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REGISTRATION

Cultivar

Release of tepary bean cultivar 'USDA Fortuna' with improved disease and insect resistance, seed size, and culinary quality

Timothy G. Porch[1] | **Juan Carlos Rosas**[2] | **Karen Cichy**[3] | **Graciela Godoy Lutz**[4] | **Iveth Rodriguez**[5] | **Raphael W. Colbert**[6,†] | **Gasner Demosthene**[7] | **Juan Carlos Hernández**[8] | **Donna M. Winham**[9] | **James S. Beaver**[10]

[1]USDA-ARS, Tropical Agriculture Research Station, Mayagüez, Puerto Rico

[2]Zamorano University, Tegucigalpa, Honduras

[3]USDA-ARS, Sugarbeet and Bean Research Unit, East Lansing, MI, USA

[4]Instituto Dominicano de Investigaciones Agropecuarias y Forestales, Estación Experimental de Arroyo Loro, San Juan de la Maguana, República Dominicana

[5]Zamorano University, Tegucigalpa, Honduras

[6]Quisqueya University and Feed the Future Haiti-AREA, Port-au-Prince, Haiti

[7]Service National Semencier, Bâtiment Protection des Végétaux, Ministère de L'Agriculture, Port-au-Prince, Haiti

[8]Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria (INTA), San José, Costa Rica

[9]Department of Food Science and Human Nutrition, Iowa State University, Ames, IA, USA

[10]Agricultural Experiment Station, Univ. of Puerto Rico, Mayagüez, Puerto Rico

Correspondence
Timothy G. Porch, USDA-ARS, Tropical Agriculture Research Station, 2200 P.A. Campos Ave., Suite 201, Mayagüez, Puerto Rico, 00680. Email: timothy.porch@usda.gov

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[†]**Current address**: Zamorano University, Apartado Postal 93, Tegucigalpa, Honduras.

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Abstract

Tepary bean (*Phaseolus acutifolius* A. Gray) is a viable and nutritious alternative to common bean (*P. vulgaris* L.) in areas with excessively high temperatures and/or chronic drought. Tepary bean is a traditional crop of the Tohono O'odham Indians of the Sonoran Desert in the Southwest United States and Mexico, as well as other Indigenous peoples of the United States, Mexico, and Central America. Despite its potential for broad applications for reduced water-input agriculture or for hot, semi-arid, marginal production zones, tepary bean remains an orphan crop. 'USDA Fortuna' (Reg. no. CV-352, PI 698459) is an improved tepary bean cultivar with enhanced seed size, seed quality, tolerance to *Bean golden yellow mosaic virus*, and resistance to local strains of rust in Puerto Rico. It has leafhopper pest resistance, common bacterial blight resistance, and moderate resistance to powdery mildew. USDA Fortuna is a high-yielding tepary bean with an attractive black speckled seed color and a quick cooking time. This cultivar was developed coopera-

Abbreviations: BGYMV, *Bean golden yellow mosaic virus*; RCBD, randomized complete block design; TARS, Tropical Agriculture Research Station; UPR, University of Puerto Rico.

tively by the USDA-ARS, the University of Puerto Rico, Zamorano University, the Instituto Dominicano de Investigaciones Agropecuarias y Forestales (IDIAF) of the Dominican Republic, Quisqueya University of Haiti, the National Seed Service of Haiti, Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria (INTA) of Costa Rica, and Iowa State University.

1 | INTRODUCTION

Given the benefits of increasing plant protein consumption in Western diets both for human health and the environment (Aleksandrowicz et al., 2016), and an increasingly hotter and drier climate in many common bean (*Phaseolus vulgaris* L.) production zones, alternative climate-resilient pulses are needed. Tepary bean (*P. acutifolius* A. Gray), a traditional crop of the Tohono O'odham and other Indigenous peoples of the Sonoran Desert region, is a nutritious and abiotic stress-tolerant orphan pulse crop (Porch et al., 2017). As a close relative of common bean, it is an important source of abiotic and biotic resistance for common bean (Singh & Muñoz, 1999; Souter et al., 2017), the most important pulse crop worldwide. With the recent publication of the tepary bean genome (Moghaddam et al., 2021), the unique characteristics of tepary bean will become more readily available using cutting edge tools now at our disposal.

