

# HYBRID BREEDING IN EARLY SPRING CABBAGE

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## ABSTRACT

1. From 1958 to 1962 research was carried out on the breeding of hybrid varieties of pointed-headed cabbage.
2. The  $F_1$  of intervarietal crosses showed heterosis for vigour and earliness. Increased vigour was coupled with increased head weight. Increased earliness resulted from a more rapid head formation.
3. Propagation of the  $F_1$  leads to a decrease in productivity and uniformity, both in inter- and intravarietal crosses. By selection in the  $F_1$  the uniformity of the  $F_2$  is increased but vigour decreases further.
4. Selfing decreased head weight in 3 generations by about 20 %. After crossing the inbred lines vigour was completely restored.
5. A new selection method is described which can supply the same information as the method of diallel crosses.

## INTRODUCTION

One of the ways to maintain the parents of hybrid varieties of cabbage is by the use of cuttings (HEEMSTRA, 1955). As large-scale production of  $F_1$  seed is difficult to carry out in this manner it is important to know whether the  $F_1$  can be propagated without affecting its quality. The  $F_2$  seed could then be put into the trade. Research on pointed-headed cabbage has shown that propagation of the  $F_1$  is sometimes justified, although the  $F_2$  so obtained may be less productive and some days later than the  $F_1$  (NIEUWHOF, 1959). To verify this, and to determine the amount of heterosis in the  $F_1$  research on this subject has been carried out since 1958.

Some research has also been done on the breeding of hybrid varieties with the aid of inbred lines, which are maintained sexually.

## MATERIAL AND METHODS

Three varieties were used, viz. First of the Market (an early type of the Dutch pointed-headed variety Eersteling), Marschländer Frühspitz (an early German pointed-headed variety) and Golden Acre (an early white cabbage variety with a round head).

First of the Market originated from a pair cross, which was afterwards propagated, first by mass selection for one generation and then by family selection for one generation. From a highly uniform family plants were selected for this research. The sample of Marschländer Frühspitz received from Germany was propagated by family selection for one generation. The plants used were selected from a uniform family. The plants of Golden Acre came from a commercial strain.

Crossing was done by hand when the flowers were in the bud stage or just after they had opened. Then the chance of selfing is small so that emasculation is not necessary. Selfing was done in the early bud stage. For bud pollination use was made of a pair of emasculation scissors (WIERING, 1958).

The different strains were tested on a light sandy soil at Wageningen. Sowing was done under glass at the end of September and the young plants were pricked off into pots or soil blocks in October or early November. The plants were overwintered in a frame under glass. In March or early April they were set out in the open at distances of  $55 \times 55$  or  $60 \times 50$  cm. In 1958 and 1960 the trials were laid down in two, in 1962 in three replications. The number of plants per plot was usually 20 to 30, but sometimes insufficient plants were available, and consequently the numbers of plants and replications had to be reduced.

Before harvest, ratings were given in the field for uniformity and cultural value. In addition the date on which the heads were mature, and the head weight were recorded. With the analysis of variance and the multiple range test of NEWMAN-KEULS the differences were tested for significance. Significant differences quoted are at the 5% level.

#### CROSSES BETWEEN SELECTED PLANTS

In 1958 three plants were selected from Marschländer Frühspitz (MF) and three plants from First of the Market (EM). In 1959 these were crossed and selfed. The resulting progenies were compared in 1960 and 1962 (table 1). In some instances the crosses were carried out reciprocally and both reciprocals tested. As differences between them were usually slight, the data in table 1 have been calculated by averaging the reciprocals.

There is a reasonably good correlation between the productivity of the various strains in 1960 and 1962. Only the cross  $MF4 \times EM4$  was not sufficiently productive in 1962. As regards earliness there is little agreement between the two years. This is probably due to the fact that in 1962 a period with a relatively low temperature, causing the crop to be later than normal, was followed by some days with fairly high temperatures. Consequently all strains reached maturity in a few days. This may account for the fact that the differences in earliness did not clearly show in 1962. Therefore we will restrict ourselves mainly to the results obtained in 1960. In 1962 the differences were usually not significant.

