MINI-REVIEW

Faba bean (Vicia faba) starch: Structure, properties, and in vitro digestibility—A review

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Abstract
The dietary consumption of legumes is associated with the prevention and management of cardiovascular disease, diabetes, and metabolic syndrome. There is a growing interest in faba bean (Vicia faba) to formulate functional products. Starch is the main component of faba bean (up to 45%), and its properties and reaction with other food components are mainly important for human nutrition, and the food industry as starch properties may greatly determine the product quality. This minireview summarizes the structural, morphological, and thermal characteristics and in vitro digestibility of faba bean starch to provide direction for new research.

KEYWORDS
digestibility, faba bean starch, scanning electron microscope, X-ray pattern

1 | INTRODUCTION

Legumes are the plants belonging to the family Leguminosae/ Fabaceae and the third largest family of angiosperms with over 16,000–19,000 species in 750 genera (Allen & Allen, 1981). The worldwide production of legumes was 96 MT. India is the world’s largest producer of legume contributing to about 24% of the total world production (FAOSTAT, 2017). Vicia faba L. (faba bean, broad beans, or horse bean) is a species of flowering plant in Fabaceae family and the fourth most widely grown winter season legume after pea, chickpea, and lentil (FAOSTAT, 2018). Faba bean seeds are the rich source of carbohydrates (51–68%), and the major carbohydrate is starch (22–45%; Hoover & Sosulski, 1991). Ross and Davies (1992) reported 35% starch and 36% protein in faba beans. Because of higher amylose content than cereal starches, legume starches provide distinctive properties, that is, high gelation temperature, fast retrogradation, high resistant starch (RS), and gel elasticity to food systems (Ratnayake, Hoover, & Warkentin, 2002). To the best of our knowledge, a review on faba bean has not been previously reported. Therefore, this minireview will provide an update on physicochemical, morphological, and thermal properties and in vitro digestibility of faba bean starch, which will facilitate the utilization of faba bean starch in food and nonfood industries.

2 | ISOLATION OF FABA BEAN STARCH

During isolation of starch fraction from legumes, insoluble proteins and fine fibres diminish sedimentation and
settled with starch, which leads to brownish deposit. These insoluble flocculent proteins and fines fibres make the process of starch isolation from legumes difficult (Hoover & Sosulski, 1991; Ratnayake et al., 2002). For starch isolation, wet milling is more effective and efficient than dry milling. Li et al. (2019) used the alkali steeping method for isolation of faba bean starch. The starch purity is determined by the method of starch isolation, and the starches with low protein, ash, and fat contents indicate high purity of the starches (Wang, Warkentin, Vandenberg, & Bing, 2014).

3 | PHYSICOCHEMICAL PROPERTIES

Starch is composed of mainly two-component amylose and amylopectin where amylose is made from α-(1/4) D-glucopyranosyl units and amylopectin is made up of small chains that are higher as compared with amylose linked together by an α-(1/6) linkage at their reducing end side. Applications of legume starches in food and nonfood industries are correlated with their physicochemical and structural properties. Starches have a major role in maintaining the quality of the food products, and therefore, it is very relevant to investigate the texture, water hydration properties, thermal stability, and digestibility during processing (Hoover, Hughes., Chung, & Liu, 2010; Kaur et al., 2013). Zhang, Tian, Wang, Jiang, and Li (2019) reported 96.64%, 33.55%, 0.30%, 0.38%, and 0.07% of starch, amylose, protein, fat, and ash content, respectively, in faba bean starch (Table 1). Amylose and amylopectin are the two primary components present in starch granules, and the amylose content and branch chain length distribution of amylopectin are critical structural features that determine the starch functionality and its digestibility (Jane, 2006). Amylopectins of the faba bean starch consisted of smaller proportions (21.5%) of degree of polymerization (DP) 6–12 branch chains while the larger proportions (56%) of DP 13–24 branch chains. Amylopectins average branch-chain lengths for faba bean starches were reported to be (DP 20.4) (Li et al., 2019).

As reported by Tester and Morrison (1990), the solubility of starch is related with the presence of soluble molecules, which shows the starch solids ability to dissolve in an aqueous solution. At a temperature of 90 °C, solubility of 9.92% was observed for faba bean starches, and this lower solubility is due to the integration of starch granules where restricted solubility and swelling power were present (Zhang et al., 2019). Swelling power measures the ability of starch hydration under specific temperature and water content, and the higher swelling power of the starch indicates weak binding forces (Hoover & Manuel, 1996). Zhang et al. (2019) reported swelling power of 12.67 g/g for faba bean starch.

