J. agric. Sci., Camb. (1982), **99**, 555–560
Printed in Great Britain

White-seeded beans (*Phaseolus vulgaris*) resistant to halo blight (*Pseudomonas phaseolicola*), to bean common mosaic virus, and to anthracnose (*Colletotrichum lindemuthianum*)

By JANET CONWAY, R. C. HARDWICK, N. L. INNES, J. D. TAYLOR and D. G. A. WALKEY

National Vegetable Research Station, Wellesbourne, Warwick

(*Received* 13 *May* 1982)

SUMMARY

Halo blight resistance was transferred in a backcrossing programme from PI 150414 to a Michigan-type bean. The resistant selections obtained gave yields that were up to 10% higher than that of cv. Seafarer and had seed of good quality that was suitable for baking in tomato sauce. These selections were also resistant to the common strains of bean common mosaic virus (BCMV) and to the lambda race of anthracnose.

In addition, selections with white seed of similar size to Seafarer were obtained from crosses between Seafarer and cold-tolerant lines with large, coloured seeds. In trials over 4 years these selections gave 20% higher yields than Seafarer and were less sensitive to environmental changes. Like Seafarer, they were homozygous for the *I* gene for resistance to BCMV but were susceptible to halo blight and anthracnose. Although not as suitable for canning in tomato sauce as other material in the National Vegetable Research Station programme, they offer useful parental material for further cycles of breeding.

INTRODUCTION

To meet the U.K. requirements for baked beans in tomato sauce, 80000 t of dried white beans (*Phaseolus vulgaris*) of the navy beans type are imported annually, mainly from Michigan in the U.S.A. and Ontario in Canada. Although British farmers have tried to grow Michigan-bred cultivars in the U.K. they have had little success, because these cultivars are poorly adapted to the U.K. environment, growing badly at the low temperatures (< 12 °C) that so often prevail in May and June (Hardwick, 1972; Innes & Hardwick, 1974; Scarisbrick, Carr & Wilkes, 1976).

In an attempt to breed improved cultivars adapted to U.K. conditions, a programme was initiated at the National Vegetable Research Station (NVRS) to breed cold-tolerant cultivars with the seed quality (colour, size, shape, resistance to transverse cotyledon cracking, and bland taste) of the Michigan types (Innes *et al.* 1977; Innes, 1977*a*). A systematic search was made for cultivars that would grow well at low temperatures by screening in growth cabinets material from many parts of the world (Austin & Maclean, 1972) and checking the performance of putative cold-tolerant types under field conditions (Hardwick, Hardaker & Innes, 1978). However, those cold-tolerant cultivars which gave the best yields in field trials did not have white seeds of the size, shape and quality required by the processors and they were extremely susceptible to bean common mosaic virus (BCMV) (Walkey & Innes, 1979). A hybridization programme between Michigan cultivars and the best of the cold-tolerant genotypes was therefore started in an attempt to find recombinants with cold tolerance and white seeds of the required quality. Seafarer, the Michigan-bred cultivar most used in the hybridization programme, is resistant to the common strains of BCMV, as it carries the dominant *I* gene for resistance (Innes & Walkey, 1979). Selection for *I* type resistance therefore became an integral part of the NVRS breeding programme. Halo blight, caused by the seed-borne bacterium *Pseudomonas phaseolicola*, spreads rapidly in wet conditions, and has already caused problems in the U.K. green bean crop, so it was decided that plant resistance to this pathogen should be one of the aims of the programme.

