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# Weed competitive cultivars as a component of integrated weed management in direct-seeded rice: A Review

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**ABSTRACT**

Lower input (water, labour and energy) demand of direct-seeded rice (DSR), compared to conventional puddled transplanted rice (PTR), is the key driver for expanding the DSR area in many countries of Asia. The success of DSR, however, lies in effective management of weeds. For sustainable weed management, DSR systems need management interventions other than herbicides. Identification and introduction of weed competitive rice cultivars offers one of the potential and safe approaches to manage weeds in DSR. This article reviews the research on role of weed-competitive rice cultivars in managing weed infestation in DSR. It is reported that higher early vigour on account of rapid early growth, leaf area and biomass accumulation; plant height, root and shoot competition; crop duration and allelopathy *etc.* are the key traits associated with weed competitiveness. We aim to provide a logical perspective of exploring and exploiting the competitiveness of rice cultivars to strongly compete for resources with the associated weed flora to overcome stress, which is essential to realize potential yields in DSR system.

## INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major cereal crops structuring the staple diet for more than half of the world's population (Kumar 2018, Khir *et al.* 2019). More than 90% of rice is produced and consumed in Asia (Singh *et al.* 2019a). Globally, India is the second largest producer and consumer of rice in the world after China, which accounts for 21% of the world's total rice production (APEDA 2021). Hence, rice is the lifeline for millions of people. The global population is predicted to reach 9 billion and food demands are projected to rise by 70-100% by 2050 (FAO 2017, Huang *et al.* 2017). Hence, there is a need to increase rice productivity with limited natural resources (as shrinking natural resources pose a challenge to attain peak productivity) to attain food security.

Rice is mainly established by two methods (1) transplanting and (2) direct seeding. Puddled transplanted rice (PTR) is water, energy and labor intensive (Jat *et al.* 2019, Shekhawat *et al.* 2020). The direct-seeding of rice (DSR) skips practices like nursery raising, puddling and transplanting, and thus reduces both labour and irrigation requirement (Bhullar *et al.* 2018). Therefore, DSR is gaining popularity over PTR due to increased economic and ecological benefits such as saving of labour (8 to 60%), irrigation water (12 to 60%), less drudgery, early maturity (7-10 days), reduced cost of cultivation, improved fertilizer use efficiency, offers better soil environment and improves the productivity of succeeding crops, and less emission of greenhouse gases (Gathala *et al.* 2011, Jat *et al.* 2014, Chakraborty *et al.* 2017, Kaur and Singh 2017, Dhillon and Mangat 2018, Kumar *et al.* 2018, Ranbir *et al.* 2019, Basavalingaiah *et al.* 2020). In parts of India, Covid-19 pandemic situation severely affected the labor movement, which delayed the crop establishment and made farmers to explore the alternative rice establishment methods such as direct-seeding and transplanting of rice using machinery (Shirsath *et al.* 2020). As the cost of irrigation water and labour are likely to rise in future which will not only make DSR economically more attractive option but will also tend to increase area under DSR (Hossain *et al.* 2016, Dhillon *et al.* 2021a).

