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GENOTYPIC VARIATION IN F1 HYBRIDS BETWEEN LOCAL RICE CULTIVAR KUM BANGPRA AND IMPROVED RICE CULTIVARS

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SUMMARY

The differences in parental genotypes can lead to significant heterosis influenced by genetic control. Understanding genetic control enables the effective utilization of genetic resources to improve various traits in the local rice. The presented research sought to evaluate four rice F1 hybrids (KBP × PTT1, PTT1 × KBP, KBP × HKL1, and HKL1 × KBP) and their parental cultivars for the genetic variation on agronomic traits. The crossing of local rice (*Oryza sativa* L.) cultivar Kum Bangpra (KBP) occurred with two improved rice cultivars, viz., Pathum tani1 (PTT1) and Hawm Khlong Luang 1 (HKL1). A completely randomized design with five replications ensued for conducting the rice experiment. Significant ($P < 0.001$) differences appeared among F1 hybrids and their parental cultivars for the flowering date, plant height, tillers per plant, and panicles per plant. The F1 hybrids of PTT1 as parent showed greater values for plant height, tillers per plant, and panicles per plant, and the F1 hybrids of HKL1 as parent showed more branches per panicle, spikelets per panicle, higher grain size, and grain weight. Significant heterosis was evident in F1 hybrids for most agronomic traits, except flowering date and seed set. Only the F1 hybrid Kum Bangpra × PTT1 revealed maternal effects. Using an improved rice cultivar as a parent for crossing with the local Kum Bangpra led to significant differences in F1 hybrids for gene control and inheritance, including maternal effects; therefore, the final selection should focus on that promising cross.

Keywords: Rice (*Oryza sativa* L.), parental genotypes, local rice cultivar Kum Bangpra, direct and reciprocal crosses, F1 hybrids, purple rice, agronomic traits

Key findings: Genotypic variations in F1 hybrids for agronomic traits were significant by utilizing improved rice cultivars PTT1 and HKL1 in crosses with the local rice cultivar KBP. The F1 hybrids of the parental cultivar PTT1 showed higher productivity at the vegetative stage, and the F1 hybrids of the parent cultivar HKL1 exhibited higher productivity at the reproductive stage.

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INTRODUCTION

Rice (*Oryza sativa* L.) local cultivar Kum Bangpra (KBP) is glutinous, with a purple pericarp. Reports on the outstanding characteristics of this local rice cultivar have occurred in several studies, particularly as being high in anthocyanin (Promsomboon *et al.,* 2017), high contents of bioactive compounds and proteins (Ratanacoon *et al.,* 2023), higher in amounts of GABA, fiber, omega-3, gamma oryzanol, and antioxidants than Riceberry (Promsomboon and Promsomboon, 2019). Anthocyanin is one of the best antioxidants that can help prevent cancer (Chen *et al.,* 2006; Wang and Stoner, 2008), heart disease, and diabetes mellitus (Chen *et al.,* 2016).

Consuming rice daily with high levels of anthocyanin is an easy way to enhance the level of antioxidants in the human body. However, the local rice cultivar Kum Bangpra has a photoperiod sensitivity. Hence, it is necessary to cultivate them on shorter days. Another unfortunate characteristic is by having taller plants. Growing under less sunny days, which coincides with the rainy season and strong wind, results in lodging and a lower grain yield. Breeding of Kum Bangpra for non-photoperiod sensitivity and shorter plant height can improve and further conserve this essential rice cultivar. Pathum tani-1 (PTT1) and Hawm Khlong Luang-1 (HKL1) are improved rice cultivars with non-photoperiod sensitivity, short plant height, and good cooking quality.

Moreover, these two improved rice cultivars received a fragrant rice classification. Consequently, these cultivars became selected parental genotypes for crossing with Kum Bangpra. Morgan (1998) reported that using modern wheat cultivars as paternal parents provided the hybrids with better heterosis for average grain weight and yield than the old cultivars. Genetic hybridity and parental genome dosage interactions influence crop heterosis (Castillo-Bravo *et al.,* 2022), while heterotic effects are mainly apparent in some specific cross-combinations (Joshi, 2003).

Heterosis with negative and positive effects have been prevalent in various rice hybrids for agronomic traits; however, they were favorable for rice improvement as negative heterosis is desirable for early maturity while positive heterosis for yield components (Nuruzzaman *et al.,* 2002). Using the line-by-tester method enabled rice hybrids to manifest remarkable heterosis for tillers per plant, 1000-grain weight, the number of filled grains per panicle, and grain yield (Al-Daej, 2022). Diverse parental genotypes always reveal the differences in their F1 hybrids for various traits.

