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Assessment of Barley Varieties as Potential Pollen-Parents for F_1 - Hybrid Varieties *

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Summary. The choice of male parents for an F_1-hybrid barley variety depends upon a number of characteristics, among which will be the combining ability for yield, the transference of disease resistance and the ability to release large quantities of viable pollen to ensure a high set of F_1-hybrid seed on the male-sterile line.

A number of cultivars were assessed as potential pollen parents using a common male-sterile variety. Various experimental methods to assess the potential of male parents were used at locations in the United Kingdom and elsewhere in Western Europe over a period of three years. Significant differences were demonstrated between the cross-pollinating ability of varieties; 'good' pollinators gave consistent results. A marked effect of crossing-block size was found and there was also some evidence of environmental interactions.

Key words: Barley – Breeding – F_1-hybrid varieties – Pollen parents

Introduction

The production of F_1-hybrid barley varieties (*Hordeum vulgare* L.) in quantities sufficient to make any impact on the agricultural production of the Old World has not yet taken place. Relatively small quantities of commercial seed have been produced in Arizona and sold in the United States, but only in limited areas of Arizona, California and Oregon. Where production has been undertaken, both the climate and the agronomy are different from those in most of Europe. The quantity and quality of cross-pollinated seed produced under irrigation are good. Also, the F_1-hybrid seed rate is low (25-30 kg per hectare) for most barley in these areas of the United States where the crop is often grown with irrigation. The use of 100-125 kg of seed per hectare, now common in the United Kingdom, will make a necessity of economical and reliable seed production, even if the F_1-hybrid varieties can be used at a somewhat lower seeding rate.

Unlike maize (*Zea mais* L.), the amount of seed obtained from each barley plant is small in relation to the quantity of seed required for sowing, which is high. The United Kingdom requirement for spring barley seed is approximately 300,000 tons. This requires about 100,000 ha of seed crops.

In the production of the male and female parents of the F_1-barley hybrid, the important factor in determining production costs and therefore the amount of heterosis in the F_1-hybrid required to offset the increased costs, will, in the case of both lines be the quantity of pure, usable seed obtained per unit area of land. In the case of the male parent, this should differ little from that normally expected during the production of a conventional inbreeding variety by the generation system now required by EEC regulations.

Selection of a male parent for an F_1-hybrid will depend heavily on its ability to combine with the female parent, which will determine heterosis in yield and in qualitative characters such as disease resistance.

The final choice of a male parent for an F_1-hybrid must be made with reference to its performance as a pollen donor and its ability to achieve a high grain set from wind pollination on male-sterile barley in the field in order to ensure a reliable supply of F_1-seed each year and a good yield per unit area.

There are few reports of data on cross-pollination in barley. Information from the United States indicates a wide range of seed sets achieved on male-sterile plants in a small number of locations differing considerably in en-

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vironmental conditions (Suneson 1940; Riddle and Suneson 1944; Wiebe 1960; Foster and Schooler 1970; Thompson 1970).

Information from Europe is scarce, being mainly limited to experiments conducted in the United Kingdom (Hayes 1968, 1970; Sage 1967, 1968; Done and Macer 1972), and Scandinavia (Svensson 1972; Stolen and Shands 1974). These data confirm substantial differences in seed-sets achieved by wind pollination on male-sterile plants.

The experiments described in this paper attempted to discover how a number of barley varieties performed as pollen parents in different locations and environments and in different years.

Materials and Methods

During these experiments the only male-sterile barley available in sufficiently large quantities for comparative testing was the line '63-j-18-17' (18-17), a six-row American coast-type barley obtained from the Ram-Bar Corporation, Phoenix, Arizona, USA. This variety was the male-sterile line in all cross-pollinating experiments used for the production of F_1-hybrid seed.