The higher weed infestation in DSR due to absence of the size (age) differential between the crop and the weeds and the lack of standing water for suppressing weed growth at crop establishment (Shekhawat *et al.* 2020, Panneerselvam *et al.* 2020, Chauhan 2012, Kumar *et al.* 2013) are among major constraints in the adoption of DSR as high weed infestation significantly reduces the grain yield (Matloob *et al.* 2015, Chauhan *et al.* 2015, Priya *et al.* 2017, Sandhu *et al.* 2019). Direct sown fields are reported to have more diverse weed flora than transplanted rice fields (Dhillon and Mangat 2018). Weed flora in DSR broadly includes grasses, sedges and broad leaf weeds (BLW) (Kumar 2018, Singh *et al.* 2019b, Sharma *et al.* 2020). Major grasses causing yield losses includes *Echinochloa colona* (L.), *Echinochloa crus-galli (*L.), *Leptochloa chinensis* (L.), *Dactyloctenium aegyptium* (L); sedges includes *Cyperus iria (*L.), *Cyperus difformis (*L.), *Fimbristylis miliacea (*L.); BLW includes *Eclipta prostrata* (L.), *Sphenoclea zeylanica (*G.) and *Ludwigia hyssopifolia* (G. Don.). Among 1800 weed species reported in rice, grasses and sedges are found predominant (Banik *et al.* 2020). Weeds cause 50-60% of yield losses in PTR and 70-80% in DSR (Pooja and Saravanane 2021, Das *et al.* 2021, Banik *et al.* 2020). In India, yield reduction of 20-85% due to presence of weeds have been reported in DSR fields (Banik *et al.* 2020) which indicates that proper weed management is a key to the success of DSR. Kumar and Ladha (2011) reported 15-100% yield reduction due to presence of weeds in DSR. Yield reductions up to 40-100% are reported under heavy weed infestations (Pooja and Saravanane 2021, Shekhawat *et al.* 2020). Competition offered by weeds for sunlight, water, space and nutrition not only reduces the crop yield but significantly deteriorates the quality of produce (Verma *et al.* 2015). Mixing of rice seeds with weedy rice during harvesting impairs the milling quality of rice (Ottis *et al.* 2005). Hence, the effective control of more intensified and diversified weed flora are major concerns for sustained productivity of rice using direct-seeding method of establishment.

## Significance of competitive cultivar in managing weeds in DSR

Chinnusamy *et al.* (2000) reported critical period of crop weed competition in medium duration genotypes under DSR to be between 15-45 days after sowing (DAS). Similar data on critical period of weed control in DSR has been revealed by Chauhan and Johnson (2011), which is between 14-41 DAS. Likewise, Raj and Syriac (2017) reported that the weed competition beyond 15 DAS in DSR can significantly reduce crop yields. Control of weeds or suppression of their competitive ability against crop before the critical period, significantly increases the quality and yield of a crop (Fahad *et al.* 2015, Hussain *et al.* 2015).

Weed management during the critical period of crop weed competition in DSR can be accomplished by various physical, chemical or cultural practices (Banik *et al.* 2020). Physical methods like hand weeding was found to be the most effective and eco-friendly method of weed control, but due to slow, cumbersome and labour intensive nature, it proved uneconomical (Dnyaneshwar *et al.* 2018). Similarly, adoption of agronomic manipulations in crop production is effective as a cultural weed control method but have limited scope under dense and diverse weed conditions. Although herbicides may provide a satisfactory control of weeds, but intensive herbicide use can cause environmental contamination and may increase the risk of evolution of herbicide resistance in weeds (Dass *et al.* 2017, Mahajan and Chauhan 2013). Therefore, eco-friendly approaches like; selection of weed competitive genotypes (Zhao *et al.* 2006a, Ramesh *et al.* 2017), alteration of seed rates (Anwar *et al.* 2011, Dass *et al.* 2017) and stale seed-bed (Chauhan 2012, Singh *et al.* 2016) could be exploited to reduce selection pressure and manage the herbicide resistance in weeds (Lutman *et al.* 2013, Chauhan 2020).

Amongst these approaches, use of competitive cultivars for weed control is the most important non-monetary strategy which can reduce herbicide use, will minimize environment degradation and delay evolution of herbicide resistance in weeds (Mahajan and Chauhan 2013). Many good weed competitive rice cultivars have been reported in different regions, such as, '*Apo*' and '*UPLRi-7*' with rapid seedling and early biomass in Philippines (Zhao 2006b), *Oryzica sabana* 6 with high leaf area index and tiller density in Latin America (Fischer *et al.* 2001), M-202 with high leaf area and root biomass in North America (Gibson *et al.* 2003).

## Weed competitive cultivars

Weed-competitive ability is a complex trait as it is the result of the interaction among several desirable traits. Commonly, it's a challenge for a plant breeder to develop weed-competitive crop cultivar without dropping any other significant trait. Consequently, it is imperative to determine the complexity of the mechanisms and agro-morphological traits that confer weed competitiveness to develop superior weed-competitive rice cultivars (Dimaano *et al.* 2017, Chauhan *et al.* 2015). Weed competitive cultivars are able to grow better even in the presence of weeds by providing them competition for survival without much loss of yield and quality of crop. It may be because of the advantage due to some added morphological traits like bigger leaves which can shade growing weeds deep roots for better water uptake (Schreiber *et al.* 2018) and other identified traits/characteristics (**Table 1**).

