Received: 27 May 2020 | Accepted: 29 July 2020

DOI: 10.1002/plr2.20084

Journal of Plant Registrations

REGISTRATION

Cultivar

Registration of 'UC Tiger's Eye' heirloom-like dry bean

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Funding information
Western SARE, Grant/AwardNumber: 2016-38640-25383; Clif Bar Family Foundation; Lundberg Family Farms;USDA-OREI, Grant/AwardNumber: 2015-51300-24157; RiodelReyFarm

Registration by CSSA.

Abstract

'UC Tiger's Eye' (Reg. no. CV-336, PI 693473) is a BC_3F_7 line of common bean (*Phaseolus vulgaris* L.) bred by recurrent backcrossing between the heirloom Tiger's Eye (recurrent parent) and UC Canario 707 (donor parent). It produces edible seed similar to the heirloom parent but is resistant to *Bean common mosaic virus* and provided 28% higher yields in multiyear, multilocation replicated trials on organic farms. Cooking evaluations have also shown that its culinary quality is similar to Tiger's Eye. UC Tiger's Eye will serve a growing market interest in heirloom-type common bean with improved agronomic properties.

1 | INTRODUCTION

'UC Tiger's Eye' (Reg. no. CV-336, PI 693473) is a BC_3F_7 common bean (*Phaseolus vulgaris* L.) developed by recurrent backcrossing between the heirloom Tiger's Eye (recurrent parent) and UC Canario 0707 (donor parent), with the pedigree Tiger's Eye*4/UC Canario 0707. The seed coat pattern of UC Tiger's Eye is similar to that of Tiger's Eye, with dark reddish purple stripes on a yellow background (Figure 1). Heirloom bean types, including Tiger's Eye, can be sold for a premium due to a reputation for culinary quality and desirable seed colors (Brouwer, Winkler, Atterberry, Jones, & Miles, 2016; Walters, Brick, & Ogg, 2015). Heirloom genotypes are typically defined as existing for at least 50 yr (DeMuth, 1998) or being passed between generations (Brouwer et al., 2016). The term *heirloom* is therefore somewhat overlapping with the term *landrace*, which refers to genotypes that have been selected over long periods of time for performance under specific ecogeographic conditions. Both heirloom genotypes and landraces often exhibit unique phenotypic characteristics that are absent in major market classes, and there are often niche markets for these. Restaurant managers and consumers at farmers market have been shown to be willing to pay an average of US$10.52 to $17.60/kg for locally and organically produced heirloom bean (Swegarden, Sheaffer, & Michaels, 2016). Despite this, Tiger's Eye suffers from relatively low yields and susceptibility to *Bean common mosaic virus* (BCMV). UC Canario 0707, the donor parent, was developed by the University of California Agricultural Experiment Station as a high yielding, heat tolerant, type I determinate canario bean (Palkovic et al., 2015). UC Canario 0707 has *I* gene-mediated resistance to BCMV. The *I* allele provides immunity or hypersensitive field-level resistance against all known races of BCMV and *Bean common mosaic necrosis virus* (Feng, Poplawsky, Nikolaeva, Myers, & Karasev, 2014). All new North American common bean cultivars are expected to have BCMV resistance (Haley, Afanador, & Kelly, 1994; Miklas, Kelly, Beebe, & Blair, 2006), without which plants can rapidly accumulate the virus due to mechanical-, seed-, or aphid-mediated transmission (Schwartz & Pastor-Corrales, 1989). *Bean common mosaic virus* is a seed-transmitted disease and can accumulate in seed lots if genetic resistance is not present in a cultivar. Currently, few specialty heirloom-like cultivars combine attractive seed color qualities with high

Abbreviations: BCMV, *Bean common mosaic virus*.

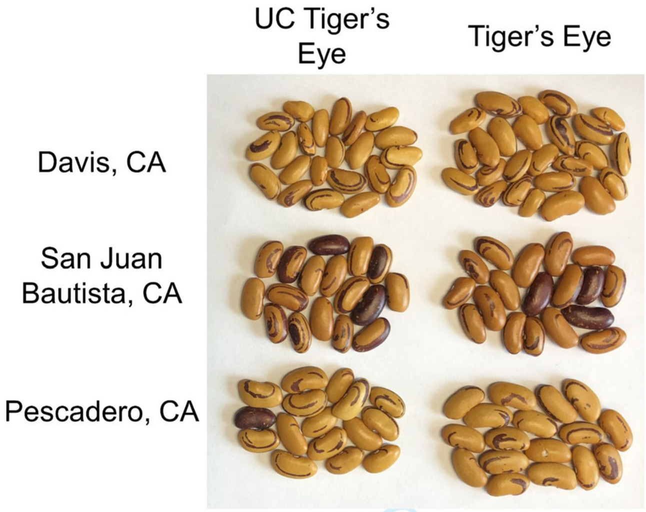

FIGURE 1 Seed of UC Tiger's Eye and Tiger's Eye have a consistent pattern between environments. Occasional "reverse-color" types that are primarily dark with a small amount of lighter color is common for types with *C* locus-mediated stripes and spots. The pattern is not heritable and progeny have the original seed pattern at the typical ratios (Bassett, 2007)

