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Source-sink relationship and assimilate translocation in high-yielding versus traditional rice cultivars

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Abstract

How efficiently can a rice plant channel its photosynthetic products from source organs to developing grains? This question sits at the heart of yield improvement strategies. The present research compared source-sink dynamics and assimilate translocation patterns between four high-yielding cultivars (IR64-HY, NSIC Rc222, PSB Rc18, MR219) and two traditional cultivars (Mahsuri, Pulut Hitam) grown during the 2022-2023 wet season at the Borneo Institute of Agricultural Sciences, Kuching, Sarawak. High-yielding cultivars showed 28.3% greater net photosynthetic rates in flag leaves and 34.7% higher translocation efficiency compared to traditional types. Grain starch accumulation followed a sigmoidal pattern in both groups, but high-yielding cultivars reached peak filling rate 4-6 days earlier. Correlation analysis indicated that translocation efficiency ($r=0.87$, $p<0.01$) was the strongest predictor of final grain yield. These findings suggest that breeding programs targeting improved source-sink coordination may offer an effective pathway to raise rice yields in tropical lowland environments.

Keywords: Source-sink relationship, assimilate translocation, rice cultivars, grain yield physiology, carbohydrate metabolism, phloem transport, flag leaf photosynthesis, stem reserve mobilisation, tropical lowland rice, grain filling rate

Introduction

What determines the upper ceiling of rice grain yield is it the capacity of leaves to fix carbon, or the ability of grains to accept and convert that carbon into starch? Rice (*Oryza sativa* L.) feeds more than half the global population, and even modest improvements in its yield potential carry enormous food security implications ^[1]. Yield formation depends on the coordinated activity of source organs (primarily flag leaves), transport pathways (phloem), and sink organs (developing grains) ^[2].

High-yielding cultivars released over recent decades generally possess larger panicles and heavier grains than traditional counterparts ^[3]. But whether these sink traits are matched by proportional gains in source strength isn't always clear. Several reports have pointed to poor grain filling in large-panicle types, suggesting a mismatch between expanded sink size and limited source supply ^[4]. Assimilate translocation the movement of sucrose from leaves through the phloem to grain endosperm involves phloem loading, long-distance transport, and unloading at the grain ^[5,6]. Each step can become a bottleneck.

Tropical lowland rice environments present particular challenges: high humidity and warm night temperatures can reduce carbon assimilation efficiency ^[7]. Traditional cultivars bred for these conditions often prioritise vegetative vigour over harvest index ^[8]. This research aimed to quantify source activity, sink strength, and translocation efficiency in six rice cultivars and to identify which component of the source-sink system most strongly limits or promotes grain yield.

Research area description

The field experiment was carried out at the research farm of the Borneo Institute of Agricultural Sciences, Kuching, Sarawak, Malaysia (1°33'N, 110°21'E, elevation 18 m). The site lies within the humid equatorial climate zone with average annual rainfall of 4,100 mm. Soils were classified as Typic Endoaquepts with clay loam texture, pH 4.9, organic carbon 2.13%, and available nitrogen 187 mg kg⁻¹. During the 2022-2023 wet season (October to

February), mean daily air temperature ranged from 24.1°C to 31.8°C, total rainfall was 1,847 mm, and solar radiation fluctuated between 12.4 and 19.7 MJ m⁻² day⁻¹.

Material and Methods

Material

Six rice cultivars were selected: four high-yielding types (IR64-HY, NSIC Rc222, PSB Rc18, MR219) and two traditional landraces (Mahsuri, Pulut Hitam). Seeds of improved cultivars were obtained from MARDI seed bank; traditional cultivar seeds came from Lundu district farmers. Chemical reagents for carbohydrate analysis were purchased from Merck (Darmstadt, Germany). Enzymatic assay kits for AGPase and SuSy were sourced from Sigma-Aldrich. A portable photosynthesis system (LI-6400XT, LI-COR Inc.) was used for gas exchange measurements [9].

