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Research Article

Relationship between Grain Yield and Biomass in Hybrid Rice and Parental Line

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Abstract

Background and Objective: Yield potential has been the main target in the hybrid rice breeding program. Rice yield potential has been increased in hybrids as compared with their parents. Grain yield is the product of harvest index and biomass. The objective of this study was to compare the relationship between grain yield, harvest index and biomass among hybrid rice and its parents. **Materials and Methods:** Five hybrids in the three-line system, six hybrids in the two-line system and offspring obtained from the three-line hybrid rice system were used to investigate. The RCBD with three replications was used to evaluate agronomic traits, yield components and yield. Statistical analyses were conducted, including analysis of variance, correlation analysis and linear regression (R^2), to evaluate the relationships among variables. The data were analyzed using ANOVA, followed by Duncan's Multiple Range Test (DMRT) for significance at $p < 0.05$. **Results:** The difference in grain yield was significant in both experiments. Hybrids had higher grain yields than their parents. This experiment showed that the harvest index was difficult to increase. The harvest index was still limited to 0.50, although the productivity was increased. On the other hand, biomass could be increased efficiently. **Conclusion:** The hybrid yield was increased as the biomass increased. Thus, biomass should be used selection index in the hybrid rice breeding technique.

Key words: Hybrid rice, yield potential, harvest index, biomass, selection index

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INTRODUCTION

Rice is the most important staple food crop. That is very important to the world and a main source of food for more than half of the world's population¹. The yield potential of irrigated rice has experienced two significant growth eras, with the first era driven via the effect of genetic improvement and increasing harvest index by reducing plant height using the semi-dwarf genes and the second era driven via the utilization of heterosis by producing hybrids^{2,3}. The technology of hybrid rice has tremendously increased rice productivity as effectively represented in China and other Asian countries⁴. Grain yield in rice is determined by sink size, which encompasses both the seed setting rate and grain weight. As a key factor influencing yield, sink size can be enhanced by increasing the number of panicles, the size of panicles or a combination of both^{5,6}. Alternatively, either increasing harvest index or biomass production or both can increase rice yield⁷. The difference in grain yield between traditional and modern rice cultivars was due to difference in harvest index⁸. High-yield variety in modern rice cultivar was achieved by increasing biomass production⁹. Among super hybrid rice ordinary hybrid rice and inbred rice, the key distinguishing factor was that high biomass production contributed significantly to the superior grain yield of super hybrid rice¹⁰. Biomass accumulation can be enhanced through an extended growth duration, an increased crop growth rate (CGR) or a combination of both¹¹. Biomass production was the product of intercepted solar radiation by the canopy and radiation use efficiency¹².

Harvest index and biomass are produced grain yield of rice. A very high level of harvest index (above 0.5) has been reached and advanced improvement of the high yield potential should depend on rise of biomass^{6,13}. The part of morphology, the increasing of biomass by increasing of plant height, was an effective and practicable way. The harvest index remaining above 0.5 and resistant to lodging were considered into a general trend in super-hybrid rice breeding by great plant height, high biomass and high grain yield. Another approach to increasing biomass was increasing stem thickness. The strength of this approach is that the developed super-hybrid rice is greatly lodging resistant. However, they are more complicated to increase stem thickness than plant height¹⁴.

Plant height and biomass per unit plant height are associated with total biomass production. However, excessive biomass accumulation in conjunction with increased plant height is generally unfavorable for grain yield as it raises the

risk of lodging. However, no clear evidence to use the increasing biomass approach over the higher biomass, a higher grain yield of hybrid rice. Recently, this study was conducted on a yield trial of elite hybrid rice via a three-line and two-line system. The objective of this study was to compare the relationship between grain yield, harvest index and biomass among hybrid rice and its parents.

MATERIALS AND METHODS

Study area: The yield trial of hybrids was conducted from June to October, 2023 in an experimental field at Phra Nakhon Si Ayutthaya Province. The evaluation of F₃ progeny was conducted from January to May 2024 in the experimental field at Sing Buri Province, Thailand.

Plant materials: Eleven hybrids were selected for this study, including five hybrids in the three-line system and six hybrids in the two-line system (Table 1). These hybrids were developed under the hybrid rice breeding project by the Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.

Additionally, the F₃ generation was generated by selfing from RDH3 (IR79156A × JN29-PTT11-1-B-12-5-5-1R), a Thai hybrid rice variety. During this process, the F₃ generation was selected based on visual assessment. A total of 48 progenies were selected and evaluated in the experimental field.

Experimental design and field conditions: Two experiments were conducted:

- **Yield trial for hybrids:** Five hybrids in the three-line system and six hybrids in the two-line system, along with their parental lines and check varieties, were grown under irrigated field conditions during the main season in Phra Nakhon Si Ayutthaya Province
- **F₃ progeny evaluation:** The 48 selected lines and 14 Thai cultivars were grown under irrigated field trials during the off-season in Sing Buri Province

The experimental field had clay soil. A Randomized Complete Block Design (RCBD) with three replications was used in both experiments. Thirty-day-old seedlings from each entry were transplanted in five rows with seven plants per row at a spacing of 20 × 20 cm. Crop management followed local hybrid rice production recommendations, including the application of 113 kg N/ha, 38 kg P₂O₅/ha and 38 kg K₂O/ha.