Core Ideas

- Heirloom-like dry bean types are high-value alternatives to major market classes, especially for the organic sector.
- Phenotypic and marker-assisted selection were used to develop UC Tiger's Eye dry bean.
- UC Tiger's Eye has improved disease resistance and yield.
- It maintains heirloom seed and culinary traits.

yields and BCMV resistance. UC Tiger's Eye will help satisfy this market opportunity.

The parents of UC Tiger's Eye each have type T phaseolin (Kami, Velásquez, Debouck, & Gepts, 1995), indicating that they are Andean (Gepts, Osborn, Rashka, & Bliss, 1986). This combination reduces the potential expression of autoimmune-related hybrid inviability, which sometimes occurs in types descended from crosses between gene pools (Gepts & Bliss, 1985; Hannah et al., 2007; Kelly, 1988, 2018; Koinange & Gepts, 1992). Several lines of evidence indicate that the recurrent parent is a member of race Nueva Granada, including its phaseolin type, seed size, shape, phenology, and tough pods (Singh et al. 1991). It is very similar to (and likely synonymous with) the landrace Pepa de Zapallo (PI 282054, G5789), which was collected in Chile in 1962. Tiger's Eye's early maturity and robust productivity across climates make it a popular heirloom across much of North America (Garretson, Tyl, & Marti, 2018; Swegarden et al., 2016), where it is grown at least as far as northern Maine (Jim Gerritsen, personal communication, 2016). The recurrent parent, Tiger's Eye, is not protected by plant variety protection (database available at https://apps.ams.usda.gov/CMS/CropSearch.aspx) or utility patents (database available at http://patft.uspto.gov/netahtml/PTO/search-adv.htm) and is eligible for use in breeding.

2 | METHODS

Tiger's Eye and UC Canario 0707 were first cross-pollinated in 2015, with three subsequent generations of backcrossing to Tiger's Eye. In each generation, plants carrying the *I* allele for BCMV resistance were identified through greenhouse inoculations and the use of a CAPS marker (Bello et al., 2014). Inoculations were conducted at 7 d after planting. To inoculate, a 1:10 mixture of (a) BCMV-infected leaf tissue and (b) pH 7.4 0.01 M potassium phosphate was ground together using a mortar and pestle. The non-necrotic type strain NL 1 (Drijfhout, 1978) was used for inoculations. A small amount of Celite was added to the first simple true leaves, and the pestle was used to gently grind the inoculum into the leaves. In susceptible plants, this led to symptoms within 2 wk, which peaked in intensity approximately 1 mo after planting. Virus-resistant plants were then used as parents for further backcrossing. The CAPS marker was used to identify individuals in the BC_3F_2 generation that were homozygous resistant to BCMV. UC Tiger's Eye is descended from two of these homozygous resistant plants. All generations after the BC_3F_2s were bulk harvested.

A single plot of UC Tiger's Eye was grown in 2017 due to limited seed availability. The 2018–2019 plantings used randomized complete block designs with three replications in each field. Plots of UC Tiger's Eye and Tiger's Eye were planted into one block at one location in 2017. This plot included 30 plants in 3 m of row length and 2.3 m^2 of total field area. The 2018–2019 trials included three plots grown at each of three locations each year. Each plot consisted of 120 seeds planted into 12.2 m of row space and 9.3 m^2 of total ground area. All trials took place on certified organic land. To improve nodulation, the seed were inoculated with Guard-N N_2–fixing bacteria immediately before planting. A randomized complete block design was used for all environments. Yield of UC Tiger's Eye and its heirloom parent were compared by paired *t*-test of block data. To avoid seed contamination and mixture during on-farm trials, UC Tiger's Eye and its recurrent parent were never grown in adjacent plots. Instead, at least one plot of a phenotypically distinct cultivar separated them in all locations and years. After producing breeder seed, 15 plants were greenhouse grown and inoculated with BCMV following the same procedure used during backcrossing. None of these plants developed symptoms, while a single susceptible control ('Zuni Gold') did show symptoms of infection.

