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The quality of leguminous vegetables as influenced by preharvest factors

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ABSTRACT

The cultivation of most legumes, aims to the production of either dry seeds consumed by humans, also known as pulses, or animal fodder. However, some legumes are cultivated for fresh consumption either as pods or as immature seeds. The economically most important legumes consumed as vegetables are green pods of common bean, cowpea, faba bean, snow pea (mangetout) and green pea seeds. As a rule, the legume vegetables are consumed after cooking and in many countries, they may be used to cover primary nutritional needs, because their protein content is high in comparison with most other vegetables. Furthermore, the legume vegetables, which have distinct organoleptic properties when compared to pulses, are also considered important sources of carbohydrates, essential minerals, vitamins, several other antioxidants and health promoting compounds, and dietary fiber. On the other hand, legume vegetables constitute a low-fat foodstuff. Legume vegetables may contain some antinutritional factors, particularly lectins, phytic acid, saponins, oligosaccharides belonging to the raffinose-family, and vicin and convicin in faba bean, but the levels of most of them are lower than in dry pulses and generally do not constitute a constraint to their consumption. Breeding is one of the most efficient tools to reduce the concentrations of antinutritional factors and increase the levels of health promotive compounds and the taste in legume vegetables. Among the legume species frequently consumed as vegetables, a relatively large number of local accessions and landraces are available, which constitute a valuable genetic material for breeding programs aiming at improving their quality. Breeding of more resilient cultivars to combined stress conditions characterized by a higher nutritional value entails also a better understanding of the physiological mechanisms underlying the biosynthesis of health promoting and antinutritional compounds, as well as the plant adaptation to adverse environmental conditions. Last but not least, agronomical practices, such as crop establishment and plant density, fertilization, irrigation, weed control, and harvesting time and practices play a crucial role for the quality of legume vegetables and deserve special attention.

1. Introduction

Legumes are plants taxonomically classified under the family Fabaceae, formerly known as Leguminosae. The Fabaceae family comprises more than 650 genera and about 18,000 species, thereby constituting the third largest family of flowering plants (Polhill and Raven, 1981). From an economic point of view, Fabaceae represents the second most important family of cultivated plants after Poaceae (grass family), accounting for approximately 27% of the world's crop production (Graham and Vance, 2003). Legumes are characterized by their ability to grow in a symbiotic relationship with N₂-fixing bacteria, thereby contributing to a continuous input of atmospheric nitrogen to

living organisms in the earth's biosphere. Many legume species, such as alfalfa (*Medicago sativa* L.), chickpea (*Cicer arietinum* L.), common bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), lentil (*Lens culinaris* Med.), peanut (*Arachis hypogaea* L.), peas (*Pisum sativum* L.), soybean (*Glycine max* L. Merr), etc., are important cultivated plants used either for food or for animal fodder or for both. Furthermore, many legume species are used as soil-enriching green manure due to their ability to fix atmospheric N₂ through rhizobia living symbiotically on their roots (Stagnari et al., 2017).

Most cultivated legumes used for food are consumed as grain seeds called pulses. However, the cultivation of some legume species is aimed at their consumption as vegetables. The most important legumes falling

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within this group are peas (*Pisum sativum* L.), faba bean referred to also as broad bean (*Vicia faba* L.), cowpea [*Vigna unguiculata* (L.) Walp. ssp. *unguiculata* cv.-gr. *unguiculata*], and yardlong bean [*Vigna unguiculata* (L.) Walp. ssp. *unguiculata* cv.-gr. *sesquipedalis*], which are grown in the open field, and common bean (*Phaseolus vulgaris* L.), which is grown both in open field and in greenhouses. Few more legume species may be locally grown for consumption as vegetables, such as soybean (*Glycine max* L. Merr, known as Edamame) (Konovsky et al., 1994; Mavlyanova, 2015), mungbean (*Vigna radiata* L. Wilczek) (Shanmugasundaram, 2007) and grass pea (*Lathyrus sativus* L.) (Kmieciak et al., 2004). Furthermore, legume sprouts, which are produced by forcing the seeds of some grain legumes to germinate and grow for a few days (Nnanna and Phillips, 1989; Lee et al., 2007), are also considered a vegetable food. Nevertheless, the quality of legume sprouts will not be addressed in the present review.

From a nutritional point of view, legumes are considered important sources of plant protein, carbohydrates, essential minerals, vitamins and several other antioxidants and health promoting compounds (Souci et al., 2000; Bouchenak and Lamri-Senhadj, 2013). Legumes consumed as vegetables contain more water and less proteins than those consumed as dry pulses. On the other hand, soluble carbohydrates are higher and starch content is lower in fresh vegetable legumes, which makes them more palatable than dry pulses. Moreover, vegetable legumes are richer sources of antioxidants and other health promoting compounds contained mainly or only in fresh plant biomass, such as carotenoids, phenolics, chlorophyll, vitamin A, and vitamin C (Bhattacharya and Malleshi, 2012). Consequently, their consumption is mainly intended to provide a more balanced nutrition full of healthy compounds rather than to serve as a primary protein source. Furthermore, vegetable legumes, which contain much more water than dry pulses, are short season crops which can be grown more than once a year being offered to the market as a fresh food with a limited shelf-life. Consequently, the quality characteristics of legume vegetables are different from those used to evaluate pulses. Another aspect to be considered when addressing the nutritional quality of legume vegetables is their content in antinutritional factors, i.e. compounds negatively affecting their taste and digestion by humans (Habiba, 2002; Wang et al., 2003).

In the last ten years, the European Commission supported several research projects on legume crops, in recognition of their importance and in an attempt to increase both their production and their consumption in EU. Among them, EUROLEGUME (www.eurolegume.eu), which is scheduled to be completed by the end of 2017, paid special attention to legume vegetables, focusing mainly on pea, faba bean and cowpea. Legume vegetables represent a very small proportion of the total arable land covered by Fabaceae crops (Stagnari et al., 2017). Thus, the number of publications which address the quality of legume vegetables is small in comparison to papers addressing the quality of grain legumes. To our knowledge, a review paper focused on the quality of legume vegetables is currently missing in the international scientific literature. On the other hand, the consumption of vegetables is constantly expanding internationally due to increasing awareness of their importance for a balanced nutrition and their high content in health promoting compounds (Kader et al., 2004; Hounsome et al., 2008). Thus, a contribution on this topic summarizing current knowledge on all factors that determine the quality of legume vegetables, including the genotype, the cultivation environment, and the agronomic treatments, is timely. Recognizing this gap in knowledge, the present review paper was commissioned to provide a comprehensive overview of all aspects related to the quality of legume vegetables. The paper is based on all available sources of relevant information, including recent results from EUROLEGUME and other EU research projects dealing with legumes.

2. Quality attributes of legume vegetables

2.1. Nutritional quality of legume vegetables

2.1.1. Contribution of legume vegetables to human health

Legume vegetables are rich in protein, carbohydrates, and dietary fiber. In addition, they constitute an important source of essential micronutrients for humans, including vitamins and minerals, which contribute to maintenance of proper metabolic functions in cells and tissues due to their role as cofactors of metabolic reactions, coenzymes, regulators of gene transcription, and radical scavenging molecules (Bouchenak and Lamri-Senhadj, 2013; Septembre-Malaterre et al., 2017). Therefore, the consumption of legume vegetables has been associated with health promotion, particularly related with prevention of cardiovascular and metabolic diseases. Furthermore, many of these benefits have been related to the nutritional and phytochemical composition of hulls (Gutiérrez-Urbe et al., 2011), which is strongly dependent on the maturation stage (Basterrechea and Hicks, 1991).

The physiological effects of legume vegetables on the human organism vary according to their composition, as well as the relative proportion of hulls and seeds in pods. Therefore, given the growing trend to consume minimally processed foods, more attention should be paid to fresh pods, to assess their potential to be used in balanced diets. In addition to the nutritional properties, the sustainability of the dietary sources of essential nutrients represents another issue that should be taken into consideration. Providing the required nutrients according to the physiological needs of a continuously increasing population represents a serious constraint, given the limited resources available. Therefore, the consumption of fresh legume vegetables, which combine protein, fiber, minerals and bio-active compounds in a balanced composition, arises as a sustainable practice that would provide a valuable contribution to overwhelm this situation (Slavin and Lloyd, 2012).

2.1.2. Protein content

One of the most frequently used parameters when assessing the nutritional quality of legume vegetables is their protein content. Overall, pods and immature seeds of legumes contain less proteins than dry seeds of the same species (Karapanos et al., 2017; USDA-ARS, 2017). For instance, crude protein in fully ripened and dried cowpea pulses from different varieties and landraces ranged from 17.4 to 30.3% d.w. (Domínguez-Perles et al., 2016) and from 29.5 to 35.6% d.w. in immature fresh pods (Machado et al., 2017). However, in terms of fresh weight, the soluble protein content in immature cowpea pods is much lower, ranging between 1.6 to 3.3% f.w., i.e. 2.25% on average (Karapanos et al., 2017). Compared with cowpea pods, those of snap bean (*Phaseolus vulgaris* L.) contain significantly less proteins. Indeed, Fujihara et al. (2001) and Sánchez-Mata et al. (2003) reported a protein content of 1.55% and 1.64%, respectively, in fresh pods of snap bean, which is by about 25% less than that reported by Karapanos et al. (2017) for cowpea pods. Fujihara et al. (2001) reported a protein content of 2.01% f.w. in green pods of pea (*Pisum sativum* L.), which is slightly lower than that of cowpea pods. Nevertheless, the protein contents in immature seeds of pea and faba bean are substantially higher than in the entire immature pod. For instance, the protein content amounts to 5.4% f.w. in green pea seeds and 7.9% f.w. in immature faba bean seeds (Young and Pellett, 1994; USDA-ARS, 2017). An overview of the protein content in green pods and seeds consumed as vegetables is provided in Table 1.

