Use of a simple physiological model to analyse yield variation in phaseolus vulgaris genotypes

R.J. Redden and G.C. Wright

Qld Department of Primary Industries, Hermitage Research Station
Q1d Department of Primary Industries, J.Bjelke-Petersen Research Station

Summary. Forty four bean *(Phaseolus vulgaris* L.) accessions were selected on the basis of high grain yield performance and were grown under rainfed conditions where post flowering water stress was experienced. A range of measurements were made throughout the season to understand the basis of yield variation. A simple analytical model was used to show that partitioning of biomass to grain accounted for a large proportion of the observed yield variability, with differences in crop growth rate and reproductive duration being of lesser importance. The paper discusses how the information derived from this simple model may have implications for future selection strategies in the breeding program.

Introduction

A range of bean *(Phaseolus vulgaris* L.) germplasm consisting of 1462 accessions was evaluated in 1983. The aims were to select parents for a breeding program and to survey the range of genetic variability for grain yield, agronomic and biotic traits. The evaluations were conducted using unreplicated plots with repeated checks, under both irrigated and water deficit conditions. Grain yield and days to flowering were directly measured, however visual scores were used for biomass, indeterminacy and plant architecture. The most outstanding accessions were identified over various criteria; grain yield under irrigated and stress conditions, grain yield efficiency (per time to flowering), harvest index and drought tolerance index (yield and canopy height ratios for stress versus irrigated). These selections provided a means for assessing the possible relevance of agronomic and physiological criteria for the breeding program. A simple physiological model was used to analyse the yield variation in terms of some basic determinants of yield.

Methods

Forty four selected accessions were sown in a 2 replicate randomised complete block trial at Hermitage Research Station on 14 Jan 92. Plots were 4 rows 0.7 m apart and 7 m in length. The trial was rainfed, receiving 294 mm during the growing season with ranges of monthly minimum temperatures 7-I4?C and monthly maximum temperatures 29-34?C, and evaporation for the same period was 503mm. Over half the rainfall occurred 2 weeks after sowing and crop water deficits was severe in the March post-flowering period (19mm rain versus I 46mm evaporation). Days to flowering and maturity, canopy width and height plus vining levels at mid-pod fill, above ground biomass from 1m row subsamples during late pod fill (to estimate maximum biomass accumulation), lodging, grain yield and 100 seed weight were all measured on the 2 central rows of each plot.

The processes determining grain yield in Phaseolus vulgaris were analysed using the simple model reported by (3), where grain yield (Y) equals:

$$Y = CGR \times Dr \times p$$

where CGR is crop growth rate (kg/ha/d) between sowing and maximum biomass accumulation, Dr is the duration of reproductive growth, and p, the partition ratio, is the fraction of CGR partitioned to Y, calculated as the fraction of pod growth rate to CGR (see (3)).

Results

A wide range of grain yields, 290 *to* 2660 kg/ha was obtained (Table 1). High biomass was associated with both high and low grain yields. Certain high yielding accessions, such as Narion 11 and Acc 53, had high harvest indices, while others (Acc 54, Acc 445 and Turrialba 4N) had intermediate values. Except for

ICA 214773, accessions with high grain yield were early to intermediate in maturity. Fully determinate accessions (vining score of I) tended to be intermediate in grain yield, while the very indeterminate types (score of 4) were mainly low in grain yield. A diverse array of pathways to high grain yield under water limited conditions was found, with no consistent trends in either phenology or agronomy.

Lodging was associated with both indeterminacy (high vining score) and high grain yield (e.g. Acc 1280 and Acc 54). Canopy height tended to be lower in lower yielding types but an exception to this trend was shown by Acc 445. There was no association of yield trends with seed weight.

Table I. Yield components and associated measurements, including derived model parameters

