Steam-Cooking and Dry Heating Produce Resistant Starch in Legumes

Juscelino Tovar* and Carmelo Melito

Instituto de Biología Experimental, Facultad de Ciencias, Universidad Central de Venezuela, P.O. Box 47069, Caracas 1041-A, Venezuela

Starch was isolated from either raw or steam-heated black, red, and lima beans. Isolates from steam-heated legumes were rich in indigestible (resistant) starch (19−31%, dmb), a fact not observed when raw seeds were used. Similarly, resistant starch measured directly in conventionally and high-pressure steamed beans was 3−5 times higher than in the raw pulses, suggesting retrogradation as the major mechanism behind the reduction in digestibility. Thus, steam-heating comes forth as an effective way to produce resistant starch in legumes. Prolonged steaming as well as short dry pressure heating decreased the enzymatically assessed total starch content of whole beans by 2−3% (dmb), indicating that these treatments may induce formation of other types of indigestible starch.

Keywords: *Beans; dry heating; legumes; resistant starch; starch digestibility; steam-cooking*

INTRODUCTION

Despite their interesting nutritional features, relatively few studies have been carried out to evaluate the impact of processing on the nutritional quality of legume starches (Tovar, 1994a), an aspect that must be carefully investigated before increasing the industrial use of edible pulses.

Most polymer isolation and analysis protocols recommend dehulling of dark-colored legumes (Sathe et al., 1982; Escarpa et al., 1994). This step is, however, tedious and time-consuming, especially for large seed numbers. Hence, in order to facilitate removal of seed coats, accelerated seed hydration in a steam current has been tried (Melito et al., 1994). Such a procedure applied to common beans in combination with the Sathe et al. (1982) purification method yielded indigestible starch-rich isolated materials, suggesting that steam-heating itself might be partly responsible for the formation of indigestible starch fractions (Melito et al., 1994).

Since cooked legume starches are prone to retrograde and thus generate indigestible—or resistant—fractions (Tovar et al., 1990a,b; Schweizer et al., 1990; Tovar and Velasco, 1995), to study the impact of steam-cooking on the enzymic availability of starch in beans was the main objective of present work. The effect of dry heating under high-pressure conditions was also investigated.

MATERIALS AND METHODS

Seeds. Dried common black beans (*Phaseolus vulgaris* L. cv. Tacarigua) were provided by the The Centro Nacional de Investigaciones Agropecuarias (CENIAP), Maracay, Venezuela. Red kidney beans (*Phaseouls vulgaris* L) were obtained from the local market. Black lima beans (*Phaseolus lunatus* L. cv. Tapiramo) were grown at the experimental garden of the School of Biology, Universidad Central de Venezuela.

Processing of Whole Beans. For steam-cooking, manually selected seeds were scattered on a fiberglass grid and placed on top of a cooking pan containing boling water (98 °C) for a variable period (between 30 and 180 min); heating for 90 min was sufficient for an easy dehulling of the seeds. For comparative purposes, seeds were steam-cooked under pressure by placing them in an open glass flask which was then autoclaved at 121 °C for 15 min. This pressure treatment was also carried out in capped flasks in order to prevent direct steam/seed contact ("dry pressure heating").

Starch Determination. Available starch content was estimated by the Termamyl/amyloglucosidase method of Holm et al. (1986). Samples were blended and extensively homogenized before analysis, a treatment that rules out analytical problems associated with physical inaccesibility of starch in whole legume seeds (Tovar et al., 1990a). Total starch content was evaluated with the same enzymic method, including the alkaline (2 N KOH) dispersion step described by Tovar et al. (1990a,b). "Resistant starch" content was then calculated as the difference between "total" and "available" starch (Tovar et al., 1990b).

Starch Isolation. Starch was isolated from both raw and steam-cooked seeds, following the multiple extraction protocol of Sathe et al. (1982), which comprises dehulling and milling of the seeds, followed by sequential extraction with water, 2% NaCl, cold 0.1 N NaOH, and 80% ethanol.

Moisture Determination. This was performed according to AOAC (1984).

Statistics. Means were compared by one-way analysis of the variance followed by the Duncan multiple comparison test, using the SPSS/PC+ program.

RESULTS

The enzymatically assessed starch content of starch isolates from various legumes is shown in Table 1. In all cases, the readily available starch content of samples prepared from 90-min-heated seeds was significantly lower than in those coming from raw seeds. These changes were accompanied by remarkably high resistant starch levels, without any significant alteration of the total starch content (Table 1).