Past studies articulated that the F1 from Dawk Pa-yawm × Hawm Mali Doi showed the highest positive heterosis for tillers and panicles per plant; however, it revealed negative heterosis for plant height. Meanwhile, F1 from Nual Hawm × Khun Nan showed the highest positive heterosis for filled grains per panicle, spikelet fertility, 1000-grain weight, and grain yield (19.86%) but negative heterosis for days to flowering and maturity (Kumala-Sari *et al.,* 2020). Over-dominance is vital in the genetic control of heterosis in rice hybrids for the number of grains per panicle, grain weight, and grain yield (Zhuang *et al.,* 2001; Zhou *et al.*, 2012). Therefore, the differences in parental genotypes may result in significant heterosis, including genetic control. Thus, the presented study sought to investigate the genetic variation in the rice F1 hybrids for various agronomic traits.

MATERIALS AND METHODS

F1 hybrids generation

Synchronizing flowering in rice (*O. sativa* L.) grew local cultivar Kum Bangpra (KBP) and improved rice cultivars Pathum tani1 (PTT1) and Hawm Khlong Luang 1 (HKL1) in plastic pots with three different planting dates (Table 1). The KBP direct crossing and reciprocally with two improved rice parental genotypes included PTT1 and HKL1. Therefore, the genetic material in this study comprised four F1 hybrids (KBP × PTT1, PTT1 × KBP, KBP × HKL1, and HKL1 × KBP) and their three parental genotypes, KBP, PTT1, and HKL1.

Table 1. Description of modern rice cultivars used as parental genotypes in the experiment.

Cultivars	Endosperm type	Photosensitivity	Pedigree
Pathum tani1 (PTT1)	Non-glutinous	Non-photoperiod sensitivity	BKNA6-18-3-2 / PTT85061- 86-3-2-1
Hawm Khlong Luang 1 (HKL1)	Non-glutinous	Non-photoperiod sensitivity	Nang Mol S-4 / IR841- 85-1-1-2

Experimental design

All these seven rice genotypes comprising F1 hybrids and their parental genotypes received a completely randomized design (CRD) with five replications and one plant per pot. All the rice genotypes incurred soaking for one night, incubating at room temperature for **a** night, and then placed in a petri dish for seven days. On July 15, 2022, uniform seedlings commenced transplanting to plastic pots with a diameter of 30 cm and a depth of 25 cm. Applying fertilizers 46-0-0 and 16-20-0 at the 20 NPK kg/rai ensued when the plants were 30 and 45 days old after transplanting, respectively.

Data recorded and analysis

Data collection on days to flowering transpired at 50% of flowering. Recording at physiological maturity included the maturity date, plant height, tillers per plant, and panicles per plant. Two randomly selected panicles per plant reached data recording on the spikelets per panicle, filled grains per panicle, unfilled grains per panicle, and seed setting (%). All the recorded data underwent analysis of variance (ANOVA) according to the completely randomized design (CRD)**.** Means' comparison and separation engaged the Least Significant Difference ($LSD_{0.05}$) test.
Mid-parent heterosis (MPH) determination followed the below formula (Geng *et al.,* 2021)**.**

$$MPH = \frac{F1 - \frac{P1+P2}{2}}{\frac{P1+P2}{2}} X100\%$$

RESULTS

Rice (*Oryza sativa* L.) parental genotypes and their F1 hybrids revealed significant differences for most agronomic traits (Figures 1, 2, and 3).

Days to flowering and plant height

By growing rice in a shorter day length, the cultivar KBP showed the earlier flowering (99 days), followed by the cultivar PTT1 (106 days), with the cultivar HKL1 giving the late flowering and taking more days (112 days) (Figure 1a). The F1 hybrids obtained by crossing KBP and PTT1 were equal to the parental genotype KBP, while F1 hybrids from **crossing** KBP and HKL1 were similar to their parental cultivar HKL1. The shortest plants with the lowest plant height appeared in the cultivar PTT1 (76.7 cm), while the cultivars KBP and HKL1 were not different, ranging from 136 to 139 cm (Figure 1b). Among the F1s, the shortest plants were visible in the F1 hybrid PTT1/KBP (88.7 cm), followed by the F1 hybrid KBP/PTT1 (118 cm). Meanwhile, F1 hybrids KBP/HKL1 and HKL1/KBP were significantly not different at 125–127 cm.

