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Cultivar

Registration of 'UC Sunrise' heirloom-like orange and white mottled bean

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Registration by CSSA.

Abstract
'UC Sunrise' (Reg. no. CV-333, PI 693474) is a new cultivar of common bean (*Phaseolus vulgaris* L.) developed by crossing the heirloom type 'Zuni Gold' with UCD 9634 pink bean. UC Sunrise has a seed type similar to heirloom cultivars such as Zuni Gold but is resistant to *Bean common mosaic virus* (BCMV) and has yields 50% higher than its heirloom parent. Tastings have also demonstrated that it maintains culinary quality similar to its heirloom parent. All evaluations were conducted on certified organic farms. UC Sunrise will help fill a growing interest in heirloom-like dry bean with improved agronomic performance.

1 | INTRODUCTION

'UC Sunrise' (Reg. no. CV-333, PI 693474) is an $F_{5:9}$ dry bean (*Phaseolus vulgaris* L.) line descended from a cross between gold and white mottled 'Zuni Gold' and UCD 9634 pink bean. Zuni Gold is an heirloom cultivar from the Four Corners region of the southwestern United States. Heirloom bean cultivars have high market values due to a reputation for culinary qualities and seed coat patterns (Swegarden, Sheaffer, & Michaels, 2016). Cultivars with these patterns remain extremely popular in the southwestern United States, where they are known from the archaeological record to have existed since prehistoric times (Kaplan, 1956). Zuni Gold suffers from relatively low and inconsistent yields, long season length, and susceptibility to *Bean common mosaic virus* (BCMV) (Palkovic, Parker, & Gepts, 2015). UCD 9634 was developed by the University of California Agricultural Experiment Station from the cross Yolano/BAT 1763 as a high yielding, heat-tolerant, medium season length, type II-B growth habit pink bean breeding line (Palkovic et al., 2015). UCD 9634 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). In UCD 9634, *I* is tightly linked with the recessive *b* seed coat allele, which allows for expression of many lighter seed coat colors. The *I-b* haplotype is ultimately derived from G6616 'Pompadour Checa', which was one of the first cultivars to combine the *I* and *b* alleles in CIAT breeding programs (Kelly, 1988a). Both Zuni Gold and UCD 9634 have type S phaseolin (Parker, Palkovic, & Gepts, 2015), indicating that the two cultivars both descend from the same (Middle American) gene pool of common bean (Gepts, Osborn, Rashka, & Bliss, 1986; Kami et al. 1995). Descent from the same gene pool decreases or eliminates the potential occurrence of hybrid inviability occasionally observed in inter-gene-pool crosses (Gepts & Bliss, 1985; Kelly, 1988b, 2018; Koinange & Gepts, 1992; Hannah et al., 2007). The parents of UC Sunrise are not protected by utility patents (database available at http://patft.uspto.gov/netahtml/PTO/search-adv.htm, accessed 30 Jan. 2020).

UC Sunrise is intended to serve as an alternative to Zuni Gold and other similar heirloom cultivars but with the introduction of BCMV resistance and improved yields. The informal yet well-enforced agreement among bean breeding programs in the United States and Canada calls for BCMV resistance in all bean cultivars (Haley, Afanador, & Kelly, 1994; Miklas, Kelly, Beebe, & Blair, 2006). Absence of this

Abbreviations: BCMV, *Bean common mosaic virus*.

resistance results in rapid accumulation of the virus in seed stocks because it is transmitted mechanically, by seed, and by aphids (Schwartz & Pastor-Corrales, 1989).

UC Sunrise is intended primarily for production in the western United States, particularly for organic producers. These producers often sell their products directly to consumers at farmers' markets or through online stores or indirectly to health food stores and restaurants. The specialty "heirloom-like" types are chosen because their seed color pattern is considered attractive by customers and consumers, unlike the main commercial classes (like navy, black, great northern, and kidney beans), which are usually self-colored (Brouwer, Winkler, Atterberry, Jones, & Miles, 2016; Walters, Brick, & Ogg, 2015). Furthermore, they are reputed to have high culinary quality in terms of flavor and texture profiles (Sando, 2011), although this remains to be confirmed in direct comparisons with mainstream, commercial classes. Consumer-demand studies have determined that restaurant managers who use heirloom cultivars are on average willing to pay US$10.52/kg for organic, locally produced heirloom beans. Participating consumers at farmers' markets showed willingness to pay an average of between $13.20 and $17.60/kg for the same products (Swegarden et al., 2016). Currently, few specialty heirloom-like cultivars combine attractive seed patterns with BCMV resistance and high yields. UC Sunrise will help fill this market demand.

Core Ideas

- UC Sunrise has heirloom-like culinary qualities.
- It has improved yields and *Bean common mosaic virus* resistance.
- UC Sunrise was bred in organic environments, making it uniquely suited to these conditions.

