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Towards the world's earliest maturing faba beans

Molecular breeding approaches in faba bean

Diseases infecting faba bean

Resistance to freezing in winter faba beans

Faba bean in cropping systems

'Why should I grow faba beans?'

There is hope for faba bean cultivation

Resistance to freezing in winter faba beans

by Wolfgang LINK[1]* and David BOND[2]

Abstract: Genuine winter faba beans (*Vicia faba* L.) are sown in autumn in North-West Europe in order to realize the agronomic advantages of a winter crop over a spring crop. European winter beans survive winter conditions as young plants; some cultivars endure frost as hard as -15°C, and even harder if there is adequate snow cover. In winter faba beans, accumulation of free proline and the desaturation of membrane-bound fatty acids is involved in the hardening response and in frost tolerance. Several putative QTL for frost tolerance were identified, with one QTL possibly involved in the response of oleic acid to hardening.

Key words: autumn sowing, faba bean, freezing, low temperatures, winter hardiness

What is a winter faba bean?

Genuine winter faba beans are sown in autumn, in North-West Europe, in order to realize the agronomic advantages of a winter crop over a spring crop. They are grown most frequently in UK (> 88.000ha), and to a much lesser extent in winter-mild, costal regions of France. Winter faba beans (and other winter pulses) are also tested and developed for regions in Serbia, where harsh frosts occur in winter (6). Although other faba beans are autumn sown they may not be considered as genuine winter beans. For instance, faba beans are also sown in autumn in the Mediterranean Basin, in parts of Australia, China, and Japan. The north-western edge of the Sichuan Basin of China, with the marked slopes of the Tibetan High Mountains in sight, is an example site where such beans are produced (summers are hot and winters are cool, with rare frost events). In parts of Australia, frost was reported to threaten faba beans at flowering time, when freezing resistance of varieties is slight.

European winter beans survive winter conditions as young plants; some cultivars endure frost as hard as -15°C, and even harder if there is adequate snow cover. At Göttingen, Germany, winter 2002/2003 was too severe even for the local winter bean population. Long-lasting frost at day and night of down to -16°C with wind from the east, absence of snow protection and all-day sunshine killed the plants. In contrast to this, several marked spells at Göttingen in winter 2009/2010 with temperatures of -15°C to -20°C were well survived by more than 60% of entries, obviously due to adequate snow protection.

Background and history of European winter beans were reported by Bond and Crofton (4). Already in 1825, small-seeded winter beans were introduced to the UK from unknown sources, maybe from Russia. Small-seeded winter beans were grown already in 1812 at high altitude in the Côte d'Or region of Burgundy, France. European winter beans in the 1800s were thus small-seeded, *minor*-type beans. The current *equina*-type winter beans replaced them in UK between 1925 and 1945. The first *equina* varieties in the UK were Gartons S.Q., and Throws M.S., a composite. Littmann's highly winter-hardy variety Hiverna (released in Germany in 1986) has ancestors in the high Pyrenees. Present-day cultivars are Wizard, Sultan, Arthur (Wherry, UK), Gladice (white-flower-and-tannin-free, INRA) and Husky (NPZ Lembke, Germany).

Beyond frost tolerance, winter beans show further important peculiarities, such as some vernalization requirement for early-node flowering and an ability of hardening, some tolerance to frost-drought and to snow-cover and a strong ability of healing mechanical injuries during winter. Good frost hardening conditions are 5°C, adequate light and short day length.

Frost tolerance of winter beans

Several physiological strategies to acquire frost tolerance are in use in the plant kingdom, where the main threat is tissue damage caused by intracellular ice. Temperature of actual ice formation in tissues is depressed by the accumulation of cryoprotective substances like free proline or glycinebetaine. Supercooling is the ice-nucleation-related ability of tissues to cool below the freezing point without actual ice formation. So-called antifreeze proteins serve for similar purposes. In winter faba beans, accumulation of free proline and the desaturation of membrane-bound fatty acids is involved in the hardening response and in frost tolerance (2, 3). These authors reported that linolenic acid (C18:3) content in leaves of young plants increased upon hardening from 51% to 57% (all fatty acid = 100%), and from 32% to 42% in stem; whereas oleic acid (C18:1) was reduced from 7% to 4% in leaves and from 6% to 4% in stem. Content of oleic acid was negatively correlated ($r = -0.55^{**}$) with frost symptoms in artificial frost tests. Proline content ($r = -0.55^{**}$) and electrolyte leakage (tested at -11°C; $r = -0.68^{**}$) was correlated with frost symptoms. Inbred lines bred from the cross of Côte d'Or/1 x BPL4628 (old French winter bean landrace x Chinese ICARDA-accession) with superior frost tolerance have been identified (3) in artificial frost tests and correspondingly high winter survival in the

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field (Fig. 1). In this cross, several putative QTL for frost tolerance were identified, the more important ones in the unhardened treatment. Furthermore, one QTL could be identified involved in the response of oleic acid to hardening. The artificial frost test has recently been modified (7); pots were insulated, number of frost steps were reduced to two (minus 13.0 and minus 17.5°C), and a regrowth phase of about one month was added after the test to quantitatively follow up late frost death and ultimate regrowth of surviving plants. Several known lines (like line 95 from Côte d'Or/1 x BPL4628) and new promising frost tolerant ones (like line 122 from the Göttingen Winter Bean Population) were identified.