Common bean production zones of Africa (Ramirez-Cabral et al., 2016), Central America, and the Caribbean (Hannah et al., 2013), among other regions of the world, are being affected by increasing temperatures, reduced or less predictable rainfall patterns, and by a general reduction in water resources. Tepary bean, a desert native species, with a thick and deep tap root, and other little-studied abiotic stress tolerance mechanisms (Suarez et al., 2020; Traub et al., 2018), maintains higher yield under heat, drought, and salinity stress (Markhart, 1985; Nabhan, 1979; Sternberg et al., 2001). Given variable production conditions worldwide, improved yield stability of cultivars under a wide range of climatic conditions is essential for ensuring consistent farmer returns and food security.

There has been limited contemporary effort using modern plant breeding methods in tepary bean improvement (Mwale et al., 2020). The first published tepary release, named 'Redfield', was a selection from the Texas landrace T.S. 3306, by Garver (1934). Modern improvement of tepary has resulted in the development of a white-seeded germplasm, TARS-Tep 22, with resistance to common bacterial blight, caused by *Xanthomonas axonopodis*, and rust, caused by *Uromyces appendiculatus* (Porch et al., 2013). TARS-Tep 32, a yellow tepary bean, was released as a selection from the landrace PI 477033 (Porch et al., 2013). Recently, TARS-Tep 23 was released as a germplasm with elevated abiotic stress tolerance, broad adaptation, and high levels of rust and common bacterial blight resistance (Porch et al., 2022). The continued improvement of tepary bean germplasm and cultivars is needed to attract broader testing and adoption of the crop by consumers and the industry.

Previous research on nutritional quality of tepary bean has shown similar protein, amino acid, starch, fiber, and elemental composition as compared to common bean (Porch et al., 2017). However, lower fiber (Benitez et al., 1994), distinct fat composition (Bhardwaj & Hamama, 2005), lower fat content and higher sucrose content (Porch et al., 2017), and a broad range of elemental concentrations (Garvin & Welch, 1995) have been found. A wide range of cooking times and the presence of the hardshell seed coat trait in some genotypes indicate areas for potential improvement (Porch et al., 2017). In addition, environmental conditions can affect nutritional composition in tepary bean (Bhardwaj & Hamama, 2004).

Biotic stresses remain a significant constraint to broadening the adaptation and yield potential of tepary bean, including response to both insects and diseases. The leafhopper (*Empoasca* spp.) is an insect pest of tepary bean, common bean (Kornegay & Cardona, 1990), and other annual crops (Lamp et al., 1994) in both tropical and temperate regions. In trials conducted in Haiti and Puerto Rico, leafhopper pressure early in the crop cycle can result in severe dwarfing of tepary bean and complete yield loss (Timothy Porch, personal communication, 2018). Leaf damage, including leaf curl and leaf burn (Murray et al., 2001), are commonly scored in common bean, but evaluations of tepary bean leaf response have not been published. However, previous studies in common bean have found yield under leafhopper pressure to be the most-effective trait for selection for resistance (Kornegay & Cardona, 1990).

Bean golden yellow mosaic virus (BGYMV) is a major constraint for common bean production in Central America and the Caribbean and a focus of extensive and successful improvements in genetic resistance (reviewed by Beaver et al., 2020). Previous evaluations of tepary bean response to BGYMV in Puerto Rico, during a period when Puerto Rico experienced regular, natural epidemics, found some tolerance in the germplasm evaluated (Miklas & Santiago, 1996). Although tolerance in tepary bean has been found and can be further improved, BGYMV resistance will likely come through introgression of higher levels of resistance from common bean.

Tepary bean germplasm has the highest levels of resistance to common bacterial blight, caused by *Xanthomonas axonopodis* pv. *phaseoli* (Smith) Dye (Xap), in the *Phaseolus* species (Singh & Muñoz, 1999). However, there is a broad range of responses from complete susceptibility to high levels of resistance within tepary bean germplasm. Genetic control of this seed-borne disease is important since chemical control has limited effectiveness and because genetic resistance is critical for future production of disease-free tepary bean seed. Tepary beans are largely susceptible to powdery mildew, caused by *Erysiphe polygoni*, and genetic resistance is needed for broadening adaptation to more humid production zones (Miklas et al., 1994).