The  $MF \times MF$ - and the  $EM \times EM$ -crosses are about equally productive, the  $MF \times EM$ -crosses being significantly 16% higher yielding. Comparison of the  $F_1$ 's with the families from which the plants were derived was not possible because seed of the latter was not available. The intravarietal crosses have, on an average, presumably been equally productive as these base populations. This could be concluded from the behaviour of some control varieties which had previously been tested with the base populations. Consequently the intervarietal crosses have presumably also been 16% higher yielding than the base populations, which points to a heterosis effect.

Assuming that head weight increases linearly with time, the mean daily increase in weight from planting to the 50% harvesting date can be calculated. In table 2 this

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 TABLE 1. NET HEAD WEIGHT AND EARLINESS OF F<sub>1</sub>'S OBTAINED FROM SELFINGS AND DIALEL CROSSES OF MARSCHLÄNDER FRÜHSPITZ (MF) AND FIRST OF THE MARKET (EM).

Plant	1960			1960			1962			1962						
	MF1	MF3	MF4	MF1	MF3	MF4	EM1	EM3	EM4	MF1	MF3	MF4	MF1	MF3	MF4	av.
1	<b>1.06</b> <sup>1)</sup>	0.93	0.98	1.14	0.99	1.04	<b>0.83</b>	0.82	1.01	1.47	1.44	1.32	1.47	1.44	1.32	1.41
3	<b>0.86</b>	1.01	1.01	1.05	1.05	1.07	<b>0.79</b>	1.02	1.06	1.47	1.39	1.43	1.47	1.39	1.43	1.43
4	<b>1.01</b>			1.28	1.12	1.23	<b>1.05</b>	1.05	1.21	1.65	1.57	1.20	1.65	1.57	1.20	1.47
av.	<i>s</i> <sup>2)</sup> : 0.99, <i>cr</i> : 0.97			1.16	1.05	1.11	<i>s</i> : 0.89, <i>cr</i> : 0.95			1.53	1.47	1.26	1.53	1.47	1.26	1.44
1	<b>7.0</b>	2.5	2.0	5.0	-2.5	1.0	<b>8.5</b>	7.0	7.5	50% harvesting date <sup>4)</sup>						
3	<b>0.0</b>	1.0	1.0	5.0	-0.5	1.5	<b>9.0</b>	7.5	7.5	17.0	17.5	18.0	18.0	18.0	18.0	18.0
4	<b>2.0</b>			6.0	0.5	4.5	<b>11.0</b>	11.0	11.0	18.0	18.4	19.0	18.0	18.4	19.0	18.5
av.	<i>s</i> : 3.0, <i>cr</i> : 1.8			5.7	-0.8	2.3	<i>s</i> : 9.5, <i>cr</i> : 7.3			<i>cr</i> : 17.5			18.0	17.8	18.8	18.2

<sup>1)</sup> Figures in bold type relate to selfings.

<sup>2)</sup> *s*: average of selfings; *cr*: average of crosses.

<sup>3)</sup> Differences in weight and earliness between the intervarietal crosses are significant if exceeding 0.11 kg and 3.7 days respectively.

<sup>4)</sup> Number of days after May 31 on which 50% of the heads were mature.

is shown for 1960. In nearly all cases the higher productivity of the intervarietal crosses appears to be due to a greater daily increase in weight.

TABLE 2. AVERAGE DAILY NET INCREASE IN HEAD WEIGHT IN GRAMS OF  $F_1$ 'S OBTAINED FROM SELFINGS AND DIALLEL CROSSES OF MARSCHLÄNDER FRÜHSPITZ (MF) AND FIRST OF THE MARKET (EM).  
LEGEND: see table 1.

Plant	MF × MF			EM × EM			EM × MF			
	MF1	MF3	MF4	EM1	EM3	EM4	MF1	MF3	MF4	av.
1	<b>12.9</b>	12.0	12.7	<b>9.9</b>	10.0	12.2	14.3	13.7	13.7	13.9
2		<b>11.5</b>	13.3		<b>9.4</b>	12.4	13.1	14.1	14.0	13.8
4			<b>13.1</b>			<b>12.2</b>	15.8	14.8	15.5	15.4
av.	s: 12.5, cr.: 12.6			s: 10.5, cr.: 11.5			14.4	14.2	14.3	14.3

In 1960 the MF × MF-crosses were on an average significantly 5.5 days, and the MF × EM-crosses significantly 4.0 days earlier than the EM × EM-crosses. The difference in earliness between the MF × MF-crosses and MF × EM-crosses is not significant.