The nutritional value of legume vegetables as protein sources depends not only on their protein content but also on the amino acid composition and the protein digestibility. Generally, the legume proteins are rich in lysine but poor in sulphur-containing essential amino acids, particularly methionine and cysteine (Yamauchi and Minamikawa, 1998). For instance, cowpea is an excellent source of lysine, but deficient in methionine and cysteine, while the tryptophan and threonine contents are also lower than the optimal levels

Table 1

Water and energy content, and nutrient concentrations in the edible part of the most common legume vegetables. All values are units in parenthesis per 100 g of edible fresh mass. The data originate from the USDA National Nutrient Database for Standard Reference Release 28 (<http://ndb.nal.usda.gov/ndb/search/list>).

| Constituent | Common bean green pods | Cowpea green pods | Pea green seeds | Faba bean immature seeds | Soybean green seeds |
|-----------------------------|------------------------|-------------------|-----------------|--------------------------|---------------------|
| Water (g) | 90 | 86 | 79 | 73 | 68 |
| Energy (kcal) | 31 | 44 | 81 | 88 | 147 |
| Total carbohydrates (g) | 7.0 | 9.5 | 14.5 | 17.6 | 11 |
| Total sugars (g) | 3.3 | 5.0 | 5.7 | 9.2 | n.a. ^a |
| Total dietary fibers (g) | 2.7 | 3.3 | 5.7 | 7.5 | 4.2 |
| Proteins (g) | 1.8 | 3.3 | 5.4 | 7.9 | 13 |
| Fat (g) | 0.2 | 0.3 | 0.4 | 0.7 | 6.8 |
| K (mg) | 200 | 431 | 244 | 332 | 620 |
| Ca (mg) | 43 | 126 | 25 | 37 | 197 |
| Mg (mg) | 24 | 51 | 33 | 33 | 65 |
| P (mg) | 53 | 53 | 108 | 129 | 194 |
| Fe (mg) | 2.1 | 1.1 | 1.5 | 1.6 | 3.6 |
| Zn (mg) | 0.3 | 1.0 | 1.2 | 1.0 | 1.0 |
| Vitamin A (IU) | 1087 | 1369 | 640 | 333 | 180 |
| Vitamin B ₁ (mg) | 0.15 | 0.15 | 0.27 | 0.13 | 0.44 |
| Vitamin B ₂ (mg) | 0.08 | 0.14 | 0.13 | 0.29 | 0.18 |
| Vitamin B ₃ (mg) | 0.06 | 1.20 | 2.09 | 2.25 | 1.65 |
| Vitamin B ₆ (mg) | 0.16 | 0.17 | 0.17 | 0.10 | 0.07 |
| Vitamin B ₉ (µg) | 42 | 53 | 65 | 148 | 165 |
| Vitamin C (mg) | 60.0 | 33.0 | 40.0 | 3.7 | 29 |
| Vitamin E (mg) | 0.39 | 0.49 | 0.13 | 1.16 | n.a. ^a |
| Vitamin K (µg) | 25.0 | 31.5 | 24.8 | 40.9 | n.a. ^a |

^a Data are not available.

(Gonçalves et al., 2016). As reported by Young and Pellett (1994), based on data of the Food and Agriculture Organization of the UN, green peas are deficient in sulphur-containing amino acids with a limiting amino acid (LAA) score of 85 (100: no limitation). However, green beans are deficient in lysine with a LAA score of 85 over the same scale according to the same authors.

With respect to the protein digestibility, data on legumes consumed as vegetables in fresh condition are scarce. The only available information on digestibility of legume proteins refer to dry pulses. Thus, in common bean, only 78% of the total protein content is digestible (Young and Pellett, 1994), while the digestibility of cowpea protein ranges from 63% to 95%, depending on the genotype and the food preparation practices (Gonçalves et al., 2016).

2.1.3. Fat content

Legume vegetables constitute a low-fat foodstuff, with values ranging from 0.2 to 0.5% in pods and green seeds of cowpea, common bean, and peas and from 0.65 to 1.0% in faba bean (USDA-ARS, 2017). Only vegetable soybean seems to contain substantially more fat which may be as high as 6.8% in green seeds. The fat content in vegetable soybean correlates positively with the sugar content (Hymowitz et al., 1972). An overview of the crude fat content in green pods and seeds of the most important legume vegetables is shown in Table 1.

2.1.4. Digestible carbohydrates

Digestible carbohydrates (sugars and starch) is another group of nutrients which needs specific attention, when addressing the composition of legume vegetables. The digestible carbohydrates contained in legume vegetables include well-known substances for their role as energy sources, such as starch, sucrose, glucose, fructose, maltose, galactose, etc. The concentrations of total carbohydrates and sugar in the most important legume vegetables are shown in Table 1.

Fast-absorbed carbohydrates, such as fructose, glucose, and sucrose have a strong impact on the nutritional and sensory quality of legume

vegetables. Therefore, their relationships with sources of genetic variations (species or cultivar), agricultural practices, maturation stage, and size of the pod have been frequently studied (e.g. Basterrechea and Hicks, 1991; Sánchez-Mata et al., 2003; VandenLangenberg et al., 2012; Selan et al., 2014; Karapanos et al., 2017). Nevertheless, the contribution of sweetness to the overall organoleptic quality of legume vegetables depends on the species. In green pods of snap beans, sweetness is generally not considered a quality attribute, although it may significantly assist flavor and consumer acceptance (VandenLangenberg et al., 2012). However, in snap pea and pea green seeds the balance between soluble sugars and starch content is of major importance, as it determines the stage of harvest in relation to sweetness, taste and the development of mealiness (Turner and Turner, 1957). As starch in legume vegetables mainly accumulates in developing seeds, increased starch levels indicate an excessive development of seeds in relation to hulls (e.g. in snap beans, snap peas and cowpea) or an overmaturation of immature seeds (e.g. in green pea seeds), which both are considered unfavourable quality characteristics.

In green peas as well as in the growing seeds of snap peas, the sucrose content increases up to the stage of storage reserves synthesis, mainly starch, which results in a decrease of the sucrose levels. This change from a sweet, succulent pea to a seed of high starch content determines the harvest stage and correlates well with seed hardness, which can be assessed using the “tenderometer” (Turner and Turner, 1957; Pate and Flinn, 1977). Basterrechea and Hicks (1991) observed that the levels of fructose, glucose, and inositol in seeds of snap pea pods decreased as ripening was progressing from the immature to overmature stage, whilst the respective content of sucrose and total sugars did not change. Sucrose is the predominant sugar in the seeds of developing snap pea pods, thereby determining the total sugar content in seeds. On the contrary, the levels of fructose, glucose and inositol in the hulls did not change with maturation, whereas that of sucrose and total sugars substantially increased. Nevertheless, at the mature and overmature stage, the concentrations of all sugars in hulls are similar to those found in green seeds, while those of glucose are 60–70 times higher, resulting in an increase by nearly 50% of the total sugar content in the hulls compared to that of seeds (Basterrechea and Hicks, 1991). Consequently, the contribution of hulls to the taste and the nutritional value of green pods is considerable.

As reported by Karapanos et al. (2017), cowpea pods from 36 different south-European landraces and one commercial cultivar contained more glucose (ranging from 2.5 to 10.9 g kg⁻¹ f.w.) than fructose (1.6–6.8 g kg⁻¹ f.w.), while the sucrose content (0.5–9.5 g kg⁻¹ f.w.) was less than that of fructose in most of them. In the same cowpea genotypes, the maltose content (0.3–1.1 g kg⁻¹ f.w.) was appreciably lower than that of sucrose. As snap bean pods contain more fructose than glucose, which is followed by sucrose (Lopez-Hernandez et al., 1994; Sánchez-Mata et al., 2003; VandenLangenberg et al., 2012), it is reckoned that snap bean pods are sweeter than cowpea pods with similar total sugar levels, given that fructose is almost twice as sweet as glucose.

A study conducted by Selan et al. (2014) with dwarf French bean provided further evidence about the co-responsibility of the genetic background (cultivar), cultural practices, and the size of hulls in the sugar composition of green legumes. During pod growth of green beans, sugars are transformed to starch which is stored in the developing seeds, resulting in loss of sweetness together with an increase of dietary fibers (Wills et al., 2007). However, contrasting to snap pea, the stage of harvest is determined by the tenderness and fiber content of the pods rather than their sugar/starch ratio. In green beans, fructose is the major sugar followed by glucose, while sucrose levels are low irrespective of the maturity stage of pods and the cultivar tested (Lopez-Hernandez et al., 1994; Sánchez-Mata et al., 2003; VandenLangenberg et al., 2012). In general, although sugar accumulation patterns and quantity were significantly affected by the tested cultivar, with increasing pod size fructose and glucose content decreased and sucrose

increased (VandenLangenberg et al., 2012; Selan et al., 2014). Furthermore, the use of hail net did not have a consistent effect on the sugar profile of snap beans in all tested cultivars, which indicates that cultivar and size of pods had a much stronger impact than this cultural practice on the sugar profile (Selan et al., 2014).