2 | METHODS

Initial crosses between Zuni Gold and UCD 9634 were made in late 2015. F_1 and F_2 plants were grown in a greenhouse during the winter and spring of 2016, respectively. One hundred nineteen F_3 families derived from this cross, each consisting of 30 individuals, were field grown in summer 2016 on organically managed (transitional organic) ground in Knight's Landing, CA, as an initial observational screening. The F_4 and F_5 progenitors of UC Sunrise were grown in the greenhouse in winter and spring 2017 and showed resistance to BCMV upon inoculation. UC Sunrise is the F_9 bulk-harvested progeny of a single F_5 progenitor.

Field BCMV screenings were complemented by greenhouse inoculations and screening with a CAPS marker (Bello et al., 2014) at the F_8 generation, which indicated that all sampled plants were homozygous resistant to BCMV. The nonnecrotic type strain NL 1 was used for inoculations (Drijfhout et al., 1978). Selections in 2016 and 2017 focused on virus resistance and desirable seed color. Starting in 2017, selections were also made at the certified organic University of California–Davis student farm for yield. Based on these preliminary results, UC Sunrise was entered into multilocation replicated yield trials in 2018 and 2019. The 2018–2019 plantings used randomized complete block designs and included three plots grown at each of three locations each year. Each plot was 9.3 m^2 in area and included 120 planted seeds planted into 12.2 m of row space. All trials were conducted on certified organic ground, and seeds were inoculated with Guard-N N_2–fixing bacteria before planting.

Seed weight was determined by weighing nine groups of 100 seeds for each genotype. These were sampled from three plots at each of three field sites, spanning the range from the coolest (Pescadero), to the intermediate (San Juan Bautista), and the warmest (Davis) locations. Culinary quality of UC Sunrise and Zuni Gold was evaluated in terms of flavor (1–5 scale) and cooked visual appearance (1–5 scale). In this evaluation, samples were randomized and labeled with three-letter codes to obscure the identity of each cultivar. The heirloom and improved types were cooked at the same time and in identical vessels based on a standard bean-cooking method provided by a grower who conducts taste tests routinely, ultimately based on recommendations from collaborating chefs. The preparation process involved an 8-h soak in a 0.15% NaCl–water solution. Before cooking, the salt-water solution was drained and replaced with water. The beans were brought to a boil for 10 min, then the heat was reduced to a low simmer for 20 further min. During the taste test, cooked samples were kept uniformly warm in a hot water bath. The meaning of each number in the 1–5 scale for each trait was determined by the evaluator. The intention of the evaluation was to gain an unbiased understanding of what the general public would think of each cultivar, so evaluators were not given any training regarding what they should desire in flavor, appearance, or quality traits. Instead, they were free to interpret ideal visual appearance and flavor as they saw fit. Thirty pairs of responses were collected for flavor and 28 were collected for cooked visual appearance. Each of these was an evaluation of the two cultivars by a single individual taster. Statistical analysis was conducted by a paired *t*-test between the new and pre-existing cultivars based on taster.

3 | CHARACTERISTICS

UC Sunrise produces characteristic orange and white mottled seed, somewhat similar to the Zuni Gold parent and the

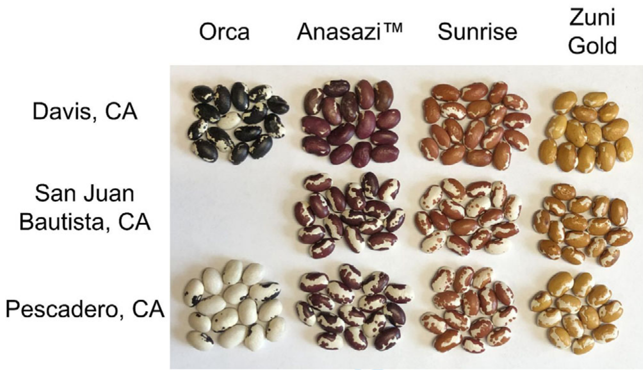

FIGURE 1 Seed type of Orca, Anasazi, UC Sunrise, and Zuni Gold across several field trial locations

heirloom 'Anasazi' (Adobe Milling; Figure 1). Plants have green stems and white flowers, with a type III growth habit (Singh, 1982). Time to 50% flowering and maturity were 46 and 101 d after planting, respectively, in Davis in 2019. Late in the season, plants display strong and uniform dry-down and provide high yields. The existence of white mottling on the seeds is highly consistent, but the extent of the colored area varies based on local environmental conditions in a way similar to other university-released mottled cultivars, such as 'Orca' (Hang, Silbernagel, & Miklas, 2003; Figure 1). UC Sunrise and Zuni Gold both have 100-seed weights of 32 g.

UC Sunrise has edible seed that are phenotypically similar to Zuni Gold (Figure 1) but provides higher yields and BCMV resistance (Table 1). During the 2018–2019 multilocation replicated yield trials, UC Sunrise averaged 1,938 kg/ha compared with Zuni Gold's 1,288 kg/ha. This represents a yield improvement of 50.5% relative to Zuni Gold. This difference is statistically significant (p = .015, paired two-tailed two-sample t-test, Table 1). No UC Sunrise plants developed BCMV symptoms at any field site in any year between 2017 and 2019. In contrast, the presence of the disease was strong in the susceptible Zuni Gold and other heirloom plots, which were planted as controls and as a source of virus (Table 1). No symptoms of any other virus infection, such as *Beet curly top virus*, were noted, and the Middle American origin of UC Sunrise indicates that it probably has full or partial resistance to *Beet curly top virus* (Larsen & Miklas, 2004). UC Sunrise had similar scores to Zuni Gold for both flavor and cooked appearance, and the difference between the two was not significant (p = .43 and p = .49, respectively, paired two-sample t-test, Table 2). This indicates that UC Sunrise is of comparable culinary quality to Zuni Gold.

