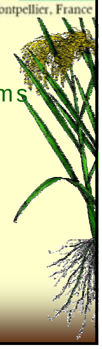
IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

Centre de coopération internationale en recherche agronomique pour le development
CIRAD
Montpellier, France

Sink regulation in hybrid rice: consequences for breeding programs and crop management



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Hybrid rice: consistently higher grain yield

- **Grain yield advantage: 10 to 15%**
- **Yield components increase: - higher shoot dry weigh**
- **- higher harvest index**

Observations from distinct experiments:

higher or similar grain yield and harvest index of hybrid

Significantly-low relation with shoot dry weight but higher values with hybrid

HI better related to grain yield than shoot dry matter

Year/ Season		GY (t/ha)	ShDW m^{-2}	HI	TilE
2007 DS	H (7)	11.03 a	2108 a	0.54 a	0.52 a
Transplanting	I (6)	9.48 b	1932 b	0.50 b	0.54 a
2006 DS	H (3)	8.45 a	1780 a	0.51 a	0.56 a
Staggered	I (3)	7.53 b	1634 a	0.45 b	0.55 a
2006 DS	H (2)	8.49 a	1587 a	0.55 a	0.63 a
AWD genotypes	I (3)	8.44 a	1611 a	0.52 b	0.62 a
2005 DS	H (2)	7.16 a	1959 a	0.45 a	0.41 b
Broadcasting	I (2)	5.94 b	1820 a	0.42 a	0.55 a
2004 WS	H (5)	5.93 a	1885 a	0.45 a	0.52 a
Wet season	I (7)	5.35 b	1748 b	0.42 b	0.49 a

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Hybrid rice: yield components of plants with same phenology

Comparing yield components of 4 hybrids and 4 inbreds with the same phenology: similar PI, flowering and maturity time, leaf emergence rate and culm elongation

Gen	GY t ha^{-1}	Pan no m^{-2}	FiGr no pan^{-1}	Grain size	ShDW g m^{-2}	HI	Sink size no m^{-2}	Gr Fill rate
H5	10.45	332	133	23.79	2276	0.54	60028	0.74
H6	10.77	329	137	23.96	2251	0.55	59424	0.72
H7	10.63	333	142	22.48	2015	0.52	65157	0.71
H8	10.73	309	142	24.35	2013	0.52	65118	0.68
I1	9.73	375	105	24.70	2113	0.51	46473	0.85
I9	9.17	331	106	26.01	1802	0.46	48448	0.71
I10	8.38	309	106	23.60	1854	0.50	46115	0.77
I12	8.72	301	109	26.55	2040	0.47	41621	0.74
Mean-H	10.65 A	326 A	139 A	23.65 B	2139 A	0.53 A	62432 A	0.73 A
Mean-I	9.00 B	329 A	109 B	25.22 A	1952 B	0.49 B	45664 B	0.77 A

Hybrid: higher biomass, sink size and harvest index triggered higher filled grain per panicle

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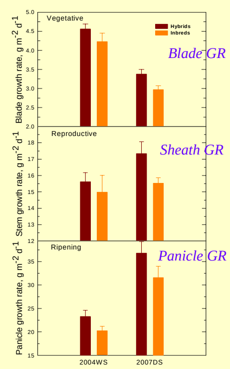
Higher biomass: which phases are involved?



Comparing crop growth rate of hybrids and inbreds of same phenology during the three phases of development

$$\text{Blade GR} = \frac{\Delta dw_{blade\ 2\rightarrow 1}}{\Delta time_{2\rightarrow 1}}$$

Higher growth rate is observed with the key organ in each of the 3 phases of development in both seasons

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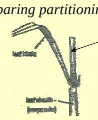
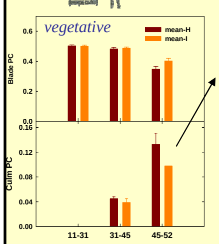
Higher sink size: better sink regulation before grain filling?

Comparing partitioning coefficients of hybrids and inbreds of the same phenology



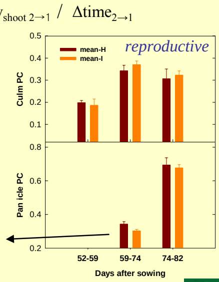
Calculation of blade partitioning coefficient:

$$\text{Blade PC} = \frac{\Delta dw_{blade\ 2\rightarrow 1} \;/\; \Delta time_{2\rightarrow 1}}{\Delta dw_{shoot\ 2\rightarrow 1} \;/\; \Delta time_{2\rightarrow 1}}$$



Hybrid: quicker increase in allocation to the culm around PI

Hybrid: quicker Increase in allocation to the Panicle before flowering



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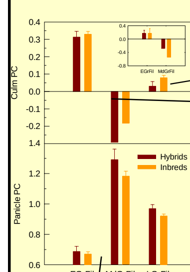
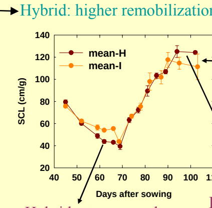
Higher harvest index: better sink regulation during grain filling?

