BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, March 2017. Vol. **14**(1), 209-217

A Study of F1 Rice Hybrids from Crossing two Subspecies: Indica and Japonica, in South Russia's Climate

P.I.Kostylev[1], A.V.Alabushev[1], E.V.Krasnova[1], A.A. Redkin[1] and L.M.Kostyleva[2]

[1]All-Russian Research Institute of Grain Crops after I.G.Kalinenko, Russia, Zernograd, Nauchnyi gorodok, 3.
[2]Azov-Blacksea Engineering Institute of the Don State Agricultural University, Russia, Zernograd, Lenin street, 21.

http://dx.doi.org/10.13005/bbra/2437

(Received: 11 January 2017; accepted: 20 February 2017)

Normally, F_1 hybrids between subspecies japonica and indica demonstrate various degrees of infertility. Previous research has shown that certain types of indica do have compatibility when crossed with japonica varieties, which causes a higher fertility in F_1 hybrids. In the light of the above, we studied several indicators affecting grain crop yield in F_1 hybrids between japonica and indica. A field experiment was done to study hybrid heterosis of plant height, head length, the number of spikelets and well-filled grain in a head, spikelet fertility, length, width and weight of bruchids, in order to find a combination with high grain yield and investigate correlations between grain weight per head and certain valuable agronomic traits. Average heterosis of plant height and number of spikelets per head was positive. Some of the hybrids demonstrated positive heterosis of the number of well-filled grains in a head, of the weight of grain from one head, of the size and weight of bruchids; on the average, however, heterosis of these traits was negative. Among other crop yield components, an increase in the number of spikelets and grains per head contributed to an increase in the weight of grains from one head in hybrids. There exists significantly strong positive correlation between crop yield in one head and spikelet fertility and a weakly positive one - with the plant height and head length. A higher yield from one head in F_1 crosses was related to an increase in the number of spikelets in it, whereas their low fertility was a limitation on yield potential.

Keywords: Rice, Sub-species japonica and indica, Hybrids, Crop yield, Fertility, heterosis.

Heterosis is very important for yield increase in various cultivated crops including rice. Heterosis of yield and of other valuable hybrid traits depends to a certain extent on a genetic distance between parent forms (Virmani, 1996). Most of the hybrids developed in tropical and subtropical environment were developed on the germ plasm of rice (Oryza sativa L.), sub-species indica. Heterosis in rice hybrids, sub-species japonica, developed in China, Japan and Korea is considerably lower (Virmani, 1996). This problem relates to a lack of fertility restorers in forms having cytoplasmic male sterility, particularly in countries with temperate climate and problematic seed industry. Heterosis in hybrids between japonica and indica was used to increase crop yield (Maruyama, 1988; Ikehashi, 1991; Peng *et al*., 1999). Such hybrids demonstrate productivity of 25 per cent above the best selection varieties (Khush, 1994). But this type of distant crossings often suffers from hybrid sterility in varying degrees of

* To whom all correspondence should be addressed.
E-mail: Editor4@academicpapers.org

intensity; on the other hand, in most cases obtaining F_1 hybrid seeds is no problem. Rice subspecies indica and japonica have strong genetic differentiation, which leads to divergence of phenotypes and adaptations. Hybrid sterility between these two subspecies is one of the key forms of post zygotic reproductive isolation in plants. There is a genetic and molecular mechanism of reproductive barriers in rice. Cross incompatibility genes have been found (Ouyang, 2013). The problem of hybrid sterility can be solved using a gene of wide compatibility - the one that originated in Indonesia and Bengalia (Ikehashi è Araki, 1984). Colleagues have established that some of indica rice varieties have genetic proximity to varieties of japonica, in crosses with which a better fertility was observed (Morinaga è Kuriyama, 1958).

Chen J. *et al*. (2008) demonstrated that the triallelic system of the S5 locus is the key regulator of reproductive barrier and compatibility in indica-japonica crosses. S5 encodes aspartic protease - the one that determines fertility of the embryonic sac. Alleles of indica (S5-i) and japonica (S5-j) do differ in two nucleotides. The wide compatibility gene (S5-N) has a larger deletion in the N-end of S5, due to which it is not functional. This triallelic system plays a crucial role in the evolution and selection of cultivated rice. Genetic differentiation between indica and japonica was the reason why a reproductive barrier arose, the one that can be overcome by the wide-compatibility gene.

Sarker *et al*. (2001) in their study of morphology of 12 F_1 crosses between japonica and indica found that these crosses produced more dry weight and had better-developed stems and heads than their parent forms.

This was the driver behind our investigation of heterosis in F_1 indica-japonica crosses by plant height, head length, number of spikelets and well-filled grain in a head, spikelet fertility, by length, width and weight of bruchids, in order to reveal correlations between them and find successful cross combinations. In later generations, transgressive forms with higher fertility emerge considerably more often from heterotic crosses. To this does contribute climatic, geographical and genetic distance between parent forms.