This programme was divided into three parts: in the first, recombinants for white seed, cold tolerance and resistance to the common strains of BCMV were sought; in the second, a navy bean was bred with resistance to both halo blight and

Table 1. *Results of testing for resistance* to halo blight (races 1 and 2), BCMV (NVRS strain) and anthracnose (lambda race) and seed weight of advanced generation breeding lines and control cultivars*

	Population	Line	Halo blight	BCMV	Anthracnose	Seed weight (mg)†	Number of days from sowing to maturity‡
107 × [Gratiot × (Seafarer × PI 150414)]	II	A	R	R	R+S	171	132
(2nd backcross to Michigan type)	II	B	R	R	R+S	199	122
	II	C	R	R	R	215	133
[Gratiot × (Seafarer × PI 150414)]	I	D	R	R	R	202	130
(1st backcross to Michigan type)	I	E	R	R	R	183	124
	I	F	R	R	R	180	124
	I	G	R	R	R	174	130
(Line 222 × Seafarer) F_7	—	H	S	R	S	238	129
	—	J	S	R	S	191	128
(Seafarer × Line 251) F_8	—	K	S	R	S	212	127
Seafarer (control)	—	—	S	R	R	195	132
Line 222 (control)	—	—	S	S	S	580	118

* R denotes homozygous resistance, S homozygous susceptibility and R+S segregation for resistance.
† from NVRS trial II, 1981.
‡ Mean value in NVRS trials I and II, 1981.

to the common strains of BCMV; and in the third, plant resistance to highly virulent strains of BCMV (as yet unrecorded in the U.K.) has been transferred to dry, white-seeded types.

This paper reports results obtained from field trials with advanced generation breeding lines from the first and second parts of the programme.

MATERIALS AND METHODS

Selections from crosses with cold-tolerant parents

Among cold-tolerant parents used in hybridization work with Seafarer were the lines 222 and 251. The provenances of these cultivars and their performance in field trials have been reported earlier (Hardwick *et al.* 1978). Crosses were made in 1976 and a pedigree line breeding programme was initiated (Innes, 1977*b*). Laboratory tests had been used to select the parents, but because these tests are slow and expensive it was not possible to use laboratory selection for cold tolerance of the segregants. It was sometimes possible to eliminate cold-sensitive plants on a visual basis if there was a cold spell in May or June (sowing was always done in mid-May) but cold spells did not occur every year. Single plants in F_2, F_3 and F_4 populations were selected for upright growth habit, early maturity and white-seededness, and those provided progenies for field trials at Wellesbourne in 1978, 1979 and 1980 (see NVRS Annual Reports). In describing the parentage of a cross as (first parent × second parent) we use the convention that 'first' was the female parent.

Progenies homozygous for the *I* gene were obtained by inoculating successive segregating populations of (222 × Seafarer) and (Seafarer × 251) with the NVRS strain of the virus (Walkey & Innes, 1979), and selecting resistant lines. These were then assessed for yield potential. Two F_7 progeny bulks from (222 × Seafarer) and one F_8 from (Seafarer × 251), which had consistently outyielded the Seafarer control in previous trials, were included in field trials in 1981. In the Tables these three lines are referred to as lines H, J and K respectively.

Breeding for resistance to halo blight

The dry bean PI 150414, which is resistant to races 1 and 2 of *P. phaseolicola* (Patel & Walker, 1965, 1966) was used as a source of resistance. The only other dry bean cultivar with resistance to both races of halo blight that was available at the onset of the crossing programme was GN Nebraska sel. 27 (Coyne, Schuster & Fast, 1967; Coyne, Schuster & Gallegos, 1971) but difficulties were experienced in getting it to flower, as it is sensitive to a long photoperiod, and there is now evidence that PI 150414 and GN Nebraska sel. 27 may contain the same resistance allele (Hill, Coyne & Schuster, 1972), as do most of the green-podded types with resistance to halo blight (Taylor *et al.* 1978). OSU 10183, which produces a very stunted, unproductive plant at the NVRS, may in the future be a useful source of polygenic resistance.

Although Hill *et al.* (1972) have suggested that resistance to leaf and pod lesions and systemic chlorosis of halo blight may be controlled by different genes, primary selection for resistance at the NVRS was based on inoculation of the primary leaves of plants raised and screened in a glasshouse (Taylor *et al.* 1978). Advanced generations of

breeding material were raised in the field to produce green pods for stab-inoculation with a needle dipped in a bacterial suspension (Hubbeling, 1973). The gene for leaf resistance in PI 150414 generally segregated as a recessive in crosses with Seafarer (Taylor *et al.* 1978).