Table 1: List of F₁ hybrids, parental lines and checks used in this experiment

Experiments	No.	Entries	Types
1	1	SPR1A/KUR4-137	Hybrid (three-line system)
	2	RD43/KUR1-18	Hybrid (three-line system)
	3	RD43/KUR9-271	Hybrid (three-line system)
	4	HCSA/KUR8-11-8	Hybrid (three-line system)
	5	HCSA/KUR8-14-2	Hybrid (three-line system)
	6	SPR1B	Parental line (B line)
	7	RD43B	Parental line (B line)
	8	HCSB	Parental line (B line)
	9	KUR1-18	Parental line (R line)
	10	KUR4-137	Parental line (R line)
	11	KUR9-271	Parental line (R line)
	12	KUR8-11-8	Parental line (R line)
	13	KUR8-14-2	Parental line (R line)
2	1	KU-TGMS1-1-1/KUR1-18	Hybrid (two-line system)
	2	KU-TGMS1-1-1/KUR4-137	Hybrid (two-line system)
	3	KU-TGMS3-3-3/KUR3-79	Hybrid (two-line system)
	4	KU-TGMS3-3-3/KUR9-271	Hybrid (two-line system)
	5	KUT3-27/KUR3-79	Hybrid (two-line system)
	6	KUT5-4/KUR7-197	Hybrid (two-line system)
	7	KU-TGMS1-1-1	Parental line (TGMS line)
	8	KU-TGMS3-3-3	Parental line (TGMS line)
	9	KUT3-27	Parental line (TGMS line)
	10	KUT5-4	Parental line (TGMS line)
	11	KUR1-18	Parental line (R line)
	12	KUR3-79	Parental line (R line)
	13	KUR4-137	Parental line (R line)
	14	KUR7-197	Parental line (R line)
	15	KUR9-271	Parental line (R line)
Checks	1	RD41	Inbred check
	2	RDH3	Hybrid check

Data collection: Agronomic traits, yield and yield components were recorded. Data on days to 50% flowering were collected at the flowering stage. At the ripening stage, healthy plants from the central rows were harvested and measured for the following traits:

- **Agronomic traits:** Days to 50% flowering, plant height, flag leaf length, panicle length, number of tillers per plant, number of spikelet's per panicle
- **Yield components:** number of panicles per plant, number of filled grains per panicle, 100-grain weight, harvest index and grain yield per plant (adjusted to 14% moisture content)

Statistical analysis: The data (mean values) were analyzed with a One-way Analysis of Variance (ANOVA) test. Duncan's Multiple Range test (DMRT) was conducted to evaluate the significance of differences between treatments at $p < 0.05$. The correlation test was conducted to determine the strength and direction of a relationship between two variables. All tests were conducted with Statistical Tool for Agricultural Research (STAR) version: 2.0.1 for all parameters.

RESULTS AND DISCUSSION

The difference in grain yield was significant in both experiments (Table 2 and 3). The grain yield of hybrids RD43A/KUR9-271 in the three-line system was higher than all inbred both parental lines and inbred check cultivar (RD41), but it was not significantly with some hybrids, RD43A/KUR1-18, HCSA/KUR8-11-8 and hybrid check cultivar (KUH3). On the other hand, KU-TGMS1-1-1/KUR1-18 in the two-line system was higher than all inbred, both parental lines and the inbred check cultivar, but it was not significant with KUT5-4/KUR7-197.

The number of panicles per plant was generally no different among hybrids in both three-line and two-line systems (Table 2 and 3). The number of spikelet's per panicle was highly significant in both three-line and two-line systems. In the three-line system, 5 hybrids and the hybrid check cultivar showed no difference in the number of spikelets per panicle, but RD43A/KUR9-271 had a higher number of spikelet's per panicle than the inbred check cultivar. In the two-line system, KUR9-271 had the highest number of spikelet's per panicle in this experiment.

Table 2: Agronomic character, yield components and grain yield of 5 hybrids in a three-line system, 8 parents and 2 checks cultivars

