

Release of ‘Poporito’ and ‘Noche Nuña’ Novel Popping Bean (*Phaseolus vulgaris* L.) Cultivars

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Nuña beans are a form of dry bean that is cooked for consumption using dry heat, a novel preparation method that is little known to bean consumers outside of South America. The beans will explosively puff or “pop” to the size the seeds would attain if imbibed and soften and become light in weight as they lose moisture through the cooking process. Once popped, nuña beans are easy to transport and they also store well without spoiling. They are traditionally consumed as snacks or eaten as a side dish with a meal. Nuña beans originated in the Andes of Peru and Bolivia, where they are generally grown at altitudes of 2000 to 2800 m (Tohme et al. 1995). Nuña beans belong to the Andean center of domestication and are classified as race Peru (Singh et al. 1991). They may have been some of the first domesticates of wild common beans in

South America because they predated use of ceramics, which facilitated the moist cooking of foods (Tohme et al. 1995). Furthermore, boiling beans at altitudes over 2000 m requires up to 3 h to cook (especially when the beans are not preimbibed) due to the lower boiling point of water (<90 °C) and necessitates the use of more cooking fuel. Dry beans must be cooked to soften the seeds and to denature antinutritional factors, especially lectins (phytohemagglutinin and α -amylase inhibitor). Phytohemagglutinin and mammalian specific forms of α -amylase inhibitor are of particular concern for human health and must be inactivated before consumption. While 12 min at 100 °C with standard atmospheric pressure is sufficient to inactivate phytohemagglutinin completely, 136 min are required at 88 °C (Coffey et al. 1985).

A traditional preparation method for nuña beans is parching the seeds, dry or with a little oil, over an open fire while agitating in a skillet until the seeds puff or pop (Zimmerer 1992). The beans may also be embedded in hot ash or sand (Tohme et al. 1995). The process takes just a few minutes and consumes little cooking fuel. The fate of lectins during the popping process has not been studied, but nuñas have been consumed for thousands of years without known adverse health effects, suggesting that these compounds are inactivated when the bean is popped.

The popping trait is under genetic control, and only nuña beans will pop when parched. Other dry beans can be parched or roasted, but cotyledons remain quite hard and will not enlarge. The popping trait is quantitatively inherited (González et al. 2014; Yuste-Lisbona et al. 2012) and appears to be related to both proximate composition, anatomical structure (Spaeth et al. 1989), potentially seed color (Rezaey et al. 2024), as well as overall seed morphology. Most nuña beans are about spherical in shape, which may facilitate uniform heating of the seed. Seeds do not need to be intact or retain their seedcoat to pop, although they will not show as great an expansion as intact beans (observed independently by Myers and Keith).

Nuña cultivars are adapted to production in the Andean highlands at near-equatorial latitudes where daylength is a virtually constant 12 h, sunlight is intense, and temperatures are generally cool (15 °C on average). Most cultivars have a type IV (Singh 1991) climbing and twining vine habit and take 140 to 200 d to mature. When these beans are grown in the higher latitudes of North America, they will not flower until daylength declines to near 12 h and, with their extended days to maturity, will not produce mature seeds before the first frost. Even in a protected culture, it is challenging to reproduce growing conditions that allow traditional nuña cultivars to thrive and produce well-developed seeds.

Nuña beans first came to the attention of public plant breeders with the publication “Lost Crops of the Incas” (National Research Council 1989). Several public bean breeders in the United States acquired nuña accessions from Centro Internacional de Agricultura Tropical (CIAT) or through the US Department of Agriculture National Plant Germplasm System (USDA-NPGS) common bean plant introduction collection. They crossed these with the intent of introgressing the popping trait into temperate region–adapted cultivars. Several ‘popping bean’ lines developed at Colorado State University were released as germplasm (Brick et al. 2013) but were not commercialized. Experimental popping bean lines developed by the University of Wisconsin–Madison program were not formally released but have been exchanged within the public bean breeding community. Myers initially crossed nuñas to adapted bean lines in 1989 at the University of Idaho–Kimberly but transferred the program to Oregon State University (OSU), where crosses made in 1996 led to the two

Table 1. Breeding history for OSU popping beans developed from the cross Pava nuña × 5-593.

Cross/advanced line no.	Location	Year	Generation	Activity
N1	OSU greenhouse	1996/1997	Cross	Crossed under short daylength during fall/winter
N1	OSU greenhouse	1997	F ₁	Bulked by cross and grown under short days in winter/spring
N1-02	OSU Vegetable Research Farm	1997	F ₂	Advanced as single plant selections; retained bush, daylength-insensitive plants; tested for popping ability postharvest; 31 lines retained
N1-02-01	OSU greenhouse	1997/1998	F ₃	Advanced as single plant selections winter/spring; 156 lines grown and tested for popping ability
N1-02-01-09, N1-02-01-02	OSU Vegetable Research Farm	1998	F ₄	Advanced as single plant selections; selected for plant type, earliness; postharvest test for popping ability with 354 lines grown and tested
N1-02-01-09-15, N1-02-01-02-12	OSU Vegetable Research Farm	1999	F ₅	Advanced as single plant selections; tested for popping ability Winter 1999/2000; 1,450 lines grown and tested
N1-02-01-09-15, N1-02-01-02-12	OSU Vegetable Research Farm	2007	F ₆	136 lines grown and tested for popping ability; bulked by family
P05: N1-02-01-09-15, P02: N1-02-01-02-12	OSU Vegetable Research Farm	2008	F ₇	24 lines grown; bulked by family; P numbers assigned
P02, P05	OSU Vegetable Research Farm	2011	F ₉	Bulked by family
P02, P05	OSU Vegetable Research Farm	2014	F ₁₀	Bulked by family
P02, P05	OSU Vegetable Research Farm	2019	F ₁₁	19 lines grown; bulked by family
P02, P05	OSU Vegetable Research Farm	2024	F ₁₂	7 lines grown, bulked by family

OSU = Oregon State University.

popping bean cultivar releases presented in this paper.