Competition between crop and weed is natural, abundant and undesirable in agriculture (Dass *et al.* 2017). Therefore, using a competitive plant that can efficiently suppress the growth of weeds around it, without sacrificing its yield, can be used as a viable option. The crop cultivars vary widely in their ability to compete with weeds within a single species and these may perform differently in different regions and growing conditions. Hence, selection for competitive cultivars is a very difficult task (Dass *et al.* 2017).

The genotypic differences were found to exist in relative competitiveness of cultivars in different crops and the use of intervention of weed competitive ability of cultivars as a part of integrated weed management systems has been experimented. Rice cultivars with early vigour, rapid growth, high leaf area index *etc*. were found to be responsible for crop competitivenes (Dass *et al.* 2017). Hence, breeding of crop cultivars for their ability to suppress weeds and its exploitation for weed management would be effective (Korres 2018). Development and use of such competitive cultivars in crops will reduce the need for mechanical weed control (Sardana *et al.* 2017), besides reduction in herbicide load and ultimately cost of production.

**Table 1. The traits/characteristics reported to be associated with rice competitiveness against weeds**

| Traits/characteristics | References |
|---|---|
| Rapid growth in early stages | Zhao *et al.* 2006a |
| Early stages leaf area | Namuco *et al.* 2009 |
| Early seedling vigour | Mahajan and Chauhan 2013, Shekhawat *et al.* 2020 |
| Biomass in early stages | Namuco *et al.* 2009 |
| Plant height: Tall | Prasad 2011, Mahajan *et al.* 2014, |
| Plant height: Short | Fukai 2002 |
| Shoot competition | Chauhan and Johnson 2010 |
| Root competition | Perera *et al.* 1992 |
| Root characteristics | Schreiber *et al.* 2018, |
| Crop duration | Dingkuhn *et al.*1999 |
| Tillers per plant | Zhao *et al.* 2006b, Shekhawat *et al.* 2020 |
| Allelo-chemicals/ Allelopathy | Shrestha *et al.* 2020 |

**Use of weed competitive cultivars**: Morphological, physiological and biochemical traits collectively control plants competitiveness. Use of strong weed competitive cultivars is a low cost and environmentally safe strategy for weed management (Shekhawat *et al.* 2020, Dass *et al.* 2017, Singh *et al.* 2016). Such cultivars reduce the weed infestation through strong competition for limited resources, production of allelo-chemicals (chemical exudates to reduce growth) (Shrestha *et al.* 2020). In general, there are two aspects of cultivar competitiveness, weed suppression and weed tolerance ability (Hansen *et al.* 2008). Weed tolerance is the ability to maintain high yields despite weed pressure while weed suppression is the ability of cultivar to reduce seed production in weeds or to suppress the weed growth *via* competition (Raj and Syriac 2017). Weed suppression is more desirable than weed tolerance as it avoids the seed buildup in soil for future infestations. The inclusion of medium-duration rice hybrid resulted in higher rice and system yields (Singh *et al.* 2020). Wang *et al.* (2002) found that "competitive" rice cultivars excelled the "non-competitive" cultivars in grain yield by 7-9 per cent. Hence, these can serve as a potential tool for long-term weed control in DSR systems through weed suppression.

**Characteristics of weed competitive cultivars**: The traits in rice that are likely to be most helpful for weed management and related to weed competitiveness includes; seed size, quicker emergence, plant height, high and early seedling vigour with rapid leaf area development during the early vegetative stage for weed suppression, rapid growth, high tillering ability, orientation of leaves (droopy), high early biomass accumulation rates, high leaf area index , rapid ground cover by canopy, deep and prolific roots, ability to withstand biotic and abiotic stresses, cultivars having an allelopathic effect, early maturity, herbicide-resistance and many more (Mahajan and Chauhan 2013, Shekhawat *et al.* 2020, Singh *et al.* 2016, Dass *et al.* 2017, Shrestha *et al.* 2020). Chauhan *et al.* (2015) suggested that genotypes with a larger leaf area could be integrated with other weed management strategies to achieve sustainable weed control in DSR production systems. This shows that there is a need to integrate cultivars with different traits for better outcomes. Hence, whole plant needs to be studied to understand the competitiveness of a genotype. Some information complied on potential traits for weed competitiveness in rice reported by different researchers has been specified in **Table 1**. Several weed competitive cultivars were identified by researchers (**Table 2**).