Entries	50 % flowering	Plant height (cm)	Flag leaf length (cm)	Panicle length (cm)	No. tillers per plant	No. panicles per plant	No. spikelets per panicle	No. filled grains per panicle	Seed setting rate (%)	100 grains weight (g)	Harvest index	Biomass per plant (g)	Grain yield per plant (g)
SPR1A/KUR4-137	79 ^d	85.67 ^{ab}	29.44 ^{bc}	26.22 ^f	8.89 ^{a-c}	8.67 ^{a-c}	179.22 ^{a-d}	117.78 ^{a-d}	65.41 ^{de}	2.81 ^{bc}	0.45 ^{b-d}	43.56 ^{b-d}	19.43 ^{b-d}
RD43A/KUR1-18	79 ^d	90.78 ^a	34.00 ^{ab}	29.67 ^{ab}	9.78 ^{a-c}	9.11 ^{a-c}	178.55 ^{a-d}	133.56 ^{a-c}	74.99 ^{bc}	2.89 ^{ab}	0.49 ^{a-c}	56.69 ^a	27.39 ^{ab}
RD43A/KUR9-271	79 ^d	83.55 ^{c-d}	34.11 ^{ab}	29.78 ^a	10.00 ^{a-c}	9.45 ^{a-c}	199.89 ^{a-c}	152.67 ^a	76.41 ^{bc}	2.74 ^{bc}	0.51 ^a	54.18 ^{ab}	27.97 ^a
HCSA/KUR8-11-8	86 ^c	75.44 ^{b-f}	35.56 ^{ab}	27.89 ^{a-e}	10.78 ^{a-c}	9.67 ^{a-c}	163.33 ^{a-c}	127.22 ^{a-c}	77.82 ^{ab}	3.01 ^a	0.48 ^{a-c}	52.00 ^{a-c}	25.45 ^{a-c}
HCSA/KUR8-14-2	86 ^c	71.33 ^{ef}	29.56 ^{bc}	28.44 ^d	9.22 ^{a-c}	8.44 ^{a-c}	164.67 ^{a-e}	130.22 ^{a-c}	79.28 ^{ab}	2.68 ^c	0.49 ^{a-c}	43.62 ^{b-d}	21.51 ^{b-d}
SPR1B	90 ^b	90.89 ^a	29.11 ^{bc}	25.78 ^f	8.33 ^{bc}	8.00 ^{bc}	133.67 ^{ef}	95.33 ^{cd}	71.46 ^c	2.68 ^c	0.39 ^{de}	40.15 ^{b-d}	15.73 ^d
RD43B	78 ^d	74.33 ^{cf}	26.67 ^{cd}	24.00 ^f	11.45 ^a	10.78 ^a	105.44 ^f	81.78 ^d	77.51 ^{ab}	2.88 ^{ab}	0.50 ^{ab}	39.20 ^{cd}	20.10 ^{b-d}
HCSB	86 ^c	70.00 ^f	33.89 ^{ab}	27.33 ^{a-f}	8.44 ^{bc}	7.78 ^{bc}	165.55 ^{a-e}	104.89 ^{cd}	62.84 ^e	2.86 ^{a-c}	0.43 ^{ce}	43.99 ^{b-d}	18.67 ^{b-d}
KUR1-18	90 ^b	80.89 ^{a-f}	36.55 ^a	28.55 ^{a-d}	9.11 ^{a-c}	8.67 ^{a-c}	169.22 ^{a-e}	118.00 ^{a-d}	69.76 ^d	2.69 ^c	0.40 ^{de}	49.06 ^{a-c}	20.05 ^{b-d}
KUR4-137	93 ^b	91.11 ^a	29.67 ^{bc}	24.33 ^{ef}	8.89 ^{a-c}	8.22 ^c	186.11 ^{a-d}	128.89 ^{a-c}	68.66 ^d	2.46 ^d	0.39 ^{de}	41.61 ^{b-d}	16.58 ^d
KUR8-11-8	93 ^b	81.00 ^{a-f}	22.78 ^d	24.44 ^{ef}	8.89 ^{a-c}	8.66 ^{a-c}	98.78 ^f	80.56 ^d	81.54 ^a	2.79 ^{bc}	0.46 ^{a-c}	31.48 ^d	14.67 ^d
KUR8-14-2	107 ^a	82.44 ^{a-e}	25.89 ^{cd}	27.22 ^f	9.89 ^{a-c}	9.00 ^c	159.33 ^{c-e}	108.89 ^{b-d}	68.35 ^d	2.18 ^e	0.37 ^e	42.95 ^{b-d}	16.57 ^d
KUR9-271	93 ^b	84.89 ^{a-c}	34.00 ^{ab}	29.33 ^{a-c}	7.11 ^c	7.00 ^c	206.89 ^a	143.67 ^{ab}	69.67 ^d	2.45 ^d	0.40 ^{de}	42.91 ^{b-d}	17.09 ^d
RD41	86 ^c	73.11 ^{df}	28.89 ^{bd}	25.78 ^{ef}	9.44 ^{a-c}	9.11 ^{a-c}	146.67 ^{de}	99.56 ^{cd}	67.99 ^d	2.79 ^{bc}	0.47 ^{a-c}	41.27 ^{b-d}	19.77 ^{b-d}
RDH3	93 ^b	87.33 ^a	30.33 ^{a-c}	25.67 ^{ef}	9.89 ^{a-c}	9.44 ^{a-c}	203.78 ^{ab}	145.67 ^{ab}	71.54 ^{cd}	2.30 ^{de}	0.48 ^{a-c}	52.81 ^{a-c}	25.46 ^{a-c}
F-test	**	**	**	**	*	*	**	**	*	**	**	*	*
CV (%)	1.66	7.15	11.10	6.83	16.07	15.65	13.55	16.96	9.40	3.71	6.81	2.07	23.24