The development of adapted popping bean lines by public breeding programs was delayed for about 12 years by utility patents with extraordinarily broad claims on transferring the popping trait into a North American-adapted bean background. In 2000, the first of two utility patents (US 6,040,503) was issued followed by US 6,419,976 in 2002, and the development of these types of beans by public breeding programs was paused. The 11.5 year maintenance fees went unpaid, and the patents were abandoned, and full breeding activity in public programs resumed. No seeds of the patented popping bean lines were deposited in public or private repositories, so no comparison with public program lines is possible. The OSU popping beans constitute the first public release of popping bean cultivars intended for commercial production.

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Origin and Methods

The popping bean breeding process at OSU involved the introgression of the quantitatively controlled popping trait into a day-neutral background (controlled by *Ppd* and *Hr* genes) and conversion of the type IV growth habit to a more manageable type I upright bush habit (controlled by the *Fin* gene). Additional quantitatively controlled traits such as internode length, plant height, and lodging resistance were selected during the screening process. No conscious selection was imposed for seed and flower color, seed shape, or seed size.

Cross and line development. ‘Poporito’ or PI 707891 (previously P02 and N1-02-01-02-12), and ‘Noche Nuna’ or PI 707890 (previously P05 and N1-02-01-09-15), originated from Pava nuña × ‘5-593’ crossed in the OSU greenhouses during the fall/winter of 1996 (Table 1). The parent plants were grown under a cool (18 °C/12 °C day/night) temperature regime and a 12-h daylength to bring Pava nuña

into flower and then were crossed using the full emasculation technique for common bean (Park 2022).

The Pava nuña accession was collected in Peru by Dr. Daniel Debouck and deposited in the CIAT germplasm collection as accession number G19646 (there are several accessions in the CIAT collection with the name “Pava”) (Genesys 2024). This nuña accession was selected as a parent because of the reputation of Pava nuña for excellent popping ability (Zimmerer 1992). It is an indeterminate climber with a 130 to 150 d maturity under short-day conditions. The seeds are spherical with black speckles on a white background and weigh 87.4 g per 100 seeds (Genesys 2024).

5-593 is a small, black-seeded germplasm line developed by Dr. Mark Bassett at the University of Florida (Bassett 1992). It was selected because it is day-neutral with a relatively short harvest maturity, has a determinate bush growth habit, is lodging resistant,

Table 2. Popping percentages, seed expansion, and seed moisture for OSU popping bean lines tested in the F₅ generation in 1999, F₆ in 2007, and F₉ in 2011.

Advanced line no.	Selection no.	Popped 1999 (%) ⁱ	Popped 2007 (%) ⁱⁱ	Expansion scale (2007) ⁱⁱⁱ	Seed moisture 2007 (%) ^{iv}	Popped 2011 (%) ^v
P01	N01-02-01-02-05	69	73.3	2.7	3.9	69.3
P02	N01-02-01-05-03	89	60.0	2.7	3.9	74.7
P03	N01-02-01-05-06	90	70.0	3.0	4.6	60.0
P04	N01-02-01-09-15	81	66.7	2.7	4.9	65.3
P05	N01-02-01-12-06	81	73.3	2.5	7.3	62.7
LSD _{0.05} ^{vi}			34.6	0.7		19.0

ⁱ Percent popped based on single replicates of 10 seeds popped in the microwave.

ⁱⁱ Percent popped based on the mean of three replicates 10 seeds.

ⁱⁱⁱ Scale of 1 to 3, where 1 is slight, and 3 is full expansion of cotyledons when popped.

^{iv} Percent seed moisture calculated as (dry wt – popped wt)/dry wt × 100.

^v Percent popped based on the mean of three replicates 25 seeds. Time in microwave across years ranged from 70 to 90 s.

^{vi} Fisher’s protected least significant difference ($\alpha = 0.05$).

OSU = Oregon State University.