4 | X-RAY DIFFRACTION

X-ray diffraction is used to examine the presence and characteristics of starch granules’ crystalline structure, and it provides the evidence of an ordered structure. Hoover and Ratnayake et al. (2002) explained that legumes starches possessed the C-type X-ray pattern, which is a

| TABLE 1  Faba bean starch characteristics | Characteristics |
|-------------------------------------------|-----------------|
| Yield                                     | 84.7% (Li et al., 2019) |
| Starch content                            | 96.64% (Zhang et al., 2019) |
| Amylose                                   | 33.55% (Zhang et al., 2019); 39.9% (Li et al., 2019) |
| Protein                                   | 0.30% (Zhang et al., 2019) |
| Fat                                       | 0.38% (Zhang et al., 2019) |
| Ash                                       | 0.07% (Zhang et al., 2019) |
| Swelling power                            | 12.67 g/g (Zhang et al., 2019) |
| Solubility                                | 9.92% (Zhang et al., 2019) |
| X-ray diffraction                         | C-type pattern (Hoover & Ratnayake, 2002) |
| Granule morphology                        | Round, elliptical, irregular, and oval shapes (Sofi, Wani, Masoodi, Saba, & Muzaffar, 2013) |
| Pasting properties                        | Peak viscosity = 3,524 cP; breakdown viscosity = 1,247 cP; trough viscosity = 2,277 cP; final viscosity = 4,814 cP (Zhang et al., 2019) |
| Thermal behaviour                         | \( T_0 = 58.9°C; \ T_p = 64.2°C; \ T_c = 72.1°C; \Delta H = 12.4 \) (J/g; Li et al., 2019) |
| In vitro digestibility                    | Rapidly digestible starch (RDS) = 15.3% |
|                                           | Slowly digestible starch (SDS) = 34.5% |
|                                           | Resistant starch (RS) = 46.7% (Li et al., 2019) |
mixture of “A” and “B” unit cells in different proportions. Schoch and Maywald (1968) characterized C type by a limited solubilization, restricted swelling, and stability of swollen granules against mechanical shearing. The “B” polymorphic content of 22.1–38.6% was observed for faba bean starch (Hoover, Hughes, Chung, & Liu, 2010). Ambigaipalan et al. (2011) reported relative crystallinity of faba bean starches in the range between 20.2–21.9%, and range of these values were supported by other researchers (Hoover et al., 2010). Faba bean starch showed a typical C-type pattern with strong reflections at 2θ of 5.6, 7.1, 9.1, 15.0, 17.0, 19.6, and 22.4 (Sofi et al., 2013; Figure 1).

5 | MORPHOLOGICAL CHARACTERISTICS

Morphological characteristics of legume starches are examined using scanning electron microscope, light microscope, polarized light microscope, and so forth. Sofi et al. (2013) examined faba bean starch with scanning electron microscope and reported that starch granules were oval, round, elliptical, and irregular in shape and possessed cavity on starch surfaces (Figure 2). A study conducted by Sivak and Preiss (1998) studied birefringence patterns of starch granules under polarized light and reported that within the starch granules amylopectin crystallites are arranged radially at right angles to the surface with their single reducing end group toward the hilum. Granules of faba bean starches exhibited both strong and weak birefringence patterns. Weaker birefringence patterns are indicative of disorganized amylopectin double helices within the crystalline lamella of these granules. Disorganized amylopectin crystallites in faba bean may have lowered granule integrity. Consequently, faba bean granules may have been fragile and thus prone to cracking during granule development (Ambigaipalan et al., 2011). They also reported the presence of many cracks in starch granules. Glaring, Koch, and Blennow (2006) concluded that low granule integrity leads to cracking and due to which an increase in strain occurs as the granule grows. Haase and Shi (1991) reported length and width range of 11–48 μm and 9–24 μm, respectively, for faba beans starch granules.

6 | PASTING AND THERMAL CHARACTERISTICS

Pasting is a phenomenon that occurs after postgelatinization heating of starch granules in excess of water (Wani et al., 2016). Pasting results in irreversible starch granules swelling, leaching of linear amylase molecules, and solubilization of branch chain amylopectin molecules, thereby forming starch paste (Gani et al., 2017). Changes in starch paste viscosity during heating indicate its stability, whereas those occurring upon cooling contribute to consistency of the product (Kaur, Sandhu, & Lim, 2010). Zhang et al. (2019) reported peak viscosity, breakdown viscosity, trough viscosity, and final viscosity of 3,524, 1,247, 2,277, and 4,814 cP, respectively, for faba bean starch. Faba bean starch's higher final viscosity after cooling process indicates its higher tendency of starch to retrograde, which may be due to the fact that leached amyllose molecules have been recrystallized. The lower values of breakdown viscosity of faba bean starch indicates restricted swelling of starch granule and lose viscosity due to which faba bean starches withstand more shear stress and heating.