METHODS AND MATERIALS

The field experiment was done on checks of Proletarskaya experimental station near city of Proletarks in the Rostov region; data gathering and processing was carried out in the Laboratory of Selection, Seed Production and Rice Cultivation Technology at I.G.Kalinenko Grain Crop Institute (46°422 n. lat. 41°432 e. long.).

F_1 seeds were obtained in 2015 in a greenhouse, by crossing 3 varieties of japonica type as male parents and 25 varieties of indica type as female ones. For anther removal, a vacuum pump DS-8 was used. Pollination was carried out relying on the Twell-method. Japonica subspecies was represented by such varieties as Kontakt, Boyarin, Komandor; indica - by BR 47, FL 478, INPARA 3, IR74099-3R-3-3, IR86384-46-3-1-B, IR86385-111-1-1-B, IR86385-117-3-1-B, IR86385-194-2-1-B, IR86385-248-2-1-B, IR86385-56-2-1-B, IR86385-87-1-1-B, IR86385-99-2-1-B, IRBB5, IRBB7, IRBB21, IRBB62, KD (Khan Dan) D18, KD Sub1 D149, KD Sub1 D27, Mazhan Red, Kharsu 80A, OM/Saltol T35, QR 1, QR 2, SHPT-1.

Hybrid and parent seeds were planted in seed boxes (60 cm õ 40 cm õ 10 cm) in the late April of 2016. Dark chestnut soil, clay loam. Mineral fertilizers N, P_2O_5 and $\hat{E}_2O$ were applied at the rate of 12.9 and 6 g/m^{-2}, respectively.

Thirty day-old plants (3-4 leaves) were reset in one row with a spacing of 30 x 15 cm. Weeds were suppressed with Citadel herbicide. Water depth was maintained at 20 cm from the moment of resetting till physiological ripeness. The flowering period was marked when 50 per cent of plants in the plot finished heading. After ripening, plant height was measured and five heads were randomly chosen at each plot, and their head length determined along with the number of spikelets, well-filled grains and their size, spikelet fertility being calculated. Heads were manually threshed and well-filled grains separated from empty spikelets. The weight of 1000 grains was measured at 14 per cent moisture. The obtained data were statistically analyzed using dispersion analysis. The degree of phenotypic dominance was found by the method suggested in Griffing (1956), true heterosis effect - by D.S.Omarov's method (1975).

Study Results

Almost all but one F_1 crosses had a much bigger plant height than the best parent (Table 1). The most significant height difference (more than 30 cm) was observed in IR86384-46-3-1-B x Boyarin and IRBB 21 x Kontakt. The Mazhan Red x Kontakt hybrid had a plant height (124.5 cm) approximating that of its tall parent Mazhan Red (127 cm).

Out of 29 crosses, 10 formed much longer heads than their best parent, with difference coming up to 33 per cent. Others demonstrated intermediate values with dominance varying between -0.25 and 0.77.

The number of spikelets in a head was considerably higher than in the parents of all crosses but one: BR47 x Kontakt that formed only 11 spikelets less than BR47. Difference for this parameter was very large: some crosses, for example such as KD (Khan Dan) D18 x Boyarin, outdid their bigger parent by 2.3 times and smaller one by 4.3 times, having formed 603 spikelets per head with only 211 grains that finally ripened in them, however.

The number of well-filled grains in a head for 13 crosses was sizeably higher than in the best parent. Particularly noteworthy were crosses Kontakt x Kharsu 80A and IRBB 62 x Kontakt, where by 50 per cent more seeds were formed than in parent varieties. In five hybrids we found intermediate values for this trait, whereas 11 other crosses were inferior to their smaller parent.

Spikelet fertility in three varieties of subspecies japonica (at the average, 90.2%) was considerably higher than that of indica (at the average, 63.5%), because they were late-ripening and insufficiently adapted to northern climates. Spikelet fertility in all the crosses was obviously inferior to that of their best parent. Five more hybrids outdid their parent having a smaller value for the parameter by 5 - 15 per cent. All the other were largely sterile; seeds formed themselves only in 16.8 - 83.9 per cent of spikelets. The highest fertility rates were observed in such crosses as BR 47 x Komandor (83.9%), Kontakt x Kharsu 80A (81.6%) and Mazhan Red x Kontakt (74.5%). Apparently, these indica varieties possess wide-compatibility genes. It should be noted that reciprocal hybrids between Kontakt (92.3%) and Kharsu 80A (66.8%) had their spikelet fertility largely varied (81.6 and 33.7%), which can be accounted for by cytoplasmic effects. This value was considerably higher when Kontakt variety was the mother form.