* Significant at 0.05 probability level, ** Significant at 0.01 probability level and within a column for each character, values followed by the same letters are not significant according to "MRT (p<0.05)

Table 3: Agronomic character, yield components and grain yield of 6 hybrids in two-line system, 8 parents and 2 checks cultivars

Entries	50 % flowering	Plant height (cm)	Flag leaf length (cm)	Panicle length (cm)	No. tillers per plant	No. panicles per plant	No. spikelets per panicle	No. filled grains per panicle	Seed setting rate (%)	100 grains weight (g)	Harvest index	Biomass per plant (g)	Grain yield per plant (g)
KU-TGMS1-1-1/KUR1-18	91.33 ^{b-d}	90.00 ^{a-d}	33.22 ^{a-d}	29.00 ^a	14.00 ^a	13.56 ^a	204.33 ^b	156.22 ^{ab}	76.39 ^{a-e}	2.51 ^{bf}	0.48 ^{ab}	75.20 ^a	36.14 ^a
KU-TGMS1-1-1/KUR4-137	89.00 ^{cd}	77.78 ^{h-i}	27.11 ^{df}	25.33 ^{ce}	11.89 ^{a-d}	11.33 ^{a-d}	144.11 ^{e-i}	97.00 ^{ef}	67.62 ^{de}	2.57 ^{be}	0.47 ^{a-c}	48.12 ^{bc}	22.50 ^{b-d}
KU-TGMS3-3-3/KUR3-79	84.33 ^d	70.00 ^k	25.11 ^{ef}	25.78 ^{be}	11.11 ^{a-d}	10.55 ^{a-d}	116.11 ^j	87.78 ^{ef}	76.05 ^{a-e}	2.75 ^{ab}	0.46 ^{a-d}	37.61 ^c	17.44 ^d
KU-TGMS3-3-3/KUR9-271	89.00 ^{cd}	85.78 ^g	31.78 ^g	28.44 ^{ab}	9.44 ^{ef}	8.78 ^{de}	173.89 ^{bf}	118.67 ^{be}	65.85 ^c	2.62 ^{a-e}	0.44 ^{be}	51.12 ^{bc}	23.78 ^{b-d}
KUT3-27/KUR3-79	85.03 ^d	82.91 ^{ch}	29.82 ^{be}	28.28 ^{a-c}	12.97 ^{ab}	12.10 ^{a-c}	158.84 ^{dh}	136.13 ^{bc}	85.80 ^{ab}	2.69 ^{a-c}	0.42 ^{de}	60.76 ^b	26.68 ^{bc}
KUT5-4/KUR7-197	89.00 ^{cd}	81.66 ^h	31.00 ^e	28.67 ^{ab}	13.11 ^{ab}	12.78 ^{ab}	178.33 ^{bc}	144.00 ^{ab}	80.45 ^{a-c}	2.40 ^{df}	0.50 ^a	60.80 ^b	30.34 ^{ab}
KU-TGMS1-1-1	103.00 ^a	79.55 ^h	31.00 ^e	27.11 ^{a-d}	11.00 ^{a-d}	10.55 ^{a-d}	153.00 ^{dh}	117.22 ^{be}	77.00 ^{a-e}	2.35 ^{ef}	0.47 ^{a-c}	41.62 ^c	19.96 ^{cd}
KU-TGMS3-3-3	91.33 ^{b-d}	90.67 ^{a-c}	33.33 ^{a-d}	27.67 ^{ad}	7.33 ^f	7.11 ^e	164.11 ^{cg}	118.44 ^{be}	71.98 ^{a-e}	2.62 ^{a-e}	0.41 ^e	41.46 ^c	17.04 ^d
KUT3-27	89.00 ^{cd}	62.22 ^k	20.89 ⁱ	23.33 ^e	12.33 ^{a-d}	11.44 ^{a-d}	92.89 ^j	81.78 ^{ef}	88.04 ^a	2.52 ^{bf}	0.47 ^{a-c}	34.71 ^c	16.26 ^d
KUT5-4	96.00 ^{a-c}	66.33 ^k	27.44 ^{de}	27.22 ^{ad}	11.56 ^{a-d}	11.44 ^{a-d}	91.55 ^j	71.67 ^f	77.77 ^{a-e}	2.62 ^{a-e}	0.43 ^{ce}	39.56 ^c	16.71 ^d
KUR1-18	100.67 ^{ab}	89.00 ^{a-e}	39.33 ^a	28.78 ^{ab}	9.67 ^{c-f}	9.56 ^{c-e}	186.45 ^{bd}	150.89 ^{ab}	80.52 ^{a-c}	2.57 ^{be}	0.48 ^{ab}	50.93 ^{bc}	24.70 ^{b-d}
KUR3-79	89.00 ^{cd}	84.56 ^{h-g}	25.56 ^{df}	27.22 ^{ad}	11.89 ^{a-d}	11.67 ^{a-d}	140.22 ^{fi}	105.66 ^{c-f}	75.90 ^{a-e}	2.85 ^a	0.49 ^a	47.44 ^{bc}	23.31 ^{b-d}
KUR4-137	93.67 ^{a-d}	94.33 ^a	34.33 ^{a-c}	26.33 ^{a-d}	10.33 ^{a-f}	9.11 ^{c-e}	200.56 ^{bc}	133.45 ^{b-d}	66.59 ^a	2.46 ^{c-f}	0.40 ^e	48.92 ^{bc}	19.33 ^{cd}
KUR7-197	96.00 ^{a-c}	81.22 ^{eh}	30.78 ^e	27.66 ^{ad}	9.56 ^{df}	9.11 ^{c-e}	182.11 ^{b-d}	144.22 ^{ab}	79.01 ^{a-d}	2.28 ^f	0.47 ^{a-c}	41.44 ^c	19.59 ^d
KUR9-271	100.67 ^{ab}	92.67 ^{ab}	36.56 ^{ab}	28.78 ^{ab}	7.78 ^{ef}	7.44 ^e	240.78 ^a	176.78 ^a	72.96 ^{a-e}	2.44 ^{c-f}	0.42 ^{de}	47.76 ^{bc}	20.46 ^{cd}
RD41	93.67 ^{a-d}	75.89 ^{h-j}	27.78 ^e	25.11 ^{de}	11.56 ^{a-d}	11.00 ^{a-d}	133.00 ^{hi}	100.78 ^{c-f}	75.89 ^{a-e}	2.66 ^{a-d}	0.46 ^{a-d}	41.82 ^c	19.67 ^{cd}
RDH3	103.00 ^a	87.33 ^{a-f}	33.67 ^{a-d}	26.22 ^{a-e}	10.56 ^{a-e}	10.11 ^{be}	205.78 ^b	154.89 ^{ab}	75.05 ^{a-e}	2.43 ^{c-f}	0.48 ^{ab}	49.30 ^{bc}	23.93 ^{b-d}
F-test	**	**	**	**	**	**	**	**	**	**	*	**	**
CV (%)	5.30	5.50	11.47	5.82	14.57	15.41	12.14	16.47	8.16	5.65	10.12	17.13	19.96