The cross between Seafarer and PI 150414 was used to produce two related populations. Population I derived from a backcross to the Michigan cultivar Gratiot, population II from a second backcross of plants from population I to line 107, a white-seeded breeding line (see Table 1). Because the gene for resistance to halo blight is recessive it was necessary to test F_2 generations and then select resistant plants for backcrossing to susceptible recurrent parents. Homozygosity for the *I* gene for resistance to BCMV was established by inoculation and selection in a glasshouse. In both populations F_3 and F_4 progenies were grown in the field in non-replicated rows and selected for plant type, white seed and earliness. A check was made on pod resistance to halo blight in the F_5 of population I and in the F_4 of population II. Thirty-nine resistant F_6 progenies from population I and 26 resistant F_5 progenies from population II were included in a replicated yield trial at Wellesbourne in 1980 (Conway & Innes, 1981). From these trials four F_7 progeny bulks (lines D, E, F, G) from population I and three F_6 progeny bulks (lines A, B, C) from population II which had produced satisfactory yields and quality were included in yield trials in 1981.

No attempt was made to select for resistance to anthracnose (*Colletotrichum lindemuthianum*) in the early part of the breeding programme, as it was known that several parents were resistant (see Zaumeyer & Meiners, 1975) and it was anticipated that a number of advanced generation progenies would be resistant, or at least segregating for resistance.

The lines that were included in yield trials were checked for their resistance to anthracnose (*C. lindemuthianum* race lambda) by Dr C. Knight of the National Institute of Agricultural Botany (NIAB), Cambridge.

1981 *yield trials*

There were three trials: one at the NVRS sown on 5 May (trial I); one at the NVRS sown on 22 May (trial II) and one at Efford Experimental Horticulture Station, Hampshire, sown on 14 May. Randomized blocks with three replicates were used in each experiment. The entries comprised breeding lines and two controls, Seafarer and line 222 (Table 1). Seed was treated with bromophos and captan and was sown at a spacing of 8 cm within rows (50 seeds/m^2) in a plot with five rows, 25 cm apart and 3 m long. An Øyjörd drill was used at Wellesbourne and a Stanhay drill at Efford. Herbicide treatments were as follows: trifluralin was incorporated into the seed bed at NVRS, whilst at Efford chlorthal-dimethyl was used. After drilling diphenamid was applied at both sites. Aphicides were applied as necessary. When the pods were dry 2·5 m lengths of the three centre rows of each plot were harvested. Each plot was threshed using a Pelz thresher. The data on yield of air-dry seed, and number of days from sowing to harvest, were analysed by analysis of variance with covariance adjustment on numbers of plants. Covariance analysis did little to change the relative position of the entries.

Seed samples of all entries except lines 222 and H were tested for quality and their suitability for canning in tomato sauce by L. V. Bedford at the Campden Food Preservation Research Association (CFPRA). Earlier tests had shown that 222 is unsuitable for baking in tomato sauce. Line H was omitted as it had a much larger seed than the Seafarer control and visual assessment of its field habit and the quality of its seed revealed shortcomings. Flavour and texture of the canned products were assessed using QAV methods that had been developed for peas (Adams, Bedford & Geering, 1981) but omitting 'mealiness' from the texture scores and replacing the category for 'green' by 'orange', and noting grey and brown seeds as 'other colours'.

RESULTS

The resistance or susceptibility to halo blight, BCMV and anthracnose of the entries in the trials is given in Table 1, as are weight per seed and number of days to harvest. Yields of dry beans in the various trials are summarized in Table 2.