During the heating process, over a range of temperature, starches undergo from order to disorder phase
transition called gelatinization (Hoover et al., 2010). The endothermic peak recorded by differential scanning calorimeter is linked with gelatinization of starch, which reflects the loss of double helices structure of starch granules (Cooke & Gidley, 1992). The gelatinization transition temperatures (To [onset], Tp [midpoint], Tc [conclusion]) and the enthalpy of gelatinization is measured by differential scanning calorimeter, and these parameters are influenced by the crystalline region’s molecular architecture, which corresponds to the distribution of amylpectin short chains (DP 6–11) and is not influenced by the crystalline region proportion, which corresponds to the ratio of amylose/amylpectin (Noda, Takahata, Sato, Ikoma, & Mochida, 1996). Faba bean starch possessed a higher relative crystallinity degree and required more energy for gelatinization (Zhang et al., 2019; Figure 3). Li et al. (2019) reported To, Tp, Tc, and ΔH of 58.9°C, 64.2°C, 72.1°C, and 12.4 (J/g), respectively, for faba bean starch. As reported by Gernat et al. (2017), native starches’ double helical order is correlated with amylpectin content, and granule crystallinity of granules increases as the amount amylpectin increases. The extent of crystalline perfection is reflected in the gelatinization temperature (Tester & Morrison, 1990).

7 | IN VITRO DIGESTIBILITY

On the basis of rate of release of glucose in the bloodstream and its gastrointestinal absorption, starches have been categorized into rapidly digestible starch (RDS), slowly digestible starch (SDS), and RS. After ingestion, a sudden rise in blood glucose is caused by RDS fraction, and SDS is that fraction of starch that is completely digested in the small intestine at a slower rate when compared with RDS. RS is the sum of starch and its derivatives that are not digested in the small intestine of healthy individuals (Asp, 1992). When compared with cereals, unripe fruits, and tubers, raw legumes contain significant amounts of RS (Bravo, Siddharaju, & Saura-Calixto, 1998). After ingestion of legumes, the release of glucose into the bloodstream becomes slower due to RS starch, which results in lowered glycemic responses. Bello-Pérez et al. (2007) reported RS content in the range between 33 and 65 g kg⁻¹ in faba bean starch. Faba bean starch generally possessed smaller RDS and SDS contents of 15.3% and 34.5% whereas larger RS contents of 46.7%, which indicates that faba bean starches are more resistant to enzymatic hydrolysis. Due to food applications and numerous health benefits of slowly digestible and RS, researchers’ interest should be developed toward the understanding of rate and extent of digestibility and relationship with the molecular structure of legume starches, which would be beneficial for food processors, starch chemists, and nutritionists.

8 | CONCLUSIONS

Faba bean represents a major protein and starch source for food, and local demand for faba bean grains is increasing. This review briefly describes the granular morphologies, thermal and structural properties, and in vitro digestibility of faba bean starch. The desirable functionality of faba bean starches makes them suitable for food applications, and modified faba bean starch may also be used to increase their characteristics for a broader purpose. This minireview helps in promoting the value-added utilization of faba bean starches by providing the fundamental knowledge of its properties.

CONFLICT OF INTEREST
None.

DATA AVAILABILITY STATEMENT
None.

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REFERENCES
Allen, O. N., & Allen, E. K. (1981). The leguminosae. A source book of characteristics, uses and nodulation. London: Macmillan.
Ambigaipalan, P., Hoover, R., Donner, E., Liu, Q., Jaiswal, S., Chibbar, R., & Seetharaman, K. (2011). Structure of faba bean, black bean and pinto bean starches at different levels of granule organization and their physicochemical properties. *Food Research International, 44*, 2962–2974.

Asp, N. G. (1992). Preface: resistant starch, proceedings from the second plenary meeting of Euresta: European FLAIR Concerted Action N11 on physiological implications of the consumption of resistant starch in man. *European Journal of Clinical Nutrition, 46*, S1.

Bello-Pérez, L. A., Islas-Hernández, J. J., Rendón-Villalobos, J. R., Agama-Acevedo, E., Morales-Franco, L., & Tovar, J. (2007). In vitro starch digestibility of fresh and sun-dried faba beans (Vicia faba L.). *Journal of the Science of Food and Agriculture, 87*, 1517–1522.

Bravo, L., Siddharaju, P., & Saura-Calixto, F. (1998). Effect of various processing methods on the in vitro starch digestibility and resistant starch content of Indian pulses. *Journal of Agricultural and Food Chemistry, 46*, 4667–4674.

Cooke, D., & Gidley, M. J. (1992). Loss of crystalline and molecular order during starch gelatinization: Origin of the enthalpic transition. *Carbohydrate Research, 227*, 103–112.

Food and Agriculture Organization of the United Nations (2017, 2018). Available from FAOSTAT Statistics database agriculture, Rome, Italy.