* Significant at 0.05 probability level, ** Significant at 0.01 probability level and within a column for each character, values followed by the same letters are not significant according to "MRT (p<0.05)

Table 4: Agronomic character, yield components and grain yield of F₃ 48 lines obtained from RDH3 and 14 checks cultivars

Traits	Maximum of check		Maximum of F ₃ progenies		Mean±SD
	Value	Entry	Value	Entry	
Plant height (cm)	95.75	CNT1	89.75	KU2300-14	78.65±10.12
Flag leaf length (cm)	46.25	CP111	48.00	KU2300-33	37.86±6.83
Panicle length (cm)	34.25	RD47	35.00	KU2300-03	27.08±3.71
No. tillers per plant	19.67	PTT1	42.50	KU2300-35	21.62±8.06
No. panicles per plant	17.50	RD23	38.00	KU2300-03	16.91±4.77
No. spikelet's per panicle	228.50	NPT#20-4	314.67	KU2300-01	216.05±47.69
No. filled grains per panicle	178.33	KU80 NLK	241.00	KU2300-02	142.92±42.08
Seed setting rate (%)	92.16	RD63	80.07	KU2300-02	67.34±17.96
100 grains weight (g)	2.76	SPR3	1.60	KU2300-29	1.40±0.58
Harvest index	0.52	RD47	0.54	KU2300-02	0.40±0.08
Biomass per plant (g)	49.69	SPR3	95.93	KU2300-12	54.52±19.51
Grain yield per plant (g)	41.91	CNT1	46.12	KU2300-01	34.28±9.09

Table 5: Correlations between agronomic character, yield components and grain yield each of populations

Traits	Grain yield		
	Parents	Hybrids	Parents and hybrids
50 % flowering	0.11 ^{ns}	0.16 ^{ns}	0.17 ^{ns}
Plant height	0.39 ^{**}	0.62 ^{**}	0.36 ^{**}
Flag leaf length	0.46 ^{**}	0.54 ^{**}	0.42 ^{**}
Panicle length	0.36 ^{**}	0.61 ^{**}	0.51 ^{**}
No. tillers per plant	0.39 ^{**}	0.69 ^{**}	0.60 ^{**}
No. panicles per plant	0.43 ^{**}	0.69 ^{**}	0.61 ^{**}
No. spikelets per panicle	0.51 ^{**}	0.78 ^{**}	0.47 ^{**}
No. filled grains per panicle	0.39 ^{**}	0.73 ^{**}	0.69 ^{**}
Seed setting rate	0.20 ^{ns}	0.38 [*]	0.26 [*]
100 grains weight	0.02 ^{ns}	0.06 ^{ns}	0.12 ^{ns}
Harvest index	0.45 ^{**}	0.35 ^{ns}	0.48 ^{**}
Biomass	0.84 ^{**}	0.94 ^{**}	0.92 ^{**}