The goal of this effort was to develop a tropically adapted, disease-resistant, tepary bean cultivar with high nutritional value and seed quality, as well as good cooking quality. 'USDA Fortuna' (Reg. no. CV-352, PI 698459) was developed cooperatively by the USDA-ARS, the University of Puerto Rico (UPR), Zamorano University, the Ministry of Agriculture of the Dominican Republic, the National Seed Service of Haiti, Quisqueya University of Haiti, Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria (INTA) of Costa Rica, and Iowa State University.

Core Ideas

- Tepary bean has promise as a nutritious plant protein source in marginal environments
- USDA Fortuna tepary bean has improved seed size and quality, and fast cooking time
- USDA Fortuna shows high common bacterial blight and moderate powdery mildew resistance, as well as leafhopper resistance

2 | METHODS

The original cross in the development of USDA Fortuna (tested as TARS-Tep 93), G40022 (TDP-13)/G40029 (TDP-18), was completed in a screenhouse at the Tropical Agriculture Research Station (TARS) in Mayaguez, Puerto Rico (PR), in 2014, and parents were selected out of the Tepary Diversity Panel (TDP) (Bornowski et al., 2023). Seed was bulked from the F_1s planted in the same screenhouse in 2015, from the F_2s planted at the TARS Station in Isabela, PR, in 2015, from the F_3s planted at the UPR Station in Juana Diaz, PR, in the winter of 2015–2016, and from the F_4s planted at the UPR Station in Juana Diaz, PR, during early 2016. The single plant selection resulting in USDA Fortuna was completed in the F_5 generation in a high-temperature field trial at the UPR Station in Juana Diaz in the summer of 2016, and the line was bulked thereafter. G40022 (PI 321637) is a cultivated yellow tepary bean landrace from the Tohono O'odham Nation in Arizona, with good symbiotic nitrogen fixation capacity (Vargas, 2015), powdery mildew resistance, caused by *Erysiphe polygoni* DC (Miklas et al., 1994), common bacterial blight resistance (Urrea et al., 1999), heat tolerance (Rainey & Griffiths, 2005), and a small yellow round seed type. G40022 was collected by Howard Scott Gentry in 1966 in Newfields, AZ, along the U.S.-Mexico border, at approximately 816 m asl. G40029 (PI 70793) has a large black speckled seed type, is a cultivated landrace, has good symbiotic nitrogen fixation capacity (Vargas, 2015), has high levels of common bacterial blight resistance (Singh & Munoz, 1999) and has moderate tolerance to BGYMV in trials conducted at Zamorano University in Honduras (unpublished data).

A total of six field trials were evaluated in Puerto Rico in 2018, 2019, and 2020 under humid conditions on an Oxisol soil at the USDA-ARS-TARS Experimental Station in Isabela and in a semi-arid environment on a Mollisol soil at the UPR Experimental Station in Juana Diaz. These trials were planted, managed, and harvested using standard commercial common bean equipment. The 2018 drought trial in Juana Diaz was planted with five replications in a randomized complete block design (RCBD) with 3-m single-row plots, spaced 0.76 m apart. The 2018 Isabela trial under low N fertility was planted with six replications in an RCBD design with 3-m four-row plots, spaced 0.61 m apart. The winter 2019 drought trial and the summer high-temperature trial in Juana Diaz were planted with two replications in an RCBD design with 3-m single-row plots, spaced 0.76 m apart. The fall 2019 Isabela trial, with relatively high levels of irrigation, was planted with six replications in an RCBD design with 3-m four-row plots, spaced 0.61 m apart. The winter 2020 Isabela trial, with relatively high irrigation and rainfall, was planted with six replications in an RCBD design with 3-m four-row plots, spaced 0.76 m apart. The field trials were all treated with pre-emergent herbicide, fertilized with 10–10–10 (N–P–K) with micronutrients, except for the 2020–2022 trials that were fertilized with 15–15–15 (N–P–K) with micronutrients, at a rate of 400 kg ha^{-1}. Cultivation was completed mechanically and by hand during the crop cycle, and the trial was treated with pesticides as needed to control insect pests. Data, including vigor, phenology, yield (kg ha^{-1}), and 100 seed weight, were collected from most of the trials.