Spikelet length in the crosses was inherited in a number of different ways. 4 crosses demonstrated depression, 2 crosses showed dominance of the smaller values of the trait, 14 crosses had intermediate values, in 2 crosses we found dominance of the larger values and in 6 crosses - a slight (by 1 mm) exceedance over the bigger parent.

Spikelet width was inherited as follows: from hybrid depression (IR74099-3R-3-3 ? Kontakt) to super dominance (BR47 x Kontakt). Prevalent were intermediate values of the trait with a tendency towards the bigger parent. In 6 crosses we observed complete dominance.

In 10 crosses the weight of 1000 grains was reliably larger than in the best parent, in 2 crosses - smaller than in the smaller parent, whereas others had intermediate values for the trait. In 5 crosses we found the largest grain weight (30.3 - 32.0 mg): BR47 x Kontakt, FL478 x Kontakt, IR86385-117-3-1-B x Kontakt, IR86385-111-1-1-B x Kontakt, IR86385-248-2-1-B x Kontakt.

9 crosses produced much more seeds in one head than their parent form having a large head. The best hybrids were KD (Khan Dan) D18 x Boyarin (5.3 g), FL478 x Kontakt (4.4 g), Kontakt x Kharsu 80A (4.7 g) and IRBB 62 x Kontakt (4.1 g).

On average, the crosses were taller than mother varieties of indica subspecies by 18.9 cm, had 114.9 more spikelets in a head and 4.3 more well-filled grains per head, 1000 of their seeds weighed 6.1 g more and the weight of seeds per head - 0.5 g more. In what concerns father varieties of japonica subspecies, hybrids were 23.9 cm taller, with a 6.4 cm longer head with 146.1 spikelets more in a head; by other parameters they were poorer that the parent. On average, spikelet fertility were higher in parents than in hybrids: by 22.5 and 49.2 per cent, respectively (Table 1).

All F1 crosses but one demonstrated positive heterosis towards better parents by plant height and by the number of spikelets per head (Table 2). The average heterosis across the hybrids by plant height was as much as 19.9 per cent. Bigger height in rice is not a desirable trait since it contributes to drowning. The optimal tallness for rice is 80 - 100 cm; crosses BR 47 x Komandor, BR47 x Kontakt, QR 2 x Kontakt and others fit within these limits.

Table 1. Yield attributes and morphology of F 1 hybrids and their parent varieties