2.1.5. Low digestible carbohydrates and other dietary fibers

Low-digestible carbohydrates represent a heterogeneous group of substances. Some of the low-digestible carbohydrates are water insoluble compounds characterized by a fibrous nature, such as cellulose and hemicellulose. Other low-digestible carbohydrates are water soluble substances, such as the raffinose-family oligosaccharides (RFOs – raffinose, stachyose and verbascose) and various pectic substances (Septembre-Malaterre et al., 2017). These carbohydrates are low-digestible because they are resistant against enzymatic degradation in the small intestine of humans (Scheppach et al., 2001). As they are not digested, they increase the volume of the intestine thereby stimulating its function. As most non-digestive carbohydrates are fibrous, they are frequently termed dietary fibers. However, dietary fibers include not only oligo- and polysaccharides but also other substances contained mainly in the cell walls of plants, such as lignin. Some dietary fibers may limit absorption of proteins, minerals and possibly vitamins (Slavin, 1987; Gonçalves et al., 2016). Despite this, dietary fibers are considered a desired dietary factor not only due to stimulation of the digestion but also because they were found to contribute to prevention and treatment of several chronic diseases such as those related to high serum cholesterol concentration, coronary heart diseases, certain forms of cancer and gastrointestinal function (Anderson et al., 1994; Slavin and Lloyd, 2012). Dietary fiber may also be beneficial against obesity, contributing to satiety after ingesting legumes and delaying gastric emptying (McCrorry et al., 2010). Nevertheless, at excessive amounts some non-digestible carbohydrates, such as RFOs, can act as anti-nutritional factors as will be outlined in more detail below. Table 1 shows the dietary fiber content of the most important legume vegetables at the stage they are harvested for human consumption.

2.1.6. Vitamins, minerals, antioxidants and other health promoting compounds

Legume vegetables are also considered an important source of some vitamins, whereas green pods are especially rich in vitamin C. The most important sources of vitamin C among the legumes consumed as vegetables are peas and soybeans. Fresh pea pods were found to contain noticeable amounts of vitamin C both in seeds and in the pericarp (around 300 and 194 mg kg⁻¹ FW, respectively, according to Jain et al., 2014). In dwarf French beans, the vitamin C is substantially lower than in peas with values ranging between 130–230 mg g⁻¹ (FW) (Selan et al., 2014). According to the USDA nutrient database as cited by Rickman et al. (2007), the vitamin C content can be as high as 400 mg kg⁻¹ FW in green peas and 163 mg kg⁻¹ FW in green beans. Nonetheless, in another study, the vitamin C concentration in pods of sugar snap pea (*Pisum sativum* L. var. *macrocarpon*) was only 76 mg kg⁻¹ FW. Legumes are also a major source of vitamin K and folate (Septembre-Malaterre et al., 2017), as well as tocopherols (Boschin and Arnoldi, 2011). The concentrations of the vitamins present in substantial amounts in legume vegetables are shown in Table 1.

Legume vegetables represent also a valuable source of minerals, particularly iron, magnesium, phosphorus, potassium, zinc, copper and manganese (Septembre-Malaterre et al., 2017). In contrast, the Ca concentrations in legume vegetables are low compared to those found in leafy vegetables. An overview of mineral concentrations in fresh legume vegetables is provided in Table 1, based mainly on data referenced in the USDA-ARS database (2017).

Green legumes contain also bioactive non-vitamin phytochemicals, including free radical scavengers, inhibitors of enzymes, lectins, phytoestrogens, oligosaccharides, and phenolic compounds, which play important metabolic roles in humans. Legumes constitute one of the

most important sources of some phytochemicals, such as isoflavones and some catechins (Septembre-Malaterre et al., 2017). Furthermore, legumes are a good source of some bioactive phenolic compounds, particularly phenolic acids, flavonoids and condensed tannins (Singh et al., 2017). Dietary intake of phytochemicals has been shown to provide health benefits by protecting the body against numerous disorders such as cardiovascular disease, diabetes and inflammation (Slavin and Lloyd, 2012). The biological activity of the phytochemicals present in legumes is strongly dependent on synergistic or antagonistic interactions with other components of the diet, and its metabolism by the intestinal microflora. Taking into account not only the high nutritional value but also the beneficial health effects of legumes that are attributed to their phytochemical composition, an increase in the consumption of this matrix becomes highly desirable (Gutiérrez-Urbe et al., 2011).

2.1.7. Antinutritional factors

An important group of proteins, relevant for quality, are lectins, which belong to the antinutritional compounds and are involved in plant defense and stress signalling as well as in microbe symbiosis (De Hoff et al., 2009). The antinutritional effect is based on their ability to resist digestion by the gastrointestinal tract, where they bind to membrane glycosyl groups of the cells lining the digestive tract. As a result, the epithelial cell turn-over, membrane integrity, nutrient digestion and absorption, bacterial flora and immune state of the digestive tract are negatively affected (Vasconcelos and Oliveira, 2004).

Another antinutritional compound present in legumes is phytic acid (phytate). Due to its six reactive phosphate groups, this compound has a strong chelating effect, which means that it can form complexes with proteins and minerals (Septembre-Malaterre et al., 2017). This leads to an inhibitory effect of phytic acid on protein and mineral solubility, nutrient availability and absorption in monogastric animals, including humans. It has an additional negative impact on the activity of digestive enzymes such as amylase, pepsin or trypsin (Urbano et al., 2000). The phytic acid content of 0.4–2.06% in legumes depends on cultivation- and climatic conditions and may vary among varieties.

Saponins are natural triterpenes that have the ability to form stable, soaplike foams in aqueous solutions and are widely distributed in all cells of legume plants. Clinical studies suggest health-promoting effects as saponins decrease blood lipids, lower cancer risks, lower blood glucose response (Shi et al., 2004), and may stimulate the immune system (Shahidi, 1997). A subject of discussions within the scientific community is their haemolytic activity (Podolak et al., 2010). Furthermore, at excessive concentrations saponins affect negatively the absorption of nutrients, either by enzyme inhibition during digestion or by an interaction with zinc, while they are the main cause of undesirable flavors that occur after their consumption by humans (Shahidi et al., 1997). Therefore, despite their beneficial actions to human health, saponins are considered unwanted components in foods.

Vicin and convicin are antinutritional components found in the *Vicia* genera with highest concentrations in fresh green cotyledons. These compounds are responsible for favism in humans who are deficient in the enzyme G6PD, i.e. glucose 6-phosphate dehydrogenase (Cappellini and Fiorelli, 2008).

The raffinose-family oligosaccharides (RFOs), i.e. stachyose, verbascose and raffinose, which are found at relatively high amounts in legumes, are causative agents of flatulence in humans, due to the lack of α -1,6-galactosidase in the intestinal mucosa (Gonçalves et al., 2016). RFOs are fermented in the large intestine by colon microflora thereby acting as probiotics (McTigue et al., 1995; Schneeman, 2008). However, during their fermentation by bacteria they release hydrogen and methane. Therefore, RFOs are considered antinutritional factors and their presence in considerable amounts is undesired, posing a constraint to legume dietary consumption (Septembre-Malaterre et al., 2017). Nevertheless, green pods contain substantially less RFOs than dry seeds and thus the consumption of legume vegetables is much less negatively

affected by these anti-nutrients than that of dry pulses (Karapanos et al., 2017).

2.2. Morphological and sensory quality traits

The most important morphological traits used to assess the external quality of green pods consumed as legumes include the pod length, the individual pod weight, the pod diameter, the number of locules and seeds per fresh pod, the firmness of the pod, and the color of the pod when harvested. In snap beans, important pod characteristics include length, cross-sectional shape, sieve size (relative to diameter – highly important in the case of processing varieties for canning), color, smoothness, fiber and seed index (Silbernagel and Drake 1978). In snap and yardlong beans in particular, the diameter of the pod, rather than the length is used as quality indicator. Snap beans of high quality should be turgid and easily snapped (as the name implies), well-formed and straight, bright in color with a fresh appearance, very tender but firm, stringless, and seeds, if present, must be small and soft, given that consumers prefer pods with no, or only slight bulges (Cantwell, 2004; OECD, 2005).

With respect to green seeds, the criteria used to assess their external quality are mainly the shape (round, oval, etc.), the texture and the individual seed weight. The texture of green seeds of pea is one of the most important quality attributes for consumers (Edelenbos et al., 2001). Green peas of high quality should be tender enough, but with high sugar content which increases with maturity. Pea tenderness, which can be measured using a tenderometer, is intimately related to the seed developmental stage (Higgins et al., 2010). Therefore, the seed tenderness is used as a maturity index to determine the optimal time for harvesting of green peas. In addition to the morphological traits, several traits indicating the sensory quality, such as mealiness, skin (testa) toughness, juiciness and crispness are important for consumers of green peas (Edelenbos et al., 2001).

