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Alternative plant types of faba bean

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SUMMARY - The traditional plant type of faba bean presents many constraints to increased production. Chief among these are the excessive vegetative growth possible under favorable conditions and severe flower and young pod drop which makes the crop sink rather than source limited. These combine to give a low harvest index as compared to cereal crops. Several mutants are being exploited in order to overcome these constraints. With the determinate mutant success has been limited because of the reduced biomass and an increased production of unproductive branches. Selection should concentrate on an increased biomass and an increase of podding nodes/branch, with a reduction of infertile branches. The independent vascular supply mutant offers a less drastic modification which almost eliminates flower drop, resulting in an effective semi-determinate plant. If the closed flower mutant is combined with high autofertility there is a possibility to modify faba bean into a self-pollinated crop with an increase in efficiency of breeding procedures.

RESUME - "Types alternatifs de la plante de fève". Le type traditionnel de plante de fève présente beaucoup de contraintes pour une augmentation de la production, en particulier la croissance végétative extrême possible sous des conditions favorables et la chute des fleurs et des jeunes gousses, donc la culture peut puiser des ressources mais pas les distribuer aux organes cibles. Ces facteurs combinés causent un faible indice de récolte par rapport aux céréales. Plusieurs mutants sont actuellement étudiés afin de surmonter ces contraintes. Le succès avec le mutant déterminé a été limité à cause de la réduction de biomasse et d'une augmentation de branches improductives. La sélection devrait se concentrer sur l'augmentation de la biomasse et du nombre de noeuds qui forment des gousses par branche, avec une diminution du nombre de branches infertiles. Le mutant avec vascularisation indépendante présente une modification moins marquée qui élimine d'une façon presque totale la chute des fleurs, donnant lieu à une plante semi-déterminée efficace. Si le mutant à fleur close se combine avec une forte autofertilité il y aura une possibilité de modifier la fève vers une culture autogame et augmenter l'efficacité des méthodes de sélection.

Introduction

The traditional faba bean (*Vicia faba* L.) plant has an indeterminate growth habit and can often grow to two meters tall. Many cultivars are prone to lodging and are difficult to harvest because of pods at or near the ground level. As with many other legumes, faba bean often suffers from severe flower and young pod drop (Hodgson and Blackman, 1956; Kambal, 1969; Gates *et al.*, 1983; Hebblethwaite *et al.*, 1984). This indeterminate growth habit with the associated intra-plant competition for assimilates and severe flower and young pod drop leads to a low harvest index. The harvest index of faba bean is only 30-35% compared to 60-65% for cereal crops.

Faba bean is a partially cross-pollinated crop with outcrossing rates of 4 to 84%, with an average of 35% (Bond and Poulsen, 1983). Outcrossing is entirely the result of insect cross-pollination (Free, 1970). This partially outcrossing nature of faba bean and the difficulties encountered in pollination control reduces the efficiency of most breeding programs. Several researchers have suggested that the conversion of faba bean to full autogamy would lead to faster genetic improvement (Kambal *et al.*, 1976; Lawes, 1980; Poulsen, 1977).

Faba bean researchers, in order to overcome some of these constraints faced with the traditional plant type of faba bean, have actively searched for alternative plant types. The determinate plant type has been produced by mutation treatment (Filippetti, 1986; Sjodin, 1971; Steuckardt *et al.*, 1982). A spontaneous semi-determinate mutant was discovered by Frauen and Brimo (1983). To reduce flower drop, Gates *et al.* (1983) have suggested the selection for synchrony of anthesis within racemes. Because of the strong interactions with the environment for synchrony of flowering, they suggested the use of an independent vascular supply (IVS) mutant to reduce interactions between flowers and pods within the same raceme.

Determinate

Performance of original sources

The determinate mutants of Sjodin (1971), Filippetti (1986) and Steuckardt *et al.* (1982) were found to be monogenic recessive. The determinate plant type is characterised by a terminal inflorescence and, in the original mutants, stem growth abruptly terminates after four to five flowering nodes. This results in a large reduction of plant height and reduces lodging. Pods are borne on the top of the plant, which facilitates mechanical harvest. Researchers felt that with the use of the determinate plant type there would be a better partition of assimilates between vegetative and reproductive growth and a corresponding increase in harvest index.

