The effect of genotype and plant density on grain yield and cooking quality in common bean (*Phaseolus vulgaris* L.)

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Abstract

Five un-named but different coloured (white, mottled brown, mottled black, black and brown seed coat) common bean (*Phaseolus vulgaris* L.) genotypes originally from the CIAT collection were evaluated for their grain production potential, and the effects of plant density on grain yield and its components. The cooking quality of harvested grain was also assessed. All genotypes proved to be bush indeterminate, with a plant height of 50-60 cm. At 10.5% grain moisture content, the black genotype produced the greatest yield (5.7 t/ha) and the brown genotype the lowest (4.7 t/ha), the difference resulting from fewer branches per plant and grains per pod, and a smaller grain size in the latter genotype. Grain yields from the other three genotypes did not differ from that for the black genotype. There was no genotype x density interaction, and the mean grain yields for the three plant densities (6.6, 13.3 and 20.0 plants/m^2 were 3.8, 5.4 and 6.7 t/ha respectively. Genotype grain coat properties differed; for example the white genotype had a greater conductivity and imbibition rate than the brown genotype. After cooking for 20 minutes, grain texture (as measured by the force required to cut the grain) differed significantly among genotypes and ranged from 6.8 Newton for the white genotype to 15.2 Newton for the brown genotype. However grain coat/cotyledonary damage was greater in the white genotype than the brown genotype. Differences in grain coat properties may therefore play a major role in the suitability of genotypes for different food requirements.

***Additional key words:** bush indeterminate, pods per plant, grains per pod, 100 grain weight, conductivity, imbibition rate, grain texture.*

Introduction

The common bean (*Phaseolus vulgaris* L.) has long been a staple part of the diet in many developing countries (Aykroyd and Doughty, 1964), as a major supplementary source of protein. However since the discovery that bean products have hypocholesterolemic effects (Uebersax *et al.*, 1991), consumption has markedly increased in developed countries. Uebersax *et al.* (1991) reported that a daily consumption of 100-135 g of dry beans could reduce serum cholesterol levels by around 20% in the short-term, and therefore reduce the risk of coronary heart disease.

Bean products are now used in exotic salads, dips, pates and deserts as well as the traditional baked beans (Morrow, 1991). In New Zealand, production has primarily been for tinned baked beans (McKenzie, 1991), but there has been increasing interest in the production of new cultivars suitable for use in fresh salads (A.K. Hardacre, pers. comm.), particularly coloured beans, as a combination of several colours is more visually attractive to the consumer (R. Coulson, pers. comm.).

SeedBank (NZ) Ltd obtained a collection of five 'genotypes' of *P. vulgaris*, originally from the CIAT collection. However, as received they were un-named and distinguishable only by their seed colour - white, black, brown, mottled black and mottled brown. Nothing was known about their genetic purity, growth habit or grain yield potential. The objectives of the trial were therefore to:

1. Determine the growth habit, and use morphological characters to assess genetic purity of the five genotypes;
2. Investigate their grain yield potential and the effects of plant density on grain yield;
3. Assess the effect of genotype on grain cooking quality.

Materials and Methods

The field trial was conducted in the 1994/95 season at Massey University, Palmerston North on a fine sandy loam soil type. The site had previously been in perennial ryegrass dominant pasture, and was desiccated (glyphosate), ploughed and harrowed in October 1994. On 25 November trifluralin (400 g a.i./ha) was applied and the site harrowed to incorporate the herbicide. Seeds were sown by cone seeder on 28 November at three sowing rates (2.8, 5.6 and 8.4 g/m^2) with 60, 30 and 20 cm respectively between the rows. Within row spacing was 25 cm. Each main plot (sowing rate) was split into subplots (genotype) which were four rows each 3.0 m long. Each sowing rate was randomly assigned to the main plots, and genotypes were randomly assigned to subplots. Each treatment (sowing rate x genotype) was replicated four times.

A granular fertiliser (125 kg/ha of 12 : 10 : 10 :2) was broadcast immediately prior to the pre-sowing harrowing. No fungicides or insecticides were applied.

The plant populations established from the three sowing rates averaged 6.6, 13.3 and 20 plants/m^2 respectively, and were the populations used in this study. Ten plants were randomly selected from rows 2 and 3 of each subplot, and identified with coloured wires. From these plants data for branches, flower and pods per plant, grains per pod, 100 grain weight and grain yield per plant were collected, the latter four data sets following destructive harvesting of the plants on 20 March 1995 when grains were around 22% moisture content. Yield per unit area was determined by hand pulling all remaining plants from rows 2 and 3 of each subplot on 30 March, and hand shelling the pods. The grains were added to those already collected from the 10 destructively harvested plants, and all grains were ambient air dried to around 10.5% grain moisture content before weighing. Grain weight was determined by weighing 10 replicates of 100 seeds at 10.5% grain moisture content.