Mean yields varied significantly between environments (trials) and between cultivars (lines) and there were also significant interactions between cultivars and environments ($P < 0{\cdot}001$). Joint regression analyses (Finlay & Wilkinson, 1963; Jinks & Perkins, 1970) were done on two sets of data. The first was the yields of the seven lines A–G and Seafarer in the three 1981 trials and the 1980 progeny row trial. A significant proportion of the cultivar × environment interaction was accounted for by the term for heterogeneity of regression; in other words cultivars (lines) differed in stability. Line C was the least sensitive (largest negative regression coefficient of $-0{\cdot}502$) which was significantly different ($P < 0{\cdot}05$) from that of Seafarer (0·154).

A second joint regression analysis on the lines H, J, K, 222 and Seafarer from the three 1981 trials and the 1979 and 1978 progeny trials revealed that only a very small proportion of the cultivar ×

Table 2. *Yields of advanced breeding lines expressed as % Seafarer*

		1981				1980 Progeny rows	1980 Progeny bulks	1979 Progeny bulks	1978 Progeny rows
		NVRS I	NVRS II	Efford	Mean				
Yield of Seafarer (g/m²)		241	357	297	298	297	278	356	154
	Line								
Yield as % Seafarer:	A*	108	107	102	106	114	—	—	—
	B	105	108	97	103	102	—	—	—
	C	121	94	97	104	104	—	—	—
	D	117	113	102	111	112	—	—	—
	E	109	96	114	106	104	—	—	—
	F	119	101	102	107	109	—	—	—
	G	112	99	93	101	105	—	—	—
	H	124	112	115	117	—	122	109	155
	J	145	122	113	127	—	123	93	161
	K	137	114	102	118	—	110	122	157
	222	136	146	147	143	—	—	122	263
S.E.†		6·23	4·20	5·03	—	8·60	8·77	4·97	12·03
D.F.		111	111	111	—	155	68	65	169

* See Table 1 for pedigree.

† Standard error for comparisons between figures within a column.

environment interaction was explained by joint regression. The proportion was increased by logarithmic transformation of the data but still fell short of statistical significance. In both analyses Seafarer and line 222 provided the extremes of sensitivity and stability.

Quality assessments of beans from the 1981 trial are summarized in Table 3. In this assessment high-yielding lines G, J and K do not have seed of acceptable quality for canning in tomato sauce. Among the halo blight resistant material, however, a number of lines had seed of acceptable quality; some were reported as being better than the CFPRA control.

DISCUSSION

In the 1981 trials the three lines H, J, K outyielded the lower yielding parent (Seafarer) by *ca.* 20%, and were ready for harvest a few days earlier, thus confirming results from earlier experiments. Joint regression analysis showed that the yields of Seafarer, which had previously been shown to be cold-sensitive (Hardwick *et al.* 1978), were very sensitive to environmental conditions while those of the cold-tolerant line 222 were relatively stable. The environmental stability of lines H, J and K appeared to be intermediate between Seafarer and 222. None was as stable, early or as high yielding as line 222.

These results serve to highlight the difficulties in a pedigree selection programme of selecting for cold tolerance in the field. The population size used in this work was normally 300–400 F_2 plants. It is possible that recombinants with the best attributes of the contributing parents might have been found if larger populations had been used. One F_4 progeny from the cross (Seafarer × 222) did have a yield equal to that of line 222 (Innes, 1979) but it was very late, had very large seeds, was still segregating for the *I* gene for resistance to BCMV, and was therefore discarded because it was considered an unsuitable replacement for Seafarer. Lines H, J and K were relatively high yielding but they failed standard canning tests. It is not known whether they would have passed if soak time or cooking time had been adjusted. Since at least 250 g seed are needed it is impracticable to use standard canning tests in the early stages of a selection programme, and there is clearly a need for a simple test using only small quantities of seed. Such tests would make possible an earlier assessment of breeding material.

