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Historical review of faba bean improvement in western Canada

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Abstract

Faba bean (*Vicia faba* L.) was considered a minor crop in the Canadian prairies until recently, but its potential for cultivation is increasing due to its positive environmental impact and economic value. This review provides a historical summary of faba bean improvement in western Canada. Although traditional breeding methods have proved useful, in the last decade faba bean improvement has benefited from advances in genetics, biochemistry and molecular breeding tools. The overall breeding goal is to develop high yielding germplasm with improved agronomic characteristics that will be of economic value to the emerging faba bean sectors, including the plant protein industry. To maximize value and acceptance by producers, processors and the food industry as a source of protein and dietary fibre, future faba bean varieties need to be high-yielding, have diverse seed size classes, disease resistance, genetically low vicine-convicine concentration, and have wider adaptation to different agro-ecological zones of Canada. The experiences over the last 40 years of faba bean improvement in western Canada may be useful to other breeding programs globally located in regions with similar agroecology. In the past 10–15 years, faba bean genetic development in Canada has benefited greatly from research and development interactions with most of the faba bean research programs in northern Europe.

Keywords *Vicia faba*, legume improvement, quality traits, disease resistance

Introduction

Faba bean seeds are a generous source of protein, starch, dietary fibre, minerals, and vitamins (Khazaei & Vandenberg, 2020; Warsame et al., 2020; Marshall et al., 2021), and are widely grown for food, feed and green manure globally (Duc et al., 2015). Faba bean has very efficient nitrogen fixation, providing about 90% of the plant's nitrogen needs (Hauggaard-Nielsen et al., 2009), probably the highest value among grain legumes. About half of the crop's nitrogen content is also left in the field for the next crop (*reviewed by* Watson et al., 2017). The low reliance on nitrogen chemical fertilizer inputs in faba bean production reduces greenhouse gas emissions, providing excellent ecological services. Faba bean has a bright future as a protein crop that provides additional legume crop rotation benefits for the prairie provinces of Canada. Its production is poised for rapid growth because of demand for plant-based protein products. Faba bean produces plant-based protein that is non-genetically modified and non-allergenic (unlike soybean). Faba bean is well adapted to wet and cold agricultural environments (Link et al., 2010). This allows further expansion of the potential pulse production areas of western Canada, which would expand the benefits of including an annual legume in the production system. Faba bean is little affected by *Aphanomyces euteiches* Drechs., the causal organism of aphanomyces root rot (ARR) of pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) crops (Moussart et al., 2008), nor is it affected by *Colletotrichum lentis* Damm, the causal organism for anthracnose of lentil. It has better standing power and harvestability than other pulse crops. Commercial production in Canada started in 1972 when greater crop diversity was sought (McVicar et al., 2005) and by 1980, 23,000 ha was devoted to the crop (Slinkard & Buchan, 1980) but the production area decreased to about half by the 1990s. In 2020, its cultivated area was near 36,000 ha (Statistics Canada, 2020). This review provides a brief historical summary of faba bean improvement in western Canada as the dominant producing region in North America, the gaps in current knowledge, and how this can be used to breed new faba bean cultivars for the region.

Historical Background of Faba Bean Improvement in Canada

Interest in faba bean in western Canada began with the introduction of European germplasm in the late 1960s. In the 1970s, faba bean breeding was established at the University of Manitoba (UManitoba) and University of Saskatchewan (USask) but both programs became dormant in the 1990s. Fifteen European cultivars were tested in Manitoba and Saskatchewan during 1970–1971 (Evans et al., 1972). More accessions were introduced and tested during the period 1971–1973 at over 20 locations in western Canada and four European cultivars (Ackerperle, Diana, Erfordia and Herz Freya) were licenced. Beginning in the early 2000s Limagrain Europe introduced a few advanced varieties (*e.g.,* Snowbird, Rodeo and Imposa) adapted to the Canadian prairie climate. In 2002, the faba bean program at the Crop Development Centre (CDC), USask was expanded to include a specific focus on developing a new germplasm base combining small seed size with reduced concentrations of the anti-nutritional factors vicine-convicine (v-c) and condensed tannins. Small-seeded, round-shaped faba beans reduce risk and seeding costs without sacrificing yield potential. At this time, 1,500 faba bean accessions were evaluated at two locations in Saskatoon. The sources of the small seed phenotype were primarily from South Asia (*e.g.,* Afghanistan and Bangladesh) and the sources of white flower (low tannin, *zt1* gene) were mainly European spring cultivars.