Grain cooking quality was assessed for grains from the 20 plants/m^2 population only. Conductivity was determined using internationally recommended methodology (ISTA, 1995), i.e., four weighed replicates of 50 grains in 200 ml deionised water at 20°C for 24 h. Grain moisture content was determined according to internationally agreed methodology (ISTA 1996). The water absorption rate was obtained by soaking three replicates of 10 g grain each in 40 ml distilled water for 2, 4, 8, 14 and 24 h at 25°C. After each soaking time the water was drained off and surface water removed by blotting. The gain in weight was taken as the amount of water absorbed and expressed as a percentage of the initial weight (Hincks and Stanley, 1986).

Before cooking, grains from each genotype were soaked at 25°C for 14 h in a volume of distilled water five times their dry weight (Hsieh *et al.*, 1992). Grains that failed to imbibe during this soaking were removed before cooking. Grains were placed in boiling water under normal atmospheric pressure, cooked for 20 minutes, drained and allowed to cool for at least 1 h. They were then separated into those with damaged/loose seed coats and/or damaged cotyledons, and intact grains. The texture of four replicates of 12 intact grains from each genotype was then assessed using an Instron Universal Testing Machine (Instron Co., Bucks, England; model 1X series (1502)) which recorded the force required to cut through the grain (Faraay, 1995). The moving blade (crosshead) speed was 5 cm/min and tests were performed at room temperature (20-21°C) (Shama and Sherman, 1973).

Results

The majority of plants within each genotype were non-climbing (bush in-determinate); the mottled brown, mottled black and brown genotypes produced from 1-3% of plants with indeterminate climbing characteristics, while in the white and black genotypes, 11± 2% and 17± 3% of the plants had climbing characteristics (i.e., longer internodes and fewer branches). Plant height ranged from 40 to 80 cm, and averaged between 50 - 60 cm depending on plant density.

There were no significant interactions between genotype and plant density for any of the parameters recorded, and data are therefore discussed separately. As plant density decreased, branches per plant and pods per plant increased, and while grains per pod and 100 grain weight did not differ among the three densities, the pod number differences resulted in yield per plant also increasing as plant density decreased (Table 1). However, the greater per plant performance did not compensate for the lack of plants, and yield on a per unit area basis increased as plant density increased (Table 1).

The genotypes differed in their ability to produce branches (Table 1) and flowers (Fig. 1), but not in the number of pods per plant (Table 1), presumably reflecting differences in the ability to set and retain pods . The white genotype for example averaged 60.8 flowers per plant and 24.4 pods per plant (40% of the potential), whereas the brown genotype averaged 46.5 flowers per plant and 23.8 pods per plant (51% of the potential). There were no differences in grains per pod among the

Treatment	Branches per plant	Pods per plant	Grains per pod	100 grain weight (g)	grain yield g/plant	grain yield t./ha
Genotype						
white	5.8	24.4	4.4	42.2	43.4	5.4
mottled brown	5.7	24.1	4.5	42.9	45.7	5.5
mottled black	5.2	26.9	4.6	35.7	43.3	5.1
black	5.4	23.9	4.4	45.2	46.7	5.7
brown	4.6	23.8	4.1	40.8	38.8	4.7
$LSD_{0.05}$	0.4	NS	0.2	1.7	7.2	0.9
Density						
6.6 plants/m^2	7.0	32.2	4.6	40.6	57.0	3.8
13.3 plants/m^2	5.2	22.6	4.4	42.1	40.2	5.4
20.0 plants/m^2	3.8	19.0	4.3	41.4	33.5	6.7
$LSD_{0.05}$	0.5	3.4	NS	NS	6.7	0.5

white, mottled brown and black genotypes, or between the mottled brown and mottled black genotypes, but the brown genotype had the least number of grains per pod (Table 1). 100 grain weight was the greatest in the black

