

Effects of Seed Moisture Content, Cooking Time, and Chamber Temperature on Nuña Bean (*Phaseolus vulgaris* L.) Popping

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Additional index words. popping beans, nuñas, postharvest, Andean, popping percentage

Abstract. Nuña beans are a type of common bean (*Phaseolus vulgaris* L.) native to the Andean region of South America that possess the unusual property of popping; however, little is known regarding postharvest environmental effects on popping. Seed of a photoperiod-insensitive, temperate-adapted nuña bean breeding line, ‘PB24’, was produced at the Arlington Agricultural Research Station, Arlington, WI, and evaluated in a hot air popper. The experimental design was a factorial with three levels of popping time (60, 90, and 120 s), five levels of chamber temperature (101, 146, 208, 244, and 268 °C), and eight levels of seed moisture (2.5%, 3.2%, 5.2%, 6.6%, 8.3%, 12.0%, 15.3%, and 20%). Percentage of popped seed, sufficiently expanded to shed the seedcoat, was calculated. A curvilinear decrease in popping percentage was observed with increasing seed moisture content. In contrast, a curvilinear increase in popping percentage was observed with increasing chamber temperature and popping time. Larger mean squares were observed for main effects and first-order interactions associated with seed moisture content and chamber temperature compared with popping time. A combination of seed moisture below 5%, popping chamber temperature of 244 °C, and popping time of 90 s resulted in popping percentages greater than 90%.

Nuña beans are a type of common bean (*Phaseolus vulgaris* L.) native to the Andean region of South America that possess the unusual property of popping when exposed to heat (National Research Council, 1989). Popped nuñas are a snack food similar to popcorn; however, the popping mechanism is different. In popcorn, the endosperm is liquefied and explosive pressure builds up in the pericarp (Hoseney et al., 1983); in contrast, popping in nuña beans is the result of pressurized steam trapped within and between the mesophyll cells in the cotyledons (Spaeth et al., 1989). The popped product is an expanded seed with a texture and flavor often

described as being similar to roasted peanuts. Nuñas are a traditional snack food in the Andean region of South America where they are commonly sold by street vendors or prepared in the home. Popping of nuña beans is a more efficient way of preparing bean protein at high altitudes compared with boiling, which requires larger amounts of fuel (National Research Council, 1989; van Beem et al., 1992; Zimmer, 1992). In the Andean region, nuña beans are popped on hot stones or in hot sand; however, nuña beans can also be successfully popped in a microwave oven or using hot oil or hot air (Tohme et al., 1995).

In popcorn, a seed moisture content above or below an optimum range will dramatically reduce popping percentage (Hoseney et al., 1983). In previous collaborative research on nuña bean popping with Dr. Robert Lindsey, Department of Food Science University of Wisconsin–Madison, Madison, WI, we observed that low-moisture nuña beans (less than 5% seed moisture) tend to have greater seed expansion after popping compared to seeds with a higher moisture content. The effects of seed production or postharvest environments on nuña bean popping was illustrated in our laboratory in 1996, when nuña seed from a winter nursery increase in Bolivia did not pop; nevertheless, seed produced from progeny grown the next summer at Hancock Agricultural Research Station (ARS), Hancock, WI, did pop. Similar observations were made in the summer of 1996 when differences in seed popping per-

centages among an array of inbred nuña bean lines produced in three different locations, Fort Collins, CO, Frutilla, CO, and Hancock, WI, were inconsistent (Dr. Mark Brick, Colorado State University, Fort Collins, CO, personal communication). Differences in moisture content of seed produced at the three locations were unknown; nevertheless, observations from other preliminary experiments indicated that popping performance of nuña beans was related to the moisture content of seeds (Kmieciak and Nienhuis, 1998). To evaluate among nuña bean breeding lines and germplasm accessions, knowledge is needed regarding the effects of postharvest environments on popping performance. The objective of this research was to determine the optimal levels of seed moisture content, popping time, and chamber temperature on the popping percentage of nuña beans.