In the halo blight resistant programme there were one or two backcrosses to Michigan-type beans and here the seed quality of a number of the selections was nearer that required by processors. Some of these lines outyielded Seafarer, were less responsive to environment, earlier maturing (up to a week in 1981), and have the *I* gene for resistance to BCMV and are resistant to the lambda race of anthracnose. Thus these lines have some potential as a source of U.K.-grown navy beans. It remains to be seen whether they will tolerate the low temperatures which occur periodically in spring and early summer in the U.K. Meanwhile, as the material that has been obtained from both parts of the NVRS programme has advantages

Table 3. *Quality assessment of canned product*

Line	Colour in tomato sauce	Flavour	Texture	Comments
CFPRA control	Slightly pale orange with slight grey and very slight brown tints. Moderately bright	Moderately weak characteristic bean flavour with slight sweetness and moderately harsh	Skins moderately firm, flesh moderately firm	—
Seafarer	Medium orange with more brown but less bright than control	Slightly stronger bean flavour than control	Better skin texture than control but beans tending to break down	Poor texture
A	Moderately deep orange with more brown and less grey, and brighter than control	Stronger bean flavour than the control	Better skin and flesh texture than control	Good quality
B	Medium orange with more brown and less grey than control	Slightly stronger bean flavour than control	Better skin and flesh texture than control	Good quality
C	Less bright than control	Stronger bean flavour than control	Tendency for cotyledons to split apart	Poorer colour than control. Beans looked different from commercial packs with splitting of cotyledons
D	Medium orange with more brown and less grey than control	Stronger bean flavour than control	Better skin and flesh texture than control	Good quality
E	Medium orange with more brown and less grey than control	Stronger bean flavour than control	Better skin texture than control	Good quality
F	Medium orange with more brown and less grey than control	Stronger bean flavour than control	Better skin texture than control	Good quality
G	Moderately deep orange with more brown and less grey than control	Stronger bean flavour than control	Better skin texture than control. Flesh slightly firm but tending to break down	Poor texture
J	Medium orange with more brown than control	Slightly stronger bean flavour than control with a slightly 'raw' taste	Better skin texture than control. Flesh slightly firm but tending to break down	Poor texture
K	Similar to control. The colour of the sauce had not been taken up by the beans	Slightly stronger bean flavour than control with a slightly 'raw' taste	Similar to control	Uptake of colour a problem

over current Michigan cultivars, it will be used in further cycles of breeding. The results of the work reported here suggest that the best strategy would be to grow large F_2 populations, and to delay selection for yield and quality to the F_4–F_5 generations. This could be done by a programme of single seed descent modified to allow early selection for disease resistance.

We are indebted to Dr C. Knight of the National Institute of Agricultural Botany, Cambridge; the Director, L. V. Bedford and Dr D. Arthey of the Campden Food Preservation Research Association; Stratford-upon-Avon Canners Limited and to the staff, especially Mr David Antill, at Efford Experimental Horticulture Station, Hampshire for their assistance. Mr D. J. Andrews, National Vegetable Research Station, helped with statistical analyses.

REFERENCES

ADAMS, M. J., BEDFORD, L. V. & GEERING, J. (1981). QAV – a method for the sensory appraisal of quality of processed vegetable varieties. *Technical Memorandum* 278, *Campden Food Preservation Research Association, Gloucestershire*, p. 33.

AUSTIN, R. B. & MACLEAN, M. S. M. (1972). A method for screening *Phaseolus* genotypes for tolerance to low temperatures. *Journal of Horticultural Science* **47**, 279–290.

CONWAY, J. & INNES, N. L. (1981). Plant breeding. *Phaseolus* beans. *Report of the National Vegetable Research Station for* 1980, p. 61.

COYNE, D. P., SCHUSTER, M. L. & FAST, R. (1967). Sources of tolerance and reaction of beans to races and strains of halo blight bacteria. *Plant Disease Reporter* **51**, 20–24.

COYNE, D. P., SCHUSTER, M. L. & GALLEGOS, C. C. (1971). Inheritance and linkage of the halo blight systemic chlorosis and leaf water soaked reaction in *Phaseolus vulgaris* variety crosses. *Plant Disease Reporter* **55**, 203–207.