Marked hybrid vigour of winter beans for frost tolerance and overwintering was repeatedly reported (1). Alas, with the lack of stable and useful CMS-systems in faba bean, the only choice to make use of such heterosis in farmers' fields is with synthetic or composite cultivars, based on the partial allogamy of the crop (about 50% crossing, with large variation (8)). Indeed most winter bean varieties grown commercially today are composite types. Focussing on this option, field experiments were conducted in 2004 and 2005 across five locations in Germany (5). Homozygous inbred lines from the Göttingen germplasm and corresponding polycross progenies were tested (plus several checks). On average, 65% of the plants survived winter, mean yield was 3.58 t/ha. Inbred lines' mean was 3.02 t/ha, polycross progenies' mean was 4.14 t/ha (proving some allogamy and showing yield heterosis). Based on these data, performances of possible synthetic cultivars were calculated and the highest yielding synthetic cultivars were compared with the highest yielding inbred lines. In four out of five locations, the highest yielding synthetic outyielded the best line (6.93>5.91; 6.66>5.76; 5.75>5.44; 3.06>2.52), in one location the contrary was true (3.16<3.40). As expected, the best line was always a component of the best synthetic. Synthetics were constructed from N=4 components throughout.

Heritability for yield was estimated to be h^2=0.60 in these data, thus, with 0.95 t/ha being one genetic standard deviation (SD), marked gain from selection is promised. For winter-survival (in % cent survival), h^2 = 0.55, with one SD = 10.7%; thus genetic increase of winter survival in Germany by more than 10% seem feasible in short time. With the advent of climate change, i.e. on average milder winters, and with some breeding success for winter hardiness, winter faba bean will very probably see an enlarged area of adaptation and of use, including Germany, Switzerland and Austria and harsher regions of UK and France.

Two factors are proposed to assist in a faster genetic progress: an increased participation of faba bean in marker-assisted selection and the collection and identification of new frost-tolerant germplasm in promising sites like the Hindu Kush region and several regions of China. ■

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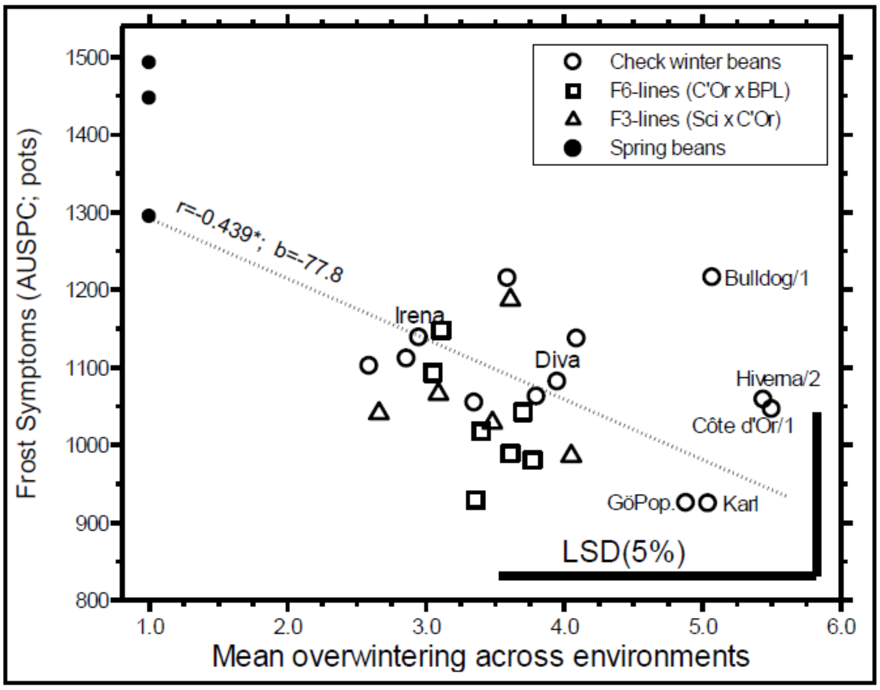

Fig. 1. Spearman's rank correlation coefficient between (1) mean overwintering (score 1-9, 9=100% survival) at 12 environments, distributed across four years (2003-2006) and across Europe, and (2) frost symptoms assessed in artificial frost tests with potted young plants (high values = severe symptoms; cf. Arbaoui et al., 2008).