However, the use of the determinate mutant has failed to increase yield of faba bean, and in general, determinate lines developed by several breeding programs have yielded considerably less than the traditional indeterminate plant type (Anonymous, 1987, 1988; Ebmeyer, 1986; Kittlitz, 1986; Saxena *et al.*, 1986). One of the major weaknesses of the original determinate mutant has been the production of a high number of unproductive branches (Austin *et al.*, 1981; Baker *et al.*, 1983). Another serious problem faced has been the production of few pods per plant due to low numbers of flowering nodes/branch and flowering abnormalities which reduce pod set. Disease resistance is another serious concern with the original determinates.

Yield and its components

Determinate mutants have been used in crossing programs by several institutions to try to improve the yield of determinate lines and improve other important characters such as seed size and adaptability to different regions. At ICARDA, the determinate mutant has been used extensively in the crossing program to try to select for a determinate plant type with better yield through increasing the seed size, reducing branching, and increasing the biomass (Anonymous, 1987, 1988).

The results of crosses with a series of Chinese parents illustrate some of the problems faced with the determinate mutant (Table 1). In this series of crosses the mean of the F_2 determinate plants for seed yield is approximately 25% of that for the indeterminate parents. The

Table 1. A comparison of F_2 determinate plants and parents for some characters (Determinate x Chinese crosses) at Tel Hadya, Syria in 1987/88.

Material	Plant height (cm)	Podded branches/plant	Pods/ plant	Seeds/ plant	Seeds/ pod	100-seed weight (g)	Seed yield/ plant (g)
H41 (Female)[a]	135.3	4.3	18.0	41.4	2.3	74.4	30.8
N87019-F2	54.3	2.8	8.1	19.2	2.4	62.3	11.9
H44 (Female)	110.4	4.8	26.4	50.2	1.9	100.1	50.3
N87020-F2	59.8	3.6	7.3	18.8	2.6	66.5	12.1
H48 (Female)	141.3	4.7	21.3	51.1	2.4	77.0	39.3
N87021-F2	56.8	3.1	7.7	18.0	2.5	68.2	12.0
H94 (Female)	142.3	5.3	25.0	40.0	1.6	107.0	42.8
N87022-F2	58.6	3.0	7.9	18.3	2.4	68.1	12.2
H96 (Female)	108.0	5.4	9.0	18.0	2.0	240.0	43.2
N87023-F2	58.2	3.3	6.9	17.2	2.5	82.5	14.1
H189 (Female)	134.0	5.0	24.4	41.5	1.7	114.4	47.5
N87024-F2	55.3	3.5	7.3	17.2	2.4	81.7	13.3
H330 (Female)	94.4	6.2	14.8	22.2	1.5	98.0	21.8
N87025-F2	53.6	2.0	3.3	7.5	2.3	81.3	5.9
H593 (Female)	150.0	2.7	17.0	34.0	2.0	160.0	54.4
N87026-F2	60.4	2.3	4.6	9.9	2.2	97.5	9.1
FLIP 84-24ILB (Male)	43.0	3.6	12.2	31.8	2.6	68.4	21.5

[a]All female parents were from China

Table 2. Performance of determinate M_2 plants and the standard indeterminate check ('Aguadulce') in preliminary evaluation at Valenzano, Italy, 1983.

Mutant plants	Number of stems[a]	Number of flowering nodes	Number of flowers	Number of pods/plant	Number of seeds/plant	Number of seeds/pod	Seed yield/ plant (g)	Seed weight (g)
1	5	50	165	11	39	3.5	72	1.84
2	4	40	115	6	18	3.0	45	2.50
3	4	33	100	7	18	2.6	31	1.72
4	4	40	120	8	24	3.0	39	1.62
5	3	50	170	10	29	2.9	47	1.62
6	3	30	90	5	16	3.2	29	1.81
7	3	35	105	5	20	4.0	43	2.15
8	4	38	115	6	20	3.3	43	2.15
9	3	50	160	9	30	3.3	48	1.60
10	3	38	120	7	24	3.4	41	1.70
Mean	3.6	40.4	126.0	7.4	23.8	3.2	43.8	1.87
Aguadulce test mean	2.5	24.0	75.0	10.5	42.0	4.0	82.5	1.96

[a]Axis + secondary stems

main reason for this is a reduction in pods/plant and seed size. However, 21 single plants yielded similar to or exceeded the Chinese parents. Similarly, in Italy, with the M_2 determinate plant progeny from a Mediterranean parent ('Aguadulce'), the mean yield was 50% of the parent, as a result of reduced pods/plant and seed size (Table 2). The number of flowers per plant was higher for the determinates.