The crosses MF3 × EM clearly exhibit heterosis for earliness; early × late → very early. As appears from table 2 the growing rate is not higher than in other intervarietal crosses. Consequently increased earliness is associated with a decrease in head weight.

There are clear differences in breeding behaviour of the parents. For instance, the crosses with MF1 and EM4 are practically always productive and late. These differences always show, regardless of the manner of propagation. Hence, from the results obtained after selfing it is possible to predict approximately the behaviour of the parents after crossing, while the results from intravarietal crosses give information on the behaviour of the parents in intervarietal crosses. There are exceptions, however. Thus the increased earliness of the MF3 × EM-crosses could not be predicted from the results of the MF3 × MF-crosses.

#### PROPAGATION OF $F_1$ 'S

Part of the seed of the 1959 crosses was sown in July of the same year in order to obtain flowering  $F_1$  plants the following year. In 1960 the  $F_1$ 's flowered separately in isolation rooms, 10 random plants per  $F_1$ . The seed was harvested per  $F_1$ . In this way  $F_2$ 's of unselected  $F_1$  plants were obtained.

In addition  $F_2$ 's of selected  $F_1$  plants were grown. For this purpose the  $F_1$ 's were grown in 1960 in the normal way, and 10 plants of similar type were selected from each  $F_1$ . In 1961 these plants were propagated separately per  $F_1$ .

The  $F_1$ 's and  $F_2$ 's were compared in 1962 (table 3). On an average the  $F_1$  is higher yielding, earlier and more uniform than the  $F_2$ . This difference is significant. Eight out of 11  $F_2$ 's propagated without selection were less productive than the  $F_1$  from which they originated; 7 were later, and all  $F_2$ 's were more heterogeneous.

Selection in the  $F_1$  leads to a further decrease in productivity, while the crop becomes still later. Although the uniformity of the  $F_2$  was slightly improved by selection in the  $F_1$ , yet it was much lower than in the  $F_1$ . The difference in head weight

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 TABEL. 3. NET HEAD WEIGHT, EARLINEES AND UNIFORMITY OF F<sub>1</sub>'S FROM CROSSES OF MARSCHLÄNDER FRÜHSPITZ (MF) AND FIRST OF THE MARKET (EM), AND OF THE F<sub>2</sub>'S OBTAINED FROM THEM WITH AND WITHOUT SELECTION (RESPECTIVELY INDICATED AS SELECTED UND UNSELECTED F<sub>2</sub>'S)

Cross	Net weight per head in kg			50 % harvesting date <sup>1)</sup>			Uniformity <sup>2)</sup>		
	F <sub>1</sub>	F <sub>2</sub>		F <sub>1</sub>	F <sub>2</sub>		F <sub>1</sub>	F <sub>2</sub>	
		unsel.	sel.		unsel.	sel.		unsel.	sel.
MF1 × MF3	1.29	1.29	1.34	17.0	18.3	18.0	4.0	3.0	3.0
MF1 × MF4	1.51	1.47	1.26	17.5	18.0	18.0	4.0	3.0	3.5
MF3 × MF4	1.40	1.23	1.23	18.0	18.0	18.3	3.0	2.0	2.5
<i>av.</i>	<b>1.40</b>	<b>1.33</b>	<b>1.28</b>	<b>17.5</b>	<b>18.1</b>	<b>18.1</b>	<b>3.7</b>	<b>2.7</b>	<b>3.0</b>
EM1 × EM3	–	1.19	0.87	–	19.0	18.3	–	4.0	4.0
EM1 × EM4	–	1.23	0.79	–	19.3	22.0	–	3.0	3.0
EM3 × EM4	–	0.88	0.58	–	21.0	22.0	–	4.0	3.0
<i>av.</i>	–	<b>1.10</b>	<b>0.75</b>	–	<b>19.8</b>	<b>20.7</b>	–	<b>3.6</b>	<b>3.3</b>
MF1 × EM1	1.47	1.17	1.29	18.0	18.3	18.7	3.0	2.0	3.0
MF1 × EM3	1.47	1.23	1.07	18.0	18.7	19.0	3.0	2.0	3.0
MF1 × EM4	1.65	1.27	1.35	18.0	19.0	22.0	4.0	3.0	1.0
MF3 × EM1	1.44	1.35	1.19	17.0	16.3	18.0	4.0	3.0	3.0
MF3 × EM3	1.39	1.22	1.24	18.0	17.7	17.7	4.0	2.5	3.0
MF3 × EM4	1.57	1.32	1.20	18.4	19.3	18.0	3.5	2.0	3.0
MF4 × EM1	1.32	1.33	1.19	18.5	18.7	18.3	4.0	3.0	3.0
MF4 × EM4	1.20	1.47	1.32	19.0	19.7	20.0	3.5	3.0	3.0
<i>av.</i>	<b>1.44</b>	<b>1.30</b>	<b>1.23</b>	<b>18.1</b>	<b>18.5</b>	<b>19.0</b>	<b>3.6</b>	<b>2.6</b>	<b>2.8</b>

