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Review

Unraveling agronomic and genetic aspects of runner bean (*Phaseolus coccineus* L.)

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ABSTRACT

The (scarlet) runner bean (*Phaseolus coccineus* L.; $2n = 2x = 22$) is an allogamous legume species from Mesoamerica that is cultivated as an annual crop for dry seeds and immature green pods in several parts of the world. It is grown especially in small-scale agriculture. From an agronomic perspective, it is predominantly indeterminate and climbing type of growth is associated with high labor and materials required to grow the crop with support structures. Intercropping (i.e., maize-runner bean) and seed inoculation using bio-compounds (i.e., rhizobacteria) have resulted in more efficient resource utilization, reduced risk to the environment and diminished production costs, which are valuable practices linked to sustainable agriculture. Cold tolerance and hive management due to allogamy are also distinctive features of runner bean production that have been studied. From a genomic standpoint, runner bean has been very little studied, despite the abundant development of molecular markers and genome sequencing of other legumes in the last decade, and more specifically common bean (*P. vulgaris*). The high genetic variability of runner bean is precious for breeding purposes, particularly as a source of disease resistance and cold tolerance. However, the lack of characterization of the *P. coccineus* germplasm restricts its utilization as donor species for inter-specific hybridization, and consequently limits its use in other *Phaseolus* breeding programs (i.e., common bean). Developing more broadly adapted, determinate cultivars that facilitate mechanical harvesting, assessing the potential presence of heterosis for hybrid seed production, and characterizing the germplasm of *P. coccineus* more extensively are great challenges and opportunities in the future that would increase its cultivation on a broader scale worldwide.

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1. Introduction

The (scarlet) runner bean (*P. coccineus* L.) is probably the third-most important *Phaseolus* species worldwide, after *P. vulgaris* (common bean) and *P. lunatus* (lima bean) (Santalla et al., 2004). *P. coccineus* is a perennial species of the tropical humid uplands of Mesoamerica that can live up to 10 years, although outside this region, it is usually cultivated as an annual for dry seeds and immature green pods production because its aerial parts cannot tolerate frost (Duke, 1981; Rodiño et al., 2007). It is also grown occasionally as an ornamental because of its showy scarlet or white flowers located on long racemes extruding from the foliage, especially in climbing plants (P. Gepts, personal observation).

Runner bean has economic relevance only in specific parts of the world, being grown in Central America, South America, Africa and Europe (Giurcă, 2009). It is of minor importance in the United States (Mullins et al., 1999). *P. coccineus* was introduced as a crop into Europe by the Spaniards after the discovery of the Americas, probably along with *P. vulgaris* (Westphal, 1974). In the United Kingdom, the unripe pods are usually sliced longitudinally or obliquely, then boiled, and the dry beans are not consumed (Santalla et al., 2004). The importance of runner bean in the United Kingdom is due to its better adaptation to cool conditions than the common bean (Rodiño et al., 2007), which is reflected in the number of registered varieties of *P. coccineus* as compared to those of common bean (Department for Environment, Food and Rural Affairs and the Plant Variety Rights Office, 2002). In the Netherlands, young pods or dry seeds are consumed, but the crop is only grown in private gardens (Zeven et al., 1993). South Italy and Spain prefer climbing cultivars of runner beans producing white seeds (e.g., 'Corona'; Campion and Servetti, 1991), which are grown commercially and exported on a fairly small scale. The runner bean is also grown in Argentina where it is locally known as *pallar* (a vernacular name used for traditional native *P. lunatus* in Peru) (Voysest, 1983), but Parodi (1966) did not mention it among the crops of aborigen Argentina, letting to assume that *P. coccineus* is an historic introduction in this country. In addition, there is a small-scale production of *P. coccineus* in home gardens in Southern Chile, which relies on trellis support. As the runner bean is unable to reach total maturity in Southern Chile, the crop is harvested at the end of summer, when the plants show distinct vegetative and reproductive phases, and produce pods displaying different development stages at that time (Tay et al., 2008).