**Table 2. Weed competitive rice cultivars**

| Competitive genotypes | References |
|---|---|
| Oryzica sabana 6 | Fischer *et al.* 2001 |
| M-202 | Gibson *et al.* 2003 |
| Apo and UPLRi-7 | Zhao *et al.* 2006a |
| CG20 | Moukoumbi *et al.* 2011 |
| R-1033-968-2-1 and Kakro | Chaudhari *et al.* 2014 |
| PR 120 | Mahajan *et al.* 2014 |
| IR 84899-B-183-CRA-19-1 and CR Dhan 40 | Kumar *et al.* 2016 |
| PI312777, PI338046, and RONDO | Shrestha *et al.* 2020 |
| B2 and B81 (weedy rice accessions) | Shrestha *et al.* 2020 |
| IR5 orIR442-2-58; Prabhat and Krishna Hamsa | Shekhawat *et al.* 2020 |

**Plant growth habits**

The traits associated to greater light interception by rice are plant height, tillering ability, leaf morphology while other characteristics like root density and biomass are important in terms of nutrients capture by rice. The early and rapid ground cover during early stages by rice cultivar results in weed biomass reduction (Schreiber *et al.* 2018, Zhao *et al.* 2006a). The strong weed suppression by Apo as compared to other aerobic genotypes like IR60080 and IRAT 216 was due to faster canopy cover by each plant (Zhao *et al.* 2006a). At early growth stages, leaf area and dry matter of rice seedling were found to be correlated with plant competitiveness (Namuco *et al.* 2009). The rice inbreds and hybrids differ in their growth and weed competitive abilities. The rice hybrids yielded 15-25 per cent more over inbred and demonstrated comparatively higher weed suppression (Chauhan *et al.* 2012, Dass *et al.* 2017). The plant vigour was found to indirectly affect the grain yield by offering strong competition to weeds (Shekhawat *et al.* 2020, Mahajan and Chauhan 2013).

**Plant stature**: Tall statured genotypes with drooped leaves were found to be more competitive although they were poor yielder than short and erect leaved genotypes (Kumar 2018). The tallest cultivar CR Dhan 40 was found successful in suppressing weeds (Kumar *et al.* 2016). The tall traditional cultivars were reported to have smothering effect against weeds (Prasad 2011) as they can intercept greater proportion of photosynthetically active radiations (PAR) for effective weed suppression while short statured cultivars were found to be overpowered by aggressive weeds and thus yields low. However, tallness is not considered a desirable trait for future rice breeding due to its susceptibility to lodge under nitrogen rich conditions and more straw biomass, the disposal of which is a serious issue in many countries including north western India. This disadvantage can be managed by considering the use of semi dwarf genotypes with medium height and stiff stem as a better option (Fukai 2002, Shekhawat *et al.* 2020).

The better competitiveness of rice cultivar '*Mahsuri*' than '*IR 8*' was reported to be due to its height and more relative leaf area growth rate (Bastiaans *et al.* 1997). A negative correlation was found between plant height and relative yield losses under partial weedy conditions (Mahajan *et al.* 2014). The plant height plays a positive part in weed suppression with a negative correlation with weed biomass (Ekeleme *et al.* 2007). However, some short stature cultivars of rice were found to be better competitors and can compete like tall cultivars (Fischer *et al.* 2001, Fukai 2002). Hence, for DSR, the stature of cultivar between traditional tall and intermediate heights is more suitable (Take-tsaba 2018).