Materials and Methods

Plant material. Seed of a photoperiod-insensitive, temperate-adapted inbred nuña bean breeding line, ‘PB24’, was produced during the 1997 growing season at the Arlington ARS, Arlington WI, using standard cultural practices (Binning et al., 1995). The breeding line ‘PB24’ was developed using inbred-backcross breeding followed by pedigree selection using the nuña landrace ‘Ayachucho’ as the donor parent and ‘Stockbridge Indian Bean’ as the recurrent parent (Kmieciak and Nienhuis, 1997). The seed was harvested at full maturity, stored at ambient room temperature for 4 years, and, before initiation of the present research, dried in a forced air oven at 50 °C for 3 weeks to ≈4% moisture (Tector Sinar™ Farmpro 6090 Moisture Analyzer; Sinar Technology, Berkshire, U.K.).

Experimental design. The experimental design was a factorial with three levels of popping times (60, 90, and 120 s), five levels of chamber temperature (101, 146, 208, 244, and 268 °C), and eight levels of seed moisture content (2.5%, 3.2%, 5.2%, 6.6%, 8.3%, 12.0%, 15.3%, and 20%). The experiment was replicated four times.

Popping time. The range of popping times was chosen to reflect times used in prior popping experiments (Kmieciak and Nienhuis, 1997, 1998; Lindsey, Department of Food Science University of Wisconsin–Madison, Madison, WI, personal communication).

Popping chamber temperature. A Presto Hot Air Popper model 04821 (National Presto Industries, Inc., Eau Claire, WI) was modified into a variable-temperature popper. A variable transformer was placed in series with the main heating coil and was bypassed using a three-way switch for maximum power. The range of chamber temperatures was measured with a mercury thermometer placed 5 cm from the bottom of the popping chamber. The range of temperatures was chosen between the boiling point of water and the maximum setting of the hot air popper at ≈50 °C increments.

Received for publication 27 May 2008. Accepted for publication 30 July 2008.

This research was supported by the Wisconsin Department of Agriculture, Trade and Consumer Protection Agricultural Development and Diversification Grant Program (WDATCP Contract No. 17076).

We thank Michell Sass, Felix Navarro, and Kenneth Kmieciak for their preliminary work on this project and for technical assistance. We also thank James Holub for his assistance in the modification of the hot air popper.

This manuscript is a portion of the thesis submitted by Jesse Vorwald in fulfillment of the requirements for an M.S. degree in Horticulture.

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Seed moisture. One-gallon glass Quantpro jars (Fisher Scientific, Pittsburgh, PA) with a sample support made from an inverted 9-cm plastic pot with the bottom removed and a piece of rigid plastic mesh to separate the seed from the salt solution was used as a moisture chamber. Seven saturated salt solutions and a control without a salt solution were used to produce seed moisture levels of 2.5%, 3.2%, 5.2%, 6.6%, 8.3%, 12.0%, 15.3%, and 20% (Bell and Labuza, 2000; McCurdy et al., 1980; National Institute of Standards and Technology, 2000a, 2000b; Weston and Morris, 1954). A random sample of 50 seeds was packaged in individual 3-inch × 4-inch plastic mesh bags (Vilutis & Co., Inc., Frankfort, IL). Sixteen bags of 50 seeds were placed in each of the eight moisture chambers, 15 bags for popping

and one for moisture analysis. These bags were allowed to equilibrate for 6 weeks. The seeds of one sample bag in each moisture chamber were chosen at random and coarsely ground using a mortar and pestle. Three- to 4-g samples were weighed in predried aluminum weighing dishes and dried in a convection oven for 24 h at 100 °C. Moisture content was calculated as the percentage of predried seed weight (Spaeth et al., 1989; van Beem and Spaeth, 1990).