A tepary bean trial, including 10 entries from USDA-ARS-TARS, was planted with three replications in an RCBD design in Zamorano, Honduras, on June 7, 2019, and harvested on August 17, 2019. Experimental units were two rows, 3 m long with 30 plants per row and 0.7-m distance between rows. The trial was conducted in a loamy soil with pH 6.01, and with 1.74 and 0.09 g 100 g^{-1} of organic matter and total nitrogen, respectively, and 151, 344, 1,452, 115 and 14 mg kg^{-1} extractable P, K, Ca, Mg, and Na, respectively.

In the 2019–2020 agricultural cycle, two experiments were planted with and without drought stress in the locality of Sardinal de Carrillo, Guanacaste, Costa Rica (47 m asl, 10˚32′36′′ N, 85˚38′20″ W). An RCBD design was used with three replications in experimental units of a single 3-m-long row, spaced 0.50 m apart and with a density of 12 seeds per meter. The frequency of irrigation was twice a week for 30 min, while the drought treatment had its water supply terminated at Day 40.

Four trials were completed on the Island of Hispaniola from 2017 to 2020. During the winter 2017–2018 season, trials were conducted in Cabaret and Damien, in the Cul-de-Sac valley area of Haiti, under high leafhopper pressure, and low fertility conditions with no fertilizer added. These two trials were planted with three replications in an RCBD design with 2-m single-row plots, spaced 0.76 m apart. During the 2018–2019 and 2019–2020 winter seasons, trials were conducted in the San Juan de Maguana valley in the Dominican Republic under moderately high and natural BGYMV pressure and moderate drought. These two trials were planted with three replications in an RCBD design with 2-m single-row plots, spaced 0.76 m apart. Numbers of plants infected with BGYMV were counted, response to powdery mildew, yield (kg ha^{-1}), and the weight of 100 seed data were collected per plot.

Water uptake and cooking time analyses were conducted at the USDA-ARS, Sugarbeet and Bean Research Unit, in East Lansing, MI, on the 2018 low N fertility Isabela trial according to Cichy et al. (2019). Prior to cooking, seed was stored at 4˚C and 75% relative humidity for 1 month to equilibrate beans to a seed moisture content of 10%–14%. Cooking time was measured with a Mattson pin drop cooker (Wang & Daun, 2005). Thirty bean seeds per replication were weighed and presoaked in distilled water for 12 hours. Percentage hard shell was recorded as the number of seeds that did not take up water during the 12-hour soaking. Water uptake was determined as the percentage of water in the soaked and drained vs. the dry seed samples. Twenty-five of the soaked seeds from a single sample were chosen for cooking time determination. The beans were placed in the wells of the Mattson cooker, and the device was placed in a metal beaker with boiling distilled water heated on a hot plate. Individual beans were considered cooked when the piercing rods had passed through the seed. A sample's cooking time was recorded when 80% of the beans were pierced.

Soil testing was completed by bulking the soil samples collected in a "W" pattern from the 2018 low N fertility Isabela trial and from the 2019 adequate fertility trial. The soil analysis was completed by Waypoint Analytical. These soil samples were collected from all six replications in the 2018 common bean and tepary bean trials for a total of 12 soil analyses and from two replications from the 2019 trial. Organic matter (%), phosphorus (P, ppm), potassium (K, ppm), calcium (Ca, ppm), magnesium (Mg, ppm), sulfur (S-SO_4, ppm), boron (B, ppm), copper (Cu, ppm), iron (Fe, ppm), manganese (Mn, ppm), zinc (Zn, ppm), sodium (Na, ppm), nitrate (NO_3N, ppm), and pH were analyzed.

