Breeding dry beans for processing

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Dry beans, *Phaseolus vulgaris* L., are one of the major crops in Latin America and annual per capita consumption reaches 20 and 25 kg respectively in Mexico and Brazil (Sanders, 1980). In these countries, dry beans represent an important source of vegetable protein for low-income families, for whom they can constitute 10% by weight of the diet (Bressani, 1972).

In North America and Europe lesser but nonetheless significant quantities are used by the food processing industry for the production of canned beans in tomato sauce. In Great Britain, where this product is particularly popular, over 80 000 tons of dry beans are processed annually, to produce 'baked beans'. Originally a product of North American origin, 'baked beans' are thought to have been initially produced by the firm of Burnham and Merrill in 1875 (Potter, 1959) to supply their fishing fleet, which could account for the beans being known as Navy beans. The first official record of this product, however, dates back to 1877 when W. K. Lewis of Boston registered a patent for the process (Bitting, 1973).

These beans which are also referred to as Pea beans are currently produced in the state of Michigan in the USA, in the province of Ontario in Canada and in minor quantities in South America and Africa.

Varieties, production and quality standards

All major varieties within this class of dry beans are derived from Robust, a disease resistant selection from a local Michigan land race released in 1915 (Spragg & Down, 1921).

Michelite, a cross between Robust and Early Prolific (Down & Thayer, 1938) gave rise by induced mutation with X-rays (Down & Andersen, 1956) to a precursor of Sanilac (Andersen *et al.* 1960) and its derivatives Seaway (Andersen *et al.* 1963), Gratiot (Adams & Andersen, 1962), Seafarer (Adams *et al.* 1964) and more recently Tuscola (Adams & Saettler, 1977).

The narrow germplasm base of these varieties (Adams, 1977; Bassiri & Adams, 1978) could account for an apparent barrier to higher yields in the state of Michigan (MBSA, 1978; 1981) demonstrated by the static yield levels over the past 30 years (see Table 1).

An important factor which has contributed to this lack of diversity is that the processing characteristics of the various genotypes have a profound influence on the appearance and acceptability of the final product.

The introduction of new varieties is therefore subject to their meeting specific standards for physical appearance and processing performance. The physical appearance of the bean seed (the beans should be small 18–20 g/100 seeds, white and oval to spherical in shape) is easily observed, highly heritable (Adams &

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Table 1. *Average yields of dry beans in the State of Michigan USA* 1951–80*

Five year average	Yields (kg/ha)
1951–55	1094
1956–60	1197
1961–65	1426
1966–70	1293
1971–75	1139
1976–80	1341

*Michigan Bean Shippers Association.

Bedford, 1973) and consequently presents few difficulties to any bean improvement programme. Processing characteristics on the other hand can only be monitored by tests which must simulate commercial practices.

These tests involve the sacrifice of seed, which is frequently not possible in the important early generations of a breeding programme. The results produced by these evaluations are essentially the subjective comparison with a standard variety, usually the variety Sanilac.

Three aspects are considered. The appearance of the processed beans, which should remain entire and not clump together. The product should be free of any distinctive flavours, since in the standard, the major perceptible taste is that of the sauce. The texture of the beans should be firm but not 'chewy' and the testa of the bean seed virtually unnoticeable. In this respect it is of interest to note that subjective assessment correlates well with the results of objective tests utilizing a Kramer Shear Press (Hosfield & Uebersax, 1980) (see Table 2).

An additional consequence of these restrictions on the introduction of new genotypes, has been the failure of the development of alternative areas of production. This has occurred, either because locally adapted varieties do not possess suitable processing characteristics or conversely, because the Michigan Navy bean varieties could not be successfully grown.

Breeding for improved productivity and maintenance of processing characteristics

The production of new genotypes with superior performance over a wide range of conditions is widely recognized as being desirable.

The assessment of this characteristic requires that the genotypes be tested over a range of environments, usually locations and years. The interpretation of the results produced has been assisted by the observation, that for many crops, the performance of individual genotypes is related linearly to a measure of the general fertility. This is usually provided by the over-all mean of the genotypes tested in each environment. (Yates & Cochran, 1938; Finlay & Wilkinson, 1963).

The linear regression coefficient characterizes the individual genotypic response to environmental change.