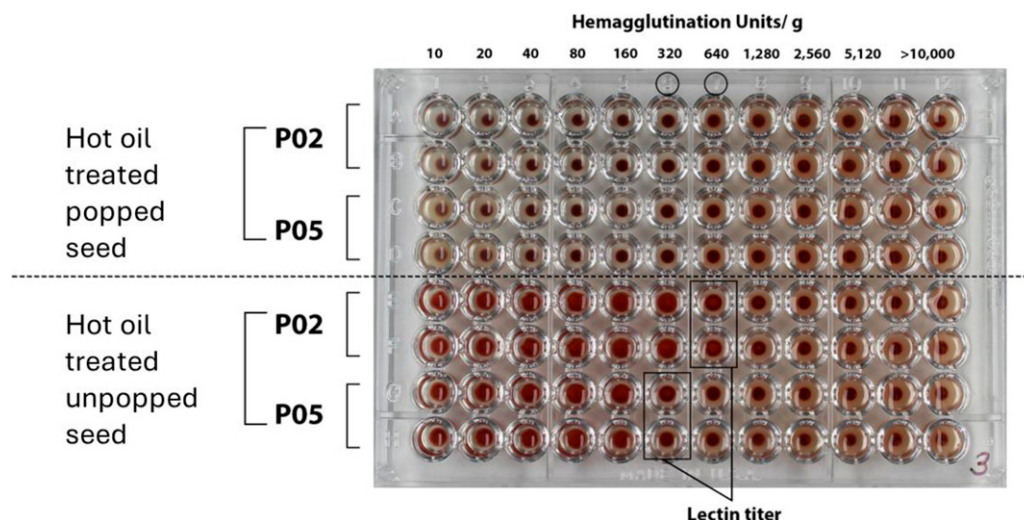


Fig. 1. Hemagglutinin assay P02 ('Poporito') and P05 ('Noche Nuña') popping bean cultivar seed either unpopped or after popping in hot oil. Dilution scale is shown at the top of the microtiter plate. Photo: Jose Hernández, Michigan State University.

and is robust to the abiotic stresses of northern Florida. 5-593 was selected from B-351, a black-seeded line developed by Dr. James Beaver at the University of Puerto Rico–Mayaguez from the cross 'Bonita' × 'Jamapa'

(both race Mesoamerica). 5-593 originated from B-351 as an $F_{2:3}$ derived determinate mutant from a seed irradiation experiment (McClellan and Schmutz 2024). This line has been deposited in the genetics stocks collection

(PI 608674) of the NPGS germplasm repository in Pullman, WA. Its seed weighs 22 g per 100 seeds.

The F_1 was grown in the OSU greenhouses during the winter/spring of 1997 under short days and harvested in bulk to produce F_2 seed (Table 1). The F_2 seeds were planted in the field at the OSU Vegetable Research Farm on 20 Jun and were grown to maturity. Plants with determinate growth habit and early flowering and maturity were selected from this population. Single plants were harvested with only 31 determinate, early maturing types retained. After harvest, up to 10 seeds of each single plant were tested for popping percentage. Remnant seeds of those plants that had some evidence of cotyledon expansion from popping were planted in the greenhouse in the spring of 1998. A total of 156 F_3 plants were grown, which generated 354 F_4 plants when planted in the field in 1998. After popping tests during the spring of 1999, these lines generated 1450 F_5 plants grown in the field in that year (Table 1). These lines were again tested for popping ability (Table 2). In 2000, the project was shelved because of the popping bean utility patent, but seed was regenerated in 2007, when F_5 selections with the highest popping ability were grown. Seed was bulked to produce $F_{5:6}$ families. Continuing from 2008–19, 24 lines were advanced in the field from the $F_{5:7}$ to $F_{5:11}$. Popping was again evaluated in 2011 in the $F_{5:9}$ generation (Table 2), coinciding with the abandonment of US 6,040,503. In 2019, seeds of P02 to P05 were provided to Dr. Carol Miles at Washington State University (WSU) at Mount Vernon, where they were placed into an unreplicated yield trial and used for seed increase (Miles et al. 2019). In 2021, seed was provided to Dr. Jim Heitholt at the Powell Research and Extension Center, University of Wyoming (UWY), Powell, where they were grown in a novelty dry bean yield trial. Seeds from the Mount Vernon trial were provided to the WSU Food Processing Extension and Research program in 2022 for

Table 3. Popping percentages, popping times, and popping temperatures for OSU popping beans grown in the Novelty Dry Bean Trial at the Powell Research and Extension Center, WY, USA, in 2021, and from beans grown in a variety trial at the WSU Research and Extension Center, Mount Vernon, WA, USA, in 2019.

Entry	WY 2021 ⁱ				WA 2019 ⁱⁱ	
	Popped (%)	Popping time to completion (min)	Temp at the beginning of popping (°F)	Temp at the end of popping (°F)	Popping efficiency at 60 s (%)	Popping efficiency at 90 s (%)
P02	99	2.9	334	468	80	89
P03	98	4.0	323	388	87	95
P04	100	1.5	363	441	89	98
P05	100	2.3	356	467	89	96
MS _{0.05} ⁱⁱⁱ	ns ^{iv}	1.4	ns	49	ns	ns

ⁱ Popping evaluation performed by Dr. Jill Keith, University of Wyoming using a cast iron skillet with 5 mL of canola oil. Temperature was measured using an infrared thermometer. From 332 to 577 seeds in total were divided among each of four replicates.

ⁱⁱ Mean of three replicates with two times (60 and 90 s); popping data excerpted from Rezaey et al. 2024.

ⁱⁱⁱ Mean separation test (Fisher's protected least significant difference for WY data and Tukey's test for WA data; $\alpha = 0.05$).

^{iv} ns = not significant.

OSU = Oregon State University; WSU = Washington State University.

Table 4. Results from popping evaluations in 2024 of OSU popping bean lines grown in different environments but popped under the same conditions in OR.