The seed proximate nutritional analyses were completed on raw seed by A&L Great Lakes Laboratories on eight tepary and four common bean lines from the 2018 low N fertility Isabela trial and on four tepary bean lines from the 2019 adequate fertility trial. The seed nutritional analyses were conducted on each of the replications of each line and included analysis of crude protein, N, crude fiber, Ca, K, Mg, P, and S measured as a percentage. Aluminum (Al), B, Cu, Fe, Mn, and zinc (Zn) were measured as ppm. Certified standards were used for calibration of the instruments. After open vessel microwave digestion (SW846-3050B), samples were analyzed by Inductively Coupled Argon Plasma (ICAP) for minerals following AOAC 985.01 methods (AOAC International, 2017). Nitrogen and crude protein assessment was performed by the Dumas combustion method (AOAC 990.03) using an Elementar Rapid N Analyzer and LECO TRUMAC Carbon:Nitrogen Analyzer (AOAC International, 2017). Crude fiber was determined using method 32-10 (AACC, 2000) which consists of chemical digestion and subsequent combustion.

Significant differences for sulfur were found between the tepary bean lines; thus, S-containing amino acids cysteine and methionine were subsequently evaluated at the University of Missouri Agricultural Experiment Station Chemical Laboratories. Performic acid oxidation and acid hydrolysis methods were used for the determination of cysteine and methionine on a weight/weight %, or grams per 100 grams of sample.

Disease evaluations for common bacterial blight were completed at the USDA-ARS-TARS in Mayaguez, PR, during 2020–2021. Common bacterial blight strain 484A was inoculated using the multiple needle technique (Andrus, 1948; Zapata et al., 1985) using plants grown in a screenhouse. *Xanthomonas axonopodos* pv. *phaseoli* cultures were grown on YDCA media and then diluted to 10^7 mL^{-1} for inoculation (Zapata et al., 1985) on plants organized in an RCBD with three replications. The disease response was evaluated 14 and 21 days after inoculation using a 1–9 scale, where 1 represents no symptoms and 9 represents complete infection of the inoculated leaf (van Schoonhoven & Pastor-Corrales, 1987). Disease response to natural powdery mildew, infection in the field was evaluated on the same 1–9 scale in the 2019 Dominican Republic trial (van Schoonhoven & Pastor-Corrales, 1987). The lines were also evaluated for resistance to *Bean common mosaic virus* through inoculation with the NL-3 strain of *Bean common mosaic necrosis virus* in a greenhouse in Mayaguez, PR, in 2020. ELISA was completed on the samples as per the Agdia protocol (Elkhart, IN) and used to detect the presence of the virus in three plants of each line.

The lines were evaluated for response to the common bean weevil *(Acanthoscelides obtectus)* at the UPR Experiment Station in Isabela in 2019 and 2021 as per the protocol described by Kusolwa et al. (2016).

All statistical analyses were performed using ANOVA for each measured trait in each trial using PROC GLM in SAS version 9.4 (SAS Institute). Fisher's protected LSD ($p = 0.05$) was used to compare entry means in trials that had significant *F*-tests for entries.

3 | CHARACTERISTICS

USDA Fortuna yielded consistently well across yield trials in Puerto Rico, Haiti, and the Dominican Republic, averaging 1,865 kg ha^{-1}. In comparison, the checks TARS-Tep 22 and the Arizona landrace Sacaton white had lower average yields of 1,445 and 1,308 kg ha^{-1}, respectively, whereas the G40001 check had the highest overall average yield of 1,917 kg ha^{-1} (Table 1). However, Sacaton white and G40001 were not included in all trials. USDA Fortuna has a prostrate plant habit, which can be classified as a Type III, while most of its pods are held above the ground surface. It has good seed quality, with round black speckled seed type, composed of an off-white background and black speckled foreground color, and minimal seed coat wrinkling. Compared with other cultivated tepary germplasm, it has larger-sized seed with an average 14.5 g 100^{-1} seed weight and higher seed quality (Table 2 and Figure 1). Compared with the unimproved cultivated checks, seed weight was 17% higher than G40001 (12 g 100^{-1}) and 22% higher than Sacaton white (11.3 g 100^{-1}) on average across the trials. USDA Fortuna matured in 64.2 days on average across the Puerto Rico and Haiti trials (data not shown).