^{*}Significant at 0.05 probability level, ^{**}Significant at 0.01 probability level and ns: Denotes non-significant

KU-TGMS1-1-1/KUR1-18, KU-TGMS3-3-3/KUR9-271 and KUT5-4/KUR7-197 had higher number of spikelet's per panicle than the inbred check cultivar but were not different from the hybrid check cultivar. The seed setting rate was different in both trials. In the three-line system, all hybrids except SPR1A/KUR4-137 had a higher seed setting rate than the inbred check cultivar. While HCSA/KUR8-11-8 and HCSA/KUR8-14-2 had higher seed setting rates than both check cultivars. In the two-line system, the seed setting rate was no different among the hybrids except KU-TGMS3-3-3/KUR3-79, that quite low. There was a significant difference in 100-grain weight in the two systems of hybrid rice. In the three-line system, HCSA/KUR8-11-8 had a higher 100-grain weight than all check cultivars. In the two-line system, all hybrids except KUT5-4/KUR7-197 were not different from the inbred check cultivar. Only KU-TGMS3-3-3/KUR3-79 had a higher 100-grain weight than the hybrid check cultivar. In the case of F₃ progenies, KU2300-01 had the highest yield (Table 4). Agronomic traits of F₃ progenies, including flag leaf length, panicle length, number of tillers per plant, number of panicles per plant, number of spikelet's per panicle and

number of filled grains per panicle were higher than check cultivars except plant height, seed setting rate and 100 grain weight.

The harvest index was generally no different among hybrids in both three-line and two-line systems except for some hybrids (Table 2 and 3). In the three-line system, RD43A/KUR9-271 had a higher harvest index than SPR1A/KUR4-137, but there is no difference between all the hybrids and both check cultivars. In the two-line system, KUT5-4/KUR7-197 had a higher harvest index than KU-TGMS3-3-3/KUR9-271 and KUT3-27/KUR3-79, yet it's not significant KU-TGMS1-1-1/KUR1-18, KU-TGMS1-1-1/KUR4-137, KU-TGMS3-3-3/KUR3-79 and both check cultivars.

The offspring of hybrid rice (F₃ progenies) had a higher harvest index than all entries of this experiment (Table 4). On the other hand, some lines showed lower harvest indexes than check varieties.

Biomass was generally no different among hybrids in both three-line and two-line systems except for some hybrids (Table 2 and 3). In the three-line system, biomass production of all hybrids was not different except RD43A/KUR1-18. It had

higher biomass per plant than SPR1A/KUR4-137, HCSA/KUR8-14-2 and the inbred check cultivar. In a two-line system, four hybrids, including KU-TGMS1-1-1/KUR4-137, KU-TGMS3-3-3/KU9-271, KUT3-27/KUR3-79 and KUT5-4/KUR7-197, did not show different biomass per plant. Interestingly, KU-TGMS1-1-1/KUR1-18 had the highest biomass production in this experiment. The biomass of F₃ progenies was higher than that of the check varieties. The highest value recorded was 95.93 g. (Table 4).

Correlation analysis was undertaken between agronomic character, yield components and grain yield in parental lines, hybrids and both populations (Table 5). The highest magnitude of significant correlation was observed between biomass and grain yield in all of the populations. Agronomic traits, including plant height, flag leaf length, panicle length, number of tillers per plant and number of spikelets per panicle, had a significant correlation with grain yield, but the variable days to 50 % flowering were not significantly