Tillers and panicles per plant

Regarding the number of tillers per plant, cultivar PTT1 showed the highest number of tillers per plant (25), and the two other cultivars, HKL1 and KBP, were not different at 18.7 to 19.3 tillers $plant^{-1}$ (Figure 1c). Among the F1 hybrids, the foremost number of tillers per plant occurred in the F1 hybrid PTT1/KBP (20.3), followed by F1 hybrids KBP/HKL1 (18) and HKL1/KBP (16.3). The parental cultivar PTT1 showed the maximum number of panicles

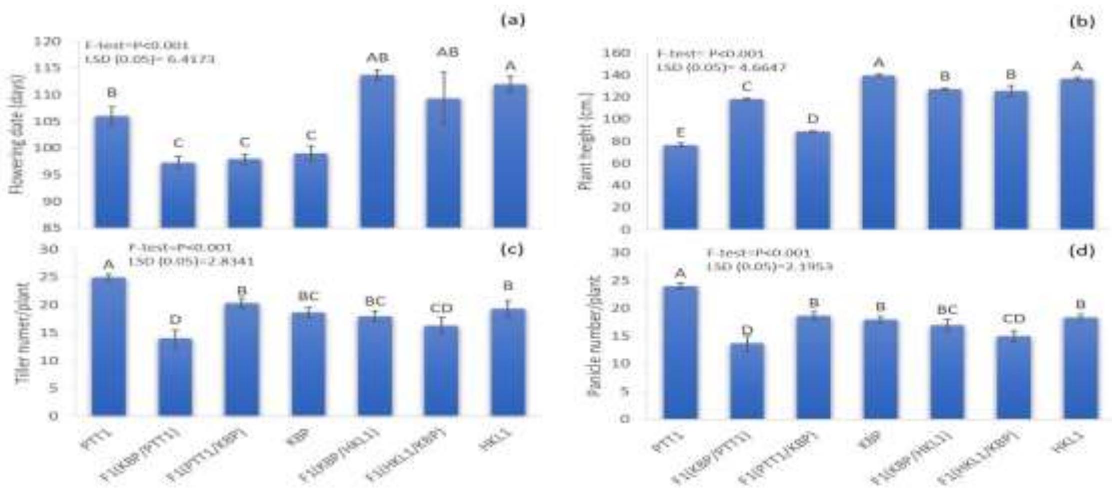

Figure 1. Mean performance of rice F1 hybrids and their parental genotypes for the flowering date (a), plant height (b), tillers per plant (c), and panicles per plant (d).

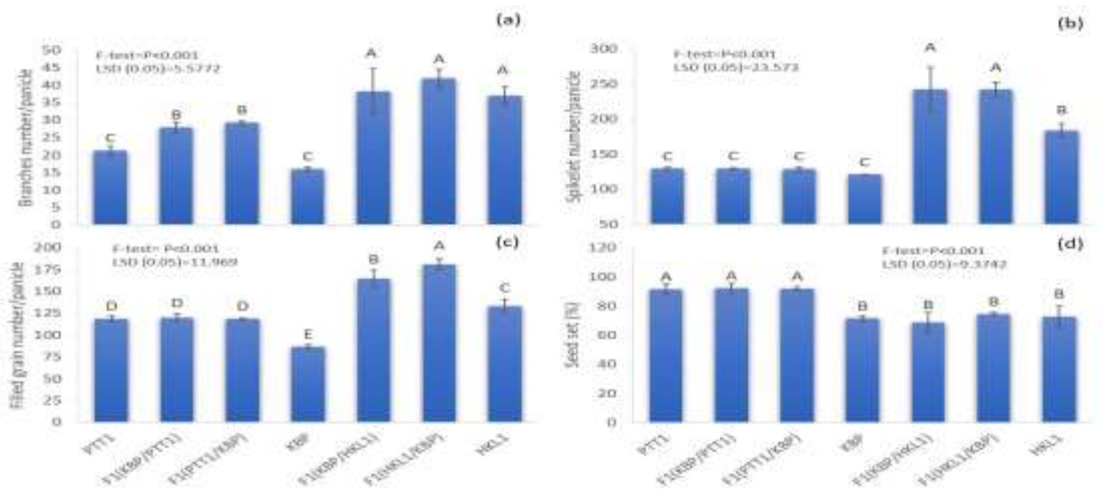

Figure 2. Mean performance of rice F1 hybrids and their parental genotypes for branches per panicle (a), spikelets per panicle (b), filled grains per panicle (c), and percentage of seed set (d).