Advanced line no.	Production site and yr ⁱ	Popping efficiency (%)	Popped in 7 and 9 categories (%) ⁱⁱ	Expansion (%) ⁱⁱⁱ	Moisture (%) ^{iv}
P02	VF19	86.0	82.0	173	11.5
P02	VF21	97.3	82.7	149	9.6
P02	WY21	89.3	89.3	185	5.8
P05	VF19	93.3	82.0	174	8.8
P05	VF21	98.0	66.1	152	8.8
P05	WY21	98.0	94.7	182	7.3
LSD _{0.05} ^v		5.9	11.2	9	—

ⁱ VF = OSU Vegetable Research farm; WY = University of Wyoming Powell Research and Extension Center, WY, USA grown in years 2019 and 2021.

ⁱⁱ From a 1 to 9 scale, where 7 and 9 represent mostly expanded to fully expanded and softened cotyledons.

ⁱⁱⁱ Expansion is calculated as prepopped volume/popped volume × 100. Volume was measured in a 100 mL graduated cylinder.

^{iv} Based on the difference between pre- and postpopping seed weight.

^v Fisher's protected least significant difference ($\alpha = 0.05$).

Means are based on six replicates of 25 seeds, each popped in a microwave for 105 s.

— = unreplicated; OSU = Oregon State University.

proximate techno-functional analysis (Rezaey et al. 2024). In 2024, they were planted at the OSU Vegetable Research Farm, Corvallis, OR, where they were grown using conventional production methods, and at the OSU Lewis Brown Research Farm, where they were grown in a certified organic field. Seed was also provided to the dry bean breeding program at USDA–Agricultural Research Station/Michigan State University (MSU), East Lansing, MI, in 2024 for increase and evaluation of popping ability and phytohemagglutinin assays.

Selection and testing methods. Popping characteristics were evaluated in different ways by different programs. At OSU, we initially placed seeds in a 200 mL beaker with a magnetic stir bar containing hot (~250 °C) canola oil for ~60 s. Only the fully expanded seeds that floated to the surface were classified as popped, and time to cotyledon expansion was not recorded. Subsequently, seeds were popped in a microwave oven (Black + Decker Model EM925ACP-P2, 900 W, 2450 MHz) set to full power and heated for 90 s to 105 s. Samples of 25 seeds were placed in 100 mL beakers arranged around the perimeter of the turntable inside the microwave oven. Microwaved beans were rated on a 1 to 9 scale, where 1 indicates seed intact with no expansion, 3 indicates seedcoat split with slight expansion, 5 indicates seeds split and partially exposing slightly softened cotyledons, 7 indicates cotyledons expanded and softened but may retain hard spots or may have a differential expansion of cotyledons, and 9 indicates cotyledons fully expanded, uniformly soft and light in weight. In general, categories 7 and 9 were considered popped and culinarily acceptable. Popped seed loses most of its moisture in the popping process and can provide an estimate of percent moisture at the time of popping. In some tests, seed moisture was recorded based on the difference in unpopped and popped seed weights. We also measured seed volume pre- and post-popping using a 100 mL graduated cylinder. No South American accessions were available for comparison in popping trials because it was not possible to produce enough high-quality seed of the original nuña accessions grown in the same environment as the experimental lines.

The WSU program used the microwave popping method. An 1100-watt, 2450-MHz home microwave oven (model EM134A2SC-X3; Hamilton Beach, Glen Allen, VA, USA) was used for testing the popping percentage of popping beans. Beans were initially subjected to microwaving for 30, 60, 90, and 120 s. Thirty seconds was not sufficient to produce complete popping, and at 120 s, the beans were burned with no observed increase in the popping efficiency. Thus, 60 and 90 s were selected for the main popping efficiency test. Twenty sets of 10 beans each per replicate were placed in 100 mL ceramic crucibles, and 10 sets were microwaved for each time treatment. Popping efficiency was measured by counting and summing the number of popped beans and expressed as a percentage. Beans were

Table 5. Assay to test for the presence of intact lectins after popping, and popping efficiencies for two popping bean lines using different methods of popping and with and without the testa present.

Accession	Popping method	Treatment	Hemagglutination units/g	Popping efficiency (%)
P02	Microwave	Whole seed	0	83.3
P02	Hot air popper	Whole seed	0	88.9
P02	Oil	Whole seed	0	96.7
P05	Microwave	Whole seed	0	86.7
P05	Hot air popper	Whole seed	0	97.8
P05	Oil	Whole seed	0	100.0
P02	Microwave	Cotyledon	0	—
P02	Hot air popper	Cotyledon	0	—
P05	Microwave	Cotyledon	0	—
P05	Hot air popper	Cotyledon	0	—
P02	All methods	Unpopped seeds ⁱ	640	—
P05	All methods	Unpopped seeds	320	—
P02	—	Raw seeds	10,240	—
P05	—	Raw seeds	10,240	—
LSD 0.05 ⁱⁱ				3.6

ⁱSeeds that were heated but failed to pop.

ⁱⁱ Fisher's protected least significant difference ($\alpha = 0.05$).

Seed was produced at the MSU Montcalm Research Center in 2024.

— = N/A; MSU = Michigan State University.

considered popped when the cotyledon had expanded enough to break the seedcoat (Rezaey et al. 2024).