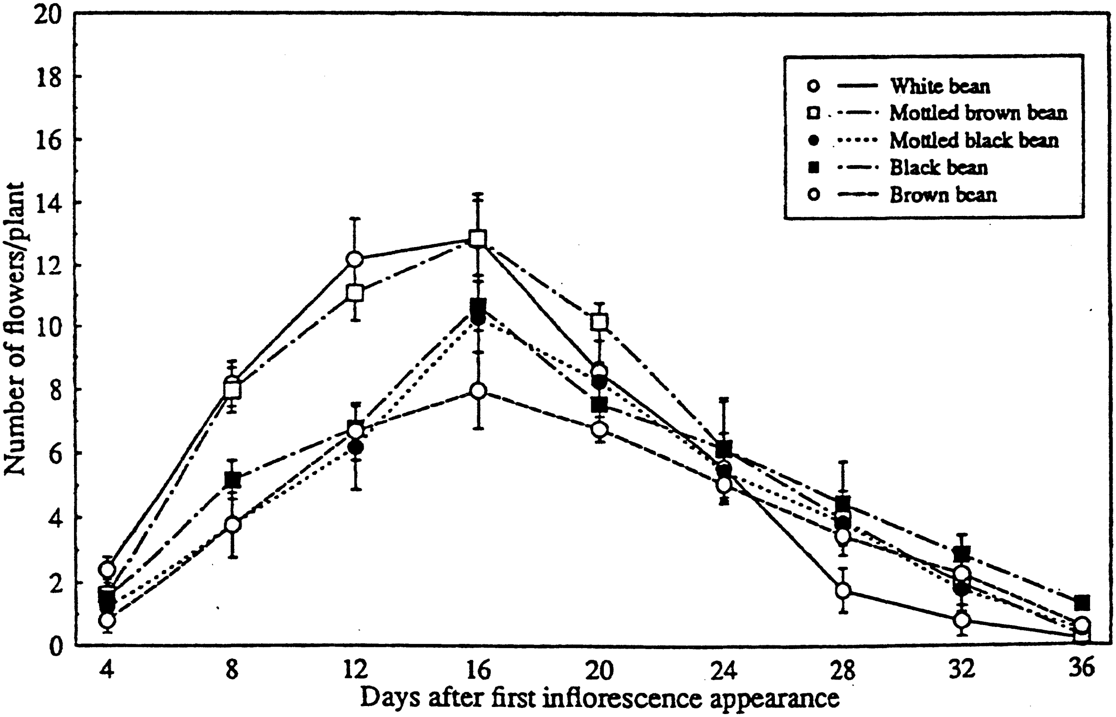

Figure 1. Number of flowers per plant for the five genotypes at a density of 20.0 plants/m^2

genotype and lowest in the brown genotype (Table 1). Grain yield did not differ significantly among the white, mottled brown, mottled black and black genotypes; the lowest grain yield was recorded from the brown genotype, but this did not differ from that of the white and mottled black genotypes (Table 1).

Grain conductivity differed significantly among all five genotypes (Table 2) being highest for the white genotype and lowest for the brown genotype. Over 50% of the brown genotype grains had failed to imbibe after 14 h of soaking, and as a consequence of this, the grain weight increase after soaking was lowest for the brown genotype (Table 2). Even after the removal of non-imbibed grains, the genotypes still exhibited significant differences in the force required to cut them, and coat/cotyledonary damage after cooking for 20 minutes (Table 2). The white and mottled brown genotypes were the softest, but had also suffered the most damage during the cooking processes.

Table 2. Effect of bean genotype on post-harvest grain properties[1].

Genotype	Conductivity (µs/cm/g)	unimbibed grains after 14 h (%)	Grain weight increase (%) after soaking for			After 20 minutes cooking	
			4 h	8 h	24 h	force to cut grains (Newtons)	grains with coat and cotyledonary damage (%)
white	15.7	3.5	27	74	106	6.8	19
mottled brown	13.8	10.0	20	53	101	9.1	20
mottled black	10.7	4.5	9	31	101	11.5	11
black	7.6	7.5	9	24	92	14.1	9
brown	4.7	53.5	6	13	49	15.2	9
$LSD_{0.05}$	1.8	4.7	4.2	3.6	4.7	2.4	6.8

[1] grain moisture contents ranged from 10.4 - 10.8% and did not differ among genotypes.

Discussion

The genetic purity of the seed lots used in this study was unknown, and the field results demonstrated some genetic admixture, even though the original seed coat colour within a genotype did not appear to differ. The existence of both indeterminate climbing and bush indeterminate plants in each population indicates genetic heterogeneity, as internode length, node numbers and climbing ability are genetically inherited (Debouck, 1991). Similarly, although not reported in the results, there was some variation in the colour of the grains produced (e.g., 1-3% of the plants from the white genotype produced pods with black grains - Mesquita, 1996). Common beans are self pollinated (Purseglove, 1968) and anther dehiscence occurs a few hours before anthesis (Gross and Kigel, 1994), leaving little chance for natural cross-pollination. Therefore the production of different coloured grains from a single original colour group is most probably due to the genetic characteristics of the parent plants. Further selection will be required to produce specific cultivars.