TABLE 1 Yield and *Bean common mosaic virus* (BCMV) comparison between UC Tiger's Eye and Tiger's Eye by year, location, and block

Year	Location	Yield		BCMV observed[a]	
		UC Tiger's Eye	Tiger's Eye	UC Tiger's Eye	Tiger's Eye
		kg ha^{-1}			
2018	Davis	1,138	690	−	+
	San Juan Bautista	2,256	1,842	−	+
	Valley Center	1,183	903	−	−
2019	Davis	1,787	1,186	−	+
	Pescadero	1,546	1,282	n.d.	n.d.
	Valley Center	663	782	−	+
Mean		1,429*	1,114	0%	80%

[a]+ indicates symptoms present; − indicates symptoms absent; n.d. indicates no data.
*Indicates significant difference ($p < .05$), paired two-tailed *t*-test of block data.

The culinary quality of UC Tiger's Eye and Tiger's Eye was also tested through a flavor evaluation. Samples of both types were soaked for 8 h in a 0.15% salt solution, then boiled for 10 min and simmered on low heat for 20 additional minutes. Half way through the simmer, 1.5 g of salt was added for each 100 g of dry seed used initially. The samples were cooked at the same time and in identical vessels and were kept uniformly warm in a hot water bath. Samples of each type were given random numbers to conceal their identity to evaluators. The samples were served to participants in a randomized order. Evaluators were asked to judge the (a) flavor quality and (b) cooked visual appearance on a 1–5 scale, with 1 being inferior and 5 being superior. These measures were intended to reflect the desirability of each type to a typical consumer, and evaluators were not given training on what they should desire in terms of flavor or patterns. The data were analyzed by paired *t*-test, controlling for the effect of evaluator.

TABLE 2 Taste test and cooked appearance of Tiger's Eye and UC Tiger's Eye (1–5 scale, 1 = inferior, 5 = superior)

Score	Tiger's Eye	UC Tiger's Eye
Flavor		
Mean	3.51	3.51
SD	0.96	0.99
SE	0.16	0.17
n	34	34
Paired t-test *p* value	1.00	
Cooked appearance		
Mean	2.95	3.35
SD	0.76	0.99
SE	0.14	0.18
n	30	30
Paired *t*-test *p* value	.08	

3 | CHARACTERISTICS

UC Tiger's Eye has production characteristics and edible seed similar to Tiger's Eye (Figure 1), with improved yields and BCMV resistance (Table 1). No UC Tiger's Eye plants developed BCMV symptoms at any field site. In contrast, the presence of the disease was confirmed in Tiger's Eye at four of five field locations (Table 1). UC Tiger's Eye had higher yields on average (1,429 kg/ha) than Tiger's Eye (1,114 kg/ha) in the 2018–2019 trials. This difference was statistically significant ($p = .012$, paired two-sample two-tailed *t*-test, Table 1). UC Tiger's Eye had an identical flavor score as Tiger's Eye, and there was no significant difference in cooked appearance ($p = 1.0$ and $p = .08$, respectively, paired two-sample *t*-test, Table 2). This indicates that UC Tiger's Eye is of the same culinary quality as its heirloom parent.

Seed of UC Tiger's Eye have dark reddish-purple stripes on a yellow background, similar to Tiger's Eye (Figure 1). During the growing season, the cultivar displays a compact habit with a short, indeterminate type IIIa vine (Singh, 1982). Flowers are white and stems are green. Leaves often have a slightly yellow hue with a rough texture. Fifty percent of plants flowered by 39 d after planting at Davis in 2019, comparable to 40 days for Tiger's Eye. UC Tiger's Eye is fast to mature, at just 85 days from planting to harvest at Davis in 2019, compared with 90 d for Tiger's Eye. The 100-seed weight of the cultivar is 58 g, comparable to 55 g for Tiger's Eye. The color of seed grown in variable environments is very similar (Figure 1).

Beans with stripes and spots caused by the *C* locus, including UC Tiger's Eye, cranberry types, and the pinto market class, will produce a small percentage of seed with a reverse color pattern (Bassett, 2007). For UC Tiger's Eye, these will be primarily dark red-purple with small yellow patches or stripes. The progeny of these individuals revert to the typical color pattern (yellow with dark red-purple stripes), and they need not be removed from the population.