To investigate the effects of tropical soil nutrition on tepary seed composition, soil was evaluated from the 2018 very low N and the 2019 low N field trials in Puerto Rico (Supplemental Table S1), all conducted with adequate irrigation and under nonstress temperature conditions. The pH of the trials ranged from 5.8 (2019) to 7.4 (2018). There were significant differences between the 2018 trials (common bean and tepary bean side-by-side trials) and the 2019 trial for N. N in the 2019 trial (7 ppm) was significantly higher and roughly double the 2018 trials (3.2 and 4 ppm). P was significantly lower in the 2018 tepary trial (15.2 ppm) when compared to the 2018 common bean trial (26.5 ppm), but both represent adequate levels of P nutrition for common bean. K levels in the 2018 common bean (212 ppm) and 2019 trials (187 ppm) were significantly higher than in the 2018 tepary trial (150 ppm), but all represent adequate K soil nutrition. Significant differences for Ca, Cu, Fe, and Mn were also found between the trials but were at adequate levels.

FIGURE 1 Images of dry seed and cooked seed samples of USDA Fortuna. Bar indicates 1 cm.

In terms of seed composition in the very low N 2018 trial, USDA Fortuna was similar to the other tepary beans (except for TARS-Tep 90) for seed protein, Fe, Zn, and S, with means lower than the common beans tested (Supplemental Table S2). In 2019, the tepary beans were again evaluated for seed nutritional composition under moderately low N fertility conditions (Table 3), and in this trial USDA Fortuna seed protein, Fe, Zn, and S were higher than the 2018 trial and at levels comparable to common bean. The 2019 results also coincide with another nutritional study conducted in a nearby field in Isabela under adequate soil fertility conditions that showed no significant difference between the common bean and tepary bean lines tested for these seed nutritional components (Porch et al., 2017). Thus importantly, the nutritional composition of Fortuna may be affected by very low levels of soil N fertility. The concentration of S-containing amino acids, important for human nutrition, including cysteine (0.25 W/W%) and methionine (0.258 W/W%), were close to the mean of the tepary beans tested (0.265 and 0.259, respectively; data not shown) for Fortuna. It is interesting to note that a common

TABLE 1 Yield of tepary bean lines from 13 trials conducted in Costa Rica, Dominican Republic, Haiti, Honduras, and Puerto Rico, 2017–2020.

Line	Haiti		Puerto Rico		Dominican Republic		Puerto Rico			Costa Rica		Honduras	Puerto Rico	Mean
	Cabaret	Damien	Juana Diaz	Isabela	San Juan		Juana Diaz		Isabela			Zamorano	Isabela	
	LH, low fert.		Drought	Low fert.	BGYMV, drought		Drought	High temp.	Non-stress	Drought	Non-stress	Drought	Non-stress	
	2017–2018	2017–2018	2018	2018	2018–2019	2019–2020	2019	2019	2019	2019	2019	2019	2020	
	kg ha^{-1}													
TARS-Tep 90	1,085	785	1882	668	1,908	1,207	1,826	1,740	1,135	448	1,715	1,912	1,019	1,333
USDA Fortuna	2,568	1,223	2,301	944	3,303	1,575	2,227	1,485	1,165	424	1,683	2,964	1,856	1,824
TARS-Tep 22	1,286	1,225	2,156	759	2,653	1,737	1,862	980	980	224	796	1,982	812	1,342
Sacaton white	NT	NT	NT	722	2,644	1,243	1,921	539	687	NT	NT	NT	1,402	1,308
G40001	2,084	1,698	2,295	896	4,100	1,815	1,668	776	NT	324	1,296	3,124	NT	1,825
Mean	1,710	940	2,319	862	2,778	1,555	2,280	1,015	943	293	1,148	2,560	1,273	1,514
LSD (0.05)	979	NS	529	390	1,240	435	NS	NS	332	218	1,170	923	595	
CV (%)	35		18.3	30.7	21.4	20.0			30	39.9	56	21	39	

Abbreviations: BGYMV, *Bean golden yellow mosaic virus*; fert., fertility; LH, leafhopper; NT, not tested.

TABLE 2 Weight of 100-seed samples of tepary bean lines from eight trials conducted in Puerto Rico and the Dominican Republic under different abiotic constraints, 2018–2020.