3. Genetic factors influencing the quality of legume vegetables

One of the most efficient tools to improve the quality of legume vegetables is breeding. The first prerequisite for successful breeding is the availability of a wide genetic variability within the particular species in question and other related species. Among the legume species frequently consumed as vegetables, a relatively large number of local accessions and landraces can be found, which constitute a valuable genetic material for breeding programs aiming at improving their quality. For instance, some recent studies with cowpea revealed a wide diversity among and within cowpea local accessions and landraces, in respect with both chemical (nutritional) quality (Table 2) and phenotypic traits (Lazaridi et al., 2016; Karapanos et al., 2017). Similarly, a wide genetic diversity within the species has been reported also for common bean (Singh et al., 1991; Escribano et al., 1997) and faba bean (Wang et al., 2012), but not for peas (Tar'an et al., 2005).

Considering Fabaceae, information on genome structure, gene sequences and molecular tools is available in model legumes such as *Medicago truncatula* and *Lotus japonicas* (Cannon et al., 2006). Newly emerging sequences from additional legume genomes, such as soybean (Schmutz et al., 2010), common bean (Schmutz et al., 2014), chickpea (Varshney et al., 2013), or medicinal plants such as *Glycyrrhina uralensis* (Mochida et al., 2017) allows a broad overview of the genome landscape of the family. The scope of tools include genetic linkage maps, genome sequences, gene annotations and gene expression atlas (Muñoz-Amatriáin et al., 2016; Verdier et al., 2013; Yao et al., 2016). The transfer of knowledge from model legumes to other legumes such as pea and faba bean is possible due to the high level of synteny and colinearity among legumes (Rispaill et al., 2010). Nevertheless, the specific genome characteristics and gene environments may affect gene function, which needs to be considered when extrapolating results from model legumes to other crops for functional genomics and breeding.

Table 2

Chemical composition of cowpea fresh pods collected from 37 accessions or local landraces originating from Greece, Spain and Portugal and harvested at a suitable stage for consumption as vegetables. For each characteristic, the range of the mean values ($n = 4$) of the 37 accessions or local landraces is presented (based on data from Karapanos et al., 2017).

| Chemical characteristic | Range of mean values |
|--|--|
| Total soluble solids | 5.07–7.57°Brix |
| Titrateable acidity | 165.3–278.0 mg malic acid/100 g f.w. |
| Total soluble proteins | 1.62–3.29 g/100 g fw |
| Nitrates | 40.8–190.1 mg NO ₃ ⁻ /100 g fw |
| Chlorophyll | 3.75–21.35 mg/100 g f.w. |
| Xanthophylls + carotenoids | 0.26–2.94 mg/100 g fw |
| Total phenolics | 48.9–181.0 mg GAE/100 g f.w. |
| Total antioxidant activity (FRAP) | 114.2–706.8 μmoles ascorbate/100 g f.w. |
| Total antioxidant activity (DPPH) | 1.27–18.50 μmoles Trolox/100 g f.w. |
| Starch | 30.8–1,017.9 mg/100 g f.w. |
| Fructose | 162.9–708.7 mg/100 g f.w. |
| Glucose | 247.0–1,087.2 mg/100 g f.w. |
| Sucrose | 52.2–947.9 mg/100 g f.w. |
| Maltose | 31.5–112.4 mg/100 g f.w. |
| Raffinose family oligosaccharides (RFO) ^a | 12.6–122.9 mg/100 g f.w. |

^a Excluding one accession, in which a mean value of 487.1 mg/100 g f.w was measured.

The following paragraphs present information on the genetic background of quality parameters as well as breeding strategies and molecular tools applied to legumes for quality improvement.

3.1. Protein content

The protein content is one of the most important dietary characteristics in legumes and a primary criterion for genotype selection in breeding programs aiming at dietary improvement of dry pulses. However, the protein content is important also for legumes consumed as vegetables, because green seeds of pea and faba bean, as well as green pods of common bean and cowpea, are frequently consumed as main meals not only in poor countries but also in developed countries, especially by vegetarians, and form a staple in the Mediterranean diet (Mutch, 1988; Trichopoulou et al., 2014). Most of the protein from green vegetable legumes comes from the developed seeds prior to the dehydration process that gives the dry seed (Martínez et al., 1998). While the protein content of dry seeds has been studied with detail, corresponding studies on fresh legumes are scarce, and most of the work has related to common bean, green peas, and faba bean (De Ron et al., 2017; Lucas et al., 2015; Multari et al., 2015). A study of the possible usage of pea pod, broad bean pod and okara from soybean to obtain functional products indicates that these parts of the plant have high potential to obtain protein but are treated as disposable by-products during food processing (Mateos-Aparicio et al., 2010).

3.2. Antinutritional factors

Although, lectins play an important role in legume-*Rhizobium* interaction required for nodulation and N₂ fixation (Downie, 2014), their presence in the edible pods and seeds is undesired because of their ability to resist digestion when consumed by humans. Therefore, the reduction of their content in edible parts is frequently one of the objectives in breeding programs with legumes. More than 70 lectins (Sharon and Lis, 1990) and a total of 359 putative lectin genes have been identified from *Glycine max* (Van Holle and Van Damme, 2015). These genes belong to nine of twelve recognized lectin gene families, mostly codifying for chimerolectins with at least two protein domains, and are thought to be the result of both tandem and segmental sequence duplications. Expression of a lectin gene in chickpea was shown to be constitutive in various tissues including flower, leaf, root and stem

(Qureshi et al., 2007). The number of lectins present in the genome of legumes and their importance in nodulation makes them a difficult target for modification by classical genetics. A synthetic biology approach to obtain plants with high root lectins and low seed/pod lectins, would be ideal, but may require many steps including proofs of concept.

Reduction of the phytic acid content in edible parts of legumes, including those consumed as vegetables, is also a goal of breeding in this plant family. A way of reducing phytic acid content in legumes and to improve their nutritional value is through genetic engineering targeting the enzyme phytase, which controls the hydrolysis of phytate to orthophosphate and lower substituted inositol phosphates. Genetic modification of crop plants for production of heterologous phytase improved phosphate bioavailability (Gupta et al., 2015). However, two problems arise when modifying phytic acid. On one hand, plants with low phytic acid display a variety of pleiotropic negative phenotypes including low germination and low resistance to stress (Lee et al., 2015; Redekar et al., 2015). Second, the effects of phytic acid on gut microbiome may be beneficial to some extent in helping increase the level of *Lactobacillus* and decreasing the levels of *Clostridium* (Sekita et al., 2016). They also have been shown to reduce the levels of proinflammatory cytokines in rats fed with high fat, and prevent fatty liver in rats fed with a high sucrose diet (Okazaki and Katayama, 2014; Sekita et al., 2016). As a result, we may need an assessment of the interventions to decrease phytic acid for animal feed and maintain it in varieties for human consumption.

The restriction of saponins content in edible legumes is also a goal of breeding. The biosynthetic pathway of saponins is not completely understood, but is predicted to have several genes involved (Naoumkina et al., 2010). Suppression of β -amyrin synthase, a key enzyme in the synthesis of a common aglycone of soybean saponins, by RNAi silencing resulted in a nearly complete inhibition of saponin production in transgenic soybean (Takagi et al., 2011).

In *Vicia faba*, a breeding priority is the absence of vicine and convicine which are responsible for favism in humans. A spontaneous mutant allele, *vc-*, confers a 10–20 fold reduction of vicin and convicine. CAPS markers cosegregating with vicin-convicin content were developed and can be used in breeding programs, replacing cost intensive chemical detection of these antinutritional compounds (Gutierrez et al., 2006).

3.3. Fibers in legumes

Attempts to reduce the content of indigestible lignin consist in transformation experiments with antisense constructs for enzymes related to lignin biosynthesis, including anionic peroxidase or caffeic acido-methyltransferase (Loughrin et al., 1990; Ni et al., 1994; Tabe et al., 1993).

Oligosaccharides belonging to the raffinose family of fibers (RFOs) are considered antinutritional factors and, therefore, their presence in considerable amounts in legumes poses a constraint to their dietary consumption. Significant differences in various fiber components were found among sixteen common bean cultivars, indicating the existence of a high genetic variability in fiber content (Prolla et al., 2010). Breeding strategies for high or low total dietary fiber content are promising due to a high broad sense heritability as estimated based on population results from crossings among five common bean lines differing in total dietary fiber content (Londero et al., 2006).

3.4. Micronutrients and vitamins

Nutrient quality and composition in legumes may be influenced by maturation stage, soil and growing conditions, and the genotype. Improvement of micronutrients stored in legumes not only prevents malnutrition, but also may increase productivity, especially when crops are grown in micronutrient poor-soils (Welch and Graham, 2004) The concentrations of vitamins B1 and C in pea was shown to be variable

among cultivars (Selman and Rolfe, 1979; Morrison, 2007) and a high degree of genetic variability exists in Fe and Zn concentration in *Phaseolus*. Fe ranges between 34 and 89 mg g⁻¹ and Zn between 21 and 54 mg g⁻¹ among 1000 common bean accessions (Graham et al., 1999, 2001). These wide ranges point to a potential for improvements in the micronutrient concentrations through breeding. In general, classical breeding programs for the improvement of a certain micronutrient requires the parameters of simple screening and high heritability (Graham et al., 2001). The bioavailability of micronutrients is also a factor that may be improved by classic and biotechnological approaches.