Variety/hybrid name	Plant height, cm	Head length, cm	Number of spikelets, psc.	Number of well-filled grains, psc.	Fertility, %	Spikelet length, mm	Spikelet width, mm	Weight of 1000 seeds r	Weight of seeds per head, g
BR 47 × Komandor	94.5	26.3	214.3	179.7	83.9	8.1	3.1	25.7	4.6
BR47 × Kontakt	84.0	18.1	136.9	27.9	20.4	8.2	3.4	30.9	0.9
FL478 × Kontakt	96.0	18.7	251.3	141.3	56.2	8.5	3.1	30.7	4.4
INPARA-3 × Kontakt	105.7	20.7	309.3	65.0	21.0	8.1	3.1	29.0	1.9
IR74099-3R-3-3 × Kontakt	92.0	19.0	181.7	74.0	40.7	7.8	2.6	26.0	1.9
IR86384-46-3-1-B × Boyarin	120.5	23.3	290.7	66.0	22.7	8.0	3.0	28.3	1.8
IR86385-111-1-1-B × Kontakt	101.0	22.3	252.0	72.0	28.6	8.8	3.0	32.0	2.3
IR86385-117-3-1-B × Kontakt	94.0	22.0	236.0	113.0	47.9	8.8	2.8	30.3	3.4
IR86385-194-2-1-B × Kontakt	102.8	19.3	233.3	56.7	24.3	8.4	2.9	27.7	1.6
IR86385-248-2-1-B × Kontakt	107.5	21.7	219.0	79.7	36.4	8.6	3.1	31.0	2.4
IR86385-56-2-1-B × Kontakt	107.3	21.2	328.7	119.3	36.3	8.5	2.9	26.5	3.1
IR86385-87-1-1-B × Boyarin	111.0	23.0	296.7	65.0	21.9	8.5	3.6	28.3	1.8
IR86385-99-2-1-B × Kontakt	111.1	23.3	263.0	97.0	36.9	9.1	2.9	29.3	2.8
IRBB 21 × Kontakt	95.7	19.0	242.3	88.0	36.3	8.9	2.9	28.7	2.7
IRBB 5 × Boyarin	103.3	20.7	304.3	161.3	53.0	8.2	3.1	26.7	4.3
IRBB 62 × Komandor	107.7	20.0	362.3	191.0	52.7	8.5	3.3	27.7	5.1
IRBB 62 × Kontakt	99.8	20.3	325.3	150.7	46.3	8.6	3.1	27.7	4.1
IRBB 7 × Boyarin	104.5	21.3	265.0	132.0	49.8	8.1	3.1	26.5	3.6
KD D18 × Boyarin	106.0	22.7	**603.7**	211.0	35.0	7.8	3.0	23.7	5.3
KD Sub1 D149 × Komandor	113.4	22.7	359.0	148.7	41.4	8.5	3.1	28.3	4.2
KD Sub1 D27 × Boyarin	97.0	22.3	476.3	119.7	25.1	8.2	3.2	23.3	3.0
Kharsu 80A × Kontakt	103.0	17.7	175.3	59.0	33.7	8.6	3.0	27.3	1.7
Kontakt × Kharsu 80A	118.3	23.0	186.7	152.3	81.6	8.3	3.1	29.7	4.7
Mazhan Red × Kontakt	124.5	27.7	181.3	135.0	74.5	8.2	2.8	22.0	2.8
OM/Saltol T35 × Boyarin	106.8	21.7	404.3	68.0	16.8	7.9	3.0	25.0	2.0
QR 1 × Komandor	108.0	22.0	375.7	159.7	42.5	8.0	2.7	20.7	3.5
QR 1 × Kontakt	97.0	19.0	231.8	103.7	44.7	8.5	2.9	23.4	2.5
QR 2 × Kontakt	91.7	18.7	310.7	171.0	55.0	8.3	2.6	24.3	4.4
SHPT-1 × Kontakt	92.0	19.3	383.0	81.3	21.2	8.4	3.0	29.0	2.3
BR47	75.3	22.4	148.1	103.6	70.0	8.1	3.0	27.0	3.3
FL478	77.4	21.5	173.3	123.9	71.5	8.9	2.6	25.5	3.2
INPARA-3	93.3	19.8	259.0	179.6	69.3	8.1	2.7	20.6	3.7
IR74099-3R-3-3	78.3	20.7	165.7	73.5	44.4	8.4	2.7	17.8	1.3
IR86384-46-3-1-B	83.3	19.0	133.6	74.2	55.5	7.9	2.7	24.0	1.8
IR86385-111-1-1-B	80.0	18.2	125.0	83.8	67.0	9.0	2.5	24.0	2.0
IR86385-117-3-1-B	86.7	16.5	114.0	76.8	67.4	8.8	2.4	25.9	2.0
IR86385-194-2-1-B	86.0	20.4	126.0	100.2	79.5	8.6	2.5	23.2	2.4
IR86385-248-2-1-B	85.0	23.5	140.8	73.5	52.2	8.8	2.5	17.8	1.3
IR86385-56-2-1-B	80.0	22.3	148.7	78.5	52.8	8.6	2.4	18.2	1.7
IR86385-87-1-1-B	94.0	26.0	178.0	137.3	77.1	9.3	2.4	23.3	3.1
IR86385-99-2-1-B	76.7	21.0	135.8	76.5	56.4	9.8	2.2	26.0	2.0
IRBB 21	65.0	15.0	165.4	107.9	65.2	8.7	2.6	17.8	1.9
IRBB 5	53.3	21.7	147.2	63.8	43.4	8.2	2.6	17.5	1.7
IRBB 62	74.7	21.5	147.3	99.0	67.2	9.1	2.7	22.3	2.9
IRBB 7	73.3	24.5	224.5	101.0	45.0	8.2	2.6	16.8	2.7
KD (Khan Dan) D18	91.7	19.7	268.0	196.4	73.3	7.9	2.6	19.3	3.8

Table 1. continue...

KD Sub1 D149	94.0	25.5	316.2	85.2	26.9	7.9	2.7	16.6	1.6
KD Sub1 D27	93.3	18.3	246.0	169.1	68.7	8.0	2.7	20.7	3.5
Kharsu 80A	100.0	24.7	134.3	89.7	66.8	8.5	2.7	22.1	2.6
Mazhan Red	127.0	21.5	180.5	146.5	81.2	8.0	2.7	22.5	3.1
OM/Saltol T35	92.0	23.3	194.0	143.5	74.0	7.9	2.5	23.0	3.3
QR 1	77.8	22.9	149.8	112.6	75.2	8.4	2.4	15.4	2.8
QR 2	82.0	21.7	155.0	133.0	85.8	9.3	2.4	19.0	3.6
SHPT-1	91.0	23.3	192.0	97.8	50.9	9.0	2.8	21.3	3.3
Kontakt	66.7	13.5	104.5	95.8	92.3	8.1	3.1	28.8	2.8
Boyarin	87.7	16.0	143.3	136.7	95.4	8.4	4.1	33.3	4.4
Komandor	84.0	15.1	182.9	151.5	82.8	8.0	3.3	28.0	4.2
Average for crosses	103.3	21.3	289.7	113.4	40.9	8.4	3.0	27.2	3.1
Average for indica parents	84.4	21.4	174.7	109.1	63.5	8.5	2.6	21.1	2.6
Average for japonica parents	79.4	14.9	143.6	128.0	90.2	8.1	3.5	30.0	3.8
Standard deviation	14.8	2.9	97.0	40.5	21.2	0.4	0.3	4.4	1.0