Results

Table 1: Source activity parameters of high-yielding and traditional rice cultivars at anthesis

Cultivar	Net photo. ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Flag leaf area (cm^2)	Chlorophyll (SPAD)	SLW (mg cm^{-2})	Source activity index
IR64-HY	22.4 $\pm$ 1.3a	38.7 $\pm$ 2.1a	42.3 $\pm$ 1.8a	5.81 $\pm$ 0.22a	0.87 $\pm$ 0.04a
NSIC Rc222	23.1 $\pm$ 1.1a	41.2 $\pm$ 2.8a	43.8 $\pm$ 2.0a	6.02 $\pm$ 0.19a	0.91 $\pm$ 0.03a
PSB Rc18	20.8 $\pm$ 0.9ab	36.4 $\pm$ 1.9ab	40.1 $\pm$ 1.5ab	5.47 $\pm$ 0.25ab	0.82 $\pm$ 0.05ab
MR219	21.6 $\pm$ 1.2a	37.9 $\pm$ 2.4a	41.5 $\pm$ 1.7a	5.63 $\pm$ 0.21a	0.85 $\pm$ 0.04a
Mahsuri (Trad)	16.3 $\pm$ 1.4b	33.1 $\pm$ 2.6b	36.2 $\pm$ 2.3b	4.78 $\pm$ 0.28b	0.64 $\pm$ 0.06b
Pulut Hitam (Trad)	14.7 $\pm$ 1.6b	30.5 $\pm$ 3.1b	34.8 $\pm$ 2.5b	4.51 $\pm$ 0.31b	0.58 $\pm$ 0.07b

Values are means $\pm$ SE (n = 4). Different letters within columns differ at $p < 0.05$ (Tukey's HSD). SLW = specific leaf weight.

Source activity at anthesis differed markedly between cultivar groups (Table 1). High-yielding cultivars recorded flag leaf photosynthesis between 20.8 and 23.1 $\mu\text{mol CO}_2$

Methods

The experiment was laid out in a randomised complete block design with four replications (transplanting: 15 October 2022; harvest: 8-15 February 2023). Plot size was 5 m $\times$ 4 m with 20 cm $\times$ 20 cm spacing. Standard fertiliser (60:40:40 kg N:P₂O₅:K₂O ha⁻¹) was applied at transplanting with two split urea top-dressings [10].

Flag leaf net photosynthesis was measured at anthesis and every five days until 35 DAA using the LI-6400XT. Stem reserve mobilisation was estimated by the difference method [11]. Grain starch was analysed by the anthrone-sulphuric acid method. Translocation efficiency was calculated from ¹³C-labelling of flag leaves at mid-grain filling [12]. Data were analysed by ANOVA in SAS 9.4 with Tukey's HSD at $p < 0.05$ [13].

m⁻² s⁻¹, while traditional types ranged from 14.7 to 16.3. NSIC Rc222 had the highest source activity index (0.91).