Comparing partitioning coefficients of hybrids and inbreds of same phenology



Inbred: increase in culm biomass at the end of grain filling to bear the panicle

Hybrid: higher remobilization



Specific culm length:

$$SCL = \frac{\text{culm length}}{\text{culm dw}}$$

Hybrid: stronger allocation to the panicle during the whole phase

Hybrid: stronger culm at flowering

Hybrid: weaker culm at maturity

Hybrid: the stronger ability of the culm to store and remobilize biomass is likely to increase grain filling

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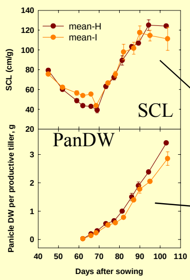
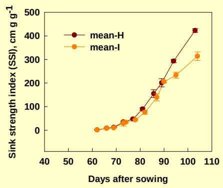
Higher harvest index: designing an improved index



Designing an index that accounts for the efficiency of the partitioning better than the harvest index: that integrates stem vigor (reverse of SCL) together with panicle dry weight without consideration of leaf and sheath dry matter: sink strength index

SSI = PaDW x SCL



Correlation of GY with	r
Stem-based SSI	0.95*
HI	0.90*
Shoot DM	0.71*
CGR at maturity	0.86*

Hybrid: a weaker stem bears a heavier panicle however, higher sensitivity to lodging

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Hybrid rice of shorter duration: yield components

Comparing yield components of hybrids of shorter duration than inbreds with all crop phases affected

Genotype	GY	Biomass at PM	HI	PanNB	FiGrNB.	ToGrNB	1000 seed wt
	t ha^{-1}	g m^{-2}		m^{-2}	pan^{-1}	m^{-2}	g
Hybrid							
H6	10.80	2093	0.54	310	145	62490	23.97
H12	10.76	2598	0.46	303	131	55241	27.13
H13	10.70	2149	0.52	290	134	48396	27.48
H14	11.18	1954	0.52	328	135	63142	25.11
Mean	**10.86 a***	**2205 a**	**0.51 a**	**308 b**	**136 a**	**57317 a**	**25.92 a**
Inbred							
I4	10.06	1904	0.52	338	124	57274	23.98
I11	10.18	2243	0.44	406	106	61014	23.69
I13	9.86	1905	0.51	369	121	59698	22.05
Mean	**10.03b**	**2017 a**	**0.49 a**	**371 a**	**117 b**	**59329 a**	**23.24 b**
LSD(0.05)	0.22	202	0.03	18.9	6.1	4457	1.17

Hybrid: higher biomass and harvest index but similar sink size
Individual seed size triggered higher yield

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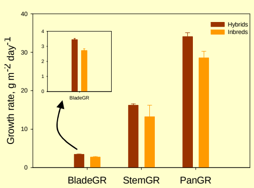
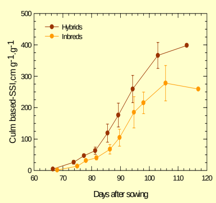
Hybrid rice of shorter duration: biomass accumulation and sink regulation





Hybrid: higher growth rate is observed with the key organ in each of the 3 phases of development in both seasons

Hybrid: more efficient biomass partitioning during the whole grain filling period

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Higher harvest index: designing an improved index

Using the sink strength index (SSI) to compare the efficiency of partitioning between hybrids and inbreds in a large set of situations

Year/ Season		GY (t/ha)	ShDW m^{-2}	HI	SSI (g cm g^{-1})
2007 DS	H (7)	11.03 a	2108 a	0.54 a	175 a
Transplanting	I (6)	9.48 b	1932 b	0.50 b	145 b
2006 DS	H (3)	8.45 a	1780 a	0.51 a	150 a
Staggered	I (3)	7.53 b	1634 a	0.45 b	102 b
2006 DS	H (2)	8.49 a	1587 a	0.55 a	156 a
AWD genotypes	I (3)	8.44 a	1611 a	0.52 b	133 b
2005 DS	H (2)	7.16 a	1959 a	0.45 a	114 a
Braodcasting	I (2)	5.94 b	1820 a	0.42 a	93 b
2004 WS	H (5)	5.93 a	1885 a	0.45 a	140 a
Wet season	I (7)	5.35 b	1748 b	0.42 b	117b