3.5. Legume carbohydrates

A large variation in the content of total soluble sugars in snap bean pods has been found, ranging from 0.6% to 5.2% f.w. Similarly, the contents of glucose, fructose, and sucrose range from 0.23% to 1.38%, 0.25% to 1.78%, and 0.1% to 0.78% f.w., respectively (Lee et al., 1970). A similar genotypic diversity has been found also in cowpea (Table 2).

A very high level of natural genetic variation for RFOs is found in peas (Jones et al., 1999). A successful approach to lower RFOs in soybean resulted from the genetic manipulation targeting the enzyme galactinol synthase, which is involved in the RFO synthesis pathway (Kerr et al., 1998).

There is ample natural genetic variation for starch content, composition, and granule structure and over 30 starch mutants are characterized for peas (Wang, 1998). In green pods of legumes, starch accumulates mainly in developing seeds and, therefore, a high starch content possibly indicates an excessively high seed to hull biomass ratio (Omueti et al., 1986). However, excessive development of seeds over the hulls is frequently considered a negative quality characteristic when the whole pod is the edible part of a legume plant (Karapanos et al., 2017). Thus, in breeding programs with legumes aimed to produce edible green pods, the starch content might be used as a screening criterion to select accessions with low seed to hull biomass ratio at commercial maturity.

3.6. Morphological quality traits

Amongst the morphological traits of vegetable legumes, there is an important body of work on pod length in a variety of legumes. The current hypothesis based on the domestication of the azuki bean is that there has been a trade-off for plants with longer pods and heavier seeds as compared to wild species that contain more seeds but of lesser weight (Kaga et al., 2008). Furthermore, the so-called “domestication syndrome”, conceived as substantial differences between the wild ancestors and the cultivated species, indicate a strong selection for genes with major effects on quality trait, and two of them are pod length and seed size (Koinange et al., 1996). A study in common bean has shown a high degree of heritability of pod quality traits, as would be expected for traits that have undergone strong selection (Escribano et al., 1997). Furthermore a detailed QTL analysis has shown a large degree of pleiotropy in the QTLs identified when referred to the quality traits under selection such as pod width, thickness, length, size index, beak length and color, indicating that the number of genes that are currently used for selection is not high (Yuste-Lisbona et al., 2014).

Pod length has been intensively studied in cowpea (*Vigna unguiculata* (L.) Walp. ssp. *unguiculata*) as there are two different types of cowpea, i.e. the short pod type (cv.-gr. *unguiculata*) and the long pod type that belongs to the cv.-gr. *sesquipedalis*. A comprehensive genomic scan in cowpea has shown that there are at least 7 QTLs involved in control of pod length and two may have been under strong selective pressure during domestication (Xu et al., 2016). This indicates that breeding efforts to improve pod length should yield significant results.

4. Physiological mechanisms implicated in the quality of legume vegetables

Legume pods are considered photosynthetically active organs during their development as long as they are green (Bennett et al., 2017). Therefore photosynthesis can be considered as an important physiological parameter for legume pod quality. In addition, cell wall division, protein biosynthesis, sink-source relationships, activities of antioxidant enzymes in fresh pods and key enzymes involved in starch synthesis in pods, as well as plant hormones such as GAs and cytokinin constitute also major physiological parameters with a significant impact on pod quality. Some information about these mechanisms was provided in Sections 2 and 3 of this review, when presenting the quality attributes of legume vegetables and the underlying genetic factors. Additional information about physiological mechanisms implicated in the quality of legume vegetables is provided in this Section.

4.1. Photosynthetic activity of legume pods and pod wall development

From an ecophysiological point of view, the green color of fruits as long as they are still unripe, which is due to the presence of chlorophyll, serves to add to the photosynthetic pool (Bennett et al., 2011). The photosynthetic capacity of reproductive structures of dicots shows a considerable interspecific variation as indicated by the rates of net CO₂ fixation (Furbank et al., 2004). While carbon fixation in pods of *Brassica napus* L. can be as high as 35% of that found in leaves (King et al., 1998), this percentage is lower in legume pods and the obtained assimilates are utilized for the growth of pod wall during early pod development (Davies et al., 1999) and for seed growth thereafter (Sheoran et al., 1987). Moreover, the stomatal density on the epidermis of pod wall in legumes is less than one-third of that observed in leaves. However, under well-watered conditions, the CO₂ released by seeds due to respiration inside the pea pod can be re-fixed by the outer pod wall and thus the carbon utilization efficiency increases considerably (Ma et al., 2001; Furbank et al., 2004). According to Delgado-Alvarado et al. (1998), although the chlorophyll content in the pod decreases with increasing pod size, the rate of gross photosynthesis based on chlorophyll in the pods increased while the reverse was the case for the photosynthetic ability of the leaves (Wang et al., 2016). As reported by Atkins et al. (1977), the photosynthetic activity of pea pods is strongly related to the requirements of the pod wall and seed for assimilates and to the rates of dry matter accumulation.

According to Bennett et al. (2011), the role of the pod in legumes alters during development and should not be considered only as a protective organ for the seed. This is ascribed to the fact that pod wall development is strongly associated to seed size and consequently to pod length, due to the strong correlation between the two latter morphological characteristics (Diepenbrock, 2000). Pod wall development is mainly associated with morphological modifications of the cell wall, accumulation of fatty acids and secondary metabolite biosynthesis. According to Pazhamala et al. (2016) during pod wall development from 10 to 20 days after anthesis, genes encoding pro-glycinin and sucrose binding protein were induced, indicating the important role of pod wall in carbohydrate acquisition.

As reported by VandenLangenberg et al. (2012), sugar concentration of legume pods often alter the perception of flavor and thus any increase or decrease in sugar concentration may change the taste and, ultimately, the consumer preference for a particular legume pod. According to Jeuffroy and Warembourg (1991), the assimilate proportion allocated to reproductive organs of pea increased fast during the period of pod formation. However, a reduced rate of new pod formation in the plant leads to a comensurate decline of the photoassimilate production in leaves due to reduced sink activity (Bennett et al., 2011). The metabolic available, however, of sucrose depends on the degradation into hexoses or their derivatives which is catalyzed by invertases (Weber et al., 2005). In a recent study, Liu et al. (2012) demonstrated that the

activities of invertases in cell walls, cytoplasm and vacuoles 10 days after anthesis were significantly smaller in pod walls of the asparagus bean line '282' compared to line '121', resulting in a reduced cell division period and earlier termination of cell expansion, and consequently in weaker pod wall development. On the other hand, sucrose synthase was not a major contributing factor to the earlier termination of cell expansion since its activity did not decrease.

4.2. Protein metabolism and antioxidant enzymes in fresh pods

The protein metabolism in pods and seeds determines both their protein content and the nutritional quality of their proteins in terms of amino acid content. According to Watson et al. (2003), pod proteome is being represented by seed storage proteins that serve as a nutrient source for developing seedlings. In a recent study of Nautrup-Pedersen et al. (2010), pod maturation was associated with decreasing content of proteins involved in protein biosynthesis and photosynthesis. Proteomic analysis in the pods of the model legume species *Lotus japonicus* revealed the presence of 604 proteins that included ribosomal, integral membrane, nucleotide binding, nuclear transport, and LEA proteins (Nautrup-Pedersen et al., 2010). In the same study, the importance of nitrogen metabolism during pod development was also highlighted since the unique detected proteins in pods were assigned to enzymes participating in the urea cycle and in nitrogen and amino group metabolism. Moreover, an enhanced expression of proteins associated to photosynthesis and oxidative stress during pod swelling were found in subterranean and aerial pods of peanut (Zhu et al., 2013).

Another important part of the growth mechanism of the pods is the formation of reactive oxygen species (ROS) since they are involved in cell wall loosening and expansion. ROS production is enhanced by nitrogen fixation and photosynthesis (Matamoros et al., 2010) and ROS generation and accumulation are evident in cell elongation and cell wall loosening in pod wall cells (Liu et al., 2014). According to Liu et al. (2014), ROS are produced in different sites of plasma membranes with the regulation of antioxidant enzymes SOD, POD and CAT which are involved in the transformation among different ROS in pods walls, while each enzyme has a specific role in early pod development. Matamoros et al. (2010) demonstrated the role of the antioxidants in the development, maturation, post-harvest shelf life and protection against abiotic stress conditions of legume pods. The same authors demonstrated that ascorbate–glutathione metabolism and cytosolic peroxiredoxin apoplastic ascorbate oxidase activity are important for pea fruit development.

4.3. Sink-source relationships during the onset of pod formation in legumes

Sink-source relationships change during the onset of pod formation in legumes (Salon et al., 2001). This is ascribed mainly to the fact that growing pods attract significant amounts of carbon and nitrogen. To cover the increasing amounts of nitrogen requirements during formation and filling, pods attract nitrogen from the nodules. If the nodules cannot cover their N requirements, pods attract nitrogen from older leaves (Schiltz et al., 2005), thereby reducing the photosynthetic capacity of the plants and determining rapidity of ripening. Therefore, the selection of rhizobia strains with increased nodulation capacity may improve N availability to pods, thereby increasing pod size, which is an important quality characteristic. Nevertheless, inoculation with rhizobia has to be combined with the application of inorganic N supply and especially NO₃-N at levels and times that do not inhibit nodulation (Kontopoulou et al., 2017).