By head length, average heterosis was not observed; however, in 10 hybrids it was positive: from 4.4 to 33.3. per cent. In our variety model, rice head must be short but compact and dense, i.e. having the biggest number of spikelets per 1 cm of length. In this respect, the best were hybrids QR 2 x Kontakt and FL478 x Kontakt having head length 18.7 cm and head density 16.6 and 13.5 pcs/cm, respectively.

The number of spikelets per head makes a large difference for grain crop yield, and heterosis of this trait is very important. In ten of the crosses, heterosis was over 100 per cent, while in three of them (KD D18 x Boyarin, IR86385-56-2-1-B x Kontakt and IRBB 62 x Kontakt) it was as much as 120 per cent. The average heterosis of this trait was 68.2 per cent. However, bruchids that actually determine yield rates were not formed in all spikelets.

The average negative heterosis in relation to the best parents manifested itself for all other studied traits. Only some of the hybrids showed true heterosis of the number of well-filled grains per head; in 10 of these crosses it amounted to 13.7 - 59 per cent. What should be noted is sample IRBB 62 whose crosses with Komandor and Kontakt showed heterosis at the rate of 26.1 and 52.2 per cent, respectively (Table 2). These combinations are of special interest for further selection.

True heterosis of spikelet fertility was lacking in all the crosses. Its value was negative, on average - 54 per cent across all combinations. This was due to reproduction barriers between subspecies indica and japonica determined by genes of incompatibility. Similar results were obtained by Murayama S., Sarker M. (2002).

For spikelet length, moderate heterosis (0.5 - 5.9%) was manifest only in 5 crosses, particularly so in KD D149 x Komandor. For spikelet width, heterosis (1.0 - 10.4 per cent) was found in only 6 hybrids, the biggest one - in BR47 x Kontakt. For the weight of 1000 grains, heterosis (0.7 - 11.1 per cent) was reported in 10 crosses and was at its maximum in IR86385-111-1-1-B x Kontakt and IR86385-248-2-1-B x Kontakt. For grain weight per head, 9 hybrids were heterotic and outpaced their best parent by 9.6 - 65.2 per cent (Table 2). The biggest heterosis of this trait was shown in the following crosses: Kontakt x Kharsu 80A (65.2%), IRBB 62 x Kontakt (40.5%) and FL478 x Kontakt (39.9%). They are of great interest and value for further selection.

The weight of seeds per head was in a positive correlation with plant height (r=0.11) and head length (r=0.23), on average - with the number of spikelets per head (r=0.40) and fertility (r=0.68), strongly - with the number of well-filled grains (r=0.97). The length and width of bruchids did not correlate with the weight of grain per head, while the weight of 1000 grains showed a weak negative correlation with the former (r=-0.21).

The graphs below illustrate a correlation of the weight of grains per head with other traits in the crosses (Fig. 1). In accordance with regression equations, the value for this trait goes up by 0.5 g with the increase of plant height by 40 cm, of head length by 4 cm, with the number of spikelets per head by 100 pcs, with the number of well-filled grains by 20 pcs, fertility by 10 per cent; however, if the weight of 1000 grains drops it rises by 6 g. At that, each of the traits has its own optimum: plant height - 105 - 110 cm, head length - 20 - 23 cm, number of spikelets per head - 300 - 400 pcs, number of well-filled grains - 180 - 220 pcs, the weight of 1000 seeds - 24 - 28 g.