In yield testing of a determinate line Kittlitz (1986) achieved only 83% of the yield of indeterminate lines. In the EEC faba bean trials, Ebmeyer (1986) compared 'Ticol', a determinate line with standard indeterminate checks, and found it gave only 77% of their yield. In comparison of several plant types Saxena *et al.* (1986) found the determinate line inferior to the indeterminate for seed yield. Again, this was mainly due to the production of infertile branches.

In the breeding program at ICARDA, a large number of derived determinate lines have been tested over several years at three locations (Table 3). At the three sites the mean yields of determinate lines ranged from 55 to 60% of the best indeterminate line. This is an improvement over the original unadapted determinate mutant (SVO 622) which yielded only 20 to 36% of the indeterminate check. There were several determinate lines with yields similar to that of the best indeterminate check.

With a set of Mediterranean F_2 crosses in Syria, the most important traits for seed yield were pods/plant and podded nodes/plant (Table 4). Since the Mediterranean parents were large seeded, seed size was also correlated with seed yield in the populations. The strong correlation

Table 3. Performance of determinate lines in advanced yield trials in 1987 and 1988 at three sites, for grain yield (kg/ha).

Location	Year	S.E.	SVO 622 (improved)	Mean of determinates	ILB 1814	Best determinate line
Tel Hadya	1987	0.24	0.57	2.24	4.00	3.39
	1988	0.36	1.00	2.54	3.71	3.74
Lattakia	1987	0.60	0.80	1.98	3.54	3.84
	1988	0.44	0.47	1.30	2.40	3.40
Terbol	1987	0.35	0.70	2.25	4.02	3.44
	1988	0.31	1.98	2.24	3.50	3.03
Mean	Mean	–	0.92	2.09	3.53	3.47

Table 4. Correlations among yield and yield components for determinate plants, 1985 (d.f.=408) at Tel Hadya, Syria.

Trait	Podded nodes/ plant	10–seed weight	Seeds/ pod	Pods/ podded node	Seed yield/ plant
Pods/plant	0.94**	-0.08	-0.16*	0.21*	0.74**
Podded nodes/plant		-0.05	-0.12*	-0.08	0.74**
10–seed weight			-0.06	-0.11*	0.24**
Seeds/pod				-0.13*	0.33**
Pods/podded node					0.06

of podded nodes/plant with yield is due to the influence on pod number, which is why one of the main goals has been to increase podded (or flowering) nodes per branch. With a set of determinate x Chinese F_2 populations a similar situation was found (Table 5), with the exception of the importance of seed size, since the Chinese parents were as small seeded as the determinate parent. Pods/plant was very important and this was due to production of more fertile branches with increased pod number.

Harvest index and biomass

The reduced yield of determinate lines has been related to production of infertile branches, less pods/plant, and reduced biomass. The reduced pods/plant and infertile branches accounts for no major increases of harvest index with determinates. Ebmeyer (1986) found 'Ticol' to have a lower harvest index than normal indeterminate lines. This coupled with a reduced biomass explains the inability of existing determinate lines to achieve the same yield level as with indeterminate lines.

Selection for increased yield in F_2 determinate plants in Italy resulted in selection of plants with a harvest index greater than 50% (Table 6). Correlations calculated for sixty determinate lines grown at three sites in West Asia show the importance of increasing biomass and maintaining or increasing harvest index for increased yield of determinate lines (Table 7). Saxena *et al.* (1986) also found the major explanation for reduced yield with determinate lines was the reduced biomass but a similar dry matter partitioning. For the previously mentioned 60 determinate lines in West Asia, the mean of determinate lines for seed yield is much less than the indeterminate check, a result of reduced biomass and no dramatic change in harvest index (Table 8). There was no major difference in the dry matter partitioning in the determinate and indeterminate lines in Italy as well (Fig. 1).

To increase yield of determinates, the major requirement is to increase biomass and control the production of infertile branches. To increase pod set, in addition to controlling infertile branches, there is a need for more flowering nodes/branch; this should result in a higher harvest index.

Table 6. Mean values of yield per plant and yield components of the better F_2 determinate plants.