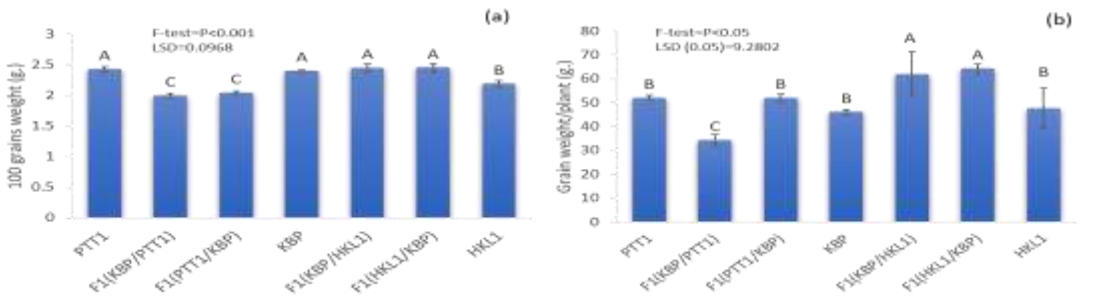

Figure 3. Mean performance of rice F1 hybrids and their parental genotypes for 100-grain weight (a) and grain weight per plant (b).

per plant (24), while the cultivars KBP and HKL1 equally performed with 18 panicles plant^{-1} (Figure 1d). Among the F1 hybrids, the utmost number of panicles per plant was evident in the F1 hybrid PTT1/KBP (18.7), followed by the F1 hybrid KBP/HKL1 (17), with the lowest in the F1 hybrid KBP/PTT1 (13.7 panicles plant^{-1}).

Branches and spikelets per panicle

The highest number of branches per panicle emerged in the rice cultivar HKL1 (37), while cultivars PTT1 and KBP did not differ, ranging from 16 to 21 branches per panicle (Figure 2a). Among the F1 hybrids, the F1 hybrid KBP/HKL1 showed an outstanding number of branches per panicle (38–42), higher than the F1 hybrid KBP/PTT1 (28–29). However, no differences occurred between the reciprocal crosses of these parental genotypes. Among the parents, the highest number of spikelets per panicle was evident in cultivar HKL1 (183.6), while the cultivars PTT1 and KBP equally performed, with a range from 121 to 129 spikelets panicle^{-1} (Figure 2b). In F1 hybrids, the KBP/HKL1 showed the highest number of spikelets panicle^{-1} (242), higher than the parental cultivar HKL1, and the F1 hybrid KBP/PTT1 had about 129 spikelets panicle^{-1}.

Filled grains per panicle and seed setting

Among the parental genotypes, the maximum number of filled grains per panicle resulted in cultivar HKL1 (133.3), followed by PTT1 (118.7) and KBP (86.7) (Figure 2c). From the F1 hybrids, the highest number of filled grains per panicle manifested in the F1 hybrid HKL1/KBP (181.3), which excelled the parent, HKL1, followed by the F1 hybrid KBP/HKL1 (164.6). However, the lowest number of filled grains per panicle was apparent in the F1 hybrid KBP/PTT1, which was also equal to the parent PTT1, with a range of 118–120 filled grains panicle^{-1}.

On seed set (%), the highest percentage of seed set appeared in PTT1 at 91.8%, while KBP and HKL1 were not different at 71%–73%. For the F1 hybrids, F1 from PTT1 and KBP was 92%, similar to the parent, PTT1, which was higher than the F1 from HKL1 and KBP that obtained 68%–75% and not different from the parent, HKL1.

100-grain weight and seed weight per plant

The parental genotypes PTT1 and KBP showed the highest 100-grain weight (2.403–2.433 g), while the cultivar HKL1 gave the lowest (2.19 g) (Figure 3a). However, the highest 100-grain weight resulted in F1 hybrids HKL1/KBP and KBP/HKL1 (2.450–2.453 g), while the F1 hybrid PTT1/KBP emerged with the lowest (2.000–2.043 g). Parental genotypes revealed nonsignificant differences in the grain weight per plant (Figure 3b). Among the F1 hybrids, the F1 hybrid HKL1/KBP provided the maximum grain weight per plant (61.8–64.22 g), which was also higher than all the parents were. The said promising hybrid had the F1 hybrid PTT1/KBP following (46.00 g grain weight plant^{-1}), similar to the parental genotypes in performance. However, the lowest grain weight per plant came from the F1 hybrid KBP/PTT1 (34.33 g).