The difference in SSI between plant types is larger than that in HI, and with consistent significance

SSI at maturity can be used more acurately than harvest index to discriminate plants in their ability to partition dry matter efficiently

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Elements supporting the higher performance of hybrids

observed when comparing hybrids and inbreds of same phenology and of distinct phenology with shorter crop duration for hybrid

- **Higher biomass accumulation in hybrid rice during the whole cycle**
  - Higher key organ growth rate
  - leaf angle during the whole cycle?
  - root and leaf senescence during grain filling?
  - remobilization from senescing tillers and leaves during grain filling?
- **More efficient sink regulation in hybrid rice during the whole cycle**
  - quicker increase in allocation to the culm before PI
  - quicker increase in allocation to the panicle during culm growth
  - more biomass remobilized from the culm

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Breeding strategy for increasing yield potential

- The potential sink size of tropical high-yielding hybrids and inbreds at IRRI is high enough to meet with the supply (moderate spikelet filling percentage)
- The actual sink size appears as a consequence of the plant's potentialities (sink regulation) and of the environment (source strength)
- The breeding strategies for higher yield potential could consider more direct traits refering to higher sink regulation and higher biomass accumulation. Such traits could be relevant to any phase of the crop cycle
- Higher sink size, as an integrated trait and a consequence of higher sink regulation, still need to be considered

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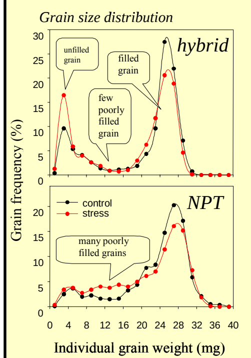
Relevant trait: better sink regulation during grain filling?



Year/ Season	Genotype	1000 FiGrDw	1000 UFiGrDw
2007 DS	H(7)	24.45	4.33
	I(6)	24.40	4.55
2006 DS	H(2)	24.82	5.01
	I(3)	26.84	5.28
2005 WS	H(3)	27.37	4.26
	I(2)	27.00	4.44
2005 DS	H(2)	24.21	4.98
	I(2)	23.41	5.06
2004 WS	H(5)	24.70	4.17
	I(7)	25.23	4.77

Can 'unfilled grain size' be used as a relevant trait?

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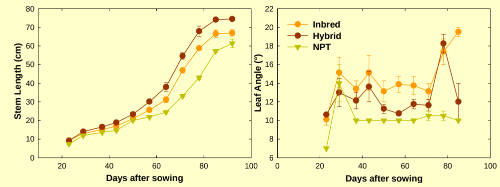
Relevant trait: more efficient plant stand during the whole cycle?

Comparing the plant height and leaf angle of the second youngest mature leaf of 4 inbreds and 4 hybrids and 1 NPT, all of same phenology



Hybrid: characterized with more erect leaves and taller canopy that may trigger higher light interception

Leaf position and orientation may be candidate traits

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Possible candidates traits for increasing yield potential

- **Increasing the source:**
  - Leaf angle and its dynamic during the whole cycle
  - Extended culm growth period vs. vegetative (Slafer et al)?
  - Extended grain filling period?
  - Delayed root senescence in order to delay leaf senescence?
- **Increasing sink regulation**
  - Increased specific leaf area at early stage
  - Low sink strength index at flowering associated with higher reserve storage
  - High sink strength index at maturity associated with high remobilization
  - Low individual unfilled grain size

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Crop response to seedling age at transplanting: leaf area growth

Transplanting, hill spacing 20 x 20 cm

Inbred1 in the main field, 34 days after sowing for all 3 situations

transplanted 7 days after sowing

transplanted 14 days after sowing

transplanted 21 days after sowing

Is there any significative effect on grain yield?

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Crop response to seedling age at transplanting: grain yield

In each season: same sowing date, same plant density, same nutrient management

Dry Season			Wet Season		
Genotype	Seedling age, d	Yield, $t\ ha^{-1}$	Genotype	Seedling age, d	Yield, $t\ ha^{-1}$
Inbred1	7	6.99 a	Inbred1	7	5.32 a
Inbred1	14	6.34 a	Inbred1	14	5.14 b
Inbred1	21	6.06 b	Inbred1	21	5.18 b
Hybrid1	7	7.75 a	Hybrid1	7	6.62 a
Hybrid1	14	6.98 b	Hybrid1	14	6.02 b
Hybrid1	21	6.97 b	Hybrid1	21	5.89 b

Grain yield was significantly higher when transplanting 7-day instead of 21-day old seedlings for both plant types in both seasons

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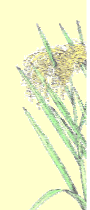

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