Those genotypes with a low regression coefficient ($b<1\cdot0$) demonstrate a below

Table 2. *Processing characteristics of high yielding genotypes of dry bean selected from the CIAT bean germplasm collection*

Variety	Origin	Appearance	Flavour	Texture	Texture* (kg force/100g)
Seafarer	MSU	Standard	Standard	Standard	—
Sanilac	MSU	Standard	Standard	Standard	72·2
PC-6	S. Africa	Standard	Standard	Standard	—
Ex Rico 23	CIAT	Standard	Standard	Tough	88·5
NEP 2	Costa Rica	Small	Standard	Tough	87·8
Brazil 2	Brazil	Large	Bean	Tough	99·2
S-630	Brazil	Standard	Bean	Very tough	—
Jamapa	Venezuela	Standard	Bean	Very tough	—
PI 309804	USDA	Standard	Bean	Very tough	—
San Fernando	Costa Rica	Standard	Bean	Very tough	118·1

*As measured using a Kramer Shear Press (Hosfield & Uebersax, 1980).

average response and conversely those with a high regression coefficient ($b>1\cdot0$) an above average response to improved fertility.

In addition the mean square deviation from regression provides a measure of the reliability of this response. (Erberhart & Russell, 1966). It has been suggested that in *Phaseolus vulgaris* L. particular attention should be given to this concept. (Evans, 1973).

Initial steps in this direction have been made by the Centro International de Agricultura Tropical (CIAT) with trials of twenty genotypes at forty different sites. (Voysest, 1977; Laing, 1978). This study has revealed that considerable variation in level of response exists within this species.

In an attempt to extend this work a number of the more promising genotypes were chosen and used as parents, where a high mean yield, level of response to environmental fluctuations and adequate processing characteristics were the primary objectives. A high mean yield and adequate processing characteristics represent clear cut objectives. The choice of specific levels of sensitivity to changes in general fertility, however, must depend upon an assessment of the requirements of the grower.

Two levels of response could be desirable. In areas of low productivity and technology, where the security of production is at a premium, insensitivity to environmental fluctuations, characterized by a low regression coefficient, will provide insurance against crop failure. Alternatively in areas where technology can be utilized to maximize the potential of that environment, a sensitivity to change, which corresponds to a high regression coefficient, will permit an adequate response to improvements in crop husbandry.

Amongst the parental genotypes chosen and tested over twenty-seven sites, the varieties Seafarer and PC6 represent the former case, albeit with a low mean yield, and S-630 and PI 309804 represent the latter (Table 3 and Fig. 1). Jamapa represents the average variety with an intermediate level of response ($b=1\cdot05$).

Table 3. *Mean yields, regression coefficients and mean square deviations from regressions of selected genotypes of dry beans*

Variety	Mean yield (kg/ha)	Regression coefficient	Mean square deviations from regression
Seafarer	1034	0·77±0·07	71595
PC-6	1038	0·71±0·06	50864
Ex Rico 23	1453	1·03±0·08	99778
NEP 2	1220	0·93±0·09	136310
Brazil 2	1397	0·97±0·09	137020
S-630	1704	1·23±0·06	66794
Jamapa	1627	1·05±0·07	68677
PI 309804	1760	1·22±0·07	77654
San Fernando	1552	1·09±0·08	93460
LSD 0·05	249		

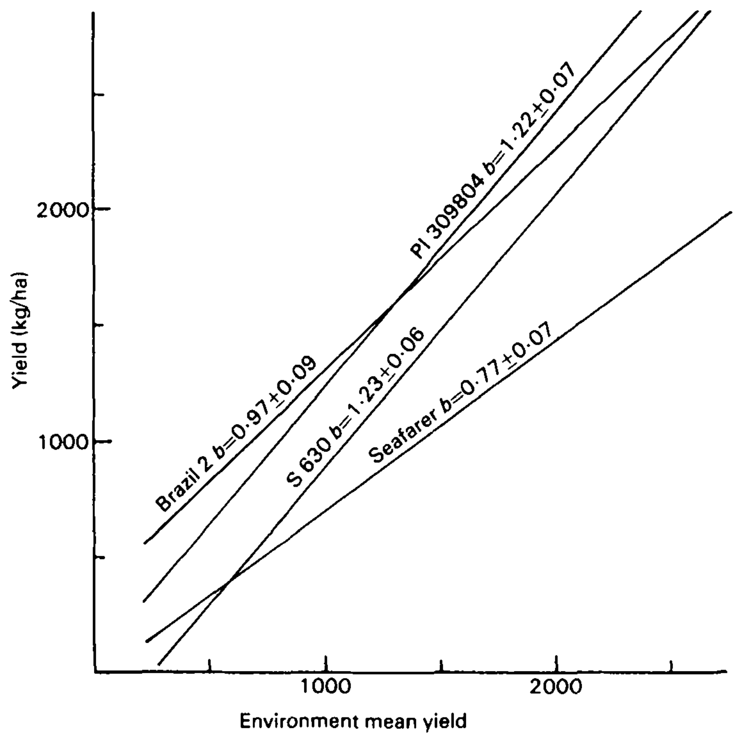

Fig. 1. Yield (kg/ha) of selected genotypes of dry beans in different environments. Nine genotypes tested over twenty-seven environments.