The runner bean is a source of variability for several traits for the genetic improvement of common bean (Gepts, 1981; Delgado-Salinas, 1988; Singh, 2001). This species possesses several useful agronomic and disease resistance traits such as lodging resistance due to thick stem bases, cold tolerance, long epicotyls and racemes, presence of a tuberous root system allowing a perennial cycle (Santalla et al., 2004), a potentially high number of pods per inflorescence (Vanderborght, 1983), and resistance to *Sclerotinia sclerotiorum* (Gilmore et al., 2002), *Ascochyta* blight (Schmit and Baudoin, 1992), and the resistance to root rot caused by *Pythium* or *Fusarium* (Dickson and Boettger, 1977), among others. The genetic improvement of common bean through interspecific hybridization requires, as a preliminary step, the characterization of the whole germplasm collections of the donor species in order to identify the best populations. Researchers have successfully introgressed from runner bean to common bean moderate levels of resistance for *Fusarium* root rot (Wallace, 1985), white mold (Miklas et al., 1998), and *Xanthomonas* bacterial blight (Zapata et al., 1985; Miklas et al., 1994a, 1994b). Wilkinson (1983) suggested that *P. coccineus* could be a potential source of high yield for common bean, although the release of commercial cultivars has been very limited so far (Hucl and Scoles, 1985; Singh, 1992, Santalla et al., 2004).

The objectives of this review are to examine the current agronomic, genomic and breeding status and advances of runner bean, focusing on the main challenges and opportunities that would allow the cultivation of *P. coccineus* on a broader scale.

2. Botanical-anatomical aspects and uses of *Phaseolus coccineus*

The *Phaseolus* genus comprises over 70 species, all of them from the Americas, and five domesticated taxa, *P. vulgaris* L., *P. lunatus* L., *P. acutifolius* A. Gray., *P. coccineus* L. and *P. dumosus* Macfady, which have distinct geographical distributions, life histories and reproductive systems (Maréchal et al., 1978; Gepts, 1996; Delgado-Salinas et al., 2006). The first scientist to make crosses with runner bean (then called *Phaseolus multiflorus*) was Gregor Mendel. In Mendel's work using pea crosses, he also performed crosses with *Phaseolus vulgaris* and runner bean (Mendel, 1866). Mendel could not confirm a 3:1 ratio in flower color segregation in the interspecific cross *P. vulgaris* (or *P. nanus*) x *P. multiflorus* (synonym for *P. coccineus*), a feature that has been observed later multiple times in interspecific crosses of *Phaseolus* (Guo et al., 1994) and other species.

P. coccineus is closely related to *Phaseolus dumosus* Macfad (synonym: *P. polyanthus* Greenman; year-bean, sometimes also called runner bean) and *Phaseolus costaricensis* (Freytag and Debouck, 2002). Hybrids between *P. coccineus* and these two species have been obtained, and natural hybridization can also occur. *P coccineus*, *P. dumosus* and *P. costaricensis* can be crossed with common bean, with the latter as female parent, without embryo rescue, although progenies are only partially viable and fertile depending on the parental combinations (Gepts, 1981; Shii et al., 1982; Singh et al., 2009). Where runner bean and common bean grow together, natural hybridization can occur (Wall, 1970; Acosta-Gallegos et al., 2007), possibly due to a close genetic relationship between *P. vulgaris* and *P. coccineus* (Smartt, 1970). Evans (1980) successfully obtained crosses between *P. vulgaris* and wild *P. coccineus* in both sexual directions. Moreover, Bassiri and Adams (1978) suggested that not only wild *P. vulgaris* contributed to the diversity and evolution of common bean in Central America but also wild *P. coccineus*. A similar suggestion was made by Liot and Hammer (1989). However, there is loss of viability and fertility in these crosses and the lack of transmission of some traits from *P. coccineus* to *P. vulgaris* has also been reported (Lamprecht, 1948a; Guo et al., 1994; Pathania et al., 2014). In addition, the formation of abnormal embryos in reciprocal crosses of these two species was the primary crossing barrier between them when *P. coccineus* was the female parent (Shii et al., 1982). In other reciprocal crosses using *P. coccineus* as the female parent, segregants naturally reverted to the cytoplasm donor parent (*P. vulgaris*) after a few generations (Baudoin et al., 1995). Ferwerda and Basset (2000) described the inheritance of two F_1 abnormalities in *P. vulgaris* × *P. coccineus* crosses: the "blocked cotyledon lethal" (BCL) and the crinkled leaf dwarf (CLD), both of which depend on the parental genotypic combination. The BCL trait is a seedling-lethal condition, whereas the CLD phenotype is sub-lethal, but not