4.4. Hormonal regulation of pod formation

Overall, information about the involvement of plant hormones in the development of legume pods and green seeds consumed as vegetables, their impact on qualitative traits, and the mechanisms

underlying their possible effects is currently scarce. Elzaawely et al. (2017) found that gibberellins (GA₇) are more intimately involved in pod development and yield of snap bean than other plant hormones. Besides gibberellins, developing pea seeds and pericarps are influenced also by auxins (4-Cl-IAA), which modulate the level of bioactive GA₁ required for initial fruit set and growth in pea (Ozga et al., 2017). According to Emongor (2015), new source-sink relationships leading to increased dry matter accumulation in the bean can also be ascribed to the stimulation of carbohydrate metabolism by cytokinins. Cytokinins are linked to increased cell division, which is an active part of the pattern development phase and play an important role in legume seed development and thus also in several quality traits (Jameson and Song, 2016).

5. Impact of agronomic factors on the quality of legume vegetables

From an agronomic point of view, the quality of vegetables at the time of harvesting is determined by genotype × environment × management interactions (Struik et al., 2005). This general statement applies also to the vegetables classified to the Fabaceae family. The genetic and environmental backgrounds of quality in legume vegetables are outlined in Sections 3 and 6 of this paper, respectively. The management practices with an impact on the quality of legume vegetables include cultivar and site selection, sowing or planting season, crop establishment, plant density, weed control, irrigation, fertilization, plant protection, and harvesting. Of these practices, cultivar and site selection determine the environmental (soil type, temperature, humidity, precipitation) and the genetic factors involved in the quality performance and, therefore, they are discussed in the corresponding sections of this review paper. The sowing or planting season has an indirect impact on quality of legume vegetables because it determines the environmental factors prevailing during the cropping period as well as at the harvesting time and, thus, it is also addressed in the corresponding section. An overview of the quality traits of leguminous vegetables that are affected by agronomic factors is provided in Table 3.

5.1. Effects of cultivation season

The pod width of snap beans cultivated during spring, summer and autumn in Spain (Pérez-Barbeito et al., 2008) and Israel (Palevitch, 1970) was significantly influenced by the cultivation season. The late growing season (summer-autumn in Spain and autumn in Israel) resulted in wider pods in relation to normal cropping period (spring-summer) in the field, and to early period (winter-spring) in an unheated greenhouse. However, pod thickening was slower during spring, thus allowing delayed harvesting, whereas in autumn a similar delay decreased the percentage of pods with suitable diameter for the market (Palevitch, 1970). By contrast, the growing season had no consistent effect on pod mean weight, length, number of seeds per pod, soluble solids content and pod tenderness, possibly because these quality characteristics were more strongly influenced by differences in growing techniques applied in each season (Pérez-Barbeito et al., 2008).

As a result of the seasonal effect on pod width and the faster development of seeds during spring in relation to summer and autumn (Palevitch, 1970), the later the crop was planted, the lower the seed index was (Pérez-Barbeito et al., 2008). Seed index is considered an indicator of maturity and fiber development for large- and medium-sized snap bean cultivars (Silbernagel and Drake 1978).

In sub-tropical and arid areas, growing snap beans during summer results in poor yields of inferior quality. Mori et al. (2011) found that in southern Italy delayed sowing (taking place by the first week of July) seriously decreased the percentage of marketable yield in relation to sowing one month earlier. Similarly, in Australia, high temperatures during January resulted in losses of yield and quality (Moss and

Muirhead, 1983). Contrasting to the favourable effect of autumn sowings on snap bean quality (Palevitch, 1970; Pérez-Barbeito et al., 2008) in temperate areas, lower temperatures during pod growth at late sowings (e.g. January-February in Australia) may impair yield and quality due to a restricted supply of photosynthates to growing pods. In those environments, higher yields of optimal quality were observed during spring-early summer, when conditions favored rapid setting and growth of pods (Moss and Muirhead 1983).

The effect of the sowing date on the nutritional value of snap bean pods harvested during summer in Mexico, was studied by Ramírez et al. (2008). Pod contents in ash, phosphorus, acid detergent fibers, lignin, protein and fat was highest when plants were sown on the 1st of May, whereas sowing on the 1st of July resulted in the highest concentrations of calcium, soluble carbohydrates, neutral detergent fibers, hemicellulose and organic matter.

5.2. Crop establishment

The crop establishment is crucial for the quality of legume vegetables because a high plant uniformity in the initial stand is essential for a uniform produce. Lack of uniformity at the initial cropping stage results in unequally sized plants and thus in huge differences in pod size. High plant uniformity in legumes such as peas can be achieved by increasing the seed germination rate through careful selection of the cultivar and the establishment of a favourable growing site (Fowler et al., 2006). Furthermore, at crop establishment it is important to avoid soil compaction as it negatively affects quality of legume vegetables such as faba bean by reducing the individual seed weight (St-Martin and Bommarco, 2016).

5.3. Plant density

Several studies have shown that the protein concentration in seeds of legumes decreases with increased plant density (e.g. Bulson et al., 1997; Abubaker, 2008). Furthermore, high plant densities may result also in lower dry matter contents and lower concentrations of mineral nutrients that are essential for human nutrition, such as P and K (Abubaker, 2008). The decreased concentrations of protein and mineral nutrients in bean pods at high plant densities originate presumably from increased competition in nutrient uptake, while the decreased dry matter content may be associated with decreased whole-plant photosynthesis at high plant densities due to increased competition for light (Konovsky et al., 1994). In vegetable soybean, lower plant densities produce pods with darker green color, which is a desired external quality trait for consumers and higher amino acid and sucrose levels at the stage of commercial maturity (Chiba et al., 1989). On the other hand, low plant densities resulted in lower total yields in common bean (Abubaker, 2008) and soybean (Konovsky et al., 1994). Consequently, the optimal plant densities for legume vegetables are those providing a fair trade-off between total yield and quality of pods.

5.4. Weed control

Efficient control of weeds is important for the production of high-quality green pods and seeds in crops of legume vegetables. Weeds compete with the crop plants for resources such as moisture, nutrient, and light and thus they may restrict not only the total yield but also quality characteristics such as pod size, number of seeds per pod, and seed size (Shalini, 2017). Nevertheless, the available information about the impact of weed control on quality traits of legume vegetables is currently scarce.

5.5. Irrigation

The cold tolerant legume vegetables (pea and faba bean) are in most cases non-irrigated crops, especially when they are sown in autumn.

Table 3

An overview of the quality parameters of legume pods and immature seeds consumed as vegetables that are influenced by different agronomic factors.

| Agronomic factor | Quality parameter influenced | Literature source(s) | |
|--------------------------|--|--|--|
| Cultivation season | Pod width | Palevitch (1970) and Pérez-Barbeito et al. (2008) | |
| | Seed index | Pérez-Barbeito et al. (2008) | |
| | Percentage of marketable yield | Moss and Muirhead (1983) and Mori et al. (2011) | |
| | Nutritional value | Ramírez et al. (2008) | |
| Crop establishment | Uniformity in pod size | Fowler et al. (2006) | |
| | Plant density | Protein concentration | Bulson et al. (1997) and Abubaker (2008) |
| Weed control | | Dry matter content | Konovsky et al. (1994) |
| | Concentrations of amino acid and sucrose | Chiba et al. (1989) | |
| | | Pod color | Chiba et al. (1989) |
| | Yield | Konovsky et al. (1994) and Abubaker (2008) | |
| | Pod size | Shalini (2017) | |
| | Number of seeds per pod | Shalini (2017) | |
| Irrigation | Seed size | Shalini (2017) | |
| | Number of seeds per plant | Guilioni et al. (2003) | |
| | Concentrations of crude protein in seeds | Al-Suhaibani (2009) | |
| | Carbohydrate content in seeds | Al-Suhaibani (2009) | |
| | Fresh pod length | Sezen et al. (2008) | |
| | Fresh pod width | Sezen et al. (2008) | |
| | Number of seed per pod | Sezen et al. (2008) | |
| | Hundred seed weight | Sezen et al. (2008) | |
| | Fiber content in the pods | Singer et al. (2003) | |
| | Colour brightness and pod greenness | Sezen et al. (2008) | |
| | Seed size | Turk et al. (1980) | |
| | Fertilization | Concentrations of proteins | Hojjati (1976), Bengtsson (1991), Sharma et al. (1993) and Babiker et al. (1995) |
| | | Concentration of S-containing amino acids | Hojjati (1976), Bengtsson (1991), Sharma et al. (1993) and Babiker et al. (1995) |
| | | Degradable protein fraction | Cazzato et al. (2012) |
| Total sugar content | | Kobayashi et al. (1989) | |
| Number of seeds per pods | | Konovsky et al. (1994) | |
| Harvesting time | Phytic acid content | Lott et al. (1995) | |
| | Crispiness | Omuetti et al. (1986) | |
| | Vitamin C content | Selman and Rolfe (1979) and Omuetti et al. (1986) | |
| | Total acidity | Omuetti et al. (1986) | |
| | Crude fiber percentage | Omuetti et al. (1986) | |
| Farming system | Crude protein | Awolumate (1983), Omuetti et al. (1986) and Brunsgaard et al. (1994) | |
| | Dry matter content | Kontopoulou et al. (2015) | |

Despite their high adaptability to semi-arid climatic conditions, pea and faba bean may occasionally be faced with drought stress, depending on the yearly variations in climatic factors, when they are grown as non-irrigated crops (Knott, 1999; Karkanis et al., 2016). Nevertheless, pea responds to water deficit mainly by immediate abortion of reproductive organs which results in reduced number of seeds per plant rather than by adverse effects on the mean seed weight or on other quality characteristics (Guilioni et al., 2003). On the other hand, reduced watering application in faba bean increases the concentrations of crude protein and carbohydrates in seeds (Al-Suhaibani, 2009).