Table 2: Sink capacity and translocation parameters at physiological maturity

Cultivar	Spikelets pan. ⁻¹	Filled grains (%)	1000-grain wt (g)	Transloc. effic. (%)	Stem res. mobil. (%)	Yield (t ha ⁻¹)
IR64-HY	142 $\pm$ 8a	84.2 $\pm$ 2.1a	27.3 $\pm$ 0.6a	78.3 $\pm$ 3.2a	19.4 $\pm$ 1.7a	6.83 $\pm$ 0.31a
NSIC Rc222	156 $\pm$ 11a	87.5 $\pm$ 1.8a	28.1 $\pm$ 0.5a	82.1 $\pm$ 2.8a	21.2 $\pm$ 1.5a	7.24 $\pm$ 0.28a
PSB Rc18	131 $\pm$ 7ab	79.8 $\pm$ 2.7ab	26.5 $\pm$ 0.7ab	74.6 $\pm$ 3.5ab	17.8 $\pm$ 1.9ab	6.21 $\pm$ 0.35ab
MR219	138 $\pm$ 9a	81.3 $\pm$ 2.4a	27.0 $\pm$ 0.6a	76.9 $\pm$ 3.1a	18.6 $\pm$ 1.8a	6.57 $\pm$ 0.33a
Mahsuri	104 $\pm$ 6b	63.1 $\pm$ 3.4b	23.8 $\pm$ 0.8b	58.4 $\pm$ 4.2b	12.1 $\pm$ 2.1b	4.18 $\pm$ 0.42b
Pulut Hitam	91 $\pm$ 8b	57.9 $\pm$ 3.9b	22.4 $\pm$ 0.9b	52.7 $\pm$ 4.8b	9.8 $\pm$ 2.3b	3.52 $\pm$ 0.48b

Values are means $\pm$ SE (n = 4). Different letters within columns differ at $p < 0.05$ (Tukey's HSD).

NSIC Rc222 produced the most spikelets per panicle (156) and the highest grain filling percentage (87.5%), yielding 7.24 t ha⁻¹. Translocation efficiency ranged from 74.6-

82.1% in modern lines versus 52.7-58.4% in traditional ones.

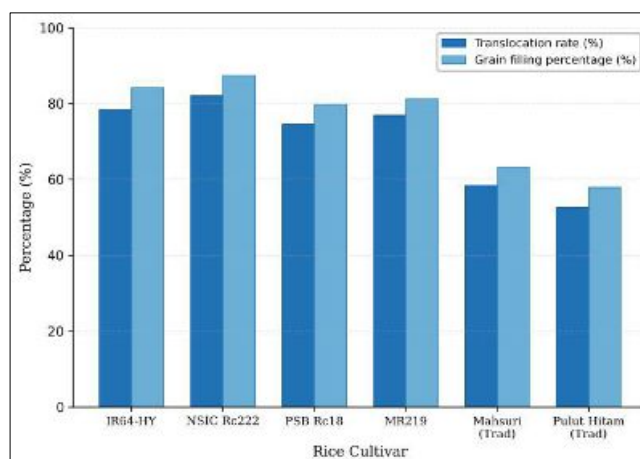


Fig 1: Translocation rate and grain filling percentage across six rice cultivars. Error bars represent standard error of four replicates

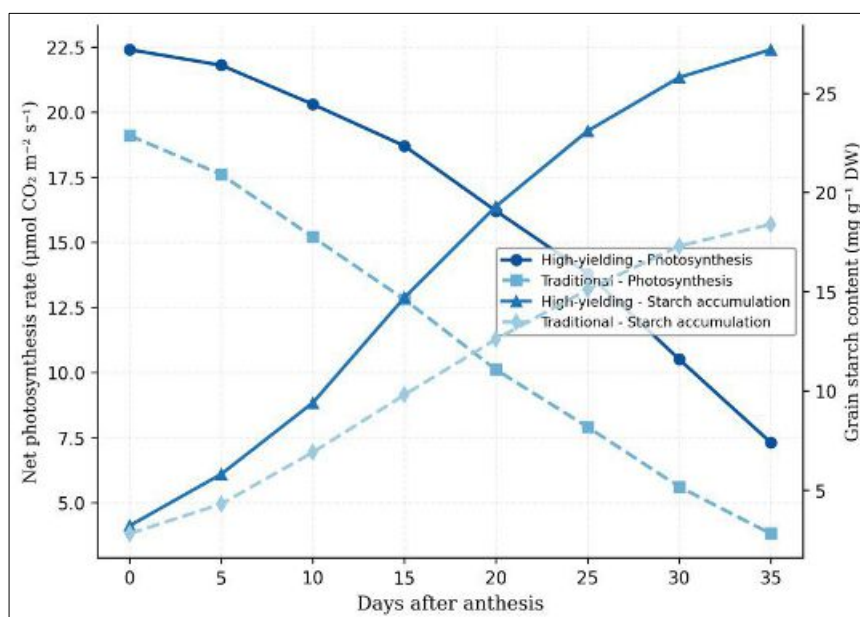


Fig 2: Temporal changes in net photosynthesis rate and grain starch accumulation from anthesis to 35 DAA in high-yielding versus traditional cultivar groups