The UWY program method for popping evaluation was a cast iron pan on a commercial gas range (Bolak et al. 2022). To induce popping, beans were heated for 1.5 to 2.0 min in 5 mL (one teaspoon) of canola oil in the cast iron skillet until the oil reached a temperature of 250 °C. Temperature was measured using an infrared thermometer (ELECALL EIRT550E) held 30.5 cm (12 inches) above

the surface of the skillet. Only fully popped beans were judged acceptable for culinary use.

The USDA/MSU program tested popping efficiency using the microwave oven (model JES1145H1SS, 950w, 2450 MHz; GE, Boston, MA, USA), a hot air popper (Presto Poplite Popcorn Popper; Presto, Eau Claire, WI, USA), and hot oil [127-mm (5 inches) non-stick pan containing 40 mL of canola oil heated to 163.5 °C]. Popping times were 60 s at full power for the microwave, 60 s for the hot air popper, and 30 to 35 s for the hot oil

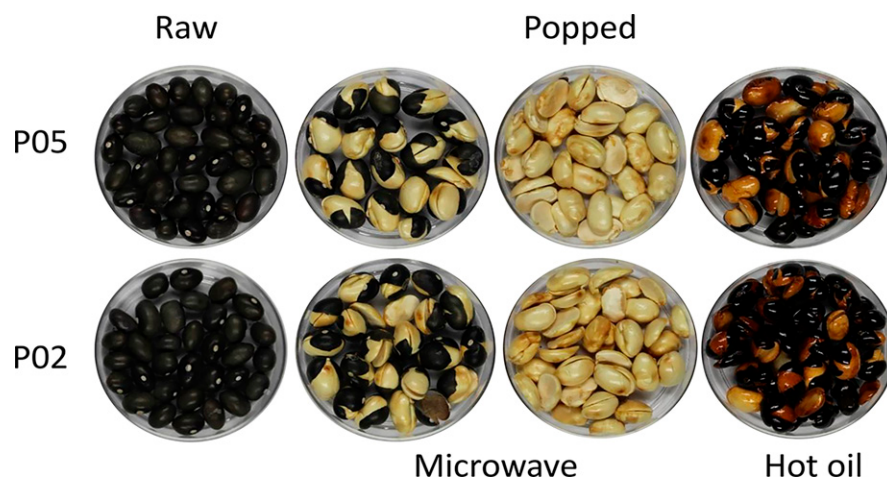


Fig. 2. Seed of P02 ('Poporito') and P05 ('Noche Nuña') popping bean cultivars. The first column shows seeds before popping and subsequent columns show beans popped by either microwave (second and third columns) or hot oil (fourth column). In the third column, the seedcoat fragments have been removed after popping. Photo: Jose Hernández, Michigan State University.

Table 6. Proximate composition of whole popping bean flours from popping bean lines.

Nuña breeding line	Starch (%)	Protein (%)	Total dietary fiber (%)	Moisture (%)	Ash (%)	Fat (%)
P02	35.4	21.3	17.5	8.6	4.2	2.7
P03	33.6	21.8	17.0	8.5	4.1	2.7
P04	33.9	23.1	19.6	8.5	4.0	2.6
P05	37.2	22.6	18.8	8.4	4.2	3.0

All values are means ($n = 3$) expressed on a wet weight basis. Mean values among breeding lines are not significantly different ($P < 0.05$). Seed analyzed was from a trial in Mount Vernon, WA, USA, in 2019. Data excerpted from Rezaey et al. (2024).

Table 7. Vegetative and reproductive growth characteristics of experimental popping bean lines compared with ‘Eclipse’ small black bean at the Washington State University Mount Vernon Research and Extension Center in 2019.

Entry	50% flowering (days) ⁱ	Plant ht (cm) ⁱⁱ	Node length (cm) ⁱⁱⁱ	Growth habit ^{iv}	Total yield (kg·ha ⁻¹)	Net yield (kg·ha ⁻¹)	100 seed wt (g)
P02	52	44	16	IA	1935	1712	36.2
P03	52	48	15	IA	2664	2302	35.3
P04	52	46	15	IB	2023	1879	34.6
P05	52	40	11	IB	2155	1956	36.4
‘Eclipse’ (irrigated)	57	52	7	II	3133	3113	20.3
‘Eclipse’ (nonirrigated)	57	46	7	II	3565	3466	20.1

ⁱ 50% flowering recorded when half the plants had at least one open flower.ⁱⁱ Plant height from base of plant to top node of 10 randomly selected representative plants.ⁱⁱⁱ Node length measured of 10 randomly selected representative plants, for the longest node near the top of the plant.^{iv} Growth habit types I to IV (Singh 1991), where type IA is compact determinate bush, type IB is determinate bush with elongated top internode(s), and type II is indeterminate but upright, ending in short vegetative growing point.

The data were recorded from unreplicated observation plots.

