period. This, in turn, contributed to higher grain yield during late sowing. This study suggests that, for widening the sowing window, and for sustained yields of DSR in north-west India, high dry matter and nitrogen accumulation at anthesis, together with high harvest index, are useful selection traits.

1. Introduction

Rice (*Oryza sativa* L.) is a staple food of South Asia, including India. In the majority of South Asia, rice is mainly grown using the traditional system of transplanting into puddled conditions, and requires a large amount of labor and water. Rice production in north-west India is critical for India's food security, as this region contributes more than 40% of the rice procured by the Indian government for distribution to the public (Dhillon et al., 2010). Water and labor for rice cultivation are becoming increasingly scarce in north-west India due to the over-exploitation of ground water (Rodell et al., 2009), and increasing demand for labor from industrial and social sectors (Chauhan et al., 2012).

One technology that significantly reduces labor and irrigation water requirements for growing rice is direct drilling of rice i.e., dry-seeded rice (DSR) into nonpuddled soil, followed by alternating wetting and drying (AWD) water management (Mahajan et al., 2012).Whilst DSR addresses some of the problems associated with labor and water shortages (Mahajan and Chauhan, 2013), there is often a yield penalty compared to puddled transplanted rice (PTR) (Mahajan et al., 2010, 2013; Sudhir-Yadav et al., 2011). The unavailability of high yielding varieties adapted to DSR, including reduced

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sink size and delayed sowing in response to erratic rains, are the main obstacles to achieving high yields in DSR.

Currently, rice varieties bred for flooded, transplanted conditions are being used in DSR systems of north-west India, and not having been developed specifically for DSR systems, these varieties are not able to achieve their potential crop productivity, particularly in response to varied sowing dates (Balwinder-Singh et al., 2015). Under DSR conditions, high-yielding lowland rice varieties have shown great potential to save water, but with a severe yield penalty (McCauley, 1990; Peng et al., 2006; Mahajan et al., 2011). In 2006, Punjab Agricultural University, Ludhiana, India, initiated a special breeding program to develop rice varieties adapted to direct seeding in irrigated systems. From the breeding material, recombinant inbred lines (RILs) were also developed. Since grain development conditions and crop dynamics are different under DSR (Sudhir-Yadav et al., 2011), it was important to evaluate possible genotypic differences of these lines in response to varied sowing dates. In DSR, optimum sowing timing is critical to achieving high yields and also has an important impact on irrigation requirement, evapotranspiration (ET) and crop water productivity (Balwinder-Singh et al., 2015). Crop water productivity is defined as water productivity with respect to ET, kg grain m^{-3} of water lost as ET. However, optimum sowing times will vary with location and genotype (Bruns and Abbas, 2006; Sha and Linscombe, 2007).

For breeding of high yielding and less water requiring genotypes for DSR in north-west India, there is a need to understand behavior of contrasting genotypes (bred under PTR and DSR) at varied sowing dates. Biomass is produced by conversion of light energy into plant dry matter. Extending the period of crop growth, and therefore the total amount of solar radiation intercepted by rice plants, is the simplest way to increase total crop photosynthesis, biomass production, and grain yield. However, scope for increasing crop growth duration is limited for DSR in north-west India due to the urgent need to reduce ET to diminish the rate of groundwater depletion (Humphreys et al., 2010).The preferred sowing time to reduce crop water requirement (ET) is during the second fortnight of June, 15–20 days before the onset of monsoon (July) (Humphreys et al., 2008; Hira, 2009; Mahajan et al., 2009a,b).

It is worthwhile mentioning here that early sowing of DSR in the period of peak evaporative demand (May) increases the water requirement for rice, but on the other hand, delayed dry seeding of long duration varieties results in late sowing of the following wheat crop, causing reductions in wheat yield (Balwinder-Singh et al., 2015). Late planting of wheat in north-west India is reported to cause yield losses of 1–1.5% per day, because of poor grain filling at high temperatures (Ortiz-Monasterio et al., 1994). Therefore, determining an optimum sowing time for newly developed DSR genotypes of shorter duration may improve the productivity of rice–wheat systems.

