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Culinary and nutritional quality of *Phaseolus vulgaris* seeds as affected by environmental factors

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Efficient selection for specific culinary and nutritional quality traits needs a better understanding of the genetic and environmental control of quality traits at the structural, physiological and biochemical levels. Field experiments indicate great variability in the *Phaseolus* gene pool regarding the content of antinutritional compounds, as well as in cooking characteristics of the seeds. These seed attributes are strongly affected by geographic location, edaphic and climatic conditions at site of cultivation. However, information on the influence of specific environmental factors (such as temperature, water availability, edaphic conditions, etc.) on seed quality traits, as well as on their stability is very scarce. This lack of knowledge impairs a faster progress in the improvement of *Phaseolus* seed quality.

Keywords. *Phaseolus vulgaris*, seed nutritional quality, seed culinary quality, flatulence, G×E effects, hard-to-cook.

Influence des facteurs environnementaux sur les qualités nutritionnelle et culinaire des graines de *Phaseolus vulgaris*. Une sélection efficace des caractères se rapportant aux qualités nutritionnelle et culinaire requiert une meilleure connaissance du contrôle génétique et environnemental de ces qualités aux niveaux structurel, physiologique et biochimique. Les expérimentations en champ indiquent une grande variabilité au sein du genre *Phaseolus* en relation avec la concentration en facteurs antinutritionnels et les caractéristiques de cuisson des graines. Ces propriétés des graines sont fortement influencées par la localisation géographique et les conditions édaphiques et climatiques du lieu de culture. Cependant, les informations concernant l'influence de facteurs environnementaux spécifiques (par exemple température, disponibilité en eau, conditions édaphiques) sur la qualité des graines et sa stabilité sont très restreintes. Cette absence de connaissance fiable ralentit les progrès dans l'amélioration des qualités nutrionnelle et culinaire des graines de *Phaseolus*.

Mots-clés. *Phaseolus vulgaris*, qualité nutritionnelle des graines, qualité culinaire des graines, flatulence, effet G×E, dureté à la cuisson.

1. STATE OFART, CONSTRAINTS AND FUTURE NEEDS

The main objectives of this paper are to review available information on the effects of abiotic environmental factors on the culinary and nutritional quality of *Phaseolus* seeds and to identify needs for future work.

The quality of bean seeds reaching the consumer depends on the characteristics of the seeds at harvest time, handling of the harvested seeds, storage conditions and processing technology. In turn, seed characteristics at harvest are determined by the cultivar genotype and by abiotic environmental factors acting during plant growth and seed development. Thus, efficient selection for specific culinary and nutritional quality traits will be improved by :

– better understanding of the genetic control of quality traits at the structural, physiological and biochemical levels,

– better assessment of the degree to which environmental factors (such as temperature, water availability, edaphic conditions, etc) influence these quality traits (trait stability).

An overview of the work published during the last years indicates that significant environmental effects on the quality of bean seeds have been found in several studies in which the interactions: Genotype × Location, or Genotype × Season (or Year) were examined (Shellie, Hosfield, 1991; Santalla *et al.*, 1995). The data are mostly related to seed size, content of protein, starch and soluble sugars, fat, minerals, seed hardness, water uptake by dry seeds and cooking characteristics. On the other hand, practically no information is available on environmental effects on the level of antinutritional factors present in the seeds. In the following, a short summary of the available information on abiotic environmental effects on culinary and nutritional traits of *Phaseolus* seeds is presented.

2. ENVIRONMENTAL EFFECTS ON CULINARY AND NUTRITIONALTRAITS

2.1. Fertilizer application to soils and seed nutritional quality

Application of nitrogen (Bengtsson, 1991) and sulphur (Hojjati, 1976; Sharma *et al.*, 1993), especially when these elements are limiting factors in the soil, usually increases seed content in proteins and in S-containing amino acids (e.g. methionine, cysteine), respectively. However, the large amounts of S required to increase S-rich amino acids in the seeds, as well as the high costs involved, limit the usefulness of this approach for improving protein quality.

2.2. Drought/irrigation effects

Drought stress during seed development reduces starch content and increases soluble sugar content in seeds. Soluble protein and amino acid contents were not affected by the stress (Pasin *et al.*, 1991).

2.3. The hard-to-cook problem

Bean seeds are generally soaked and must be cooked to render the seeds palatable to inactivate heat labile antinutritional components, and to allow the digestion and assimilation of protein and starch. Prolonged storage, especially under high temperature and high relative humidity (%RH) conditions that predominate in tropical regions, promotes the hard-to-cook defect. This irreversible change in the seed increases the time and fuel needed for preparation. Over cooking may also result in a loss of essential nutrients.