UC Tiger's Eye produced higher yields than Tiger's Eye across diverse environments. Both Davis (July average high/low temperatures = 34/14 ˚C) and Valley Center (July averages = 33/15 ˚C) have warm summers, and in these environments UC Tiger's Eye produced yields of 1143 kg/ha on average. In the same locations, Tiger's Eye yielded an average of 890 kg/ha. This is a 34% yield increase for the improved cultivar. In the moderate climate of San Juan Bautista (July averages = 27/12 ˚C), UC Tiger's Eye yielded 2,256 kg/ha compared with Tiger's Eye's 1,842 kg/ha (+22%). In the coolest location, Pescadero (July averages = 22/11 ˚C), UC Tiger's Eye yielded an average of 1,546 kg/ha versus Tiger's Eye's 1,282 kg/ha (+21%). UC Tiger's Eye is a strong competitor against Tiger's Eye in diverse environments.

UC Tiger's Eye and Tiger's Eye both have compact and relatively low growth habits. This makes them poorly suited to direct harvest and, in humid regions, may lead to issues with fungal and bacterial pathogens. A more upright growth habit could be achieved in the future by introgression of the lodging-resistance locus of chromosome Pv07 (MacQueen et al., 2020; Moghaddam et al., 2016; Parker, Palkovic, & Gepts, 2020). Planting UC Tiger's Eye at relatively high density (e.g., 5-cm spacing) may also be ideal due to the cultivar's compact structure. This is particularly true if seed are handled roughly during cleaning, which may disproportionately damage large-seeded types like UC Tiger's Eye. UC Tiger's Eye and Tiger's Eye both express pod shattering if pods are left in the field several weeks after maturity, particularly in arid climates. The genetic control of this trait has recently been discovered (Rau et al., 2019; Parker, Berny Mier y Teran, Palkovic, Jernstedt, & Gepts, 2020; Parker, Sousa, Floriani, Palkovic, & Gepts, 2020) and could be the basis of further improvement in the cultivar.

UC Tiger's Eye was developed through both marker-assisted genetic selection and phenotypic selection. This allowed the combination of the strengths of each method (Beaver & Osorno, 2009). The use of genetic markers, for example, allowed the rapid and efficient identification of homozygous resistant individuals without the need for extensive progeny testing, while phenotypic screens eliminated the chance of undesirable recombination between the marker and underlying gene during backcrossing. The combination between genotypic- and phenotypic-based selection may be of increasing importance for plant breeding.

4 | AVAILABILITY

Breeder seed has been provided to the UC Davis Foundation Seed Program, which will produce and distribute seed for this cultivar. Small quantities of seed for breeding and research may be available through the corresponding author. Seed has also been deposited with the USDA–ARS National Plant Germplasm System, where it will be available immediately upon publication.

AUTHOR CONTRIBUTIONS

Travis Parker: Parent evaluation; Methodology planning; Crosses; Field trial design and management; Genotyping; Phenotyping; Intern mentorship; Data analysis and selections; Manuscript writing. **Antonia Palkovic**: Parent evaluation; Field trial design and management; Intern mentorship. **E. Charles Brummer**: Conceptualization; Funding acquisition. **Paul Gepts**: Conceptualization; Parent evaluation; Methodology planning; Manuscript writing; Funding acquisition. All authors have read and approved the final draft of the manuscript.

ACKNOWLEDGMENTS

Mike and Chris Reeske managed trials at their farm (Rio del Rey Farm), provided guidance, and provided financial support for the project. Steve Peters, Yolanda Guzman, Angelina Bahena, Laura Roser, Ariel Herrera, Jose Pimentel, Natalie Hamada, Emily Yang, Matthew Bustamante, Emily White, Julia Gonzales, Paige Augello, Vivian Wu, Nathalie Gonzalez, Aung Nyein, and Talissa de Oliveira Floriani contributed to field management and phenotyping. Jim Muck and Raoul Adamchak of the UC Davis Student Farm assisted in farm management. Collaborating farms include Rio del Rey Farms, Coke Farms, and Fifth Crow Farms. The project was funded by the Clif Bar Family Foundation, Lundberg Family Farms, the Organic Agriculture Research & Extension Initiative Grant no. 2015-51300-24157/Project Accession no. 1007379 from the USDA National Institute of Food and Agriculture, and USDA–Western SARE Award no. 2016-38640-25383, Subaward no. 200592-448 (Project no. GW18-062).

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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How to cite this article: Parker T, Palkovic A, Brummer EC, Gepts P. Registration of 'UC Tiger's Eye' Heirloom-like Dry Bean. *J. Plant Regist*. 2020;1–5. https://doi.org/10.1002/plr2.20084