Similarly, the available starch content in raw black and lima beans was higher than in the corresponding heat-processed seeds (Table 2). No major difference was observed between conventional and high-pressure steaming (Table 2), although final moisture content achieved after each type of treatment was significantly different (Figure 1).

Extensive (≥120 min) steam-heating of the pulses produced only marginal changes in the resistant starch content of black and lima beans, but it was associated with a significant drop in both available and total starch

* Author to whom correspondence should be addressed (fax) +58 2 752 5897; telephone +58 2 751 0111 and +58 14 325 792; e-mail jtovar@dino.conicit.ve).

S0021-8561(95)00824-7 CCC: $12.00

Table 1. Total and Available Starch Content in Purified Starch from Raw and Steam-Heated Beans

legumes	preisolation treatment	yield,[a] %	total starch,[b] %	available starch,[b] %	resistant starch,[c] %
black bean	raw	35 ± 0.2	89.8 ± 1.2[e]	87.6 ± 1.4[e]	2.2
	steam-heated[d]	25 ± 0.6	91.2 ± 0.2[e]	72.3 ± 1.5[f]	18.9
red bean	raw	30 ± 2.5	90.2 ± 1.1[e]	88.5 ± 1.5[e]	1.7
	steam-heated[d]	23 ± 1.7	89.2 ± 0.4[e]	68.0 ± 1.0[g]	21.2
lima bean	raw	29 ± 2.3	98.5 ± 2.7[f]	96.5 ± 1.5[h]	2.0
	steam-heated[d]	26 ± 0.7	97.4 ± 0.8[f]	66.7 ± 1.9[g]	30.7

[a] Starch obtained (g) × 100/seed weight (g); dry matter basis. [b] Starch content (g) × 100/isolated starch weight (g); dry matter basis. Values are means of at least six determinations ± SEM. Means in columns not sharing the same superscript letter are significantly different ($p < 0.05$). [c] Total starch − available starch. [d] Steam-heated for 90 min.

Table 2. Total and Available Starch Content in Variously Treated Beans

legumes	treatment	total starch,[a] %	available starch,[a] %	resistant starch,[b] %
black bean	raw	39.3 ± 0.2[e]	37.4 ± 0.6[e]	1.9
	steam-heated[c]	38.7 ± 2.9[e]	32.7 ± 1.6[f]	6.0
	high-pressure steaming[d]	41.3 ± 4.0[e]	35.7 ± 4.5[g]	5.6
lima bean	raw	39.9 ± 0.6[e]	39.1 ± 0.5[e]	0.8
	steam-heated[c]	38.9 ± 0.4[e]	34.9 ± 0.3[g]	4.0
	high-pressure steaming[d]	40.9 ± 0.7[e]	36.5 ± 0.7[g]	4.4

[a] Starch content (g) × 100/seed weight (g); dry matter basis. Values are means of at least six determinations ± SEM. Means in colums not sharing the same superscript letter are significantly different ($p < 0.05$). [b] Total starch − available starch. [c] Steam-heated for 90 min. [d] High-pressure steaming for 15 min.

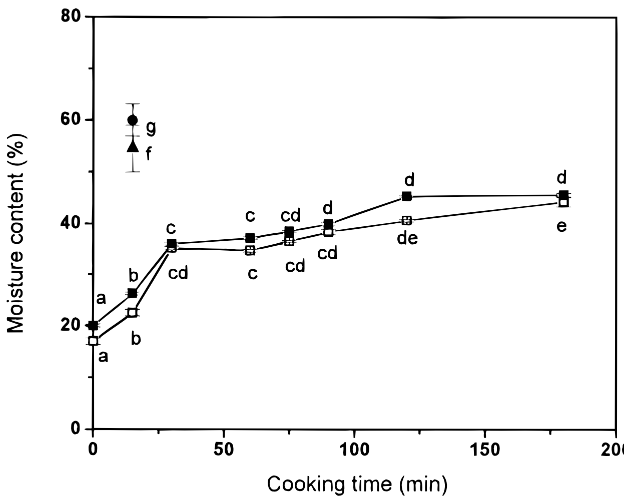

Figure 1. Changes in moisture content during steam-cooking of black (□) and lima (■) beans. Points along each curve were statistically compared. Those without common letters are significantly different ($p < 0.05$). Moisture content of 15 min high pressure steamed black (▲) and lima (●) beans are also shown.

levels (Figure 2). Similar results were observed after short dry-heating (Table 3).