The need for prolonged cooking can be related to two different processes (Hohlberg, Stanley, 1987).

– Hardshell: when the seeds do not absorb enough water during cooking and therefore do not soften when cooked. This can be due to low permeability of the seed coat to water. Agbo *et al.* (1987) showed differences in micropyle size and in other microstructural differences that were related to seed coat permeability and water uptake by the seed.

– Hard-to-cook: when the seeds absorb enough water but fail to soften upon soaking and cooking.

Seed coat permeability, seed hardness and water absorption are affected by environmental factors and genetic × environment interactions (G×E) are usually present. In a detailed research performed with 10 dry bean cultivars in 3 locations in Rwanda — 1,400 masl (22 °C) and 1,700 masl (19 °C) both with 1,200 mm rain vs. 2,300 masl (16 °C) and 810 mm rain— environmental (location) effects and G×E interactions were found for cooking time, water absorption and protein content (Shellie, Hosfield, 1991). The "location" main effect for water absorption was significant. The amount of absorbed water corresponded with the average temperature and precipitation of a particular location. Seed at the driest and warmest location absorbed the largest amount of water while seed from the coolest and moistest location absorbed the least. This "location" effect on water absorption was due to factors intrinsic to the seed, and not to the moisture content of the seed at harvest. G×E for cooking time and protein content were much smaller. In another study in Canada with 20 bean cultivars produced in 3 different locations, the effects of storage at high temperature and RH on the hard-to-cook defect were indirectly evaluated by measuring seed hardness. G×E interactions accounted for 69% of the phenotypic variance of seed hardness after harvest (Michaels, Stanley, 1991). Significant G×E interactions for seed hardness and water absorption were also found in a three year study in Spain with 64 bean accessions grown in the same location (environmental effects were climatic differences among years in the same location) (Escribano *et al.*, 1997). G×E interactions for seed splitting and water absorption were found in processed seeds of navy and pinto bean cultivars (Ghaderi *et al.*, 1984).

Edaphic characteristics, like soil mineral content, also affect seed characteristics. Cooking time and seed hardness were increased by growing beans in a location with soils rich in Ca and Mg and higher average annual temperature (15–24°C), compared to a location with lower temperature (11–18°C) and soils poor in Mg and P (Paredes-Lopez *et al.*, 1989). Seeds produced on a calcic chernozem in Bulgaria needed a longer cooking time compared to those produced in soils with lower Ca levels (Stoyanova *et al.*, 1992). Zn application to soils poor in this element in Bulgaria reduced cooking time and percent of seed coat, while greater plant density tended to increase them.

Higher rainfall was associated with thinner seed coat and shorter cooking time. This suggest that rain effects on cooking time were due to changes in seed coat characteristics and in its permeability to water (Stamboliev *et al.*, 1995).

What are the processes during seed development that are regulated by the various environmental factors and affect the development of the hard-to-cook defect during storage ? When beans are cooked, native protopectin within the middle lamella forms a soluble pectin that depolymerises rapidly during heating and allows quick water entrance and movement trough cotyledonary cells (Stanley, Aguilera, 1985). A high state of cellular hydration and heating thus allows cells to soften and separate. Thus, it is conceivable that the hard-to-cook defect is the result of physical and chemical changes that occur in the cotyledons at the intercellular level during storage, resulting in an increased stability of the middle lamella.

Several processes have been proposed to explain the increase in middle lamella stability.

– Insolubilisation of the pectic substance due to the activation of phytases, phytate degradation during storage, release of cations and eventual crosslinking of pectins by formation of Ca and Mg pectinates, render the cells resistant to water penetration and swelling and to the subsequent failure of adjacent cells to separate upon cooking (Kilmer *et al.*, 1994). Loss of phytate in beans is faster at high temperature and RH during storage, conditions that enhance the hard-to-cook defect (Ockenden *et al.*, 1997).

– Lignification of the middle lamella: according to Hohlberg and Stanley (1987), proteins are degraded during storage, especially under both high temperature and RH, releasing small polypeptides and free aromatic acids that migrate to the middle lamella where polymerization/lignification reactions take place (polyphenol synthesis), catalyzed by peroxidases which are present in the seeds. Accumulation of lignin or other insoluble polymers in the middle lamella may cause failure in cell separation upon cooking. The co-appearance of small polypeptides and aromatic amino acids together with the development of the hard-to-cook defect during storage suggest a relation between these phenomena.

– Removal of methyl groups from pectins by pectinsterases.

– Oxidation of polyphenols assisted by oxidases or polyphenolases present in the seeds.