The list of faba bean varieties released in western Canada is shown in Table 1. Canadian faba bean breeding was initially based on selections from introduced European germplasm. Aladin and Outlook, the first two varieties officially released in Canada, had Czechoslovakian and British origin, respectively. Two landraces from Afghanistan (PI 221517 and PI 222129) were also used in the pedigree of early released varieties mainly due to their reduced seed size. The cultivars released later were based on single crosses undertaken in Canada. However, recent progress has seen the release of varieties such as 219-16 (low tannin), 1142-16 and 1139-11 (both with low tannin and v-c, known as FEVITA® type, Duc et al., 2004) which resulted from multiple crosses to combine yield potential, small seed size, food quality and agronomic performance. Table 1 also shows the broad diversity in origin of faba bean germplasm used in the pedigree of Canadian breeding materials compared to those from Australia that are mainly based on Mediterranean germplasm.

Over the past decade, DL Seeds (http://www.dlseeds.ca/pulses.shtml) has been evaluating, selecting and releasing lines from NPZ (Norddeutsche Pflanzenzücht, Holtsee, Germany) that are adapted to the western Canadian climate zones. These include Vertigo, Fabelle (low v-c), Taifun (low tannin), Tabasco (low tannin), DL Rico (FEVITA type), and DL Tesoro (low tannin). Breeding strategies used by NPZ are based on pedigree selection and so-called "synthetic" cultivars (Sass, 2016), where three or more founder lines are allowed to intercross for a limited number of generations as the seed supply is increased. Breeding of synthetic cultivars is an alternative to hybrid breeding and is the most widely used breeding strategy for faba bean breeding due to its elevated level of cross-fertilization (Link et al., 1994). Most faba bean cultivars bred in western Canada (Table 1) have been developed by recurrent/mass selection or pedigree selection. The current USask breeding program is based on the F_2-derived family breeding method that has been successfully used in lentil and pea, the major pulse crops of western Canada.

Faba Bean Genetic Resources in Canada

Of about 43,000 faba bean accessions maintained in genebanks worldwide, Plant Genetic Resources of Canada at Agriculture and Agri-Food Canada Saskatoon hosts only 84 accessions. This is not surprising as to date the crop is not yet widely cultivated in Canada. The Faculty of Agriculture, UManitoba deposited 278 faba bean research lines with the ICARDA (International Center for Agricultural Research in Dry Areas) genetic resources system (https://www.genesys-pgr.org/wiews/CAN086) during 1974–1983. The breeding materials developed at UManitoba nearly 40 years ago may have limited viability or may have already been discarded. USask currently keeps a collection of about 1,000 exotic faba bean accessions along with several research lines and segregating populations that were developed for genetic studies of various agronomic and biochemical traits.

Table 1. List of faba bean cultivars released in western Canada.

Cultivar	Year released	Pedigree	1000-seed weight (g)	Description	Breeding institute	Reference
UMFB-9	1977	Selection from a European line	346	High productivity. It was supported for licensing in 1977 (the first attempt for releasing a faba bean variety in Canada).	UManitoba	Furgal & Evans (1980)
Aladin (UMFB-19)	1981	Single plant selection from cv. Stagania (Czechoslovakia)	437	Stagania is registered as ILB 626 (IG 11820).	UManitoba	McVetty et al. (1981)
Outlook	1981	Single plant selection from cv. Tarvin (UK)	368	Tarvin is an old British late-maturing high-yielding spring bean with long straw from Gartons Ltd., UK.	USask	Rowland et al. (1982)
Pegasus	1984	Ackerperle (Germany) × PI 221517 (Afghanistan)	376	Ackerperle also known as Francks Ackerperle. Breeder company was Pflanzenzucht Oberlimpurg Dr. Peter Franck. The original source of PI 221517 is Lai, Panjab, 66 miles west of Kabul. It has small round seeds.	UManitoba	McVetty et al. (1985)
Encore	1985	Single plant selection from PI 222129 (Afghanistan)	368	Seeds of PI 222129 were obtained from a local market in Kabul.	USask	Rowland et al. (1986)
Orion	1987	Diana (Germany) × HBNYT-73-I-37 (UManitoba)	350	HBNYT-73-I-37 was an early-maturing, black-seeded line from UManitoba.	Agriculture Canada	Berkenkamp & Meeres (1988)
CDC Blitz	1994	Chinese Broad Bean × Outlook	410	Chinese broad bean is a large-seeded landrace from China.	USask	https://bit.ly/34mIyxw
CDC Fatima	1994	Selection from Chinese Broad Bean	520-600	CDC Fatima is an established cultivar developed for the prairie provinces of Canada.	USask	Graf & Rowland (1987)
CDC Snowdrop	2011	Snowbird (Netherlands)× Ascot (Australia)	330	Low tannin (*zt1*), Snowbird pedigree: Alfred × 8103. Alfred pedigree: Minica (Netherlands) × Horse bean released in the Netherlands. Ascot is a selection from cv. Fiord from Australia. Original source of germplasm is Greece.	USask	https://bit.ly/3gVuU9Q
CDC SSNS-1	2013	Bulk selection from Ackerperle	330-350	Francks Ackerperle (see above)	USask	https://bit.ly/2KuBJDb
CDC Malik (FB 9-4)	2013	MO-1 (Egypt) × Earlibird (Netherlands)	680	MO-1 was an Egyptian landrace provided by Mohammad Zakaria. Earlibird was bred at Innoseeds B.V., the Netherlands.	USask	
247-13	2014	Snowbird × (Puebla × Taboar)	620	Puebla is an accession from Mexico. Taboar was developed by Globe Seeds, the Netherlands. Taboar pedigree: Rowena × Herz Freya	USask	https://bit.ly/37rqJQc