In contrast to pea and faba bean, warm-season legume vegetables such as common bean, cowpea and vegetable soybean rely in most cases on appropriate irrigation to provide high quality produce (Graham and Ranalli, 1997; Sezen et al., 2005). Reduced irrigation frequency and shortages in total water supply negatively affect pod quality characteristics in common bean such as fresh pod length, width, number of seed per pod and hundred seed weight (Sezen et al., 2008). Inadequate supply of irrigation water to snap beans may increase also the fiber content in the pods, as indicated by relevant results of Singer et al. (2003) obtained after reduction of the water supply from 100% to 75% or 50% of the field capacity. Furthermore, irrigation frequency may have an impact also on the color of pods. Indeed, as reported by Sezen et al. (2008), large irrigation intervals reduced the color brightness (L^* parameter) and increased the pod greenness (a^* parameter) in snap bean pods.

With respect to cowpea, this legume species is mostly grown in the arid and sub-arid zones of the world where the production mostly depends upon rain as a sole source of water supply, taking advantage of its high drought tolerance (Singh and Reddy, 2011). Currently, published research results relevant to the impact of irrigation on quality traits of green pods are scarce. Perhaps the only relevant information is that the

size of both pod and seed are restricted by inadequate supply of irrigation water to cowpea (Turk et al., 1980).

5.6. Fertilization

Fertilization is another agronomic practice with strong effects on the quality of legume vegetables. Increasing the supply of nitrogen (Babiker et al., 1995; Bengtsson, 1991) and sulphur (Hojjati, 1976; Sharma et al., 1993), usually increases the concentrations of proteins and the S-containing amino acids methionine and cysteine in the seeds of legume plants, respectively, especially when the levels of these nutrients in the soil are below the optimal levels. Cazzato et al. (2012) also found that sulphur application via fertilization enhanced the protein quality in faba bean, by increasing its degradable fraction. On the other hand, excessive nitrogen application can decrease the total sugar content (Kobayashi et al., 1989), and reduce the number of seeds per pods, as has been observed in vegetable soybean (Konovsky et al., 1994). Furthermore, very high rates of phosphorus fertilization are not advised because they may increase the levels of phytic acid in pods, which is considered an antinutritional factor. Indeed, as reported by Lott et al. (1995), high levels of P in the soil increase phytate levels.

5.7. Harvesting time

The harvesting time also plays an important role in the quality of vegetable pods consumed as vegetables. Harvesting pods at an early developmental stage provides superior quality in most cases. Omuetti et al. (1986) reported that green cowpea pods harvested between 7 and 10 days after flowering were crisply tasty and high in nutrients and therefore nutritionally the most acceptable for consumption, while those aged between 11 and 13 days exhibited significant decreases in

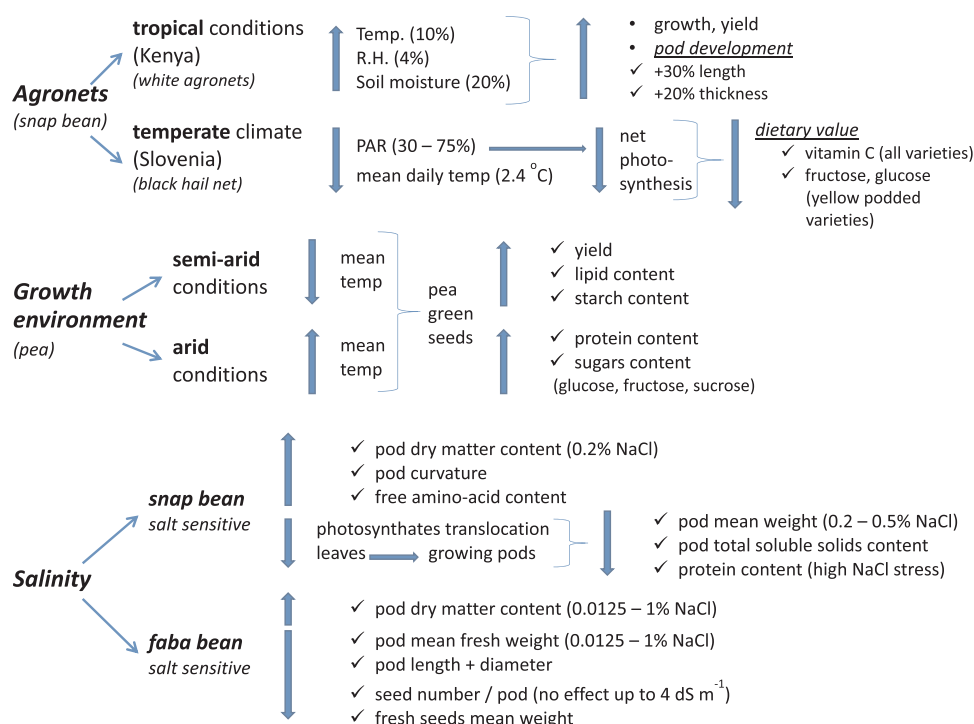


Fig. 1. Impact of environmental factors on quality traits of leguminous vegetables, as documented by the currently available literature.

Vitamin C, total acidity, crude fiber and crude protein percentage. Awolumat (1983) also found a gradual decrease of the crude protein content in pods of cowpea, mung bean and soya bean as maturity was progressing. At early stages of development, crude protein formed about one-third of dry weight in the pods of these legume species but decreased to about one-quarter at maturity. Therefore, pods of most legume vegetables should be harvested at an early stage of growth, for example 8–10 days after anthesis (DAA) for snap bean and common cowpea pods and 10–12 DAA for yardlong beans (Cantwell, 2004; Karapanos et al., 2017). By contrast, faba bean pods are usually harvested at a more advanced stage of growth, at the “milk stage”, when pods have reached full size but they are still green and the seeds are immature, attaining a dry matter of 20–35% (Lisiewska et al., 1999). Faba bean pods of high quality should be shiny green and the seeds should be tender, creamy and uniformly developed (Nunes, 2008).

The harvesting time has a strong impact also on the quality of green seeds. Both the nutritional value and the texture of green seeds are influenced by the developmental stage. As reported by Selman and Rolfe (1979), the vitamin C content changes during development of the pea seed due to structural changes and the partition of the vitamin between the cotyledons and the testa. On the other hand, the protein content in green seeds does not seem to be influenced by the time of harvesting (Brunsgaard et al., 1994). Nevertheless, the consumer perception about green pea quality is mainly determined by the texture quality. Therefore, in pea crops aiming to produce green seeds for fresh market, freezing, or canning, the time of harvesting is commonly determined using an instrument that provides an arbitrary numerical measure of pea softness known as tenderometer (Visscher and Lovink, 1999; Edelenbos et al., 2001). To obtain optimal quality produce, peas for fresh market and freezing should be harvested when the tenderometer reading is about 100, whereas seeds for canning could be slightly firmer, which corresponds to a reading of 120 (Salunkhe et al., 1993). An alternative approach to determine the stage of commercial maturity in green peas is the measurement of whole pea transmittance in the near infrared (NIR) region, which entails the development of a portable NIR analyzer suitable for field application (Kjølstad et al., 1990; Chalucova et al., 2000). The advantage of a NIR analyzer is that it indicates not only the texture quality but also the internal sensory

quality.

5.8. Farming system

The farming system may also have an impact on the quality of legume vegetables. This is reasonable, since different farming systems may be associated with differences in the availability of nutrients and water, weed competition, level of exposure to pest and diseases, etc. For instance, green pods of common bean produced in organic farming systems are characterized by a significantly higher dry matter content than pods obtained from conventional farming systems (Kontopoulou et al., 2015). An increased dry matter content in pods from organic farming may be due to decreased nitrate levels in the cell vacuoles. Since nitrate is a low-molecular-weight osmoticum in comparison with organic solutes, higher nitrate contents in the cell vacuoles of conventionally-produced pods may be associated with a higher water content, assuming that in both cases the osmotic potential in the pod cells is adjusted to the same level. An enhanced dry matter content in edible plant tissues points to a higher nutrient density and is, therefore, considered a positive quality attribute (Alföldi et al., 2006).

6. Impact of environmental factors on the quality of legume vegetables

Notwithstanding the economic and dietary importance of legume vegetables, there is a scarcity of information regarding the effect of the environment (e.g. soil environment, climatic conditions) on their market quality, their sensory characteristics and their nutritional and anti-nutritional value. Most of the published studies in this area refer to snap bean and pea. Although numerous studies are available on the effects of either salinity or drought/deficit irrigation on plant growth and yield of grain and vegetable legumes, only few of them address also pod and/or immature seed quality parameters; studies about the impact of climatic parameters on quality traits of legume vegetables are even scarcer. The impact of environmental factors on quality traits of leguminous vegetables, as documented by the currently available literature, is shown schematically in Fig. 1.