FINLAY, K. W. & WILKINSON, G. N. (1963). The analysis of adaptation in plant breeding programmes. *Australian Journal of Agricultural Research* **14**, 742–754.

HARDWICK, R. C. (1972). The emergence and early growth of French and runner beans (*Phaseolus vulgaris* L. and *Phaseolus coccineus* L.) sown on different dates. *Journal of Horticultural Science* **47**, 395–410.

HARDWICK, R. C., HARDAKER, J. M. & INNES, N. L. (1978). Yields and components of yield of dry beans (*Phaseolus vulgaris* L.) in the United Kingdom. *Journal of Agricultural Science, Cambridge* **90**, 291–297.

HILL, K., COYNE, D. P. & SCHUSTER, M. L. (1972). Leaf, pod and systemic chlorosis reactions in *Phaseolus vulgaris* to halo blight controlled by different genes. *Journal of the American Society of Horticultural Science* **97**, 494–498.

HUBBELING, N. (1973). Field resistance in *Phaseolus* beans to *Pseudomonas phaseolicola*. *Mededelingen van de Fakulteit Landbouwwetenschappen, Gent* **38**, 1351–1363.

INNES, N. L. (1977*a*). Using world genetic resources to breed a British baked bean. *139th AGM British Association for the Advancement of Science*, Sept. 1977, Aston University, Birmingham.

INNES, N. L. (1977*b*). Plant breeding. *Phaseolus* beans. *Report of the National Vegetable Research Station for* 1976, p. 31.

INNES, N. L. (1979). Plant breeding. *Phaseolus* beans. *Report of the National Vegetable Research Station for* 1978, p. 64.

INNES, N. L. & HARDWICK, R. C. (1974). Possibilities for the genetic improvement of *Phaseolus* beans in the UK. *Outlook on Agriculture* **8**, 126–132.

INNES, N. L., HARDWICK, R. C., TAYLOR, J. D. & WALKEY, D. G. A. (1977). Research on *Phaseolus vulgaris* at the National Vegetable Research Station, Wellesbourne, England. *Report of the Bean Improvement Cooperative* **20**, 106–107.

INNES, N. L. & WALKEY, D. G. A. (1979). Gene for resistance to bean common mosaic virus in cvs Seafarer and Aurora of *Phaseolus vulgaris*. *Journal of Agricultural Science, Cambridge* **93**, 129–131.

JINKS, J. L. & PERKINS, J. M. (1970). Environmental and genotype-environmental components of variability. VII. Simultaneous prediction across environments and generations. *Heredity* **25**, 475–480.

PATEL, P. N. & WALKER, J. C. (1965). Resistance in *Phaseolus* beans to halo blight. *Phytopathology* **55**, 889–894.

PATEL, P. N. & WALKER, J. C. (1966). Inheritance of tolerance to halo blight in bean. *Phytopathology* **56**, 681–682.

SCARISBRICK, D. H., CARR, M. K. V. & WILKES, J. M. (1976). The effect of sowing date and season on the development and yield of navy beans (*Phaseolus vulgaris* L.) in south-east England. *Journal of Agricultural Science, Cambridge* **86**, 65–76.

TAYLOR, J. D., INNES, N. L., DUDLEY, C. L. & GRIFFITHS, W. A. (1978). Sources and inheritance of resistance to halo blight of *Phaseolus* beans. *Annals of Applied Biology* **90**, 101–110.

WALKEY, D. G. A. & INNES, N. L. (1979). Resistance to bean common mosaic virus in dwarf beans (*Phaseolus vulgaris* L.). *Journal of Agricultural Science, Cambridge* **92**, 101–108.

ZAUMEYER, W. J. & MEINERS, J. P. (1975). Disease resistance in beans. *Annual Review of Phytopathology* **13**, 313–334.