F_2 plant	Number of pods per plant	One-seed weight (g)	Total biological yield (g)	Seed yield (g)	Harvest index
1	19	0.77	74	47.0	0.64
2	15	0.83	54	33.3	0.62
3	15	0.85	59	38.1	0.65
4	16	0.85	58	31.4	0.54
5	12	0.85	42	26.5	0.63
6	11	0.85	47	28.2	0.60
7	12	1.11	52	34.4	0.66
8	11	1.21	58	39.9	0.69
9	11	1.21	63	41.1	0.65
10	15	1.23	64	39.5	0.63
11	11	1.10	68	46.4	0.68
12	10	1.11	58	37.6	0.66
13	15	0.68	54	35.3	0.65
14	11	1.10	43	30.8	0.72
15	10	1.21	64	42.5	0.66
16	12	1.25	50	32.5	0.65
Mean	12.8	1.0	56.7	38.5	0.69
F_2 mean	8.3	1.2	46.1	29.5	0.63

Yield stability

With determinates there has been concern expressed for stability of yield. In the EEC joint field test Ebmeyer (1986) found 'Ticol' with a regression coefficient of 1.48 and small deviations from regression, indicating respon-

Table 5. Correlations among yield and yield components for 226 F_2 determinate plants from 8 parental combinations of determinate growth habit and Chinese parents planted at Tel Hadya (Syria) during the 1987/88 season.

Trait	Plant height	Podded branches/plant	Pods/ plant	Seeds/ plant	Seeds/ pod	100–seed weight
Podded branches/plant	0.169*					
Pods/plant	0.169**	0.539**				
Seeds/plant	0.171*	0.485**	0.911**			
Seeds/pod	0.048	0.029	0.042	0.406**	1.000	
100–seed weight	0.072	-0.179*	-0.276**	-0.346**	-0.288**	
Seed yield/plant	0.218**	0.471**	0.869**	0.916**	0.315*	-0.022

Table 7. Mean correlation among yield components for 60 determinate lines planted at Tel Hadya and Lattakia in Syria and Terbol in Lebanon, 1986/87.

Trait	Flowering date	Plant height	Pods/ plant	Seeds/ plant	100–seed weight	Grain yield	Biomass
Plant height	0.142						
Pods/plant	0.016	-0.157					
Seeds/plant	0.091	-0.173	0.765**				
100–seed weight	-0.202	0.006	-0.493**	-0.520**			
Grain yield	-0.122	0.140	0.354**	0.353**	0.170		
Biomass	-0.036	0.445**	0.086	0.059	0.142	0.637**	
Harvest index	-0.189	-0.341**	0.388**	0.440**	0.060	0.607**	-0.173

Table 8. A comparison of characters for 60 new determinate faba bean lines and the original determinate mutant from Sweden with the best indeterminate check line in the Advance Varietal Trial in 1986/87, at various ICARDA research sites[a].

Faba bean lines and locations	Plant height X±S[b] (cm)	Pods/plant X±S	Seeds/plant X±S	Seeds/pod X±S	100 seed weight X±S (g)	Grain yield X±S (kg/ha)	Harvest index X±S (%)
NEW DETERMINATE LINES							
Tel Hadya (Syria)	51.6± 3.60	9.6±1.55	24.1± 3.76	2.6±0.30	88.8± 8.59	2760.2±329.36	45.7± 4.29
Terbol (Lebanon)	43.8± 4.59	16.7±2.14	31.2± 3.58	1.9±0.23	83.7± 9.49	2473.5±385.39	45.4± 3.43
Lattakia (Syria)	76.5± 8.13	12.2±3.14	33.3± 8.48	2.8±0.28	93.4± 8.44	2155.8±657.46	31.7± 6.61
Mean, all sites	57.3± 4.44	2.8±1.71	29.5± 3.81	2.4±0.23	88.6± 7.86	2463.2±285.33	40.9± 3.45
SWEDISH DETERMINATE LINE							
Mean, all sites	64.8±14.90	11.3±0.02	22.8±12.18	2.3±1.26	48.2± 3.39	758.4±109.18	12.8± 2.92
INDETERMINATE (ILB 1814)							
Mean, all sites	71.8± 2.59	12.7±3.80	22.1± 4.08	1.8±0.17	166.6±16.48	3422.8±870.24	43.3±11.85

[a]60 determinate lines planted at Tel Hadya, Terbol and Lattakia
[b]X±S = Mean value ± Standard deviation

siveness to good environments with predictable performance. With eleven sites in the ICARDA International Determinate Trial, a stability analysis revealed that the linear and non-linear proportions of genotype x environment interactions were non-significant, indicating that the determinate lines had average stability (b=1) and they were predictable (non-significant deviations from regression), as shown in Table 9.

Important for stability of performance would be the incorporation of disease resistance into determinate lines. At ICARDA, using the disease resistance sources from the germplasm collection, resistance to chocolate spot and ascochyta blight has been successfully incorporated into determinate lines (Anonymous, 1987, 1988).