Table 8. Field data from Powell Research and Extension Center 2021 Novelty Dry Bean Trial, University of Wyoming.¹

Entry	Yield (kg·ha ⁻¹) ⁱⁱ	100 seed wt (g)	50% flowering (days)	Maturity (days)	Upright scale ⁱⁱⁱ	Height (cm)
P02	3,643	41.8	45	101	9.5	42
P03	3,449	39.1	48	105	8.5	51
P04	3,404	39.5	46	101	8.5	48
P05	3,514	41.6	44	97	8.5	47
Othello (pinto check)	3,983	37.1	42	81	4.7	57
Windbreaker (pinto check)	3,726	43.9	47	96	7.3	64
LSD _{0.05} ^{iv}	749	2.1	3	5	1.3	10

¹ Trial sown on 1 Jun 2021 in 22-inch rows in a completely randomized design. There were two replicates for the P0 lines and three replicates for the two pinto check lines. Plots were six rows of 15.3 m², of which 3.4 m² of the center two rows were harvested for yield. Plots were furrow irrigated every 10 d through early September.ⁱⁱ Grain yields were corrected to 14% moisture (moisture at the time of weighing ranged from 8.9% to 10.5%).ⁱⁱⁱ Upright rating was assessed visually at or about the time of maturity; this value is inversely related to lodging; higher values represent more upright stature; low values represent prostrate plants.^{iv} Fisher’s protected least significant difference ($\alpha = 0.05$).

treatment. The samples were adjusted to 8.5% moisture content before popping.

Lectin hemagglutination was assessed by the USDA/MSU program by first extracting the proteins from each sample, which had been previously milled using a laboratory scale knife mill. A total of 300 mg of flour was suspended in 3 mL of phosphate-buffered saline and stirred overnight at 4 °C for 16 h. After incubation, the samples were centrifuged at 3400 g_n for 10 min at 4 °C, and the supernatant was collected. The samples were serially

diluted in a 1:1 ratio for a total of 10 dilutions. A 100-μL aliquot of each dilution was mixed with 100 μL of a 1% rabbit red blood cells (catalog no. 88R-R001; Biosynth, Enderby, UK) in a round-bottom 96-well microtiter plate and incubated for 2 h at room temperature. For the determination of agglutination activity, the samples were observed, and the highest dilution at which agglutination was visualized was recorded as the lectin titer (Fig. 1). Hemagglutination was calculated as the reciprocal of the highest dilution that caused hemagglutination,

multiplied by the initial dilution factor of the sample (Adamcová et al. 2021). The maximum observable titer with 11 serial dilutions was 10,240 U·g⁻¹.

Statistical methods. Analysis of variance was performed in SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) using the PROC GLM (general linear model) statement to evaluate popping and field performance. Mean separation was evaluated using Fisher’s protected least significant difference or Tukey’s test ($\alpha = 0.05$).

Description

Popping parameters. Popping percentage and expansion are shown in Tables 2-5 and Fig. 2 provides a visual expression of expansion using different popping methods. In the earlier tests, where seed sample sizes were smaller and with minimal replication, popping percentages ranged from 60% to 90% (Table 2), whereas in later trials with larger seed sample sizes and production in low humidity environments, popping percentages of the P02 and P05 ranged from 86% to 100% (Tables 3–5). Where popping to completion tests were performed (Table 3), P02 and P05 had complete popping in 2.3 to 2.9 min. Popping percentage and expansion varied depending on the location of seed production (Table 4), but a genotype × environment interaction was not observed (data not shown). When different methods were compared with identical seed

Table 9. Performance of popping bean lines with Peruano check cultivars in a dry bean trial conducted at the OSU Vegetable Research Farm in 2024.¹

Entry	Growth habit	50% bloom (days) ⁱⁱ	80% buckskin (days)	Seed fill duration (days)	Yield (kg·ha ⁻¹)	Seed filling efficiency (kg·ha ⁻¹ ·d ⁻¹) ⁱⁱⁱ	Yield efficiency (kg·ha ⁻¹ ·d ⁻¹) ⁱⁱⁱ	100 seed wt (g)
5-593 (small black)	IA	49	93	44	1211	27.8	13.0	21.6
Myasi (Peruano)	IA	52	87	35	1314	37.6	15.1	46.7
Patron (Peruano)	IA	49	87	38	3985	106.3	46.2	42.2
P02	IB	49	111	62	2492	40.6	22.6	34.0
P03	IB	51	103	52	2306	44.7	22.5	36.5
P04	IB	50	108	58	1922	33.4	17.9	32.5
P05	IB	51	109	58	1674	28.9	15.4	34.3
LSD _{0.05} ^{iv}			5		834		9.8	3.5

¹ Trial was replicated four times. 5-593 is a parent to the popping bean lines; two Peruano (yellow-seeded) bean check cultivars are included to show performance of popping beans relative to other dry beans.ⁱⁱ Days to 50% of plants with at least one bloom based on a single replicate.ⁱⁱⁱ Seed filling efficiency is calculated as yield/(days to maturity – days to bloom), and yield efficiency is yield/days to maturity. Both are measures of reproductive gain per day. Because days to flowering was unreplicated, seed filling efficiency calculated using trial means.^{iv} Fisher’s protected least significant difference ($\alpha = 0.05$).