**Tillering ability**: Tillering is among foremost traits in rice which significantly affects biological and economic yields. It is evident that tillering in rice is governed by multiple factors like genetic character, cultivar duration, seedling age at transplanting, time of transplanting/seeding, seed rate and spacing, crop establishment method, in-season crop management factors (water-, nutrient-, weeds-, pest- management etc.), climate, etc (Dhillon *et al.* 2020 and Dhillon *et al.* 2021b). Occurrence of weeds substantially affects the tillering which subsequently leads to loss in yield and quality. Panicle density is the true representation of plant population which finally contributed to the yield.

Saito *et al.* (2010) found that cultivars with more biomass, produced more tillers during vegetative growth stage showed strong weed suppressive ability. The tillering, plant height and grain yield were highly positively correlated with weed-competitiveness (Moukoumbi *et al.* 2011, Zhao *et al.* 2006 b). However, Fischer *et al.* (2001), found no relationship between plant height and tiller ability regarding weed-competitiveness. Sunyob *et al.* (2015) also observed that tillering ability is not significantly important for weed competition.

**Above and below ground competition**: Both shoot and root competition of rice were found to be important for competing with against weeds. The better shoot competition helps in greater interception of light and, on the other hand, better root competition will help the rice to absorb water and nutrients more vigorously than weeds. Chauhan and Johnson (2010) reported that magnitude of reduction in growth and yield of rice plant growing along weeds (*Echinocloa colona* or *Ludwigia* spp.) was more due to shoot competition than root competition indicating shoot competition as a primary mechanism in determining the competitive ability.

Very few investigations have been made on below ground part studies in cereal crops. It may be partly due to difficulty associated in studying below ground parts and measuring root traits (Andrew *et al.* 2015). However, studies have revealed the importance of root competition to be stronger than competition for light, specifically for nitrogen in many cereal crops (Lamb *et al.* 2007). Rice traits associated with the development of root systems are found important in respect to absorb more nutrients (Schreiber *et al.* 2018, Shekhawat *et al.* 2020). Role of below ground parts is important for competitive success as nutrient uptake during initial stages reduces the nutrition availability for nearby plants, hence offering competitive advantage.

**Duration to maturity**: The time of flowering and duration of crop have proved to be useful in selection of weed competitive rice cultivars as they help to handle initial competition. The early maturing short duration hybrids were reported as more competitive than long duration genotypes due to their ability of early growth and ground cover which was responsible for better smothering effect of cultivars on weeds (Namuco *et al.* 2009, Mahajan *et al.* 2011). Similalry, Sunyob *et al.* (2015) concluded that early maturing varieties had an advantage over weed competition *i.e.* shorter duration varieties minimize the effect of weed competition. On contrary, Rodenburg *et al.* (2009) reported that genotypes with late maturity have greater weed suppression abilities. Chaudhari *et al.* (2014) reported genotypes R-1033-968-2-1 and Kakro as high yielder under both weedy and weed free conditions due to their early seed vigour, tall height, high yield potential and good competitive ability.

The limited information of suitable weed-competitive cultivars is the major constraint to utilize rice cultivars as a component of integrated weed management in DSR. Hence, more research is needed to develop and identify high yielding weed-competitive cultivars suited to DSR conditions.

## CONCLUSIONS

The area under DSR is more likely to increase in future due to both water and labour crisis. Risk free crop establishment coupled with efficient weed management are the key to success of DSR. Weeds need to be managed for wider-scale adoption and better yield realization in DSR. Competitive rice cultivars could provide a potentially attractive, non-monetary, socially acceptable, technically feasible and environmentally safe weed management option which can minimize environment contamination and delay weed resistance by curtailing the herbicide usage. Competitive rice cultivars suppress the growth of weeds on account of variation in growth habits, morphological advantages offered by cultivar or by strong competition etc. Hence, there seems tremendous scope to incorporate these competitive rice cultivars in DSR systems to manage weeds. As part of integrated weed management strategies, weed competitive inbreds or hybrids should be included all together with other chemical, mechanical and cultural measures as a sustainable approach. In near future, it is proposed to consider the weed competitive score as a key trait along with other criteria for DSR breeding and varietal release programs operational in different geographies across the country.

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