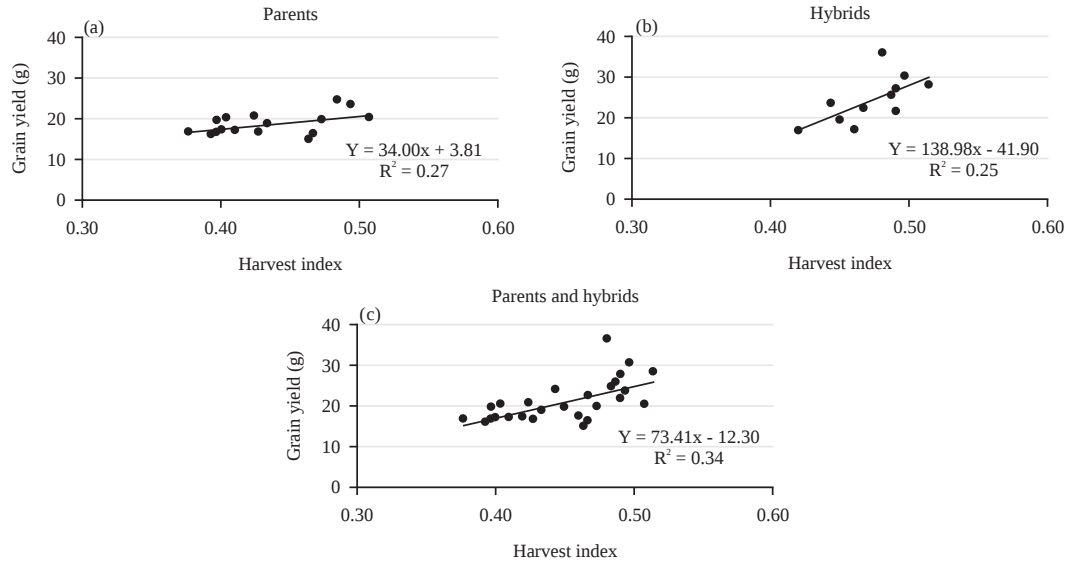


Fig. 1(a-c): Relationships between grain yield and harvest index, (a) Each point represents the mean values of parents, (b) Each point represents the mean values of hybrids, (c) Each point represents the mean values of parents and hybrids and the harvest index was still limited

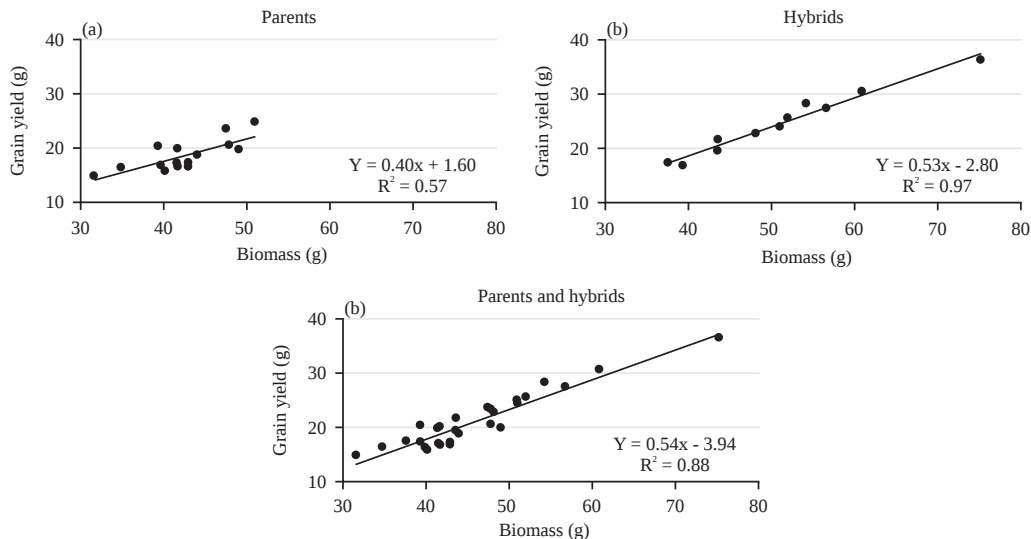


Fig. 2(a-c): Relationships between grain yield and biomass, (a) Each point represents the mean values of parents, (b) Each point represents the mean values of hybrids, (c) Each point represents the mean values of parents and hybrids and the grain yield was increased as the biomass increased

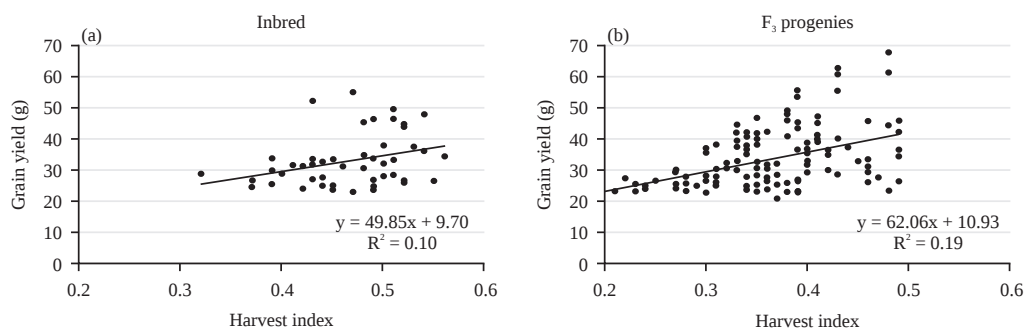


Fig. 3(a-b): Relationships between grain yield and harvest index, (a) Each point represents the mean values of inbred, (b) F_3 progenies were generated by selfing from RDH3 (IR79156A $\times$ JN29-PTT11-1-B-12-5-5-1R) and the harvest index was still limited