DISCUSSION

Since its discovery in the last decade, indigestible—or resistant—starch has been the subject of numerous investigations. Three major types of indigestible starches are presently recognized: ungelatinized B-type granules, physically inaccessible starch fractions, and retrograded amylose (Englyst et al., 1992). Although the relative proportions of each category vary from one food to another, retrograded amylose seems to constitute the main source of resistant starch (RS) in common processed foods (Asp and Björck, 1992; Englyst et al., 1992; Tovar, 1994b).

Previous studies with common beans indicated that conditions prevailing during the isolation procedure may affect the enzymic availability of the resulting starch preparation (Melito et al., 1994). Present data make it clear that, despite its usefulness for dehulling, steam-heating applied as a preisolation step contributes to the

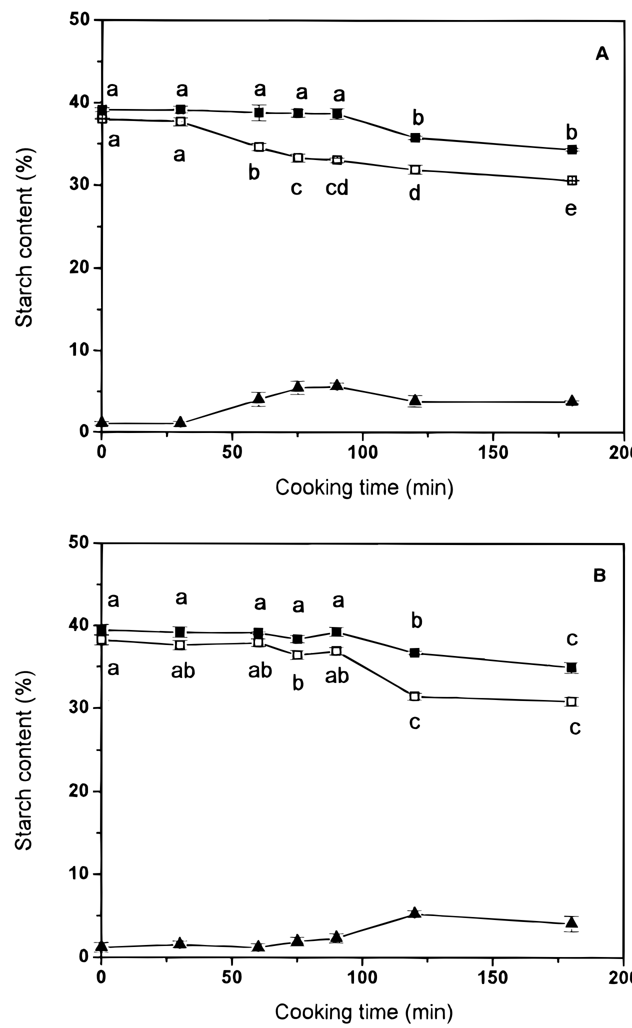

Figure 2. Effect of steam-cooking on starch content in black beans (A) and lima beans (B). (■) Total starch content; (□) available starch content; (▲) resistant (total − available) starch content. Points along each curve were statistically compared; those without common letters are significantly different ($p < 0.05$).

formation of RS, as the isolates coming from raw beans contained 9−15 times less RS than starches prepared from preheated seeds (Table 1). Taking into account

Table 3. Dry Pressure Cooking Effect on Starch Content in Beans

legumes	treatment	moisture, %	total starch,[a] %	available[a] starch, %	resistant[b] starch, %
black bean	raw	17. 06 ± 0.2[d]	39.3 ± 0.2[d]	37.4 ± 2.6[d]	1.9
	dry pressure cooking[c]	17.25 ± 0.5[d]	35.63 ± 2.5[e]	33.9 ± 0.4[e]	1.7
lima bean	raw	20.05 ± 0.3[e]	39.9 ± 0.6[d]	39.1 ± 0.5[d]	0.8
	dry pressure cooking[c]	19.78 ± 2.7[e]	37.5 ± 1.2[d]	35.4 ± 0.4[e]	2.1

[a] Starch content (g) × 100/isolated starch weight (g); dry matter basis. Values are means of at least six determinations ± SEM. Means in colums not sharing the same superscript letter are significantly different ($p < 0.05$). [b] Total starch − available starch. [c] Dry pressure cooking for 15 min.

that a similar heat treatment had no influence on the digestibility index of wheat starch (Holm et al., 1985) and the established capability of the difference method employed here to report only retrograded indigestible fractions content (Tovar et al., 1990b; Champ, 1992), present results on the effect of steam-cooking seem to corroborate the remarkable retrogradation tendency of legume starches.