Taifun	2014	A synthetic line derived from NPZ3-7410, NPZ2-7540, NPZ2-7560, NPZ2-7510, and NPZ3-7401.	485	Low tannin (*zt1*), with the exception of Taifun, all the other lines from NPZ Germany were selected in Morden, Canada and then trialled using the coop system.	NPZ	https://bit.ly/2XCmdZf
219-16	2014	(IPK296-78 × Snowbird) × (IPK251-78 × Snowbird)	356	Low tannin (*zt1*)	USask	https://bit.ly/3gUHfLu
186s-11	2014	Reina Blanca (Spain) × Puebla	880	Reina Blanca is an early vegetable type large-seeded faba bean from Semillas Fitó Global, Spain.	USask	https://bit.ly/3gU6AoR
Fabelle	2015	Lady (France) × Marcel (Denmark)	527	Low v-c	NPZ	https://bit.ly/2LKNTbR
Vertigo	2015	A synthetic line derived from NPZ4-7610, NPZ4-7640, NPZ6-7480, and NPZ5-7820	565	It was developed by NPZ Germany using internal breeding materials.	NPZ	https://bit.ly/3ick6Vx
DL Rico	2018	(NPZ0.27410 × P 14119.9) × (Espresso × (Gloria × Divine))	588	FEVITA† type. Bred and selected in NPZ Germany. Parental lines are from European and NPZ breeding lines. Gloria is white-flowered (*zt1*) from Saatzucht Gleisdor, Austria.	NPZ-DL Seeds	https://bit.ly/35zEtXD
DL Tesoro	2018	((Gloria × Divine) × NPZ06.7101) × (Mélodie)	512	Low tannin (*zt1*). Mélodie and Divine are low v-c from INRA, France.	NPZ-DL Seeds	https://bit.ly/38BzUxW
1142-16	2019	(405-6 × AO1155) × (AO1155 × 469-1)	350	FEVITA type. 405-6 and 469-1 are U of S experimental lines. AO1155 was developed by INRA, France and was the source of the low v-c and low tannin (*zt1*).	USask	https://bit.ly/38ba0Qa
1139-11	2019	(224-34 × AO1155) × (AO1155 × 224-56)	351	FEVITA type. Breeding lines 224-34 and 224-56 are selected from cross IPK251/81 × Snowbird.	USask	https://bit.ly/38fFBQy

UManitoba, University of Manitoba. *USask*, University of Saskatchewan. *CDC*, Crop Development Centre. *NPZ*, Norddeutsche Pflanzenzücht. *INRA*, Institut National de la Récherche Agronomique.

† FEVITA® has been given to improved-quality faba beans in which seeds have both reduced tannin content and vicine–convicine, v-c (Duc et al., 2004).