6.1. Impact of the aerial environment

As snap beans are cultivated in the field during the warm period of the year in temperate and sub-tropical areas, the use of hail nets or agronets in order to prevent adverse climatic incidents (e.g. hail, excessive solar or UV radiation) and/or limit pest infestation is advisable. The same applies also for other summer-grown legume vegetables, such as cowpea or vegetable soybean. Yet, little information is currently available on the effect of microclimate modification caused by net covering on market quality and nutritional characteristics of snap bean or any other summer-grown legume vegetable.

Gogo et al. (2014) studied the effect of crop covering with white agronets entailing a reduction in the light transmittance to approximately 90% of the non-shaded control on microclimatic parameters, pest populations, growth, yield, and pod quality in a field crop of a bush-type snap bean during September–April under tropical conditions in Kenya. Net covering increased by 10%, 4% and 20%, on average, the temperature, relative humidity and soil moisture, respectively. Apart from its positive effect on growth and yield of plants, the utilization of agronets seriously decreased pest infestation and enhanced quality, as pods from net-covered plots were 30% longer and 20% thicker than those harvested from the uncovered plants. Nevertheless, the impact of net covering on pod quality is variable since the concomitant changes in microclimate at the crop level depend on the growing season, the local climatic conditions, and the characteristics of the nets. Indeed, Selan et al. (2014) who used black hail net to cover four snap bean varieties grown in the field during spring-summer in Slovenia found that the photosynthetically active radiation (PAR) and the mean daily temperature under at the crop level were reduced by 30–75% and 2.4 °C, respectively. In the experiment of Selan et al. (2014), net covering decreased significantly the vitamin C content of pods in all varieties and the fructose and glucose concentration in the varieties producing yellow-colored pods. These reductions are attributed to the lower PAR levels under covering, as sugars and vitamin C production are linked to net photosynthesis.

The quality of green pea is also influenced by environmental conditions. Pea grown in a semi-arid Mediterranean environment showed higher green seed yield, lipid and starch content but lower protein, glucose, fructose and sucrose contents than those grown in another Mediterranean location characterized by arid climatic conditions and higher mean temperatures (Al-Karaki and Ereifej, 1997).

Overall, the environmental effects on morphological and nutritional quality traits of snap bean pods are strongly affected also by genotype × environment interactions. Indeed, De Ron et al. (2004) cultivated 121 common bean landraces in six different environments in Spain and found that fifty one of them were adapted to specific environments and only four of them exhibited a broad geographical adaptability with similar performance under different conditions. Irrespective of the genotype, all pod quality traits that were tested (mean pod weight, length, curvature, texture and color) were strongly affected by the growing environment and only pod shape (round or flat, as determined by width/thickness) was consistently expressed across all environments.

Another pod quality characteristic that is influenced by environmental conditions is the fiber content. A typical example is reported by Sistrunk et al. (1989), who found that high temperatures during pod development increase the fiber content in snap bean pods.

The use of brassinosteroids (BS) has been proposed as an alternative to alleviate the adverse effects of high temperatures on snap bean quality. As reported by El-Bassiony et al. (2012), foliar spraying of snap bean plants with the brassinosteroid analogue β -sitosterol at a dose of 25–100 mg L⁻¹ was effective in alleviating the heat stress during spring-summer when temperatures reached 35 °C. Brassinosteroids increased yield at all doses as well as pod weight and length when applied at 50 or 100 mg L⁻¹. Furthermore BS application increased also the levels of N, P, K, total phenolics, free aminoacids and proteins in snap

bean pods, to levels depending on the spraying concentration.

6.2. Impact of the root environment

The quality of legume vegetables may be influenced by both physical and chemical soil characteristics. With respect to the chemical soil characteristics, the nutrient availability has been addressed under the heading “fertilization”, while the soil pH is related to nutrient availability. The physical soil characteristics affect mainly the availability of air or water to the plants and may expose the roots to hypoxia or soil water deficit. To our best knowledge, currently no published data are available about the impact of waterlogging and other hypoxic conditions on quality characteristics of legume vegetables. Therefore, in this section, only the effects of soil water deficit and salinity on quality characteristics of legume vegetables will be addressed. Generally, legume crops are classified as either sensitive or moderately tolerant to salinity (Subbarao and Johansen, 1993). Nevertheless, considerable variability in salinity tolerance among these species has been found (Saxena et al., 1993).

Salinity has a strong impact on several quality traits of legume vegetables. In snap bean, De Pascale et al. (1997) found a significant reduction in the mean weight of pods when the water used to irrigate the plants contained 0.25 and 0.5% NaCl, compared with that of pods from non-salinized plants. According to Bhivare and Chavan (1987) exposure of snap beans to salinity adversely affects the translocation of photosynthetic products from the source leaf to growing pods. As reported by Osman and Salim (2016), a NaCl concentration of 2000 mg L⁻¹ (34.2 mM) in the water used to irrigate snap beans had no effect on pod length and width, but decreased pod mean weight while increasing the dry matter content, and induced pod curvature. NaCl markedly increased the free amino acid concentration in pods (from 0.8 to 6.5 mg g⁻¹ f.w.), although the respective increase in proteins was insignificant, and had a strikingly negative effect on the total soluble solids content in pods. Nevertheless, Rady (2011) and Howladar (2014) found significant reductions in the pod protein concentrations when snap bean plants were exposed to markedly higher levels of NaCl-salinity stress.

In faba bean (*Vicia faba* L.), which is also considered a salt sensitive plant species, increasing the salinity level in the irrigation water from 0.0125 to 1% NaCl decreased the mean fresh weight, the diameter and the length of the pod, as well as the number of seeds per pod and the mean weight of fresh seed, while increasing the dry matter percentage in pods. (De Pascale and Barbieri, 1997). Al-Tahir and Al-Abdulsalam, (1997) also found that faba bean responds with a reduction in the mean seed weight and the seed number per pod when it is exposed to high salinity levels. Nevertheless, exposure of faba bean to low salinity levels (up to 4 dS m⁻¹) has no impact on the number of seeds per pod (Katerji et al., 1992).

Snap beans are most sensitive to drought stress during flowering and pod sizing, and, therefore, exposure of plants to water deficit during this period has a strong impact on yield and pod quality (Sanders, 1993). As reported by Sezen et al. (2008), important parameters of marketing quality such as pod length and width, number of seeds per pod and mean pod weight are strongly reduced by inadequate water regimes in the soil. Furthermore, snap beans exposed to soil water deficit produce pods with reduced color brightness, as indicated by the L* parameter, increased greenness, as indicated by the a* parameter (Sezen et al., 2008) and a higher fiber content (Singer et al., 2003).

7. Conclusions and perspectives

The use of different legumes species as vegetables for fresh consumption is not yet very common, apart from the well-known green pods of beans, peas and faba beans, and immature seeds of peas and faba bean. To these typical products can be added immature pods and/or

immature seeds of soybean and some other underutilized legume species, which are not grown in many countries. A typical example is cowpea, which can bring into the market a good range of innovative products (Gonçalves et al., 2016; Karapanos et al., 2017), including young tender leaves. In this review we have shown that these legume species have relevant interest and benefits at both agronomic and nutritional levels and open good perspectives for improvement of the cropping systems and as well to create innovative food products.

Fostering the introduction of these crops in the agricultural systems has positive overall effects, since the crop growth period is much shorter than growing the same crop for dry seeds. However, this does not represent less plant biomass since the plant has already reached its maximum biomass potential, even in the root system where the biological nitrogen fixation has already been established. After harvesting the fresh product, the incorporation of this green biomass in the soil creates a much more beneficial impact on the soil physical and chemical characteristics. Legumes consumed as fresh vegetables are indeed short-season crops with all the benefits on crop rotations, costs of production and overall a more sustainable production, since the required general inputs are much lower. Since water is a very scarce resource, these short-season crops use less water and the water use efficiency is higher than in crops growing further till the production of dry seeds.

Regarding the nutritional quality, the consumption of vegetable protein needs to be increased to ensure a more sustainable use of natural resources, since, on average, the production of 1 kg of animal protein requires 5 kg of vegetable protein. Growing legumes to be consumed as fresh vegetables renders a high quality product when compared to other vegetables; the product can be much faster prepared than dry pulses fitting into the modern and more demanding consumption habits of consumers. Protein digestibility in immature snapped pods, which eventually is higher than in pulses, could be a focus of further studies. If this is proved, the high vitamin C content of pods, particularly in peas, the sugar content of pods and the quality of the dietary fibers in the hulls renders legume vegetables a very attractive product for consumers, which deserves a better dissemination.

There are substantial differences in quality features between legumes used either as vegetables or as dry pulses. The genetic features involved in the quality of legumes, which are very complex, are linked to relevant agronomic aspects and any change might influence the overall adaptation and performance of the crop to biotic and abiotic factors. Further work will be necessary in Fabaceae to elucidate links between genetic changes and the respective effects on the crop. The available biodiversity and the identified large variation in quality between genotypes on Fabaceae is an underutilized resource, still requiring further studies to expand our knowledge about the quality and uses of particularly minor crops cultivated for consumption either as fresh vegetables, or after freezing or canning.

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