Heterotic effects for agronomic traits

Among the F1 hybrids (direct and reciprocals), the heterosis over mid-parent varied for all the agronomic traits (Table 2).

***F1 hybrid KBP/PTT1*:** In this hybrid, positive heterotic effects were notable for plant height (9.09%), branches per panicle (50%), spikelets panicle^{-1} (3.59%), and filled grains panicle^{-1} (16.94%), while negative heterosis was prominent for tillers plant^{-1} (-35.87%), panicles plant^{-1} (-34.92%), 100-seed weight (-17.43%), and grain weight plant^{-1} (-29.93%) (Table 2). However, no recording of heterosis for days to flowering and seed setting percentage occurred.

F1 hybrid PTT1/KBP: In the said hybrid, positive heterosis was evident for the branches panicle^{-1} (57.14%), filled grain panicle^{-1} (15.64%), and seed setting (12.67%), with negative heterosis recorded for days to

Table 2. Heterosis in F1 hybrids (direct and reciprocal) for agronomic traits in rice.

Traits	Mid-parent	F1(KBP/PTT1)		F1(PTT1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Flowering date (days)	102.5	97.33^{ns}	-4.39	98.0*	-5.04
Plant height (cm)	108.2	118.0**	9.09	88.7***	-18.02
Tillers/plant	21.9	14.0**	-35.87	20.3^{ns}	-6.87
Panicles/plant	21.0	13.7*	-34.92	18.7*	-11.11
Branches/panicle	18.7	28.0**	50.00	29.3***	57.14
Spikelets/panicle	125.2	129.7*	3.59	129.0^{ns}	3.06
Filled grains/panicles	102.7	120.0*	16.94	118.7**	15.64
Seed setting (%)	81.7	92.5^{ns}	13.27	92.0*	12.67
100-grain weight (g)	2.418	2.000***	-17.43	2.043***	-15.50
Grain weight/plant (g)	49.00	34.33**	-29.93	52.00^{ns}	6.12
Traits	Mid-parent	F1(KBP/HKL1)		F1(HKL1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Flowering date (days)	105.5	113.67^{ns}	7.74	109.33^{ns}	3.63
Plant height (cm)	138.0	127.0***	-7.97	125.67*	-8.93
Tiller/plant	19.0	18.0^{ns}	-5.26	16.33^{ns}	-14.03
Panicles/plant	18.2	17.0^{ns}	-6.42	15.0**	-17.43
Branches/panicle	26.5	38.33*	44.65	42.0**	58.49
Spikelet/panicle	152.3	242.0*	58.86	242.67***	59.30
Filled grains/panicle	110.0	164.67***	49.76	181.33***	64.92
Seed setting (%)	72.2	68.64^{ns}	-4.91	74.74^{ns}	3.52
100-grain weight (g)	2.297	2.450*	6.67	2.453*	6.82
Grain weight/plant (g)	46.80	61.83^{ns}	32.12	64.22**	37.22

*, **, and *** = Significant at the $P < 0.05$, 0.01, and 0.001, respectively, N.S. = Non-significant.

flowering (-5.04%), plant height (-18.02%), panicles plant^{-1} (-11.11%), and 100-seed weight (-15.50%) (Table 2). However, no mid-parent heterosis appeared for the traits tillers plant^{-1}, spikelet panicle^{-1}, and grain weight plant^{-1}.

F1 hybrid KBP/HKL1: In the said hybrid, positive heterosis occurred for branches panicle^{-1} (44.65%), spikelets panicle^{-1} (58.86%), filled grains panicle^{-1} (49.76%), and 100-seed weight (6.67%). Meanwhile, negative heterosis manifested for plant height (-7.97%) (Table 2). No heterosis existed for days to flowering, tillers plant^{-1}, panicles plant^{-1}, seed setting percentage, and grain weight plant^{-1} in the rice hybrid.

F1 hybrid HKL1/KBP: This rice hybrid showed positive heterosis for branches per panicle (58.49%), spikelets per panicle (59.30%), filled grains per panicle (64.92%), 100-seed weight (6.82%), and grain weight per panicle (37.22%) and negative heterosis for the traits plant height (-8.93%) and panicles per plant (-17.43%) (Table 2). No heterosis prevailed by the said hybrid for days to flowering, tillers per plant, and seed setting percentage.

Grain shape

Significant differences were evident among the parental genotypes and their F1 hybrids for the seed width, length, and thickness traits of the paddy and brown rice (Table 3). Overall, the F1 hybrid seeds seem tinier than the parental genotypes in paddy and brown rice (Table 3). In the parental genotypes and their F1 hybrids, a discussion on the paddy and brown rice classification follows.