The low mean yield and low regression coefficient obtained for the variety Seafarer, which is similar to that obtained for the variety Sanilac by CIAT (Laing, 1978), is a possible additional explanation of the limited yield levels in Michigan.

The processing characteristics of these genotypes have been examined (Table 2). It is of interest to note that the genotypes with coloured seeds have a distinct bean flavour which the white seeded genotypes do not. Since the genotypes NEP 2 and San Fernando are isogenic for P, the pigmentation factor (Moh, 1971), it is likely that this flavour and indeed some textural differences, possibly due to a lower moisture uptake, are associated with the pigmentation of the seed coat.

The progeny of crosses is selected for desirable seed characters, and various aspects of plant architecture, appearance and disease resistance. In the F3 or F4 generation processing tests permit the elimination of undesirable genotypes (Table 4).

Testing over varied environments in the early generations will also, it is hoped, provide a means of selection for yield and response to environmental fluctuations (Table 5 and Fig. 2).

Table 4. *Processing characteristics of the progeny from crosses of various dry beans*

Variety	Appearance	Flavour	Texture
Sanilac (STD)	Standard	Standard	Standard
(EXR × PI)	Standard	Standard	Standard
(EXR × J)	Standard	Standard	Tough
(SF × PI)	Standard	Beans	Soft
(SF × J)	Standard	Standard	Standard
(SF × EXR)	Standard	Standard	Very tough

Table 5. *Mean yields, regression coefficients and mean square deviations from regressions of progeny from crosses of various dry beans*

Variety	Abbreviation	Mean yield (kg/ha)	Regression coefficient	Mean square deviations from regression
PI 309804	PI	1718	1.33 ± 0.16	70037
Jamapa	J	1593	1.16 ± 0.13	43938
Ex Rico 23	EXR	1310	0.70 ± 0.16	69056
Seafarer	SF	841	0.48 ± 0.11	28942
PI × J	—	2013	1.09 ± 0.18	81400
EXR × PI	—	1986	1.35 ± 0.24	151772
EXR × J	—	1864	0.85 ± 0.09	24356
SF × PI	—	1951	0.75 ± 0.30	237119
SF × J	—	1664	1.07 ± 0.19	100614
SF × EXR	—	1444	0.79 ± 0.23	137632
LSD 0.05		590		

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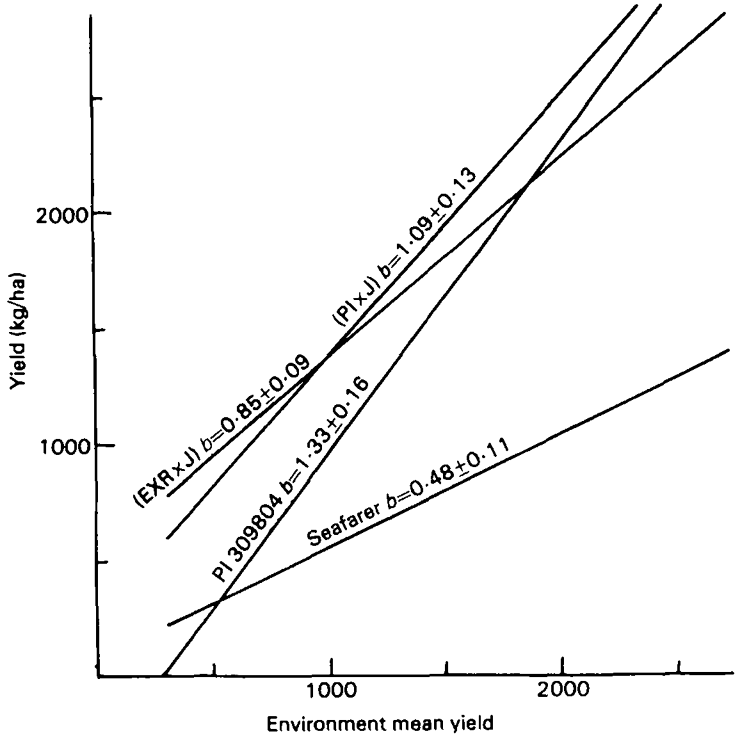

Fig. 2. Yield (kg/ha) of selected genotypes of dry beans in different environments. Thirty-seven genotypes tested over nine environments.

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