Genotype	Seed yld (kg/ha)	Dr (d)	Dtot (d)	TDM (kg/ha)	Seed weight (g)	Plant height (cm)	Plant width (cm)	Vining (1-5)	Lodging (%)	Seed no. (/m2)	Hvst Index	CGR (kg/ha/d)	p
ACC 1280	2,661	36.5	79.0	3,895	21.0	41.0	42.5	3.0	45.0	1,267	0.68	49.3	1.48
ACC 53	2,599	39.0	83.0	3,521	19.1	44.0	38.5	2.0	25.0	1,361	0.74	42.4	1.57
ACC 54	2,590	34.5	78.5	4,993	21.3	40.0	38.5	3.0	40.0	1,216	0.52	63.6	1.18
Narino 11	2,522	36.5	80.0	3,078	22.3	40.0	38.5	3.0	10.0	1,185	0.82	38.5	1.79
ACC 52	2,482	37.0	80.0	4,014	19.4	43.5	36.5	2.5	32.5	1,279	0.62	50.2	1.34
ACC 547	2,313	34.0	76.0	3,634	18.0	43.5	31.0	3.0	37.5	1,283	0.66	47.8	1.42
S-219-N	2,296	39.5	82.5	3,275	19.3	41.5	38.5	3.5	40.0	1,193	0.71	39.7	1.46
ACC 445	2,292	35.5	80.0	4,176	19.7	38.0	38.5	3.5	40.0	1,164	0.55	52.2	1.24
Actolac	2,286	36.0	78.5	3,155	20.5	45.0	32.5	2.0	22.5	1,117	0.73	40.2	1.58
Turrialba4	2,110	39.5	82.0	4,486	20.1	47.0	35.0	3.0	35.0	1,048	0.48	54.7	0.98
ICA 214773	2,107	49.5	94.0	4,148	37.0	51.0	41.5	1.5	27.5	570	0.50	44.1	0.97
ACC 48	2,068	35.5	77.5	3,704	18.2	45.0	29.0	2.5	27.5	1,136	0.56	47.8	1.22
ACC 570	2,032	33.0	76.0	3,078	20.1	46.0	33.5	3.0	37.5	1,011	0.66	40.5	1.52
ICA Pijao	2,031	33.5	76.5	3,197	18.8	51.5	30.0	2.5	25.0	1,079	0.64	41.8	1.45
US PI 163372	2,031	36.0	79.5	3,233	19.5	40.5	34.5	3.0	35.0	1,042	0.63	40.7	1.39
ACC 219	1,947	34.5	76.5	3,880	17.3	39.0	28.5	3.0	30.0	1,124	0.51	50.7	1.11
ACC 122	1,941	43.0	89.0	4,754	20.0	41.0	40.0	4.0	45.0	972	0.41	53.4	0.85
SEL(X 37)	1,832	41.5	82.5	2,690	17.7	41.5	33.0	2.5	27.5	1,033	0.71	32.6	1.35
CPI 95917	1,803	57.5	100.0	2,859	46.9	47.0	37.5	1.0	27.5	384	0.67	28.6	1.10
ICA 21659	1,795	54.0	98.0	2,303	42.9	43.5	38.5	1.0	30.0	419	0.76	23.5	1.41
Bianco	1,751	42.0	86.5	3,155	18.2	36.0	37.5	2.0	37.5	965	0.56	36.5	1.14
A-79	1,713	36.0	78.0	3,521	21.8	36.0	37.0	3.5	55.0	786	0.49	45.1	1.05
PI 310725	1,705	35.0	78.0	3,387	19.1	41.5	31.5	3.0	32.5	893	0.51	43.4	1.12
Bush Blue	1,635	35.0	75.0	2,683	18.7	38.5	30.0	2.5	32.5	926	0.60	35.8	1.31
A 182	1,581	38.0	79.0	2,986	37.6	43.5	33.5	3.0	37.5	420	0.55	37.8	1.10
Antioquia	1,573	56.0	98.0	2,859	33.9	38.5	36.5	1.5	35.0	434	0.55	29.2	0.96
ACC 281	1,560	35.5	77.5	2,599	18.1	40.0	31.0	3.0	35.0	862	0.60	33.5	1.31
Uride redo	1,503	53.0	95.0	2,887	33.0	36.0	37.5	1.5	37.5	456	0.54	30.4	0.93
G 6617	1,473	49.5	92.0	2,711	33.9	39.0	42.5	4.0	47.5	435	0.53	29.5	1.00
G 6636	1,462	51.5	89.0	3,169	35.4	45.0	35.0	1.0	30.0	413	0.46	35.6	0.80
Diacol nima	1,403	54.0	94.5	2,937	40.9	43.5	40.0	1.0	30.0	343	0.48	31.1	0.84
ACC 607	1,370	46.5	88.0	3,233	34.2	37.5	34.0	1.5	25.0	401	0.41	36.7	0.80
G 13250	1,268	43.0	78.5	3,486	33.4	36.5	27.0	2.0	32.5	380	0.37	44.4	0.66
G 6636A	1,202	53.5	90.5	3,592	37.4	37.5	32.5	1.0	25.0	321	0.33	39.7	0.57
G 7600	1,177	52.0	94.0	3,613	37.3	42.5	35.0	1.0	22.5	315	0.33	38.4	0.59
C 40	1,089	48.5	95.0	2,747	29.3	45.5	39.0	1.5	30.0	371	0.39	28.9	0.78
Mexico 116	1,034	48.5	94.0	2,394	21.1	32.5	34.0	2.5	50.0	491	0.45	25.5	0.84
Orbit 131373	891	39.0	77.0	2,479	29.9	40.0	30.0	2.0	35.0	298	0.36	32.2	0.71
Cauca 47	881	52.0	104.0	2,394	21.4	43.0	36.0	3.0	50.0	412	0.65	23.0	0.74
Zebra	844	41.5	85.5	4,641	26.7	30.0	43.5	4.0	65.0	316	0.18	54.3	0.30
Ricobaio	789	49.0	101.5	2,021	17.4	32.5	32.0	2.0	32.5	453	0.42	19.9	0.81
CPI 109859	728	43.0	89.0	2,578	16.2	28.5	35.0	2.5	45.0	450	0.29	29.0	0.58
Mexico 6	583	49.5	102.5	3,338	16.4	32.5	35.0	4.0	65.0	355	0.17	32.6	0.36
Purple bell	290	44.0	91.5	2,648	18.7	25.0	27.0	4.0	80.0	155	0.12	28.9	0.23
l.s.d. P <0.05	770	5.7	6.1	1407	5.9	7.1	7.5	0.9	11.8	314	0.33	15.3	0.37