Paddy rice grains

Among the parental cultivar grains, the largest width resulted in KBP (3.270 mm), followed by HKL1 (2.830 mm) and PTT1 (2.250 mm). The F1 hybrids of KBP and PTT1 were similar to the

Table 3. Grain shape of paddy and brown rice in the F1 hybrids (direct and reciprocal) and their parental genotypes.

Genotypes	Paddy rice			Brown rice		
	Width (mm)	Length (mm)	Thickness (mm)	Width (mm)	Length (mm)	Thickness (mm)
PTT1	2.250 C	9.770 B	2.200 A	2.170 C	7.680 A	2.130 A
F1(KBP/PTT1)	2.250 C	7.320 C	2.200 A	2.201 BC	6.633 C	2.102 A
F1(PTT1/KBP)	2.250 C	9.800 B	2.200 A	2.200 BC	6.603 C	2.150 A
KBP	3.270 A	7.190 C	2.210 A	2.250 B	7.000 B	1.270 D
F1(KBP/HKL1)	3.230 A	9.670 B	2.170 AB	2.160 C	7.560 A	1.700 C
F1(HKL/KBP)	3.250 A	9.730 B	2.180 A	2.230 B	7.620 A	1.900 B
HKL1	2.830 B	10.500 A	2.060 B	2.350 A	7.770 A	1.700 C
F-test	***	***	**	***	***	***
C.V. (%)	1.51	3.13	2.89	1.70	2.65	3.78
$LSD_{0.05}$	0.073	0.500	0.110	0.066	0.337	0.122

, * = Significant at $P < 0.01$ and $P < 0.001$, respectively.

parent genotype PTT1, while the F1 hybrids of KBP and HKL1 were equal to the cultivar HKL1, with no maternal effects in both crosses. For grain length, the longest grains appeared in cultivar HKL1 (10.500 mm), followed by PTT1 (9.770 mm.), and the shortest was in cultivar KBP (7.190 mm.). The F1s did not differ, ranging from 9.670 to 9.800 mm, except the F1 hybrid KBP/PTT1, which has the shortest grains (7.320 mm). For the trait thickness, parental cultivars KBP and PTT1 showed similarity (2.200 mm) and were higher in thickness than the cultivar HKL (2.060 mm). In this case, all F1 hybrids had nonsignificant differences from the rice KBP, ranging from 2.170 to 2.200 mm.

Brown rice grains

Among the rice parental cultivar grains, the widest width appeared in the cultivar HKL1 (2.350 mm), followed by KBP (2.500 mm) and PTT1 (2.170 mm). The F1 hybrids of KBP and PTT1 ranged from 2.000 to 2.001 mm, with no maternal effects; however, slight effects of reciprocal crossing manifested in F1 hybrids of the KBP and HKL1. The F1 hybrid HKL1/KBP (2.230 mm) was broader than the F1 hybrid HKL1/KBP (2.160 mm). For grain length, the parental cultivars PTT1 and HKL1 were similar (7.680–7.770 mm), while the cultivar KBP was the shortest (7.000 mm). The F1 hybrids of KBP and PTT1 did not differ (6.603–6.633 mm) and were lower than their parents' length. These hybrids proved similar to the F1 hybrids of KBP and HKL; however, the grain length in these crosses did not differ from their parent HKL1. For grain thickness, cultivar PTT1 showed the maximum thickness (2.130 mm), followed by HKL1 (1.700 mm) and cultivar KBP (1.270 mm). The F1 hybrids of KBP and PTT1 were similar to their parent PTT1, with no difference between the reciprocal cross, which differed from the F1 hybrids of the cultivars KBP and HKL1. The results further revealed that the F1 hybrid KBP/HKL1 was equal to the parental cultivar HKL1 (1.700 mm.). Meanwhile, the F1 hybrid HKL1/KBP (1.900 mm) gave higher grain thickness than both parental genotypes.

Heterosis effects for grain traits

Paddy rice grains

In paddy rice F1 hybrid KBP/PTT1, negative heterosis appeared for grain width (-18.28%) and grain length (-13.67%), with no recorded heterosis in grain thickness (Table 4). In the F1 hybrid PTT1/KBP, positive heterosis emerged in grain length (15.56%), negative heterosis for grain width (-18.40%), and no heterosis for grain thickness. In F1 hybrid KBP/HKL1, positive heterosis occurred for grain width (6.14%) and grain length (9.26%), while no heterosis for grain thickness. In the fourth F1 hybrid HKL1/KBP, positive heterosis resulted in grain width (6.79%) and grain length (10.02%), with no heterosis attained in grain thickness.

