Considerations on heterosis utilization in rapeseed (*Brassica napus*)

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RAPESEED INDUSTRY DEVELOPMENT IN CHINA

High-yield rapeseed varieties have become widely spread since 1980's, while hybrid rapeseed varieties just started to be cultivated at that time. Along with the spread of rapeseed hybrid varieties in 1990's-2000's, the mean yield and economic benefits were increased gradually and thus promoted the expansion of rapeseed acreage and the increase of annual output. Several reasons including the improvement of cultivation measures have contributed to the increase of mean yield since 1980s, but there is no doubt that the improvement of rapeseed variety has played the most important role in the development of rapeseed production.

Table 1. Rapeseed heterosis utilization and Rapeseed industry development in China

Year	Percent of hybrids （%）	Mean yield (Kg/ha)	Yearly acreage (million Ha)	Annual output （×104 tons）
1970's	0	652.05	2.13	138.7
1980's	10-20	1153.65	4.25	489.9
1990's	30-40	1331.7	6.25	832.1
2000's	50-70	1705.65	7.07	1203.07

WAYS TO UTILIZE HETEROSIS IN CHINA

In recent years, rapeseed hybrid varieties were grown on 4.8~4.9 million hectares in China, covering about 70% of the average area of 7 million hectares yearly. Heterosis in rapeseed has been exploited in multiple ways in China. Three-line system based on CMS (Cytoplasmic Male Sterility) is the major approach to develop hybrids (Table 2).

Table 2. Rapeseed varieties released in China during 2000-2005 (Data provided by Mr Zhang Dong-xiao)

Total		217			Percentage %
Conventional		47			21.7
Hybrid		170			78.3
Of hybrid	CMS	GMS (Genetic MS)	EMS (Ecotype MS)	GC (Gametocides)	
	107	47	12	4	
Percentage (%)	62.9	27.6	7.1	2.4	100.0

HETEROSIS FROM DIFFERENT GENE RESOURCES

High heterosis is obtained in crosses between Chinese Spring types and European Spring types due to large genetic distance and of being different ecologic types.

It is suggested to have Chinese genetic background in maintainer lines and European genetic background in restores lines as much as possible.

Table 3. Yields of CMS based hybrids

Hybrid	CMS line	Restorer line	Yield increase (%)
Huaxie No 1	HUA 1141A	SW AB: Sv02002R	+21.08 (Ranks first among the varieties tested in 3 years' average in 5 sites in Gansu province)
Xinyou 16	HUA 1141A	SW AB: Sv8625937R	+33.6% (Ranks first among the varieties tested in 2 years' average in 5 sites in Xinjiang Autonomous Region)

QUALITY TRAITS AND HETEROSIS

The heterosis of agronomic traits: heterosis on vegetative mass is greater than that of seed yield, and the later is greater than that of quality trait (vegetative heterosis - seed yield trait heterosis - seed quality trait heterosis). The average rate of heterosis of 9 rapeseed varieties is: vegetative traits- 25.05 %-30.15 %, individual plant yield 7.92 %, oil content 3.67 % (Zhang Shufen, 1992), and negatively correlated with protein content (Serney, 1993). The average rate of heterosis of sorghum is 43.3 % for 4 yield traits, -13.02 % for 4 quality traits (Zhang Wenyi, 1983).

Reasons for weak heterosis of quality traits lie in: First, quality trait relates to not only "source, sink and flow", but also the matter transformation in the "sink". The physiological and biochemical processes are more complicated. Second, it is determined by the quality trait itself: (1) The quality is judged by man's demand. (2) The direction of artificial and natural selection is different, so it is very rare to have a fine quality material in wild type. (3) The author read a large number of papers, and found that the majority of the fine quality traits are controlled by recessive genes if they are controlled by major genes (Table 4).

Table 4. Fine quality traits in different crops.

Crop	Traits	Genes
rapeseed	low erucic acid content	recessive, el1el2
rapeseed	Low glucosinolate content	recessive, g1g2g3
cotton	gossypol free	recessive genes
cotton	High lysine content	recessive genes
cotton	high oil content	recessive genes
maize	glutinous maize	recessive genes
maize	High sugar content	recessive genes
sorghum	High lysine content	recessive genes
sorghum	Low tannin content	recessive genes
persimmon	Low tannin content	recessive genes

What is the reason? Wild species have the dominant trait (AA) of poor quality. The high quality trait of aa gene is resulted from artificial selection when AA gene mutated to be Aa. Thus, it is not easy to use the dominant effect of heterosis because the majority of high quality traits are controlled by major recessive genes. To utilize the heterosis of high quality trait, the parents must have high quality.

DISEASE RESISTANCE AND HETEROSIS

Disease resistance trait has the same direction of both artificial selection and natural selection. More disease resistant resources are found in wild species. The author found, having read a large number of publications, that majority of disease resistant traits are controlled by dominant genes if they are controlled by major gene (Table 5).

Among the 8 sources of resistance to bacterial leaf blight in rice, 5 are dominant, 2 are incomplete dominant, and only one is recessive.

The reasons lie in: First, the resistance can only express when it is controlled by dominant gene (RR)(Rr), and the trait would be eliminated through natural selection before it is getting homozygous if it is controlled by recessive gene (rr). Second, the wild species due to natural selection are usually highly resistant to diseases and the wild trait is usually dominant.

Table 5. Disease resistant traits in different crops

Crop	Traits (resistance to)	Genes
rapeseed	white rust	3 dominant genes
rapeseed	blackleg at seedling stage	one dominant gene
rice	blast	1 to 3 dominant genes
sunflower	downey mildew	dominant genes
sunflower	rust	dominant genes
sunflower	sclerosporiosis	dominant genes
cotton	angular leaf spot	dominant genes
cotton	wilt	dominant genes
soybean	frogeye leaf spot	dominant genes
soybean	downey mildew	dominant genes
soybean	frog eye	dominant genes

Thus, it is a very effective and simple way to solve the problem of disease resistance by using F1.

RR × rr → Rr (resistant to disease)

R1R1 r2r2 × r1r1R2R2 → R1r1R2r2 (resistant to 2 physiological races of disease

RRbb × rrBB → RrBb (resistant to 2 diseases)

r1r1r2r2 (horizontal resistance) × RR (vertical resistance) → F1 (strong and stable resistance)

SOURCE AND SINK BALANCES

The “source and sink” are more surplus than conventional varieties and the “flow” is limited for higher yields in rapeseed hybrids

The average heterosis rate for biomass, pods per plant, seeds per pod and 1000-seed weight are 25-30 %, 73.3 %, 17.5 % and 1.8 %, respectively (based on analysis of 46 hybrid varieties in 6 years).

Leaf and pod surface, producing photosynthetic products, are the “source”, seed and pod is the “sink”. That the hybrid seed is not full enough and the heterosis rate of 1000-seed weight is low means that the flow is not so smooth. Hybrids have more surplus “source and sink”, but insufficient “flow”. Therefore, the relationship between “source, sink and flow” has to be harmonized to make more photosynthetic product “flow” to “sink” to further enhance the hybrid rapeseed yields.

Harvest index is the criterion of judging whether it is harmonizing between the “source”, “sink”, and “flow” of hybrid or not. The harvest index of hybrid rapeseed varieties (26-28%) is lower than that of conventional varieties (28-30%) (Guan Chunyun, 1995). It’s important to enhance the harvest index for hybrid yield improvement.