A range of cultivars with known flowering times (anthesis) ranging from very 'early' (cultivar 'Akka') to very 'late' (cultivar 'Deba-Abed') were chosen to act as pollen parents and sown together with the male-sterile line in crossing-blocks. Data on 'maturity' were taken from the National Institute of Agricultural Botany, Cambridge, Recommended List of Cereal Varieties, which although it applies to harvest maturity, can be used approximately to represent the time taken to reach anthesis. All crossing-blocks were sown to the same design (Fig. 1). Unless specified otherwise, male and male-sterile (female) blocks alternated, and were isolated from other barley crops by a minimum of 500 metres. Sowing rates for both male and male-sterile lines were standardised at 100 kg/ha.

A minimum of 100 male-sterile ears (5 x 20) were taken at random from each block for calculating percentage seed-set. This was determined as:

$$\frac{\text{Number of seeds set per ear}}{\text{Number of available sites per ear}} \times 100$$

The average number of available sites for seed-set on ears was measured from 25 random samples of male-sterile ears taken from each male-sterile area. As the growth of the male-sterile line '18-17' itself varied greatly between locations, which affected ear size, this technique provided the most valid method of comparing seed-set data. Experiments were carried out over a period of three years (1970-1972).

Small-scale crossing-blocks gave an initial assessment of the out-pollinating ability of various potential male parent lines. This would not necessarily provide an accurate prediction of the performance of a variety as a pollen donor when used on the larger scale required for commercial seed production.

In 1971 two larger crossing-blocks, each 8,500 sq m in area were grown to assess the performance of the cultivars 'Sultan' and 'Maris Concord' as out-pollinators when used on a larger scale. These crossing-blocks also provided an opportunity to find out whether or not plot orientation with respect to the prevailing direction of the wind influenced the set of seed within a crossing-block. The design for each block is indicated by Fig. 2. The prevailing wind direction was from the south-west; each block was situated on flat land over which the wind blew freely. Each crossing-block was hand-rogued three times during growth to remove the residual fertile trisomic plants from the male-sterile plants, and sprayed with Centrol (A.H. Marks & Co. Ltd.) for weed control.

At harvest each male-sterile area was sampled in the order 1-10 as indicated in Figure 2. Twenty ears were taken from each sampling point in each block and the average number of seed set per ear was determined. (Percentage seed-set was then calculated on the number of seeds set in relation to the number of potential sites, as previously described).

Where large fields of barley were available, a simpler method of providing isolation while testing a cultivar for cross-pollinating ability involved sowing, at the time of normal drilling, a single block of the male-sterile line in the centre of the variety to be assessed. If the F_1-hybrid seed set on the male-sterile line was an accurate reflection of the ability of the cultivar under test to shed pollen, differences between cultivars in pollen-shedding ability could then be distinguished. In all the small crossing-blocks, the ratio of male to male-sterile plants was one to one, but with male-sterile plots growing in a normal field of barley, the ratio of male to male-sterile would be many thousands to one.

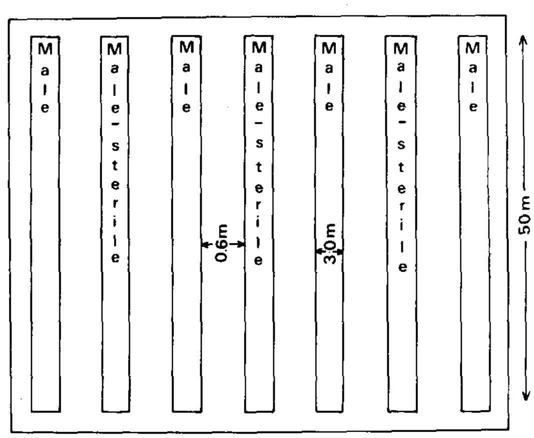

Fig. 1. Small-scale crossing-block design for the production of F_1-hybrid seed by wind pollination