The plant response to density was a classic one (Davis and Gracia, 1987), in that pods per plant and therefore grain yield per plant (Husain *et al.*, 1988) increased as plant density decreased. Grains per pod and grain weight did not differ among the densities, responses previously reported by Aguilar *et al.*, (1977) and Jiang and Egli (1993). The grain yield per unit area was also a classic one, in that the number of plants was the major component influencing grain yield. The yield of 6.7 t/ha for the 20 plants/m^2 population is high when compared with previous reports (e.g., 4.2 t/ha from a density of 28.8 plants/m^2 - Aguilar *et al.*, 1977), and much greater than the Canterbury yields of 2-3 t/ha produced from densities of 30-70 plants/m^2 as reported by Love *et al.* (1988). However McKenzie (1991) noted that in Canterbury, grain yield may depend more on factors such as water availability than plant population. At Palmerston North the crop did not suffer from moisture stress, diseases or pests (Mesquita, 1996), and was hand harvested. Commercial grain yields are therefore likely to be less than this, particularly as farm trials in Manawatu have identified sclerotinia rot as a yield constraint (R. Coulson, pers. comm.). It may therefore be necessary to investigate higher plant densities which lift the pods further from the ground

(Love *et al.*, 1988), reducing the risk of fungal infection (McKenzie, 1991). All five genotypes possess a high grain yield potential.

The desirable grain characters for human consumption depend on the type of end product, i.e., grains for bean salads must maintain their integrity after cooking, whereas grains for baked beans should be moderately split after cooking (Bressani, 1993). However, of all the characteristics, in many countries cooking time is considered the most important (Hosfield, 1991). Two grain traits influence cooking time (Shellie-Dessert and Bliss, 1991) *viz.* grains which are slow to imbibe water and therefore require a longer cooking time, and grains which imbibe water, but the cotyledons do not soften sufficiently during cooking. Beans are usually soaked prior to cooking to reduce cooking time, and thus grain coat permeability is an important factor. The grain coat is important in controlling the exchange of water between the grains and their environment (Lush and Evans, 1980). The soak water conductivity, percentage of non-imbibed grains and percentage grain weight increase after soaking results all suggest that four of the five genotypes have reasonably thin grain coats, and that water readily move into the grains. However grains from the brown genotype behaved differently, in that during the 14 hour soak period less than 50% of grains imbibed water, and for grains which did imbibe, the rate after 24 hours was around half that of the other genotypes. This was not because of the presence of 'hard' grains, because germination was over 98% for all genotypes (Mesquita, 1996), but was probably a result of the presence of what Kuo (1989) described as 'delayed-permeable' grains, i.e., grains which require a longer time to imbibe than others because of the low permeability of the grain coat.

Imbibition rate was obviously not the only factor affecting softening after cooking, because the force required to cut cooked grains from the black and brown genotypes did not differ. Uebersax *et al.* (1991) reported that the degree and rate of hydration of starch and proteins influenced cooking rate and final texture of cooked beans, but these properties were not investigated in this trial. The two genotypes with the greatest imbibition rates (i.e., the white and mottled brown genotypes) suffered the most damage after cooking. This may have been as a result of cell damage through water inrush (i.e., imbibition damage), or because of lower lignin content in the coat; lignin prevents softening and disintegration of the tissue during cooking by binding the cellulose fibre together in a layer that is not as readily disintegrated by boiling water (Matz, 1962). It is obvious that more information about the grain properties of the genotypes is required, particularly so that they can be processed in a way which ensures the end product meets the needs of the consumer.

Conclusions

1. All five genotypes produced a high grain yield under the experimental conditions, but genotypes were not genetically pure.
2. Yield increased as plant population increased, but whether 20 plants/m^2 was optimal will require an investigation of the effects of higher populations.
3. Grain characteristics had a significant effect on post-cooking quality; these were in part related to imbibition rate, but other factors are also involved. This requires further investigation.

Acknowledgements

We thank Robert Coulson (SeedBank NZ Ltd) and Alan Hardacre (Crop and Food Research Ltd) for their cooperation in supplying the five genotypes, and Robert Southward for technical assistance. Filipe Mesquita also gratefully acknowledges the financial support of the New Zealand government.

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