Table 4. Heterosis in F1 hybrids (direct and reciprocal) for paddy rice grain traits.

Traits	Mid-parent	F1(KBP/PTT1)		F1(PTT1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Grain width (mm)	2.753	2.250***	-18.28	2.250***	-18.40
Grain length (mm)	8.480	7.320*	-13.67	9.800*	15.56
Grain thickness (mm)	2.205	2.200^{ns}	-0.22	2.200^{ns}	-0.22
Traits	Mid-parent	F1(KBP/HKL1)		F1(HKL1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Grain width (mm)	3.040	3.230**	6.14	3.250*	6.79
Grain length (mm)	8.846	9.670**	9.26	9.730*	10.02
Grain thickness (mm)	2.138	2.170^{ns}	1.32	2.180^{ns}	2.10

*, **, and *** = Significant at the $P < 0.05$, 0.01, and 0.001, respectively, N.S. = Non-significant.

Table 5. Heterosis in F1 hybrids (direct and reciprocal) for brown rice grain traits.

Traits	Mid-parent	F1(KBP/PTT1)		F1(PTT1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Grain width (mm)	2.210	2.201^{ns}	-0.36	2.200^{ns}	-0.36
Grain length (mm)	7.341	6.633**	-8.35	6.630**	-8.35
Grain thickness (mm)	1.700	2.102**	18.14	2.150**	20.40
Traits	Mid-parents	F1(KBP/HKL1)		F1(HKL1/KBP)	
		Means	Heterosis (%)	Means	Heterosis (%)
Grain width (mm)	2.301	2.160*	-5.86	2.230*	-2.96
Grain length (mm)	7.383	7.560^{ns}	2.48	7.620^{ns}	3.16
Grain thickness (mm)	1.483	1.700*	14.61	1.900**	28.09

*, ** and *** = Significant at the $P < 0.05$, 0.01, and 0.001, respectively, N.S. = Non-significant.

Brown rice grains

In F1 hybrid KBP/PTT1, positive heterosis was notable in grain thickness (18.14%), negative heterosis in grain length (-8.35%), and no heterosis in grain width (Table 5). In F1 hybrid PTT1/KBP, positive heterosis showed for grain thickness (20.40%), negative heterosis in grain length (-8.35%), and no mid-parent heterosis resulting in grain width. In hybrid KBP/HKL1, positive heterosis was prominent in grain thickness (14.61%), negative heterosis in grain width (-5.86%), and no apparent heterosis in grain length. In F1 hybrid HKL1/KBP, positive heterosis was evident in grain thickness (28.09%), negative heterosis in grain width (-2.96%), and no heterosis manifested in grain length.

Endosperm type

The endosperm type of all the rice F1 hybrids, whether obtained by crossing the parental genotypes KBP and PTT1 or KBP and HKL1, were non-glutinous (Figures 4 and 5).

DISCUSSION

In hybridization, the genetic divergence in parental genotypes led to different phenotypes of the F1 hybrids based on the traits. Two improved rice cultivars, PTT1 and HKL1, became options to serve as parental genotypes for further improvement in the local rice cultivar Kum Bangpra. The results revealed that the effects of the two different rice

Figure 4. Endosperm type of rice F1 hybrids between the parental genotypes KBP and PTT1.

Figure 5. Endosperm type of rice F1 hybrids between the parental genotypes KBP and HKL1.

parents in crossing with the local cultivar Kum Bangpra were evident in the F1 hybrids at the two growth stages. Past studies also enunciated that using such parental genotypes in hybridization produced promising F1 hybrids with an enhanced grain yield in rice (Kaewwiset *et al.,* 2010; Sansanoh *et al.,* 2019).

The F1 hybrids of PTT1 as parent displayed distinctly shorter flowering times and higher vegetative productivity, as reflected by the shorter plant height, higher number of tillers per plant, productive tillers per plant, and the number of panicles per plant. In contrast, the F1 hybrids obtained through HKL1 as parent showed prominence in panicle development, including the number of branches per panicle, spikelets per panicle, the filled grains per panicle, 100-grain weight, and grain weight per plant. Tillers per plant is an influential factor in enhancing rice productivity; therefore, selecting genotypes that first produce more productive tillers per plant has more scope with higher yields in the breeding program (Wang and Stoner, 2008; Wang *et al.,* 2018).