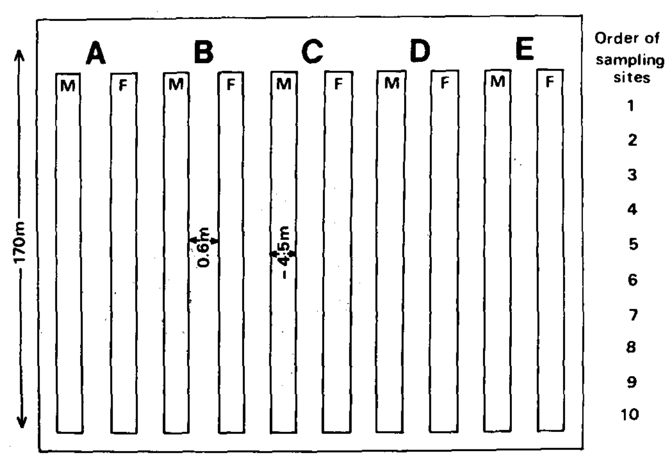

Fig. 2. Design of a large crossing-block for F_1-hybrid seed production by wind pollination

Table 1. Seed-sets recorded on male-sterile 18-17 using a number of lines as pollen parents over three years at different locations in small crossing-blocks

Year	Pollinator cultivar under test		Location of crossing-block		% Seed-set on ms parent (18-17)
1970	'Zephyr'		England		8.2
	'Maris Concord'		England		28.5
	'Deba-Abed'		England		4.0
	'Julia'		England		1.0
	'Midas'		England		7.3
	'Sultan'		England		11.0 (bird damage)
	Local selection I		Italy		28.0
	Local selection II		Italy		39.0
	Local selection III		Italy		26.0
	Local selection IV		Italy		18.0
	Local selection V		Italy		9.0
	Local selection VI		Italy		9.0
				S.E. = ±	4.82
1971	'Wing'		England		15.0
	'Akka'		England		3.0
	'Vada'		England		28.0
	'Clermont' (6-row)		England		27.0
	'Berac'		England		17.0
	'Clermont'		Portugal		33.0
	'Imber'		Portugal		18.0
	'Feronia'		Portugal		37.0
	'Berac'		Portugal		35.0
	'Maris Concord'		Portugal		52.0
	'Wing'		Portugal		37.0
	'CB 6913'		Portugal		27.0
	'INRA CF 17/68'		Portugal		22.0
	'W 6156'		Portugal		6.0
	'Prelude'		France		5.0
	'Nymphe' (6-row)		France		4.0
	'Carina'		France		14.0
	'Ceres'		France		1.0
	'Mamie'		France		1.0
	'Julia'		France		2.0
	'Delisa'		France		19.0
	'Trait d'Union'		France		16.0
	'Arivat' (6-row)		Spain Seville		42.0
	'Arivat' (6-row)		Spain Cartagena		42.5
				S.E. = ±	3.53
1972		sample size			
	'Feronia'	(30 X 6)	U.K.		16.0
	'Nackta'	(30 X 6)	U.K.		37.0
	'Ark Royal'	(30 X 6)	U.K.		34.0
	'Albacus'	(25 X 5)	U.K.		13.0
	'Ansgar'	(30 X 6)	U.K.		34.0
	'WR341/65'	(30 X 6)	U.K.		44.0
				Av S.E. = ±	4.07
	'Albacete' 25 X 3		Spain Seville		7.1
	'Albacete' 25 X 3		Spain Madrid		44.1
				S.E. = ±	2.61

Experiments were carried out in 1971 and 1972 to determine whether, under conditions in which the male parent occupied a considerable area, varietal differences in out-pollinating ability could still be detected. A high total quantity of male parent would in some ways more closely resemble the actual conditions in a large scale crossing-block where the total areas covered by both male and male-sterile lines would be considerable.

Blocks 5 m x 50 m of the cultivar '18-17' were sown in multiplication fields of 3 hectares of normal barley cultivars. The seeds were sown on the same day and each male-sterile area received the same amounts of fertiliser as the normal barley cultivar. Samples were taken at random from various points within the male-sterile area and seed-sets assessed as indicated previously.

Male-sterile flowers appeared receptive during the whole period of flowering of the male parent in all the crossing-blocks described in this paper.