Table 10. Performance of popping bean lines with a Peruano check cultivar in an organically managed dry bean trial conducted at the OSU Lewis Brown Research Farm in 2024.ⁱ

Variety	Emergence (%)	50% bloom (days) ⁱⁱ	Harvest maturity (days)	Seed fill duration (days)	Yield (kg·ha ⁻¹)	Adjusted yield (kg·ha ⁻¹) ⁱⁱⁱ	Adjusted yield efficiency (kg·ha ⁻¹ ·d ⁻¹) ^{iv}	Adjusted seed filling efficiency (kg·ha ⁻¹ ·d ⁻¹) ^{iv}	100 seed wt (g)
P02	75	53	120	67	2411	3027	25.2	45.2	38
P03	80	54	118	64	2219	2663	22.7	42.0	35
P04	70	53	120	67	1433	1848	15.4	27.5	34
P05	38	51	118	67	994	1613	13.8	24.4	39
Patron ^v	83	52	120	69	3605	4267	35.6	62.4	44
LSD _{0.05} ^v	18	ns ^{vi}	ns	ns	1572	1857	16.4	29.2	6

ⁱ Trial was replicated two times. 'Patron' Peruano market class cultivar included as a high yielding check to show performance of popping beans relative to other dry beans.

ⁱⁱ Days to 50% of plants with at least one bloom.

ⁱⁱⁱ Yield adjusted for variation in emergence.

^{iv} Yield efficiency is calculated as adjusted yield/harvest maturity and seed filling efficiency is adjusted yield/seed fill duration. Both are measured as re-productive gain unit area per day.

^v Fisher's protected least significant difference ($\alpha = 0.05$).

^{vi} ns = not significant.

OSU = Oregon State University.

batches (Table 5), hot oil produced the highest popping efficiency, followed by hot air popper, and the microwave was the least efficient. Overall, when P02 and P05 are grown under optimum conditions to produce fully mature seed and the seed is adjusted to an optimum moisture of 8.5% (range 5% to 11%), popping percentages of essentially 100% can be achieved. Unpopped seeds are often smaller and/or immature, and it may be advantageous to separate smaller and discolored seeds from normal seeds before popping in commercial production.

Antinutritional analysis. Lectin hemagglutination assays revealed no agglutination activity in expanded cotyledons after popping by any of the three methods (Table 5). However, seeds that had been heated but failed to pop were positive for agglutination but at relatively low levels (320 to 640 U·g⁻¹; Table 5 and Fig. 1). For comparison, raw P02 and P05 seeds had at least 10,240 U·g⁻¹ (Table 5). Hemagglutination of various common beans ranged from ~13,000 to over 26,000 U·g⁻¹ (Adamcová et al. 2021). These data support the hypothesis that a combination of heat and pressure and the sudden release of pressure renders lectins biologically inactive even with a short cooking time.

Proximate analysis. P02 and P05 were not significantly different in starch, protein, or fiber content (Table 6). Starch and protein content for P02 and P05 were 35% to 37% and 21% to 23%, respectively. P05 had 18.8% fiber and P02 had 17.5%. Reported content for

dry beans ranges from 27% to 58% for starch, 15% to 25% for protein, and 24% to 27% for fiber. In general, the two popping bean cultivars are not substantially different from other dry beans in starch and protein, but the lower fiber content in the popping bean cultivars should be investigated to determine whether this trait is related to popping ability.

Seed and plant color. The seeds of P02 and P05 are black, with a dull sheen of the testa (Fig. 2). There are no established market classes for popping beans, and traditional nuña beans range from light to dark color seeds and patterns. While the original nuña parent had a white background color with black speckles and the progeny segregated for various seed colors, as we selected for high popping percentage, lines with dark-colored seed were retained over light-colored seed because of their superior popping performance. Rezaey et al. (2024) found that dark seedcoat color was associated with the highest popping percentages, but whether this is a chance association or due to linkage between seed color and popping quantitative trait loci remains to be further studied. As would be expected with black seed color, flowers of P02 and P05 are purple, and foliage has purple pigmentation.

Seed size. The seeds of P02 and P05 are intermediate in size of the two parents. Seed size for P02 ranged from 34.0 g per 100 seeds to 41.8 g per 100 seeds in trials from WA, WY, and OR (Tables 7-10). Similarly, for P05,

seed size ranged from 34.3 to 41.6 g 100⁻¹ in the same trials. Pava nuña's reported seed size was 87.4 g per 100 seeds (Genesys 2024), whereas 5-593 was 19.8 g per 100 seeds from WA (Miles et al. 2019) and 21.6 g per 100 seeds in OR trials (Table 9). The seeds of P02 and P05 are similar in size to cultivars in the pinto market class.

Plant architecture and lodging. P02 and P05 both have a determinate bush (type IA or B) growth habit that generally keeps the pods elevated and is suitable for mechanical harvest (Tables 7 and 9). P05 had a shorter plant height and internode length compared with P02 in WA and MI (Tables 7 and 11), while height differences were reversed in the WY trial (Table 8). The lines had superior lodging resistance, as indicated by upright scale scores recorded in WY and MI (Tables 8 and 11).

Days to flowering and maturity. P05 was earlier in maturity by 2 to 17 d (Tables 8-11) compared with P02. In OR, P02 matured in 102 to 103 d in 2014 and 2019, while P05 had the same maturity of 100 d both years (data not shown). Elevated temperatures during bloom and seed fill delayed maturities in OR in 2024 to 111 and 109 d for P02 and P05, respectively (Table 9). While days to 50% flower were similar (Tables 7-11), the 97 to 120 d to harvest maturity indicates that these lines will mature satisfactorily given enough heat units in most traditional bean growing regions in North America.