The sink size is a limited factor for enhancing the productivity of DSR. Research is needed to determine optimum sowing dates for DSR genotypes for improved assimilation and nutrient uptake, in order to fill physiological gaps that limit the sink size and productivity in DSR. Grain filling in DSR is limited by the low contribution of post-anthesis assimilates (Mahajan and Chauhan, 2016), and it may be further influenced by varied sowing times. Higher yields of rice genotypes can be promoted by increasing total biomass production, harvest index, or both. Increasing biomass production requires an optimum leaf area index (canopy intercepts approximately 95% of the incoming solar radiation), coupled with an appropriate canopy architecture, ensuring better light interception, high photosynthetic efficiency and high dry matter accumulation, especially at early crop growth stages. An improvement in the harvest index can be achieved mainly by increasing the number of spikelets per unit land area (sink size) and the percentage of filled grains. Important factors in achieving this include high photosynthetic rates during the grain filling period, efficient storage of non-structural carbohydrates in the culm and leaf sheath before heading and their efficient translocation to grain, sink strength (ability of the grain to accept carbohydrates), and longer duration of grain filling (Horie et al., 2003). It was hypothesized that all these traits might be influenced by altering sowing dates. However, there is a paucity of experimental data on the ideal sowing time for improved assimilation and translocation of genotypes specifically designed for DSR in the irrigated ecology of north-west India. This research needs to be conducted for generating preliminary physiological data related to the performance of these newly designed DSR genotypes. Such information will provide a sound scientific basis for the conduct of research to develop new genotypes for DSR and for effective and sustainable agronomic practices for DSR in South Asia, including north-west India, and thus establish appropriate information systems to support better decision making.

The objectives of this study were: (1) to assess dry matter and nitrogen accumulation, and nitrogen translocation, of selected genotypes in response to sowing dates,(2) to identify the factors underlying high yielding genotypes, by comparing sink production in DSR, (3) identify possible associations between sowing dates and genotypes to maintain or increase grain yield and increase the crop water productivity in DSR, and (4) to assess the average growth rate of newly-developed DSR genotypes for their suitability in multiple cropping systems.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the research farm of Punjab Agricultural University (PAU), Ludhiana, India (30°88/N, 75°80/E; 247 m above sea level), in 2014 and 2015. The rice growing season (mid-June to September) coincides with the monsoon rains. The average annual rainfall is 734 mm, 85% of which falls during the monsoon season. The soil at the experimental site was a Fatehpur loamy sand (Typic Ustipsament): pH 7.2; total N content, 0.042%; organic C content, 0.38%; 0.5 N $NaHCO_3{}^{-1}$–extractable P, 5.2 $\mu g\, g^{-1}$; and NH_4OAc extractable K, 30 $\mu g\, g^{-1}$. The groundwater depth at the site was below 25 m and the water was non-saline. The soil had a bulk density of 1.58 $Mg\, m^{-3}$ and the saturated hydraulic conductivity was 24 $mm\, h^{-1}$. The site was under a lowland rice–wheat (*Triticum aestivum* L.) cropping system for 5 years before the establishment of the experiment.

2.2. Weather parameters

Daily rainfall, pan-evaporation, sunshine hours, wind speed, relative humidity, solar radiation, and maximum and minimum temperatures were measured at the PAU meteorological station, located approximately 200 m away from the experimental site.

2.3. Experimental design

The experiment was laid out in a split-plot design with 12 treatments (3 × 4), replicated three times. The main factor comprised three sowing dates (1, 10, and 20 June), and the subfactor comprised four genotypes (PR-115, PR-121, RIL-367, and RIL-1649). Genotypes were selected on the basis of their early maturity and high yields in our previous breeding trials in DSR (data not shown). All the selected genotypes were indica rice. Genotype PR-115 (the best check for DSR) and PR-121 (the best check for puddled transplanted rice) were inbreds released by PAU and widely used by the growers of this region for DSR as well as PTR. RIL-367 and RIL-1649 were the new recombinant inbred lines selected from the two RIL populations of DSR genotypes.RIL-367 was selected from the cross of PAU