Results

Table 1 shows the results from all small-scale crossing-blocks at all locations over 3 years. Wide variation in seed-setting ability was detected between cultivars in all three years within sites.

The effect of the environment on the performance of cultivars as pollen parents can be seen by comparing seed-sets achieved in Portugal and in England in 1971 with the male parents 'Clermont', 'Wing' and 'Berac'. The site chosen in Portugal was both warmer and drier at anthesis than was the English site. Each location allowed free access of the wind and none of the crossing-blocks suffered extensively from disease or pest attack, drought or poor establishment.

The results in Table 1 indicate that at Beja, Portugal, in 1971 the cultivar 'Clermont' did not shed significantly more viable pollen than it did in England. This was the only six-row barley tested at these two sites. The six-row barley, 'Nymphe', tested as a pollen parent in France in 1971 also shed little effective pollen.

The two cultivars 'Wing' and 'Berac' had higher levels of seed-set on the male-sterile lines in Portugal than they did in England.

Two further crossing-blocks were grown in Spain in 1971, one at Seville and one at Cartagena, using the cultivar 'Arivat' (already known to perform well as an out-pollinator in Arizona) as pollen parent in an attempt to produce in Spain the American F_1-hybrid variety 'Amy' ('18-17' x 'Arivat') on an experimental scale under European conditions. The blocks were irrigated at both locations and only small differences were detected in the amounts of seed-set on the '18-17'. A further experiment was carried out in Spain in 1972 to determine the performance at two locations of the Spanish cultivar 'Albacete', originally developed for non-irrigated, dry farming areas in Spain, as a pollen parent. 'Albacete' is now widely grown on both irrigated and dry land. One crossing-block was grown near Seville and the other near Madrid. The Seville site, situated in the fertile Guadalquivir Valley, was not irrigated. The Madrid site, situated at Ciemposuelos, was irrigated as is normal for crops in that area.

The plant stand at Seville was poor as a result of an exceptionally low rainfall shortly after emergence of the crop. This resulted in both male and male-sterile lines establishing poorly, despite the male parent having been chosen to withstand drought conditions. At Madrid both male and male-sterile lines were well-grown and vigorous.

In the large scale crossing-blocks where 'Maris Concord' was used as the pollen parent, the maximum seed-set recorded was 45 per cent, 38 per cent was the maximum in the crossing-block using 'Sultan'.

From the pattern of seed-set, it was clear that the local movement of pollen was more important than overall wind direction since slightly more seed set occurred in the middle of the crossing-block than on either edge (Figs. 3 and 4). In neither of the two crossing-blocks did the north-east corner have any advantage over the south-west,

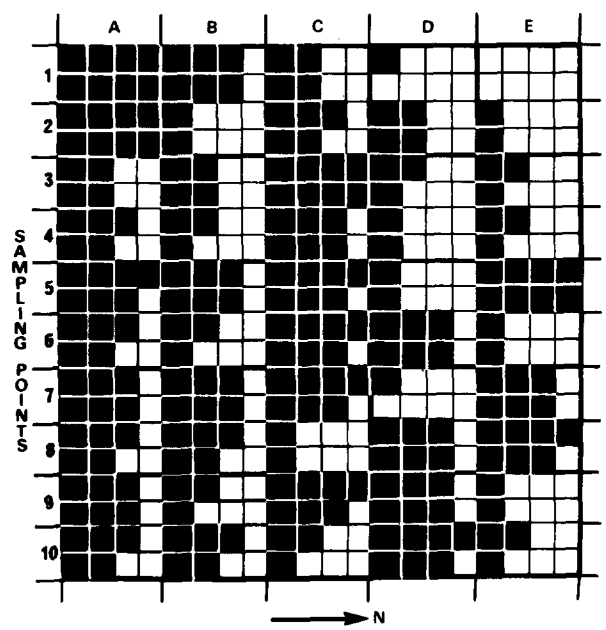

Fig. 3. Distribution of F_1-hybrid seed set on female strips in a crossing block '18-17' x 'Maris Concord'