Table 11. Performance of nuña experimental bean lines in a preliminary dry bean trial conducted at the Montcalm Research Station in Michigan in 2024.ⁱ

Entry	50% Flowering (days)	Maturity (days)	Plant ht (cm)	Common bacterial blight ⁱⁱ	Lodging ⁱⁱⁱ	Desirability ^{iv}	Yield (kg·ha ⁻¹)	Seed moisture (%)
P02	39	110	36.8	5.0	1.0	4.0	2671	16.2
P05	37	93	30.5	6.5	1.0	2.5	2189	16.1
LSD _{0.05} ^v	ns ^{vi}	7.52	ns	1.43	ns	1.05	ns	ns

ⁱ Trial was replicated twice.

ⁱⁱ Natural infection of common bacterial blight rated on a scale of 1 to 9, where 9 indicates the most disease.

ⁱⁱⁱ Scale of 1 to 5, where 1 is completely upright.

^{iv} Desirability rating is on a 1 to 5 scale, with 1 being most desirable.

^v Fisher's protected least significant difference ($\alpha = 0.05$).

^{vi} ns = not significant.

Yield and productivity. Yield data are available from trials in WA, WY, MI, and OR (Tables 7-11). In the WA trial, net yield for P02 and P05 were 1712 and 1956 kg·ha⁻¹, respectively (Table 7). These yields were 40% lower than the small-seeded black check cultivar Eclipse. However, this trial was not replicated. The WY yield trial (Table 8) produced 3643 and 3514 kg·ha⁻¹ net yield for P02 and P05, respectively. This compares to 3726 to 3983 kg·ha⁻¹ yields for the two pinto check cultivars. In the Oregon Vegetable Farm trial, yields were 2492 and 1674 kg·ha⁻¹ for P02 and P05, respectively, like the commercially grown Peruano cultivar Myasi (1314 kg·ha⁻¹) but significantly less than Patron (3985 kg·ha⁻¹) (Table 9). In the Oregon Lewis Brown Farm trial, the unadjusted yield of 994 kg·ha⁻¹ for P05 was lower (but not statistically significant) than the 2411 kg·ha⁻¹ yield for P02 (Table 11). When adjusted for emergence, The ranking of the two cultivars remained the same. There were 812 growing degree days (GDD, base 10°C) from planting to harvest (22 May to 25 Sep) in WA, 1678 GDD for P05 and 1704 GDD for P02 in OR, and 1748 GDD for P05 and 1811 GDD for P02 (1 Jun to 9 Sep) in WY. These differences in GDD at each location partially explain the yield differences observed among environments. These data indicate that in productive environments, the popping bean lines do have the potential to yield >3000 kg·ha⁻¹.

Disease resistance. At the OSU vegetable research farm, P02 and P05 have been selected under pressure from the root rot complex (predominantly *Fusarium solani*) that is present. In trials in Washington, Wyoming, Michigan, and Puerto Rico, no particular disease issues were observed (Table 11).

For bean common mosaic virus/bean common mosaic necrosis virus (BCMV/BCMNV), tests were conducted in 2002 on the F₅ generation using the BCMNV NL-3 isolate, and lines showed necrotic local lesions at the site of inoculation and systemic necrosis (black root) after about 1 wk. This indicated that the lines carried the *I* gene, which provides resistance to all pathogroups of BCMV and BCMNV. Lines were rescreened at the University of Idaho in 2024 and showed a systemic necrotic response with BCMNV isolate NL-8-CA (pathogroup IV; Feng et al. 2017), again indicating that unprotected *I* gene was present. Three isolates of BCMV, 3PF (pathogroup I), RU1-CA (pathogroup VI), and RU1-OR (pathogroup VII; Feng et al. 2018), were found unable to infect these popping bean lines, confirming the presence of the *I* gene. In the OSU field, P02 and P05 have been planted next to dry bean cultivars with seedborne BCMV symptoms but have remained symptom-free.

Resistance to beet curly top virus is recommended for production in the intermountain region of the Pacific Northwest. The new

popping bean lines carry the SAS8 SCAR marker linked to *Bct*.

Summary

The cultivars described in this release represent the first popping beans to be released from a public breeding program for commercial development in the United States. They represent a new and novel use of dry beans for which no market currently exists. Because they do not require hydration and prolonged cooking times, these beans are quick and convenient to prepare. One application may be as a high-protein, low-fat snack food. After popping, they may also be rehydrated as whole beans or milled to produce a flour or powder to create various bean products, such as reconstitutable refried beans. Substantial energy savings may be realized in the preparation of these reconstitutable foods because the hydration-cooking-dehydration steps are bypassed. Because there are no commercial cultivars for comparison, these lines establish a benchmark for this new market class. The lines have excellent popping ability demonstrated across environments combined with relatively early maturity and a growth habit suitable for mechanical harvest. The two cultivars are similar but differ in maturity, where P05 is earlier maturing and may show optimal performance in northern latitudes with shorter growing seasons. The later maturity of P02 may allow it to produce higher yields in environments with longer growing seasons.

Availability

Small quantities of seeds of these cultivars are available under material transfer agreement for trialing and crossing. Plant Variety Protection is pending (Noche Nuña: PVP 202500424 and Poporito: PVP 202500425).

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