Gani, A., Ashwar, B. A., Akhter, G., Shah, A., Wani, I. A., & Masoodi, F. A. (2017). Physico-chemical, structural, pasting and thermal properties of starches of fourteen Himalayan rice cultivars. *International Journal of Biological Macromolecules, 95*, 1101–1107.

Glaring, M. A., Koch, C. B., & Blennow, A. (2006). Genotype-specific spatial distribution of starch molecules in the starch granule: a combined CLSM and SEM approach. *Biomacromolecules, 7*, 2310–2320.

Haase, N. U., & Shi, H. L. (1991). A characterization of faba bean starch (Vicia faba L.). *Starch-Stärke, 43*, 205–208.

Hoover, R., Hughes, T., Chung, H., & Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: a review. *Food Research International, 43*, 399–413.

Hoover, R., & Manuel, H. (1996). The effect of heat-moisture treatment on the structure and physicochemical properties of normal maize, waxy maize, dull waxy maize and amylo maize V starches. *Journal of Cereal Science, 23*, 153–162.

Hoover, R., & Ratnayake, W. S. (2002). Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada. *Food Chemistry, 78*, 489–498.

Hoover, R., & Sosulski, F. W. (1991). Composition, structure, functionality, and chemical modification of legume starches: a review. *Canadian Journal of Physiology and Pharmacology, 69*, 79–92.

Jane, J. (2006). Current understanding on starch granule structures. *Journal of Applied Glycoscience, 53*(3), 205–213.

Kaur, A., Kaur, P., Singh, N., Virdi, A. S., Singh, P., & Rana, J. C. (2013). Grains, starch and protein characteristics of rice bean grown in Indian Himalaya regions. *Food Research International, 54*, 102–110.

Kaur, M., Sandhu, K. S., & Lim, S. T. (2010). Microstructure, physicochemical properties and in vitro digestibility of starches from different Indian lentil (Lens culinaris) cultivars. *Carbohydrate Polymers, 79*, 349–355.

Li, L., Yuan, T. Z., Setia, R., Raja, R. B., Zhang, B., & Ai, Y. (2019). Characteristics of pea, lentil and faba bean starches isolated from air-classified flours in comparison with commercial starches. *Food Chemistry, 276*, 599–607.

Noda, T., Takahata, Y., Sato, T., Ikoma, H., & Mochida, H. (1996). Physicochemical properties of starches from purple and orange flesheled sweet potato roots at two levels of fertilizer. *Starch, 48*, 395–399.

Ratnayake, W. S., Hoover, R., & Warkentin, T. (2002). Pea starch: composition, structure and properties—a review. *Starch-Stärke, 54*, 217–234.

Ross, H. A., & Davies, H. V. (1992). Sucrose metabolism in tubers of potato (Solanumtuberosum L.): effect of sink removal and sucrose flux on sucrose degrading enzymes. *Plant Physiology, 98*, 287–293.

Schoch, T. J., & Maywald, E. C. (1968). Preparation and properties of various legume starches. *Cereal Chemistry, 45*, 564–573.

Sivak, M. N., & Preiss, J. (1998). Structure of the starch granule. In *Advances in food & nutrition* (Vol. 41) (pp. 13–32). New York, NY: Academic Press.

Sofi, B. A., Wani, I. A., Masoodi, F. A., Saba, I., & Muzaffar, S. (2013). Effect of gamma irradiation on physicochemical properties of broad bean (Vicia faba L.) starch. *LWT- Food Science and Technology, 54*, 63–72.

Tester, R. F., & Morrison, W. R. (1990). Swelling and gelatinization of cereal starches I. Effects of amylopectin, amylose and lipids. *Cereal Chemistry, 67*, 551–559.

Wang, N., Warkentin, T. D., Vandenberg, B., & Bing, D. J. (2014). Physicochemical properties of starches from various pea and lentil varieties, and characteristics of their noodles prepared by high temperature extrusion. *Food Research International, 55*, 119–127.

Wani, I. A., Sogi, D. S., Hamdani, A. M., Gani, A., Bhat, N. A., & Shah, A. (2016). Isolation, composition, and physicochemical properties of starch from legumes: A review. *Starch/Stärke, 68*, 834–845.

Zhang, Z., Tian, X., Wang, P., Jiang, H., & Li, W. (2019). Compositional, morphological, and physicochemical properties of starches from red adzuki bean, chickpea, faba bean, and baiyue bean grown in China. *Food Science & Nutrition, 7*, 2485–2494.

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**How to cite this article:** Punia S, Dhull SB, Sandhu KS, Kaur M. *Faba bean (Vicia faba) starch*: Structure, properties, and in vitro digestibility—A review. *Legume Science*. 2019;1:e18. https://doi.org/10.1002/leg3.18