	Percentage seed set on 18-17 using 2 male parents	
	'Maris Concord'	'Sultan'
1/8 shading	12.0-18.5	5.0- 8.5
2/8 „	18.5-21.5	8.5-12.5
3/8 „	21.5-24.5	12.5-16.5
4/8 „	24.5-28.5	16.5-20.5
5/8 „	28.5-31.5	20.5-24.5
6/8 „	31.5-34.5	24.5-28.5
7/8 „	34.5-37.5	28.5-32.5
8/8 „	37.5-45.0	32.5-38.0

showing that general wind direction did not cause a build-up of a pollen cloud as it moved over the crossing-block. This finding is in general agreement with Hirst and Stedman (1971) in their work with sugar-beet pollen movement within wheat crops. In their study, high concentrations of pollen were found within source crops with lower concentrations above and outside the source crop area.

The results recorded in 1971 for the production fields used to assess pollen shedding ability by varieties are shown in Table 2. A similar experiment was repeated in 1972 at two locations with the varieties 'Mazurka', 'Lofa-Abed' and 'Ymer' as the male parents. The results are given in Table 3.

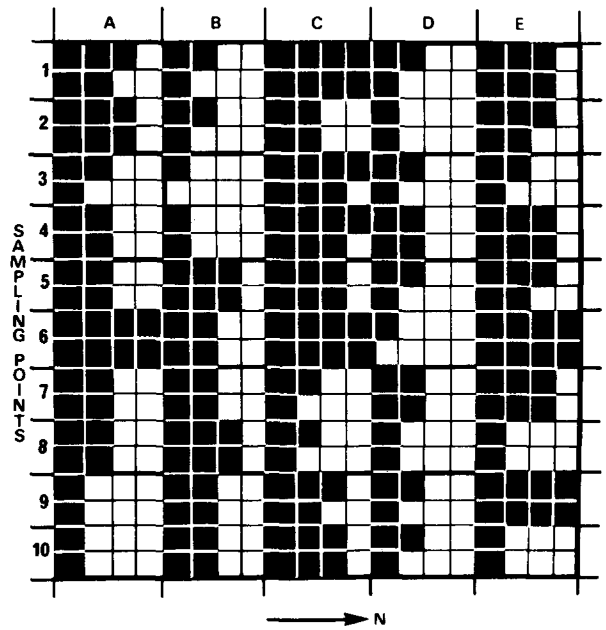

Fig. 4. Distribution of F_1-hybrid seed set on female strips in a crossing block '18-17' x 'Sultan'

Table 2. Production barley fields used as pollen parents in F_1-hybrid seed production 1971

Pollen parent	% Seed-set on 18-17
'Mazurka'	82.5
'Hassan'	40.0
	S.E. = ± 6.46

Table 3. Production barley fields used as pollen parents in F_1-hybrid seed production 1972

Pollen Parent		% Seed-set on 18-17	Location of Experiment
'Mazurka'	(25 X 8)	74.2	Lincolnshire
'Lofa-Abed'	(25 X 6)	16.3	Cornwall
'Ymer'	(25 X 6)	11.6	Cornwall
		Av S.E. = + 3.17	

The cultivar 'Mazurka' performed consistently well over two years as a donor of pollen. Differences in seed-set on the female parent between 1971 and 1972 may be due in part to the different sampling methods used in these two years. Sampling of the blocks in 1971 may have favoured the collection of leading ears which are often taller, more easily gathered and which may receive more pollen from air currents than the shorter, secondary ears in the plot. In 1972 all ear samples were collected so as to include all grain bearing tillers. This method may have included a larger proportion of secondary tillers than the former one.