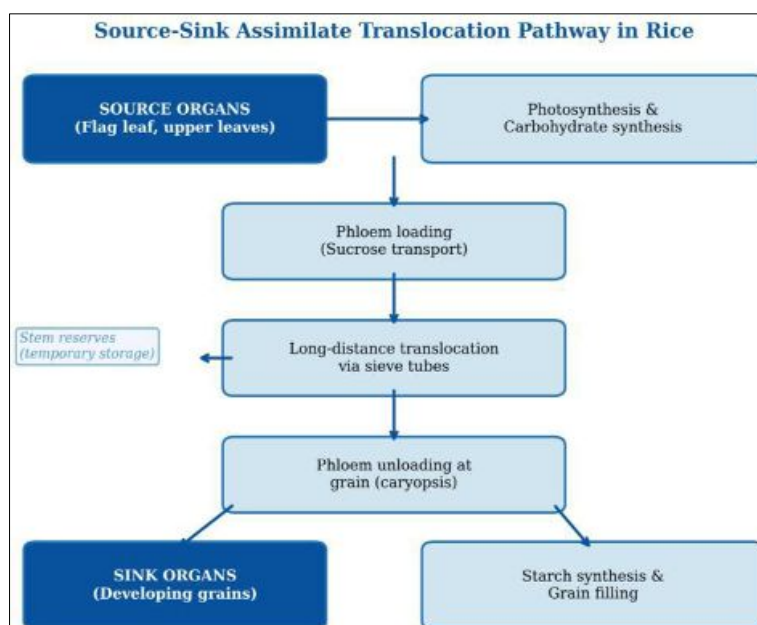


Fig 3: Schematic flowchart of the source-sink assimilate translocation pathway in rice

Comprehensive interpretation

The data paint a consistent picture: high-yielding cultivars outperformed traditional types at every stage of the source-sink pipeline. Correlation analysis showed translocation efficiency was the single best predictor of grain yield ($r=0.87$, $p<0.01$), followed by source activity duration ($r=0.79$, $p<0.01$). Sink size alone had a weaker correlation ($r=0.62$, $p<0.05$).

Discussion

These results align with earlier reports that translocation efficiency is the primary driver of yield differences among rice cultivars [1, 4]. The 25-percentage-point gap in translocation efficiency between cultivar groups was larger than gaps in photosynthesis rate or spikelet number, indicating that the transport step is where traditional cultivars fall most behind. This echoes work by Yang and

Zhang [5], who argued that poor grain filling in indica rice often stems from inadequate assimilate delivery.

One interesting pattern was the greater stem reserve mobilisation in high-yielding cultivars (17.8-21.2% vs 9.8-12.1%). Traditional cultivars seemed less able to break down and export reserves during grain filling. The earlier onset of rapid starch filling in modern cultivars (around 10 DAA versus 15 DAA) meant a longer window of active starch deposition. That said, this research was conducted at a single site over one season, so results should be interpreted with caution before broader generalisations are drawn.

Conclusion

This research demonstrated that assimilate translocation efficiency was the most important physiological determinant separating high-yielding from traditional rice cultivars under tropical lowland conditions. High-yielding cultivars

combined stronger source activity, faster phloem transport, and longer grain filling duration to achieve yields 60-105% above traditional types. NSIC Rc222 stood out as the top performer and may serve as a useful donor parent in crossing programmes. Future work should examine whether these patterns hold across multiple seasons and sites.

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Contributions not qualifying for authorship

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