Targets for Breeding

Anti-nutritional Factors

Faba bean seeds contain vicine-convicine, one of the main factors limiting faba bean cultivation and usage. Consumption of v-c is harmful for human carriers of a widespread genetic defect (glucose-6-phosphate dehydrogenase deficiency, G6PD), and is also a concern for monogastric animal and poultry production (*see review by* Khazaei et al., 2019). One of the most immediate breeding goals in Canada was to phase out faba beans with high v-c content. This work began with the introduction of the crop to the country at UManitoba in the 1980s (*see* Marquardt & Fröhlich, 1981; Gardiner et al., 1982). This process has been accelerated at USask by the improvement of high-throughput biochemical phenotyping methods (*e.g.*, Purves et al., 2018) combined with the development of a robust and low-cost molecular marker for the low v-c gene (vc^{-}, Khazaei et al., 2017). The entire USask faba bean program will be converted to low v-c status in the near future. High v-c parents in the crossing program will still be used, if needed, but only in initial crosses. In this case, F_1s will be crossed only to low v-c parents and the resulting F_1s will be grown out only if crossed seeds are homozygous for the low v-c allele based on the molecular marker test. Maintenance of low v-c status throughout the faba bean breeding and production system requires deliberate and active management over time to ensure isolation from sources of high v-c contamination by pollinators, for example, at off station breeding nurseries.

In faba bean, white flower colour, together with a low seed coat tannin, is determined by either one of two complementary genes (*zt1* and *zt2*). Seed coat tannins reduce protein digestibility and add colour to seed coat fibre products. Although tannins are entirely in the seed coat and can easily be removed mechanically, dehulling brings an additional cost. Reliable molecular markers for both genes have been developed (Gutierrez & Torres, 2019; Zanotto et al., 2020). CDC Snowdrop was the first small-seeded zero tannin (*zt1*) cultivar released in Canada. Although all the Canadian-bred low tannin faba beans carry *zt1* (Table 1), the *zt2* gene may have been used in the background of some pre-breeding materials. Cross pollination of the two low tannin sources leads to the loss of expression of the low tannin trait in the progeny. Most of the recent breeding materials released by CDC are FEVITA type, combining low v-c and low tannin *zt1* (Table 1). The risk of contamination from sources of the *zt2* allele are much lower than the risk posed by contamination with high v-c because the *zt2* is not widely used in breeding programs. Some earlier studies showed the poor emergence of low tannin cultivars from cold soil which was associated with testa cracking (*e.g.*, Kantar et al., 1996). A recent study reported the frost susceptibility of low tannin faba beans (Henriquez et al., 2017). Further research on the role of tannins and their association with physiological basis of frost tolerance is needed.

Disease Resistance

Since the introduction of the crop in western Canada, chocolate spot (CS) caused by (*Botrytis fabae* Sard.) was the major biotic stress affecting faba bean productivity (Furgal & Evans, 1980; Sumar et al., 1981). The disease can reduce yield by 71% (Sahile et al., 2008). Several fungicides are registered for control of CS in faba bean crops, but they are effective only for suppression and not control. The current extent of CS damage and genetic diversity of its pathogens are not well defined in Canada, so the development and release of cultivars with superior resistance remains an active breeding goal. One of the UManitoba research lines that was deposited to the ICARDA germplasm collection in 1974 (ILB 611, IG 11805), was shown to be very resistant to CS (Maalouf et al., 2016). Genetic resistance breeding and genomic approaches to improve resistance to CS is in progress at USask using germplasm derived from ILB 938 (IG 12132), an accession with proven resistance to CS (Khazaei et al., 2018). The genomic tools required as part of this effort are provided by the University of Reading, UK.

Faba bean rust, *Uromyces viciae-fabae* (Pers), has also been reported occasionally (*e.g.*, McKenzie & Morrall, 1975). A high degree of pathogen variability was reported (Conner & Bernier, 1982) and several sources of resistance were found via screening trials in Manitoba (Rashid & Bernier, 1991). Considerable attention was given to this disease compared to CS, however, faba bean rust is much more common throughout the Mediterranean regions (warm and humid conditions, > 20°C and 80% relative humidity) and is relatively less harmful for faba beans grown in the north temperate zones (Stoddard et al., 2010).

Ascochyta blight (*Ascochyta fabae* Speg.,) was reported to be the most destructive faba bean disease in Manitoba but not in Alberta and Saskatchewan in the 1970s. However, it has potential to become a threat for faba bean production in western Canada. Several sources of resistance along with reliable molecular markers have been developed in the Mediterranean regions of Europe and Australia (*reviewed in* Khazaei et al., 2020), where the disease is widespread. These tools can be adapted by Canadian breeding programs.