Discussion

Production of F_1-hybrid seed will initially be attempted by the use of crossing-blocks (at a later stage in F_1-hybrid barley development more sophisticated techniques may be employed). Many factors will contribute to the efficiency of seed production and, in particular, the amount of seed-set on male-sterile plants. All experiments described in this paper, with the exception of F_1-hybrid seed production by male-sterile block in production fields, utilised a 1:1 ratio of pollen parent to male-sterile parent. With this ratio as the crossing-blocks were increased in size, the percentage of set-seed also increased. No crossing-blocks investigated have been comparable in size to those that would be required for large scale F_1-hybrid seed production; therefore, the maximum seed-set achievable on a male-sterile line in any commercial crossing-block has not yet been determined. It would seem reasonable to argue that crossing-blocks of a larger size could considerably improve the set of seed so far obtained, even with cultivars reported as having good potential as pollen parents (Hayes 1968). Seed-sets approaching those reported from small areas of male-sterile barley in the south-west United States of America may be achieved in a European environment when large amounts of the chosen pollen are available (Thompson 1970). The ratio of male to male-sterile plants may not need to be as high as 1:1 in larger crossing-blocks. It may be commercially advantageous to harvest more F_1-seed from a greater area, in spite of a lower average seed-set per plant when the male-sterile parent is sown over a relatively larger area than the pollen parent. Further large scale experimentation will be required to determine the minimum proportion of pollen parent to male-sterile line which ensures maximum yields of seed of an F_1-hybrid per total unit area. The ratio may well be different from country to country.

Where male-sterile plots of barley have been placed in larger areas of pollinators, very high seed-sets have been achieved, and it can be expected that high sets of seed will be achieved also in large-scale crossing-blocks. Nevertheless, blocks of the size used in 1971 showed little advantage in seed-set over small blocks of 0.05 ha: It may be that the critical area of pollen parent is very much larger than those tested.

The effect of environment can be seen in the levels of seed-set recorded on similar crossing-blocks in which the same cultivars were used as pollen parents both in England and Portugal. With two-row lines, the warmer and drier climate in the centre of Portual resulted in a higher level of seed-set within each crossing-block. Isolation was also more easily obtained in Portugal where less barley is grown. The importance of climatic features has also been demonstrated in Scandinavia by Stolen and Shands (1974). The importance of location and agronomy are illustrated by the failure of crossing-blocks in Spain to provide good plant populations under unsuitable conditions, even when the cultivar chosen as pollen parent was known to have performed adequately as an inbred. Irrigation would be essential where dry periods may affect growth and reduce the release of viable pollen, even though the dry conditions may not be severe enough to cause sterility in self-fertile lines.

The use of an unadapted male-sterile line as a tester for the pollen shedding ability of adapted European barley lines has obvious disadvantages since dates of anthesis of male and male-sterile lines are different. The American line, '18-17', has a much shorter life-cycle and earlier flowering date than the male lines under test, and, although the male-sterile line appeared to be receptive throughout the period of pollen shed of the male parent, male-sterile plants may have become less receptive towards the end of the flowering period. In addition, the male-sterile line was six-row in contrast to almost all the test (male) lines which were two-row. An F_1-hybrid developed for north-west Europe would almost certainly be a 2 x 2 row cross.

From these results, cultivars which have been in commercial use (e.g. 'Maris Concord', 'Berac' and 'Midas') have been shown to differ widely in their ability to achieve seed-set on the male-sterile line.

Cultivars like 'Mazurka' and 'Maris Concord' appear to give consistent results in seed-set over different years despite differences of climatic conditions during anthesis. Further experimentation is required to determine whether this consistency extends to all cultivars that show high levels of cross-pollination.

This work has indicated the considerable potential for cross-pollination of barley even in the relatively cool, humid conditions normally experienced in north-west European summers, thus providing some encouraging information to help answer the question 'Is adequate cross-pollination possible in north-west Europe with a normally cleistogamous species such as barley?' Providing heterosis in yield of an F_1-hybrid barley can be demonstrated as substantial, stable and sufficient to more than repay the inevitable increased cost of seed production, cross pollination should be adequate to develop efficient production systems in most areas. Such systems will, however, be dependent upon the breeding and choice of suitable pollen parents and upon careful attention to husbandry in the seed crop.

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