<sup>1)</sup> Number of days after May 31 on which 50 % of the heads were mature.

<sup>2)</sup> 1 = bad, 5 = good; the data on uniformity relate to one replication only.

between the selected and unselected F<sub>2</sub>'s of the EM × EM-crosses was significant. Further differences between the F<sub>2</sub>'s were not significant.

Only in one case was the F<sub>2</sub> more productive than the F<sub>1</sub>, namely in the cross MF4 × EM4. In the foregoing it has already been said that in 1962 the F<sub>1</sub> of the cross MF4 × EM4, compared with 1960, was too low yielding. In 1962, in comparison with the other strains, the heads of this F<sub>1</sub> should have been at least 0.25 kg heavier. Also in view of the general tendency that the F<sub>1</sub> is at least equally productive as the F<sub>2</sub>, we had expected a heavier head. Very probably the low productivity of this F<sub>1</sub> in 1962 has arisen from accidental causes. Apart from this case not a single F<sub>2</sub> exceeded the F<sub>1</sub> in productivity. There were three F<sub>2</sub>'s raised without selection, which did not differ in productivity from the F<sub>1</sub>'s (MF1 × MF3, MF1 × MF4, MF4 × EM1). However, these were later. This indicates that these F<sub>2</sub>'s also grew less rapidly than the F<sub>1</sub>'s. Only one F<sub>2</sub> obtained after selection was about equally productive as the F<sub>1</sub>, but this was later too.

## SELFING

Two plants of MF and two plants of EM were propagated by selfing for three generations in succession. For this purpose plants were always taken at random. In 1962 the successive generations were compared (table 4).

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TABLE 4. NET HEAD WEIGHT AND EARLINESS OF SOME INBRED GENERATIONS OF TWO PLANTS OF MARSCHLÄNDER FRÜHSPITZ (MF) AND TWO PLANTS OF FIRST OF THE MARKET (EM)

	Net weight per head in kg			50 % harvesting date <sup>3)</sup>		
	I <sub>1</sub> <sup>1)</sup>	I <sub>2</sub>	I <sub>3</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>3</sub>
MF	1.43 (2) <sup>2)</sup>	1.25 (3)	1.21 (6)	16.6	18.3	18.1
EM	1.08 (3)	0.91 (2)	0.91 (4)	18.2	16.6	17.9

<sup>1)</sup> I<sub>1</sub> = selfed once, I<sub>2</sub> = selfed twice, I<sub>3</sub> = selfed three times.

<sup>2)</sup> (..) = number of inbred lines to which the average relates.

<sup>3)</sup> Number of days after May 31 on which 50 % of the heads were mature.