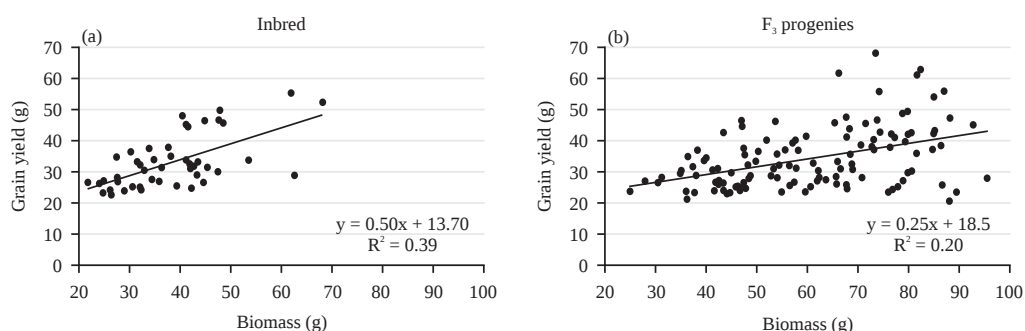


Fig. 4(a-b): Relationships between grain yield and biomass, (a) Each point represents the mean values of inbred, (b) F_3 progenies were generated by selfing from RDH3 (IR79156A $\times$ JN29-PTT11-1-B-12-5-5-1R) and the grain yield was increased as the biomass increased

correlated to grain yield in all of the populations. Yield components consist of a number of panicles per plant and the number of filled grains per panicle had a significant correlation with grain yield, yet 100-grain weight had no significant correlation with grain yield in all of the populations. Harvest index showed significant correlation with grain yield in parents and parents with hybrid populations, whereas hybrid populations showed not significant correlation between harvest index and grain yield.

Grain yield could be divided into several components, namely spikelet's number per square meter comprised of panicles' number per square meter and spikelets number per panicle, grain filling percentage and grain weight¹⁵. In the present study, hybrids with high yield had greater yield components than their parents. Moreover, the correlation between grain yield and yield components in the hybrid had a higher value than the parents. However, the correlation between grain yield and grain weight was not significant. Since plant materials in this study used indica rice, the grain size was not different. The results were consistent with previous studies¹⁶, which indicated that grain weight was not

significantly correlated with yield. A medium number of tillers per plant and large panicle size have been the goal traits in rice breeding programs, for example, at IRRI, the new plant type (NPT) breeding program¹⁷ and in China, the super hybrid rice breeding program¹⁴. The achievement of hybrid rice is based on the availability of genetic divergence and selection of germplasm that makes it possible to exploit hybrid vigor commercially¹⁸. Parental lines of appropriate hybrids should be adaptable to the environment¹⁹. Moreover, the number of spikelets per panicle is one of the important traits to increase yield potential²⁰. Hybrids in this experiment had quite a medium number of tillers per plant and large panicle size. These hybrids were just the beginning of development by Kasetsart University. Thus, they still require continuous research and development to achieve the goal traits in hybrid rice breeding programs.

Grain yield is the product of harvest index and biomass¹⁵. The harvest index was increased significantly when the sd1 gene was utilized by rice breeders in the 1950s²¹. This experiment showed that the harvest index was difficult to increase. The yield of parental lines tended to increase very

little as the harvest index increased (Fig. 1a-c). It seems to be different from the hybrid in that the hybrid yield was increased as the harvest index increased. When parents and hybrids were combined, data. The harvest index was still limited to 0.50, although the productivity was increased. This evidence revealed that the increase in grain yield was not a large consequence of the harvest index. But biomass might be the key to increasing grain yield. The increase in biomass has been significant since the end of the 1970s²². This investigation showed that biomass was not limited. The yield of parental lines tended to increase as the biomass increased (Fig. 2a-c.). Additionally, the hybrid yield was increased as the biomass increased. Moreover, the experiment of F₃ progenies showed results like both experiments (Fig. 3a-b and 4a-b). In the selection process like F₃ progenies were found that biomass was high biomass values. It has the potential to develop into a high-yielding variety if the proportion of grain to biomass is balanced at 50%. Sorghum hybrids using cytoplasmic male sterility are distinguished by a high yield of biomass and grain²³. When hybrids and parental lines were combined, data. The biomass still increased when the grain yield was increased. The results were consistent with previous studies that improving rice yield depends on increasing biomass accumulation²⁴. This evidence indicates that using biomass as a selection index may also be a feasible approach to achieve high grain yield.

CONCLUSION

Yield potential has been the main target in the hybrid rice breeding program. Rice yield potential has been increased in hybrids as compared with their parents. Grain yield is the product of harvest index and biomass. This experiment exposed that the harvest index was difficult to increase. On the other hand, biomass could be increased efficiently. Thus, biomass should be used selection index in the hybrid rice breeding technique.

SIGNIFICANCE STATEMENT

Enhancing rice yield remains a central goal in hybrid rice breeding programs to meet global food demand. This experiment reveals that while increasing the harvest index key determinant of yield efficiency remains challenging, significant gains in biomass can effectively boost grain yield in hybrid rice. By demonstrating a strong correlation between biomass and yield in hybrid rice, the findings emphasize the strategic value of using biomass as a selection index. These insights contribute to optimizing hybrid breeding strategies and improving rice yield potential.

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