DISCUSSION

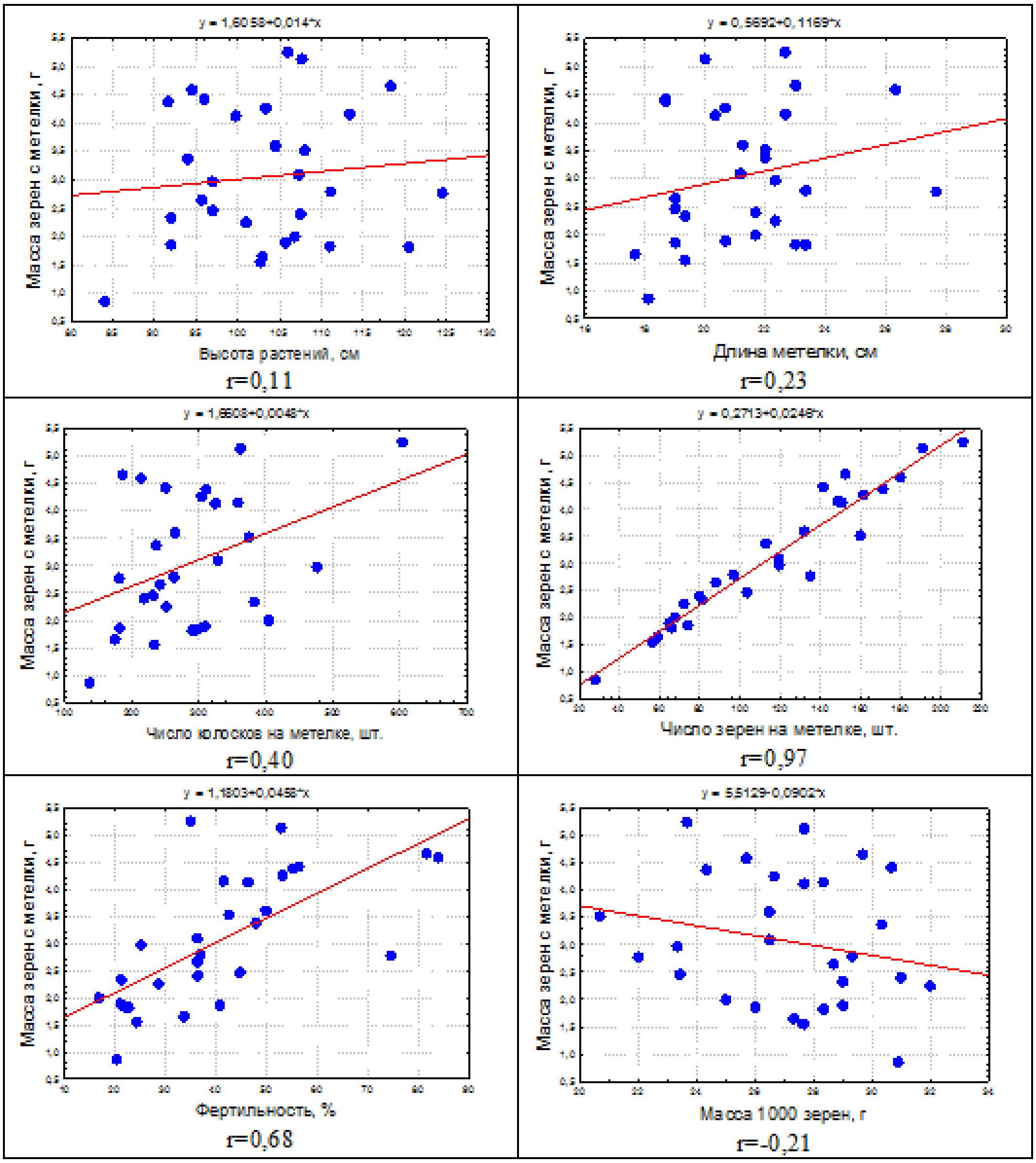
In F_1 hybrids, the number of spikelets per head is more strongly correlated with its size in the mother (r=0.60) than in the father variety (r=0,28); the former correlation is a positive average.

Kabaki (1993) and Murayama *et al*. (2002) wrote about positive heterosis of the number of spikelets and the weight of 1000 seeds. In the