		Puerto Rico		Dominican Republic		Puerto Rico				
		Juana Diaz	Isabela	San Juan		Juana Diaz		Isabela		
		Drought	Low fert.	BGYMV		Drought	High temp.	Nonstress	Nonstress	
Line	Seed type	2018	2018	2018–2019	2019–2020	2019	2019	2019	2020	Mean
		g								
TARS-Tep 90	Black	14.7	11.1	17.2	12.6	19.8	15.1	16.0	13.2	15.0
USDA Fortuna	Black speckled	16.8	12.3	14.7	12.3	18.7	12.4	15.1	13.9	14.5
TARS-Tep 22	White	13.2	9.3	14.6	12.5	16.7	11.8	13.4	11	12.8
Sacaton white	White	NT	9.8	NT	10.2	15	10.6	11.6	10.4	11.3
G40001	White	14.3	9.3	13.7	10.9	14.1	9.4	NT	NT	12.0
Mean		14.8	10.5	14.9	12.2	17	12	14.1	12.2	13.5
LSD (0.05)		1.9	0.9	1.7	1.5	1.5	2	1.1	1	
CV (%)		10.1	5.5	5.5	8.4	4.3	8	6.4	6.7	

Abbreviations: BGYMV, *Bean golden yellow mosaic virus*; fert., fertility; NT, not tested.

TABLE 3 Seed composition of tepary bean lines from a trial with adequate soil fertility in Isabela, Puerto Rico in 2019.

Line	Seed type	N[a]	Crude protein	Crude fiber	Ca	K	Mg	P	S	Al	B	Cu	Fe	Mn	Zn
		% dry wt.								ppm					
TARS-Tep 90	Black	3.87	24.22	4.77	0.20	1.87	0.24	0.54	0.42	9.67	14.67	11.00	72.00	34.33	33.33
USDA Fortuna	Black speckled	3.98	24.84	4.70	0.21	1.63	0.22	0.53	0.38	9.67	14.00	13.67	61.33	40.67	33.33
TARS-Tep 22	White	4.07	25.44	5.80	0.22	1.78	0.21	0.53	0.34	4.33	12.00	10.67	68.67	37.67	30.33
TARS-Tep 51	White	3.75	23.44	4.90	0.24	1.82	0.20	0.55	0.33	7.50	10.50	10.50	71.50	28.50	30.50
Mean		3.9	24.5	5.1	0.23	1.78	0.225	0.53	0.35	7.1	12.8	11.2	67.1	34.1	31.8
LSD (0.05)		0.32	2	NS	0.03	0.06	NS	NS	0.03	3.8	2.7	1.8	6.5	6.1	NS
CV (%)		2.2	2.1		3.9	0.83			3.75	25.7	10.2	7.7	4.7	8.7	

[a]Seed composition components including raw seed crude protein, nitrogen, crude fiber, calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), and sulfur (S) were measured as a percentage of dry weight. Aluminum (Al), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were measured as ppm.

bean cultivar developed in Puerto Rico, 'Verano' (Beaver et al., 2008), showed high protein, Fe, and Zn concentrations in the 2018 very low N field trial, which may indicate indirect breeding for improved nutrient uptake or translocation to the seed under these soil fertility conditions. In low N field trials conducted at the Isabela Substation from 2015 to 2018, Verano had among the highest mean nitrogen derived from the atmosphere (NDFA) values (56.1%) among 27 lines from the Bean Abiotic Stress Evaluation (BASE) 120 panel (Beaver et al., 2021).

USDA Fortuna showed superior seed quality overall. Whereas some of the tepary bean and common bean lines grown in this trial showed hardshell (Stanley, 1992), which means they did not imbibe water during soaking, USDA Fortuna took up water readily during soaking and was uniform across the seed samples. USDA Fortuna also had excellent cooking quality (Figure 1). The cooking time was 58.8 min, which was faster than most other samples. This genotype maintained its integrity during cooking and retained some of its speckled seed phenotype after cooking (Table 4), which is unusual. The relatively low water uptake of Verano and 'Stampede' (Osorno et al., 2010) may be related to the high temperature production and storage environments in Puerto Rico, which can result in the hardshell seed phenotype.

In the disease evaluations, USDA Fortuna showed tolerance to BGYMV in field trials in the Dominican Republic in terms of yield performance (Porch et al., 2021). Yields in these trials were high in 2018 and somewhat lower in 2019, despite a proportion of the plants in each plot showing typical BGYMV symptoms in both trials. Response to common bacterial blight in the screenhouse in Mayaguez, PR, was evaluated with an average rating of 2.8 for USDA Fortuna

TABLE 4 Water uptake and cooking performance of tepary and common bean lines from a very low-N trial conducted in Isabela, Puerto Rico in 2018.