The obtained F1 hybrids provided more desirable agronomic traits and plant architecture than the parental rice cultivars HKL1 and PTT1. Therefore, these parental genotypes have been previously beneficial in various studies, such as rice breeding, which is insensitive to photoperiod and has a shorter plant height (Khitka *et al.,* 2021; Kaewmungkun *et al.,* 2023). In addition, the plant height is usually in inverse proportion to the number of tillers per plant (Choi *et al.,* 2012), and the said findings were consistent with the presented results, where the plant height of the F1 hybrids obtained through parental genotype HKL1 were taller than that of the F1 hybrids of the PTT1. The number of tillers per plant and productive tillers per plant of the F1 hybrids of HKL1 were lower than the

F1 hybrids of PTT1. However, the parental cultivar HKL1 had a higher grain width, grain length, and grain weight than the cultivar PTT1, which considerably affected F1 hybrids.

In F1 hybrids, the significant heterosis for most agronomic traits indicates that an over-dominant gene action controls these traits, except for days to flowering date and seed setting percentage. These results were analogous to past findings as they reported that high heterosis was prominent for agronomic attributes, such as tillers per plant, panicles per plant, filled grains per panicle, and 1000-grain weight (Kumala-Sasi *et al.*, 2020; Al-Daej, 2022). Non-glutinous traits receive control from complete dominance, similar to discovering that the dominant waxy (Wx) gene produced the amylose content (Mikami *et al.,* 1999).

Related to paddy grain rice, an additive gene effect in grain thickness was evident in both F1 hybrids obtained through the parental genotypes HKL1 and PTT1. Meanwhile, an overdominance type of gene action was notable for grain width and grain length. Unlike paddy rice, brown rice showed the additive gene effect in the grain width of both types of F1 hybrids of PTT1 and HKL1, with these results associated with Nurhidayah *et al.* (2021), who reported that grain length, grain width, and grain thickness bore control from an additive type of gene action. Bassuony and Lightfoot (2019) also reported that additive and dominance effects controlled the kernel length. In the presented study, however, an overdominance type of gene action only surfaced for the grain thickness. Different parents have varying gene activities, which affect the offspring. In this study, in paddy rice, grain thickness should be an option in the early generation, while grain width and grain length selection in later generations. In brown rice, grain thickness should be favorable in the late generations, while grain width and length should be in the early generations. In particular, F1 hybrids obtained through HKL1 as a parent tend to be more effective than PTT1 for selection on grain shape.

The maternal effects were only apparent in the F1 hybrids of the parent cultivars KBP and PTT1. Past studies revealed that maternal effects in rice were also notable for grain weight (Chandraratna and Sakai, 1960; Kartina *et al*., 2021) and other yield-related traits, i.e., plant height, flag leaf length, number of effective tillers, panicle length, grain weight per plant, and 1000-grain weight (Siti *et al.,* 2021; Samonte *et al*., 2023). In soybeans, the maternal effects were also prominent in plant height, the number of productive nodes, the number of filled pods, and the seed weight per plant (Isnaini *et al.,* 2020; Badiaraja *et al.,* 2021). However, only a few studies on maternal effects in rice exist, probably due to such results mainly depending on the parental genotypes used in the hybridization.

In the presented study, the progeny of the parental cultivar PTT1 as a female parent formed the outstanding F1 hybrids for various agronomic traits, such as plant height, tillers per plant, panicles per plant, grain weight per plant, and paddy grain length. Among Thai rice cultivars, PTT1 served as a female parent to improve the photoperiod insensitivity of the non-sticky promising strains for the northeastern region of Thailand (Homsombat, 2014). Therefore, the maternal effects require consideration before crossing to improve the traits controlled by the maternal effects in crop plants. Based on the latest findings, the three-way crossing (PTT1/KBP//HKL1) is highly recommendable for attaining perfect genotypes to obtain a higher grain yield in the new cultivar of KBP.

CONCLUSIONS

Using improved rice (*O. sativa* L.) cultivar as a parental genotype for breeding with the local rice cultivar Kum Bangpra led to differences in F1 phenotypes and variations in the gene control, including maternal effects. Therefore, selection should primarily rely on those crosses. Selection in the early generations was a better choice for the traits controlled by additive genes. Meanwhile, selection in the later generations was favorable for the characteristics controlled by dominant genes. The triple cross (PTT1/KBP//HKL1) is the best recommendation for getting an ideal rice genotype with a higher grain yield in the new cultivar developed through the local cultivar KBP.

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