Data analysis. A sample of 50 seeds from each replication and factorial level was popped and the percentage of fully popped seed was calculated. A seed was considered fully popped when the cotyledons had expanded sufficiently to shed the seedcoat and lacked a mottled appearance. For purposes of the analysis of variance, popping percentage data were transformed using arcsine⁻¹ and levels of the three factorial treatments were considered random effects. Means for each level of a factorial treatment adjusted for the other effects in the model (least mean squares) were estimated. Graphs and contour plots are presented using untransformed data to facilitate interpretation of the results. The data were analyzed using the Standard Linear Models procedure of JMP statistical software (SAS Institute, Inc., Cary, NC). Single degree-of-freedom orthogonal contrast for factorial levels of treatments were calculated using PROC IML (SAS/IML Software, 1989).

Results and Discussions

The main effects, first- and second-order interactions associated with the three factorial treatments popping time, chamber temperature, and seed moisture were significant (Table 1). The main effects with the largest mean squares were seed moisture and chamber temperature, which were ≈20 times larger than the mean square associated with popping time (Table 1).

Popping percentage decreased as seed moisture content increased (Table 1; Fig. 1). Nuña beans pop as a result of the buildup and release of steam pressure within the cellular structure of the cotyledons (Spaeth et al., 1989). The rate of mass transfer of steam is similar to that of heat (Toledo, 1991); thus, the observed results may be the result of greater steam channeling by mass transfer within the mesophyll of the cotyledons of lower compared with higher moisture content of nuña bean seeds. In higher moisture content (greater than 5%) nuña bean seeds, steam was observed escaping from the surface of unpopped seeds. Thus, the reduced popping percentage of higher moisture content nuña bean seed may also be the result of the effect of the latent heat of steam formation and adiabatic cooling resulting from the escape of moisture from within the seed. The results of this study indicate that a seed moisture content less than 5% is optimal for successful popping.

An increase in popping percentage was observed with increasing chamber tempera-

ture (Table 1; Fig. 2). Higher temperatures may produce larger amounts of steam within the mesophyll cells of the cotyledons of nuña bean seeds and more effectively bring the internal steam pressure above the deformation point of the cell walls. The results of this study indicate that chamber temperatures greater than 244 °C are optimal for successful popping.

Popping percentage increased with increasing popping time from 60 to 120 s (Table 1; Fig. 3). The curvilinear response indicated no increase in popping percentage after 90 s (Fig. 3). To avoid a burnt flavor of popped nuña beans, caution should be taken with combinations of cooking temperatures greater than 244 °C and cooking times longer than 90 s, because undesirable scorching can result.

The largest magnitude first-order interaction was observed between seed moisture content and chamber temperature (Table 1). Popping percentages greater than 90% can be achieved with a seed moisture content of less than 5%, a chamber temperature above 244 °C, and cooking times of 90 s (Fig. 4). The optimal combination of seed moisture and chamber temperature may result in the water

Table 1. Analysis of variance and orthogonal polynomials associated with the factorial effects of seed moisture content, popping chamber temperature, and popping time on popping percentage of nuña breeding line 'PB24'.

Source	df	Popping percentage ^z	
		Mean squares	Significance ^y
Repetitions	3	1,015.6	***
Seed moisture (SM)	7	19,918.7	***
SM linear	1	10,072.2	***
SM quadratic	1	654.5	***
SM cubic	1	133.5	NS
Chamber temperature (CT)	4	22,720.3	**
CT linear	1	84,088.0	***
CT quadratic	1	0.4	NS
CT cubic	1	5,749.7	***
Pop time (PT)	2	825.8	**
PT linear	1	1,299.7	***
PT quadratic	1	351.9	*
SM × CT	28	4,063.2	***
SM × PT	14	292.2	**
CT × PT	8	649.7	***
SM × CT × PT	56	210.4	***
Pooled error	357	95.1	

^zFor purposes of the analysis of variance, popping percentage data were transformed to arcsine⁻¹. ^y***, **, *, and NS indicate significance at $P \leq 0.001$, 0.01, 0.05, and nonsignificant, respectively.