– Oxidation of lipids by lipoxygenases.

Environmental conditions during seed development may change the levels or activity of enzymes or substrates involved in the above reactions, thus indirectly affecting proneness to hard cooking of the seeds.

Several seed traits are correlated with cooking time.

– Slow cooking beans tend to imbibe less water than fast cooking beans. But the phenotypic correlation between cooking time and water absorption was relatively low ($r = -0.37$), to justify use of water absorption as an indirect selection method for cooking time (Shellie, Hosfield, 1991).

– Cooking time showed a positive correlation with seed size in 27 bean accessions grown in Tanzania, suggesting that small to medium seed size should be selected for shorter cooking time (Mwandemele, Nchimbi, 1992).

– Hard-to-cook defect caused by prolonged (5 years) storage at high temperature (30–40 °C) and >74% RH, was associated to an overall decrease in soluble N-fractions, particularly proteins, lower a-amylase inhibitors, an increase in lectins, but no changes in the content of trypsin and chemotrypsin inhibitors (Martin-Cabrejas *et al.*, 1995).

3. FLATULENCE PROMOTERS

Flatulence in humans is often the result of ingesting foods containing the oligosaccharides raffinose, stachyose and verbascose. Together with fructose these oligosaccharides represent the major reserves of soluble carbohydrates in seeds that are mobilized during the very early stages of germination. During maturation of bean seeds, sucrose and fructose content decrease while the content of raffinose, stachyose and verbascose increase (Meredith *et al.*, 1988). Although the human digestive system cannot degrade these oligosaccharides due to the lack of α-galactosidase, the microflora present in the lower intestine possess the enzyme and ferment these sugars producing intestinal gas.

Considerable variability exists between bean genotypes in oligosaccharide content. Content of raffinose and stachyose decreased with increase in seed size in 16 Polish cultivars (Kosson, 1989). However, very little is known about the effects of environmental factors acting during seed development on the levels of these oligosaccharides, even though large effects are expected. Drought stress during seed development increases soluble sugar content and reduces starch content in bean seeds (Pasin *et al.*, 1991).

4. ANTINUTRITIONAL FACTORS IN SEEDS

Several antinutritional factors are present in seeds, but practically nothing is known on environmental effects on their levels in the seeds.

– Phenolic compounds and tannins: total phenolic compounds increase during seed development until ca. 30 days after anthesis, but decreased thereafter in parallel to polymerization of tannins (Coelho, Lajolo, 1993). No information is available on environmental effects on these changes during seed development and in mature seeds. Tannin content, as well as polyphenoloxidase activity and associated changes in seed colour, also change during storage at rates that depend on storage temperature (Iaderoza *et al.*, 1989).

– Phytates: phytic acid is a chelating agent and is considered as an antinutrient factor because it can decrease the bioavailability of essential elements such as Ca, Fe, Mg, Zn. It is the main reservoir of P and other minerals in the seed that are mobilized with germination. Higher levels of P in the soil apparently increase phytate levels (Lott *et al.*, 1995).

– Trypsin and chemotrypsin inhibitors: lack of irrigation increased trypsin inhibitor activity in bean seeds (Nemeskeri, 1997).

– Lectins, arcelins and α-amylase inhibitors: similarities among arcelin variants, phytohaemagluttinin and α-amylase inhibitors in bean suggest that they are all encoded by related members of a lectin gene family (Hartweck *et al.*, 1991; Suzuki *et al.*, 1995). Arcelins are considered as insecticidal storage proteins, while α-amylase inhibitors confer seed resistance to bruchid beetles since these glycoproteins are toxic to their larvae. Genes of these proteins are candidates for genetic engineering approaches to make legume seeds resistant to bruchid infestations (Shade *et al.*, 1994).

5. CONCLUSIONS

Attempts are usually made to correlate quality response patterns and the climatic and edaphic characteristics that predominate in the different seasons and locations in which the seeds are produced. In this kind of approach, however, it is difficult to identify cause-effect relationships between quality traits and a specific acting external factor or combination of factors. This constraint can be partially solved by experimental work in which different genotypes showing contrasting differences in culinary and nutritional traits, as well as their hybrids, are grown under controlled conditions to study trait responses to changes in specific environmental factors (e.g. water availability, temperature, light intensity, fertilizer application, etc.). This approach will also allow an initial assessment of cultivar responses in the field to varied climatic conditions, irrigation treatments, etc.

Breeding for lower content of antinutritional factors seems to be possible in *Phaseolus* due to the wide variation in content present in the gene pool. However, the protective role of these factors needs to be assessed to avoid any adverse effect of breeding resulting in low content of antinutritional factors in the seeds.

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