Selfing reduces productivity. In both varieties the head weight of the I<sub>3</sub> (generation obtained after three selfings) was 85 % of that of the I<sub>1</sub> (generation obtained after one selfing). The families from which the parents were selected were not included in the trial so that it could not be ascertained whether a decrease in yield also occurs after one selfing. However, the data in table 1 show that the yield depression, upon one selfing, compared with the intravarietal crosses, is nil for the MF plants and only 6 % for the EM-plants. Nor were there any differences between the selfed and open-pollinated progenies of two EM-plants selected in 1957. So the difference in productivity between the I<sub>1</sub> and the families is presumably mostly small. Therefore, the decrease in yield of the I<sub>3</sub>, compared with the populations has probably not exceeded 20 % for the plants shown in table 3.

For earliness the tendencies are less pronounced, although it seems that the crop may sometimes be retarded by selfing.

## CROSSES BETWEEN INBRED LINES

The two MF plants and the resulting I<sub>1</sub> and I<sub>2</sub> have been crossed with the corresponding generations of the two EM-plants. Of the EM-plants, only one plant per generation was selfed; of the two MF plants sometimes two or four, as indicated in the head of table 5. The crosses were compared in 1962 (table 5).

The decrease in vigour due to selfing is completely eliminated by crossing. The I<sub>1</sub> × I<sub>1</sub>- and I<sub>2</sub> × I<sub>2</sub>-crosses are as productive as the P × P-crosses. So increased heterosis after selfing of the parents does not occur.

## DISCUSSION

Little research has so far been carried out on heterosis in cabbage. ODLAND and NOLL (1950) mentioned the occurrence of heterosis for head weight after crossing two late white cabbage varieties. In our trials, too, heterosis was clearly exhibited. However, heterosis in intervarietal crosses of white cabbage is not a common phenomenon. In our research on clubroot resistance a number of intervarietal crosses have been carried out. The resulting F<sub>1</sub>'s were generally intermediate.

The inheritance of the head weight and mostly of the earliness of the parents, as manifested in the intervarietal crosses, did not differ from the inheritance after selfing or crossing within the variety. So the genetical behaviour of the plant is not masked by the heterosis effect.

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TABLE 5. NET HEAD WEIGHT AND EARLINESS OF CROSSES BETWEEN PLANTS OF MARSchLÄNDER FRÜH-SPIZ (MF) AND FIRST OF THE MARKET (EM), AND BETWEEN THE LINES OBTAINED FROM THEM BY SELFING.

	P × P <sup>1)</sup>	I <sub>1</sub> × I <sub>1</sub> <sup>1)</sup>			I <sub>2</sub> × I <sub>2</sub> <sup>1)</sup>					
P →	MF4									
I <sub>1</sub> →		MF2-1	MF2-2	MF4-1	MF2-1-1	MF2-1-2	MF2-2-1	MF2-2-2	MF4-1-1	MF4-1-2
I <sub>2</sub> →										
		Net weight per head in kg								
EM1	1.60	1.47	1.39	1.52	1.41				1.47	
EM2	1.47	1.79	1.66	1.70	1.55	1.50				
		50 % harvesting date <sup>2)</sup>								
EM1	16.3	15.7	14.3	16.3	16.7				15.7	
EM2	17.7	16.7	18.0	17.3	18.4	18.0				

<sup>1)</sup> P = parents, I<sub>1</sub> = selfed once, I<sub>2</sub> = selfed twice.

<sup>2)</sup> Number of days after May 31 on which 50 % of the heads were mature.

In intervarietal crosses propagation of the F<sub>1</sub> leads to a decrease in vigour. Where propagation of the F<sub>1</sub> is not preceded by selection this decrease is coupled with a decrease in yield of 10 %. Although in intravarietal crosses heterosis does not occur, vigour nevertheless decreases after propagation of the F<sub>1</sub>. In the MF × MF-crosses the decrease in yield was 5 %, assumedly due to inbreeding. This assumption agrees well with the fact that when the variability is further reduced by selection of similar plants in the F<sub>1</sub>, the decrease in productivity of the F<sub>2</sub> is still greater. In the MF × MF- and MF × EM-crosses the decrease in productivity by selection in the F<sub>1</sub> was 4 and 5 per cent. respectively; in the EM × EM-crosses the decrease was even greater. So if it is intended to propagate the F<sub>1</sub> it may be advisable not to select in it, even if this should be at the expense of uniformity.