One of the most important characteristics of faba bean is its high level of resistance to the root rot pathogen *A. euteiches* (Moussart et al., 2008). ARR is now widespread in the Canadian prairies and represents a severe threat to future pea and lentil production. This makes faba bean a great candidate for inclusion in extended crop rotations that include pea and lentil, the major pulse crops in western Canada. There are no easily accessible good sources of ARR resistance in pea and lentil and extending rotations with faba bean will likely ameliorate the problem to some extent, while maintaining an excellent supply of plant-based protein.

Yield and Abiotic Stresses

Faba bean has the highest potential yield of any food legume (Cernay et al., 2015). The average faba bean yield in western Canada is about 3 t ha^{-1} about 100% and 25% higher than lentil and pea, respectively (unpublished data). Faba bean has beneficial associations with two groups of organisms–nitrogen-fixing bacteria and pollinators. The main nitrogen fixing organism is *Rhizobium leguminosarum* biovar. *viciae* that has positive impact on the yield (Elsheikh & Elzidany, 1997). The main pollinators are honey bees (*Apis mellifera*) and bumblebees (*Bombus* spp.) that can enhance yield (Stoddard, 1986; Stoddard & Bond, 1987), particularly under abiotic stress conditions (Bishop et al., 2016). Among pulses grown in western Canada faba bean is the most drought susceptible (Muktadir et al., 2020). Development of commercially acceptable and adapted faba bean germplasm and breeding lines with improved drought adaptation for use in the dry/non-irrigated region of western Canada is needed. Maximizing the genetic potential for drought adaptation is a key feature of the future genetic base for faba bean in western Canada and a major long-term breeding goal. Both conventional and molecular breeding tools are needed to accelerate the development and release of improved drought-adapted faba bean cultivars with relatively high and stable yield. Recently, we have developed a speed breeding protocol for faba bean (Mobini et al., 2020) as a tool for developing diverse germplasm and improved varieties in a shorter time span.

Utilization of Faba Bean - Past, Present and Future

Currently, most Canadian faba bean production is targeted to the animal feed protein industry locally and the food market globally. For example, CDC Malik is the only cultivar that is produced in large volumes that is suitable (large-seeded, normal-tannin) for the Middle East export market. Snowbird, which is a medium-sized, low tannin faba bean cultivar, dominates production with over 50% of production in Saskatchewan (https://www.scic.ca/resources/smp/smp-data/). Faba bean seeds typically have 30% protein (dry matter basis) (Warsame et al., 2020) which can be made into protein concentrates (more than 60%) through air classification, or into isolates of more than 90% protein through wet processing (Gueguen, 1983). The seed coat fraction is potentially valuable as a dietary fiber concentrate in the pet food industry which now uses pea seed coat fibre. Therefore the protein and fibre, which are the most valuable fractions, make up almost 45-50% of the seed, a total that is about 15% higher than in pea (Heuzé et al., 2018). To maximize value and acceptance by processors and the food industry as a source of protein and dietary fibre, the future faba bean varieties should ideally be small-seeded to reduce seeding costs, and have the characteristics of low tannin and low v-c to be acceptable in the food market. The damages of lygus bugs (*Lygus* spp.) and seed weevils (*Bruchus* spp.) are detrimental to faba bean seed quality, but genetic resistance to these major pests is less understood (Kaur et al., 2018; Carrillo-Perdomo et al., 2019).

Conclusions and Perspectives

The focus of this contribution is progress in faba bean breeding in western Canada in the past four decades, but the experiences may be used for any other regions in the world where the crop is under development. One of the main breeding challenges is partial allogamy of this crop. In the open field, seed production suffers from cross-pollination unless special isolation is applied, however, transition to a germplasm base that is genetically uniform for the *vc*⁻ allele and the *zt1* allele could be worthy goals to achieve rapid expansion of the emerging faba bean industry. There is an urgent need to expand the role of faba bean in western Canada for economic and environmental reasons. Addition of early maturing, small-seeded, white-flowered, low v-c faba bean varieties will help expand plant-based protein production while extending crop rotations for pea and lentil production. These new varieties must be able to tolerate early sowing, and should ideally have round seed shape to accommodate the uniform seed simulation systems designed for a new generation of zero tillage planting systems. This will require additional coordinated investment in both plant breeding and agronomy research to help maximize production potential and to reduce production risk for the plant-based protein industry.

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Conflict of Interest

The authors have no conflict of interest.

Author Contributions

Writing—Original Draft: HK. Writing—Review & Editing: AV, GH, HK. All authors read and agreed to the published version of the manuscript.

Ethics Statement

This manuscript does not contain any studies with human or animal subjects.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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