The major sources of yield variation occurred due to cultivar differences in p and CGR (Table 2), which together accounted for 76% and 37% of the variation about the mean. Indeed, in a multiple regression of seed yield on CGR and p, a significant positive correlation was observed which accounted for 92% of the variation in seed yield.

Partitioning ratios well in excess of 1.0 were observed (Table I) in the high yielding genotypes, indicating substantial remobilisation of pre-anthesis assimilate may have occurred. It should be noted however that while high seed yield was generally associated with high p, it was not essential. For instance, genotypes such as Acc 54 had intermediate p (1.18) and compensated by having very high CGR (63.6 kg/ha/(1).

A negative association between seed yield and Dr was also evident, although the magnitude of this correlation (r=-0.52) was not as high as for p and CGR. Interestingly, Dr was inversely related to both p (r=-0.54) and CGR (r=-0.62).

Table 2. Correlation matrix between seed yield and model parameters in 44 *Phaseolus vulgaris* genotypes. n=44, 2-tailed significance: * -P<0.01 ** -P<0.001

	Seed Wt	Dr	CGR	p
Seed Wt	1.00	-0.52*	0.61**	0.87**
Dr		1.00	-0.62**	-0.54**
CGR			1.00	-0.22
p				1.00

Discussion

This experiment evaluated accessions under water limiting conditions during the latter half of the season, and thereby disadvantaged late maturing types. Partial indeterminacy provides flexibility under water stress by allowing seed set following rains, however if indeterminacy is associated with lateness its advantage is limited to those seasons with late rainfall. The results presented here provides a useful interpretation for the most common form of water limitation, i.e. late stress.

The simple analysis presented here has provided useful information with regard to maximising yield of *Phaseolus vulgaris* by cultivar selection, which could ultimately guide the future direction of the navybean breeding program. Under the conditions of this experiment where late season stress was experienced, high seed yield was achieved by quite different strategies. For instance, the highest yielding cultivar Acc 1280 which produced 2661 kg/ha had short Dr (36.5 d), moderate CGR (49.3 kg/ha/d) and high p (1.48). This strategy apparently involved the early establishment of a large reproductive sink, and the partitioning of most of subsequent growth to seeds. Another high yielding cultivar, ICA 214773 (2107 kg/ha) had much longer Dr (49.5 d), similar CGR (44.1 kg/ha/d), but much lower p (0.97). This genotype although partitioning less of its assimilate to seeds, compensated by having a longer reproductive duration. Clearly, the analysis has shown that high yield can be achieved via many different pathways. Thus, although we cannot categorically state that the breeding program should actively select for one particular trait, our study has demonstrated that substantial variation exists for each of the model parameters. Further studies are warranted to assess the optimal combination of traits for specific target environments.

There was wide variation among the accessions for seed yield and its determinants of yield (Table 2). The partitioning characteristics of genotypes accounted for a large proportion of this yield variability, with p ranging from 0.23 to 1.79. It seems that much of the genotype yield improvement in the breeding program has been associated with increasing p, in common with other indeterminate legumes (e.g. peanut, (1); chickpea, (3)). It is interesting that p values in excess of 1.0 were recorded, suggesting a substantial movement of pre-flowering assimilate to seeds had occurred. This response appears to be an important adaptation to drought, acting as a buffer against the effects of water deficits on current assimilation (2). Similar effects have been observed in peanut (4).

A significant negative correlation between Dr and seed yield (and p) occurred. This may be due to a physiological effect, or it could be a function of the selection pressure which has led to improved genotypes. Indeterminate growth may mean that since seed growth competes with the initiation of new fruiting nodes for the available assimilate, Dr may as a consequence be limited by high p. The alternative hypothesis is that domestication of the crop for mechanised production may have led to the selection of genotypes with short duration and high partitioning characteristics. There may have been unconscious selection for short season types with high partitioning. The longer season types therefore tend to be considerably more "wild", with associated high levels of indeterminacy, vining and low partitioning. The latter hypothesis appears to be the most likely, since exceptions to the above trend seem to exist, with genotypes such as CPI 95917 and ICA 21659 having long Dr (98-100 d) with moderately high p (1.1-1.4).

The results show that a better understanding of the physiological attributes of genotypes is possible using a simple analysis of yield. The characters in the analysis are easily measured and could easily be used in large scale breeding programs to improve plant breeders' understanding of genotype x environment interaction.

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