Large-scale commercial production of F<sub>1</sub> seed may present difficulties if the parents have to be propagated by cuttings. With sexually propagated inbred lines this is easier although the breeding of hybrids takes longer. Inbred lines to be used for this purpose should not have declined too much in vigour. Our first impression is that loss in vigour resulting from repeated selfings remains limited. This is also shown from the results obtained by PEARSON (1931). The production of an inbred line will generally be at least half that of a normal population. Further, the inbred lines have to be self-incompatible and have to flower simultaneously.

The crosses between inbred lines were about equally productive as those between the originally selected parents.

The reason why pointed-headed varieties are used for early production presumably is that these varieties bolt less rapidly than varieties with a round head. The early round-headed variety Golden Acre, in which also some selection was done, appeared to bolt very rapidly, a character which was dominant in crosses with pointed-headed cabbage. Inbred lines of Golden Acre obtained after one or two selfings bolted very rapidly too, although they grew more slowly.

With the method of diallel crosses it was ascertained in these experiments what plants will give the best  $F_1$ . A drawback of this method is the large number of crosses required, for  $n$  plants this number is  $\frac{1}{2}n(n-1)$ . The same information can be obtained from a simple polycross, in which the plants flower separately in groups of three. When three plants designated as A, B and C flower together and the seed of each plant is harvested and sown out separately, it is easy to calculate the results from the crosses  $A \times B$ ,  $A \times C$  and  $B \times C$ :

$F_1(A) = \frac{1}{2}AB + \frac{1}{2}AC$ ,  $F_1(B) = \frac{1}{2}AB + \frac{1}{2}BC$ ,  $F_1(C) = \frac{1}{2}AC + \frac{1}{2}BC$ , assuming that the reciprocals do not differ.

The number of groups of three plants to be formed if each plant is to occur at least once with another plant in a group is one third or slightly more than the number of pairs required when using the method of diallel crosses, e.g.

Number of			Number of		
Plants	Pairs in diallel crosses	Groups of 3 plants	Plants	Pairs in diallel crosses	Groups of 3 plants
3	3	1	10	45	17
4	6	3	11	55	27
5	10	4	12	66	25
6	15	6	13	78	28
7	21	7	14	91	34
8	28	10	15	105	35
9	36	14	16	120	43

This method, indicated as *triangle cross*, only gives reliable information if the plants flower simultaneously and are fertilized to the same extent by the other two partners of the group. If insects are used for pollination and insufficient isolation rooms are available for diallel crosses, the use of this triangle cross may be called for.

After carrying out diallel crosses we can calculate the behaviour of the plants after a normal polycross. As the behaviour of the parent plants in the various crosses did not differ much, the polycross method, also, would have yielded sufficient information on the characters of the different parents. Where the general combining ability and the specific combining ability differ considerably the polycross method alone will not be sufficient. For if this method is applied in the usual way, i.e. removing the plants with a bad general combining ability in the successive generations, it is not unthinkable that certain good combinations may not be found since plants can be removed which combine well with only a few plants, but combine poorly with others. Hence, after using the polycross method for some generations it may be advantageous to proceed to one of the methods mentioned above.

#### SAMENVATTING

##### *Het kweken van hybriderassen bij spitskool*

1. Van 1958 tot 1962 is onderzoek uitgevoerd over het kweken van hybriderassen bij spitskool.



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2. In de  $F_1$ 's van kruisingen tussen planten uit verschillende rassen trad heterosis op voor de groeikracht en de vroegheid. De grotere groeikracht ging gepaard met een hoger koolgewicht. De grotere vroegheid was het gevolg van een snellere koolvorming.
3. Bij vermeerdering van de  $F_1$ 's namen de productiviteit en de uniformiteit af. Door selectie in de  $F_1$  nam de uniformiteit van de  $F_2$  toe, maar de groeikracht nam hierdoor verder af.
4. Door zelfbestuiving verminderde het koolgewicht in 3 generaties met ongeveer 20%. Na kruising van de inteeltlijnen trad weer volledig herstel van groeikracht op.
5. Een nieuwe selectiemethode wordt beschreven die dezelfde informatie kan opleveren als de methode van de diallele kruisingen.

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