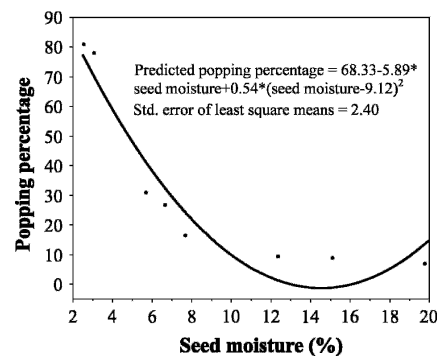


Fig. 1. Curvilinear decrease in popping percentage (least square means, arcsine⁻¹ transformed data) with increasing seed moisture percentage in nuña bean breeding line 'PB24'.

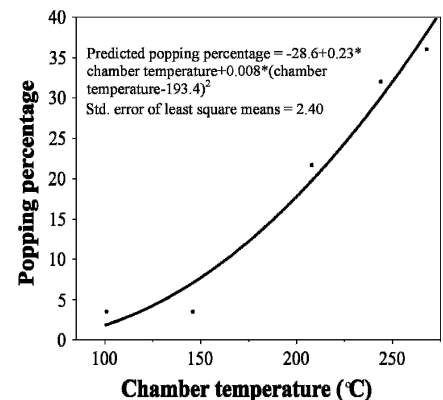


Fig. 2. Curvilinear increase in popping percentage (least square means, arcsine⁻¹ transformed data) with increasing chamber temperature in nuña bean breeding line 'PB24'.

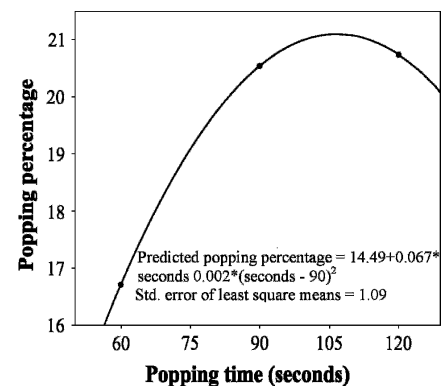


Fig. 3. Curvilinear increase in popping percentage (least square means, arcsine⁻¹ transformed data) with increasing popping time in nuña bean breeding line 'PB24'.

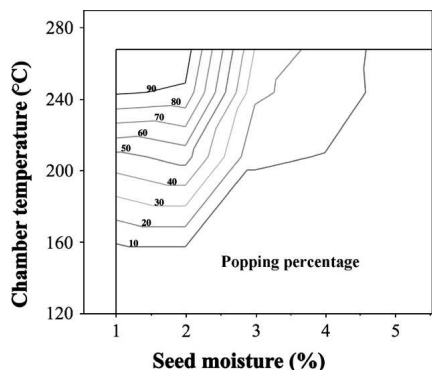


Fig. 4. Contour plot of popping percentage (arcsine⁻¹ transformed data) in nuña bean breeding line 'PB24' as a function of seed moisture content and chamber temperature. Data represent least square means adjusted for the effects of replications and popping time.

within the seeds achieving the vapor point in a shorter period of time, thus increasing popping and minimizing scorching. The relationship between seed moisture and popping temperature has also been observed in other popped products. In popcorn, low-moisture kernels pop at high temperatures and high-moisture kernels pop at lower temperatures (Lucas and Rooney, 2001). In puffed rice products, the rice is brought to a moisture content of 12% to 15% and fried in 220 °C oil; in contrast, rice with a 5% to 7% moisture is fried at 240 to 250 °C (Lucas and Rooney, 2001).

Consistent popping at or above 90% is important for successful commercialization of popped nuña beans. A high popping percentage allows for greater profitability, less waste, and less labor to remove undesir-

able unpopped seeds from the product. Optimal popping was achieved in seeds with seed moistures below 5%, chamber temperatures of 244 °C or higher, and popping times of 90 s. Chamber temperatures of 244 °C with a popping time of 90 s minimize the amount of seed carbonization resulting in a more desirable product. Future nuña popping research may focus on combinations of factors associated with the popping environment that may result in a further reduction of the level of carbonization of the popped product. In addition, in future research, greater attention should be paid to popping volume that may contribute to a more versatile and palatable snack food product and increased consumer acceptance.

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