Line/cultivar	Seed type	Soaked seed increased weight	Soaked seed weight	Hardshell	Cooking time
		%	g per 100 seed	%	min
Tepary bean					
TARS-Tep 90	Black	148.5	29.3	6.0	78.6
USDA Fortuna	Black speckled	138.5	29.2	0.0	58.8
TARS-Tep 22	White	110.1	20.3	10.6	71.3
Sacaton white	White	98.0	19.2	32.0	95.0
Common bean					
Stampede	Pinto	39.2	44.3	67.2	86.2
TARS-MST1	Black	117.3	41.3	0.0	38.8
Verano	White	36.1	24.2	57.2	80.7
Zorro	Black	129.9	37.0	1.7	33.8
Mean		99.9	27.7	21	69.4
LSD (0.05)		14.2	2.8	11.7	30
CV (%)		11.8	8.3	46.2	35.8

at 21 days after inoculation, while controls VAX 6 and Morales had ratings of 3.3 and 8.4, respectively. USDA Fortuna showed a low percentage of powdery mildew damage, 27.8% to 33.3%, among the 10 tepary bean lines tested in the 2018 and 2019 Dominican Republic trials, where the means were 48.6% and 36.5%, respectively (Porch et al., 2021). USDA Fortuna showed a high titer of virus using ELISA when inoculated with the NL-3 strain of the *Bean common mosaic necrotic virus*, thus indicating susceptibility to *Bean common mosaic virus*. The development of genetic resistance to this seed-borne disease is important for production of disease-free seed and remains a key goal of ongoing improvement efforts. USDA Fortuna was resistant to endemic races of rust in Puerto Rico but was susceptible to rust in an observational trial planted in the field in Fort Collins, CO, and tested in the greenhouse at USDA-ARS, Beltsville (data not shown).

Under high leafhopper insect pressure in Cabaret and Damien, Haiti, in the 2018–2019 winter season, USDA Fortuna yielded 2,568 and 1,223 kg ha^{-1}, respectively (Table 1). These yields were significantly higher than the mean yield of both tepary bean trials, and the plants showed reduced leaf curl and leaf burn symptoms compared with the susceptible check TARS-Tep 22, and a similar response to the leafhopper resistant accession G40001. In controlled trials in Puerto Rico, USDA Fortuna was susceptible to the common bean weevil.

4 | AVAILABILITY

Seed of this cultivar has been deposited in the USDA-ARS National Plant Germplasm System (http://www.ars-grin.gov/npgs/index.html), where it is available for research purposes, including development and commercialization of new cultivars. A limited quantity of seed of the cultivar may be obtained by writing to orders@ars-grin.gov or to the corresponding author (timothy.porch@usda.gov). It is requested that appropriate recognition be made if this germplasm contributes to the development of new breeding lines or cultivars.

AUTHOR CONTRIBUTIONS

Timothy G. Porch: Conceptualization; data curation; formal analysis; investigation; writing—original draft; writing—review and editing. **Juan Carlos Rosas**: Formal analysis; investigation; methodology; writing—review and editing. **Karen Cichy**: Investigation; writing—review and editing. **Graciela Godoy Lutz**: Investigation; writing—review and editing. **Iveth Rodriguez**: Investigation; writing—review and editing. **Raphael W. Colbert**: Investigation; writing—review and editing. **Gasner Demosthene**: Investigation; writing—review and editing. **Juan Carlos Hernández**: Investigation; writing-review and editing. **Donna M. Winham**: Investigation; writing—review and editing. **James S. Beaver**: Formal analysis; investigation; writing—review and editing.

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or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

ORCID

Timothy G. Porch https://orcid.org/0000-0002-5107-2448
Juan Carlos Rosas https://orcid.org/0000-0003-4396-702X
Karen Cichy https://orcid.org/0000-0002-4311-0774
Graciela Godoy Lutz https://orcid.org/0000-0002-0543-0857
Donna M. Winham https://orcid.org/0000-0003-3924-2560
James S. Beaver https://orcid.org/0000-0002-1112-8224

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