Table 2. True heterosis values for several traits of rice F_1 hybrids

	Hybrid name	Plant height, cm	Head length, cm	Number of spikelets, pcs.	Number of grains, pcs.	Fertility, %	Spikelet length, mm	Spikelet width, mm	Weight of 1000 seeds, g	Weight of grain per head, g
1	BR 47 × Komandor	12.5	17.5	17.2	13.7	-2.9	-0.5	-4.9	-8.2	9.8
2	BR47 × Kontakt	11.5	-19.1	-7.6	-73.1	-77.9	1.1	10.4	7.3	-73.9
3	FL478 × Kontakt	24.0	-13.2	45.0	14.0	-39.1	-4.5	1.0	6.5	39.9
4	INPARA-3 × Kontakt	13.3	4.4	19.4	-63.8	-77.2	0.0	2.0	0.7	-48.9
5	IR74099-3R-3-3 × Kontakt	17.5	-8.1	9.7	-22.8	-55.9	-6.8	-14.3	-9.7	-34.0
6	IR86384-46-3-1-B × Boyarin	37.4	22.8	102.8	-51.7	-76.2	-4.8	-26.6	-15.0	-58.6
7	IR86385-111-1-1-B × Kontakt	26.3	22.7	101.6	-24.8	-69.0	-1.9	-3.3	11.1	-20.2
8	IR86385-117-3-1-B × Kontakt	8.4	33.3	107.0	18.0	-48.1	0.0	-9.8	5.3	19.5
9	IR86385-194-2-1-B × Kontakt	19.5	-5.2	85.2	-43.4	-73.7	-2.3	-6.8	-4.0	-45.0
10	IR86385-248-2-1-B × Kontakt	26.5	-7.8	55.5	-16.8	-60.6	-1.9	2.0	7.6	-14.9
11	IR86385-56-2-1-B × Kontakt	34.1	-5.2	121.1	24.5	-60.7	-1.7	-4.9	-8.0	9.6
12	IR86385-87-1-1-B × Boyarin	18.1	-11.5	66.7	-52.7	-77.0	-8.6	2.0	-15.0	-58.4
13	IR86385-99-2-1-B × Kontakt	44.9	11.1	93.7	1.3	-60.0	-6.8	-6.5	1.8	-1.1
14	IRBB 21 × Kontakt	43.4	26.7	46.5	-18.4	-60.7	2.0	-4.6	-0.5	-6.0
15	IRBB 5 × Boyarin	17.9	-4.6	106.8	18.0	-44.4	-2.4	-12.3	-20.0	-3.2
16	IRBB 62 × Komandor	28.2	-6.8	98.1	26.1	-36.4	-7.0	0.3	-1.2	22.7
17	IRBB 62 × Kontakt	33.5	-5.4	120.9	52.2	-50.4	-5.3	0.0	-3.9	40.5
18	IRBB 7 × Boyarin	19.2	-13.3	18.0	-3.4	-47.8	-2.9	-10.6	-20.5	-18.2
19	KD (Khan Dan) D18 × Boyarin	15.6	15.1	125.3	7.4	-63.4	-7.2	-28.1	-29.0	19.3
20	KD D149 × Komandor	20.6	-11.1	13.5	5.4	-51.3	5.9	-4.0	1.2	-0.7
21	KD Sub1 D27 × Boyarin	4.0	22.0	93.6	-29.2	-73.7	-1.7	-23.2	-30.0	-32.5
22	Kharsu 80A × Kontakt	3.0	-28.4	30.5	-38.4	-63.5	0.6	-3.3	-5.1	-41.5
23	Kontakt × Kharsu 80A	18.3	-6.8	39.0	59.0	-11.6	-2.9	2.6	2.9	65.2
24	Mazhan Red × Kontakt	-2.0	28.7	0.4	-7.8	-19.3	2.0	-9.8	-23.6	-11.2
25	OM/Saltol T35 × Boyarin	16.0	-7.0	108.4	-52.6	-82.4	-5.6	-27.4	-25.0	-54.5
26	QR 1 × Komandor	28.6	-3.9	105.4	5.4	-48.7	-5.2	-16.3	-26.2	-15.8
27	QR 1 × Kontakt	24.7	-17.0	54.8	-7.9	-51.5	0.5	-6.2	-18.7	-12.8
28	QR 2 × Kontakt	11.8	-13.8	100.4	28.6	-40.4	-10.5	-16.3	-15.5	23.4
29	SHPT-1 × Kontakt	1.1	-17.1	99.5	-16.9	-77.0	-6.0	-2.3	0.7	-29.6
	On average	**19.9**	**0.0**	**68.2**	**-8.6**	**-54.0**	**-2.9**	**-7.6**	**-8.1**	**-11.4**

present study, true heterosis was revealed for the number of spikelets per head and plant height (Table 2). Heterosis of plant height is not desirable as tall plants are given to drowning. To ensure a high yield, the most important are such its components as the weight of 1000 seeds, the number of grains in a head and the number of productive stems per square unit. The latter we did not consider as it is linked not to an individual plant but to a population. For the weight of 1000 seeds, heterosis was found only in 1/3 of the studied crosses and very moderate at that (not



Translation for the figure:
Weight of grains per head, g; Plant height, cm; Head length, cm; Number of spikelets per head, pcs; Number of seeds per head, pcs; Fertility, %; Weight of 1000 seeds, g

Fig. 1. Correlation between the weight of grains per head and other traits in F_1 hybrids

beyond 11.1 %). In addition, this trait was in a negative correlation with the weight of seeds per head. It is due to this fact that the key indicator of productivity is the number of grains per head. If in all the spikelets or, at the very least, in 90 per cent of them seeds did ripen, than all the hybrids would be heterotic by productivity.

But here intervenes the factor of hybrid sterility that controls heterosis for spikelet number. Although the number of spikelets per head in hybrids was higher than in parent varieties, many of them did not show a better productivity of grains per head due to a lower spikelet fertility. Only 1/3 of the crosses showed a noticeable heterosis of the number of well-filled seeds per head.