Independent vascular supply

The large flower and young pod drop in faba bean has been attributed to physiological interactions among flowers and pods in the same raceme and the use of the IVS mutant with independent vascular traces to each flower has been suggested to circumvent this (Gates *et al.,* 1983). Lines with this trait are effective semi- deter-

Table 9. Stability analysis for 11 locations for the 1987/88 FBIYT-Deter.

Entry	Mean yield (kg/ha)	b	S^2d
FLIP 86-107FB	2501	1.05	n.s.
FLIP 86-146FB	2512	1.09	n.s.
FLIP 86-145FB	2378	1.11	n.s.
FLIP 86-118FB	2327	1.08	n.s.
FLIP 84-244FB	2277	1.03	n.s.
FLIP 84-246FB	2205	1.11	n.s.
FLIP 84-230FB	2178	0.99	n.s.
FLIP 86-143FB	2128	0.90	n.s.
FLIP 84-144Fb	2124	0.88	n.s.
FLIP 84-237FB	2079	0.91	n.s.
FLIP 84-240FB	2065	0.89	*
FLIP 84-243FB	2033	0.94	n.s.

minates with a heavy pod set over the first five to six flowering nodes, providing a strong sink for assimilates, which leads to the early death of the vegetative apex. This results in yield being limited by the ability of the plant to supply assimilates, rather than by sink capacity, which is the usual case for faba bean (McEwen, 1972). This is a less pronounced modification than with determinates and would allow a more flexible response to favorable environments in regard to photosynthetic area.

At ICARDA, the IVS source of Gates *et al.* (1983) has been crossed with Mediterranean cultivars and there has been good success in increasing seed size and incorporating disease resistance (Anonymous, 1987, 1988). This area of research will receive increasing attention in the future.

Self-pollination

The closed flower mutant of Poulsen (1977) offers hope of modifying the breeding system of faba bean to self-pollination. The closed flower, besides having a tightly closed flower, has neither scent nor nectar. Selfing rates greater than 95% have been reported in some lines with the closed flower mutant. For a functional self- pollinated faba bean, the closed flower mutant would have to be combined with highly autofertile sources, such as reported by Robertson and Sherbeeny (1988); otherwise there would be reduced yield as reported by Ebmeyer (1986) for a closed flower line in the EEC joint trial.

The degree of selfing with the closed flower mutant has been found to vary from 0.4 to 36% (Knudsen and Poulsen, 1981), most likely the result of modifying genes affecting the tightness of the closure of the flower. Because of the necessity for selecting for this, it is desirable that several breeding programs work on the closed flower mutant so that when crosses are made for important traits such as yield, disease resistance, quality traits, etc., reselection does not have to be done for tightly closed flowers. Selection for self-fertility should make it possible to produce high yielding inbred lines which are self- pollinated. This would greatly increase the efficiency of breeding programs for *Vicia faba* and simplify seed production.

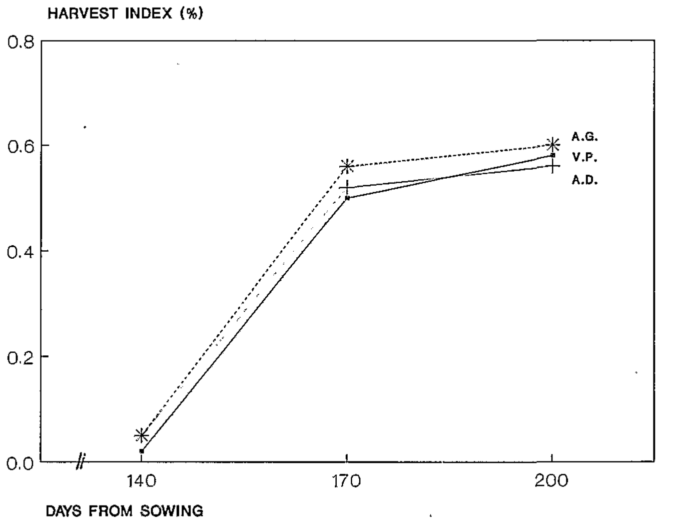

Fig. 1. Harvest index in three genotypes of *Vicia faba* L. *major* evaluated in 1985/86 season at Valenzano (Bari, Italy). V.P.='Violetta di Policoro'; AG.='Aguadulce'; A.D.='Aguadulce' with determinate growth habit.

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