UC Sunrise may be particularly resistant to heat stress relative to Zuni Gold. In the warm-season climates of Davis (July average high/low temperature = 34/14 ˚C) and Valley Center (July averages = 33/15 ˚C), UC Sunrise produced average yields of 1,326 kg/ha, whereas Zuni Gold produced yields of 654 kg/ha. This represents a yield improvement of 103%. The difference was less pronounced in the cooler climates of San Juan Bautista (July averages = 27/12 ˚C) and Pescadero (July averages = 22/11 ˚C), where UC Sunrise averaged 3,162 kg/ha compared with 2,555 kg/ha for Zuni Gold, a difference of 24%. In addition to providing higher yields, UC Sunrise may also mature more quickly than Zuni Gold. In Davis in 2019, the three UC Sunrise plots reached harvest maturity in 100–102 d, while none of the three Zuni Gold plots were at harvest maturity at 108 d after planting. The extent to which yield improvement is due to BCMV resistance versus other genetic factors is not yet entirely clear. In similar programs with backcrossing for BCMV resistance alone, yield increases ranged from 19–28% (Parker, Palkovic, Brummer, & Gepts, 2020a, 2020b), whereas the pedigree method with selection for yield in addition to BCMV resistance improved yields by 51–60% (Parker, Palkovic, Brummer, & Gepts, 2020c, 2020d). This indicates that the yield improvement of UC Sunrise may be the result of both BCMV resistance and other genetic factors.

UC Sunrise expresses a relatively large type III growth habit. This trait is common in many cultivars of common bean and may be useful for weed suppression but makes the

TABLE 1 Yield and *Bean common mosaic virus* (BCMV) observation comparison between UC Sunrise and Zuni Gold by year and location

		Yield		BCMV observed	
Year	**Location**	**UC Sunrise**	**Zuni Gold**	**UC Sunrise**	**Zuni Gold**
		——kg ha^{-1}——			
2018	Davis	200	187	–	+
	San Juan Bautista	4,177	2,757	–	+
	Valley Center	565	230	–	+
2019	Davis	3,107	1,216	–	+
	Pescadero	2,148	2,353	n.d.	n.d.
	Valley Center	1,433	982	–	+
Mean		1,938*	1,288	0%	100%

[a] + indicates the presence of BCMV symptoms, – represents the absence of virus symptoms, n.d. represents no data collected.
*Significant difference (p < .05) by a paired two-tailed t-test of block data.

TABLE 2 Taste test and cooked appearance evaluation of Zuni Gold and UC Sunrise (1–5 scale, where 1 indicates inferior and 5 indicates superior)

	Zuni Gold	UC Sunrise
Flavor score		
Mean	3.27	3.45
SD	1.09	0.99
SE	0.20	0.18
n	30	30
Paired *t*-test *p* value	.43	
Cooked appearance score		
Mean	3.43	3.57
SD	1.02	1.01
SE	0.19	0.19
n	28	28
Paired *t*-test *p*	.49	

cultivar poorly suited to direct harvest. This growth habit can also lead to greater humidity in the plant canopy, exacerbating certain fungal and bacterial diseases when bean is grown in humid climates, such as the eastern United States. In the western United States, semiarid conditions typically prevent these diseases from being problematic. Zuni Gold and UCD 9634 also display viney or semi-viney growth habits and are therefore also susceptible to these lodging-related issues. This trait is largely controlled by a major locus on chromosome Pv07, and incorporating the lodging-resistant allele could be a goal of future breeding projects (MacQueen et al., 2020; Moghaddam et al., 2016; Parker, Palkovic, & Gepts, 2020). Growers in humid regions should evaluate UC Sunrise under their local conditions before planting it on a large scale. Both parents of UC Sunrise have resistance to pod shattering mediated by *PvPdh1* (Parker, Berny Mier y Teran, Palkovic, Jernstedt, & Gepts, 2020), and UC Sunrise displays very low levels of shattering in the field.

Cultivars of common bean with *t*-locus-based seed coat mottling show variable amounts of colored area on the seed due to local environmental conditions. The colored area may be positively related to temperature during pod set, although little information is available on the causes of the difference.

4 | AVAILABILITY

Breeder seed has been provided to the UC Davis Foundation Seed Program, which will produce and distribute seed for this variety. 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 and will be available immediately upon publication. Seed is also available from the corresponding author.

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AUTHOR CONTRIBUTIONS

Travis Parker: Parent evaluation; Methodology planning; Crosses; Methodology planning; 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.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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