In the indica subspecies, such varieties as BR 47, Kharsu 80A, Mazhan Red, FL 478 and QR 2 can possess wide genetic compatibility because all F_1 crosses between them and japonica varieties form more fertile spikelets. Due to this, they have strong genetic proximity to varieties of japonica, particularly so to Kontakt and Komandor.

Some of the parent varieties (KD D149 and IRBB 5) did show low spikelet fertility (26.9 and 43.4 %) and a moderate weight of grain per head (1.6 and 1.7 g) if compared with the others; however, crosses with them demonstrated a better fertility of spikelets (41.4 and 53.9 %) and yielded a larger head such as in their father forms Komandor and Boyarin (4.2 and 4.3 g). Therefore, in some cases hybrid spikelet fertility can rise in comparison to one of the parent forms, but never if compared to both of them.

Thus, among all of the yield capacity components, the number of spikelets per head and the number of well-filled grains per head contributed to a rise in grain weight per head in hybrids (Fig. 1). The weight of 1000 seeds insignificantly affected this parameter; the best were the average values of 24 - 28 g. A substantial positive correlation was found between spikelet fertility and productivity per head in hybrids (r=0.68).

Our findings demonstrate that F_1 hybrids in certain crossing combinations can yield more grain per head without any change to the genetic traits of parent varieties. Due to the fact that the number of spikelets per head was larger in all F_1 crosses than in their parents, while the number of seeds was basically lower due to a poorer spikelet fertility, these crosses may have a higher grain productivity if we solve the problem of inter-subspecific sterility by including the neutral S allele in one of the parent forms (Ikehashi, 1991), or else by selecting varieties for crossing that carry that sort of wide compatibility gene.

REFERENCES

1. Chen J., Ding J., Ouyang Y., Du H., Yang J., Cheng K., Zhao J., Qiu S., Zhang X., Yao J., Liu K., Wang L., Xu C., Li X., Xue Y., Xia M., Ji Q., Lu J., Xu M., Zhang Q. metricconverterProductID2008. A2008. A triallelic system of S5 is a major regulator of the reproductive barrier and compatibility of indica–japonica hybrids in rice / PNAS, **105**(32). p.11436–11441.
2. Griffing B. Concepts of general and specific combining ability in relation to diallel crossing systems // *Austral. J. Biol. Sci.* 1956. N 9. P. 463-493
3. Ikehashi, H. 1991. Genetics of hybrid sterility in wide hybridization in rice (Oryza sativa L.). In Y.P.S. Bajaj ed., Biotechnology in Agriculture and Forestry. Springer Verlag, Berlin. 14 (Rice) : 113-127.
4. Ikehashi, H. and Araki, H. 1987. Screening and genetic analysis of wide-compatibility in F 1 hybrids of distant crosses in rice, Oryza sativa L. Tech. Bull. Trop. Agric. Res. Center. No. 23. TARC, Japan. 1-79.
5. Kabaki, N. 1993. Growth and yield of japonica-indica hybrid rice. JARQ 27: 88-94.
6. Khush, G.S. 1994. Challenges in rice breeding and biotechnology. In Recent Progress in Rice Research and Challenge Towards the 21st Century. Japan-IRRI Day. Tsukuba Seminar. Tsukuba. 11-19.
7. Maruyama, K. 1988. Strategy and status for developing hybrid rice. Iden (Heredity) **42**(5) : 28-31*.
8. Morinaga, T. and Kuriyama, H. 1958. Intermediate type of rice in the subcontinent of placecountry-regionIndia and Java. *Jpn. J. Breed.* **7**: 253-259.
9. Murayama S., Sarker M. Agronomic performance of f_1 hybrids of rice (*Oryza sativa* L.) in japonica-lndica crosses - Heterosis for and relationship between grain yield and related characters / *Plant Prod. Sci.,* 2002. **5**(3): 203-210.
10. Ouyang Y. / Volume 5 of the series , 2013. pp 317-328.
11. Peng, S., Gassman, K.G., Virmani, S.S., Sheehy,

J. and Khush, G. S. 1999. Yield potential trends of tropical rice since release of IRS and the challenge of increasing rice yield potential. *Crop Sci*. **39**: 1552-1559.

12. Sarker, M.A.Z., Murayama, S., lshimine, Y. and Nakamura, placeI. 200la. Physio-morphological characters of F1 hybrids of rice (Oryza sativa L.) in japonica-indica crosses. II. Heterosis for leaf area and dry matter accumulation. *Plant Prod. Sci*. **4**: 202-209.

13. Virmani, S.S. 1996. Hybrid rice. *Adv. Agron.* **57**: 377-462.

14. Omarov D.S. To the issue of methods used for measuring and assessing heterosis in plants. *Agricultural Biology*, **10(**1**)**. 1975. Pp. 123 – 127.