Manipulation of RS content and other nutritional properties of starchy foods has been pointed out as a challenge to the food industry (Tovar et al., 1992b; Björck and Asp, 1994). In this context, steam-cooking could provide new ways to increase today's limited industrial utilization of pulses (Sosulski et al., 1989, Tovar et al., 1992b). Such an affirmation is stressed by the RS formation observed also in steam-heated whole beans (Table 2). However, the RS amount produced under these conditions was significantly smaller than in the isolated starches (Table 1), a fact that seems to support the already suggested influence of other steps in the isolation protocol on the digestibility of the final preparation (Melito et al., 1994). It should be mentioned that during processing of intact beans the interaction of amylose with protein, and possibly other seed constituents, may also modify the polysaccharide recrystallization proclivity (Cerletti et al., 1993).

In spite of the different final moisture of samples processed by the two heating methods (Figure 1), the influence of high-pressure steaming on the availability of starch in common beans was similar to that exerted by conventional steam-cooking (Table 2). Dry pressure heating, on the other hand, had a detrimental influence on the total starch content measured by enzymatic means (Table 3), which might be the consequence of transglycosidation reactions. These chemical alterations of starch take place under extreme conditions, such as low-moisture heating, leading to the formation of atypical glycosidic bonds and the concomitant reduction in amylolytic susceptibility (Siljeström et al., 1989).

A decreased total starch content was recorded as well after prolonged bean steaming, i.e., more than 90 min (Figure 2), a treatment that resulted in significant seed hydration (Figure 1). These observations suggest that transglycosidation changes may occur also by wet overheating. However, the contribution of other carbohydrate side-reactions (i.e., Maillard and caramelization) (Asp and Björck, 1992) to the final overall digestibility cannot be ruled out.

Interestingly, during both prolonged steam treatment and short dry-heating, total and readily available starch decreased parallelly and calculated RS levels tended therefore to stabilize or decrease (Figure 2, Table 3). This phenomenon should be kept in mind when the RS content of processed samples is to be reported, since indigestible transglycosidated, and other types of modified, starches will probably add in vivo to the unchanged retrograded resistant starch values (Asp and Björck, 1992; Tovar, 1994b). Furthermore, physically inaccessible starch fractions contribute to the limited extent of physiological utilization of starch in pulses (Tovar et al., 1992a). As such a phenomenon is not quantified by the analytical method used, it must be considered as another source of underestimation of the real in vivo RS content of here-studied samples.

Complementary comparative studies on the effect of various heat treatments on the process-related formation of RS in legumes are currently in progress.

LITERATURE CITED

AOAC. *Official Methods of Analysis*, 14th ed.; Association of Official Analytical Chemists: Washington, DC, 1984.

Asp, N.-G.; Björck, I. Resistant starch. *Trends Food Sci. Technol.* **1992**, *3*, 111−114.

Björck, I.; Asp, N.-G. Controlling the nutritional properties of starch in foods—a challenge to the food industry. *Trends Food Sci. Technol.* **1994**, *3*, 213−218.

Cerletti, P.; Eynard, L.; Guerrieri, N. Resistant starch: a negative or positive entity in foods? *AgroFood Industry Hi-Tech.* **1993**, *4* (3), 27−29.

Champ, M. Determination of resistant starch in foods and food products: interlaboratory study. *Eur. J. Clin. Nutr.* **1992**, *46* (Suppl. 2), S51−S62.

Englyst, H. N.; Kingman, S. M.; Cummings, J. H. Classification and measurement of nutritionally important resistant starch fractions. *Eur. J. Clin. Nutr.* **1992**, *46* (Suppl. 2), S33−S50.

Escarpa, A.; Mañas, E.; Gonzalez, M. C.; Garcia-Diz, L.; Saura-Calixto, F. Studies of resistant starch formation by the use of a heating controlled high pressure autoclave. In *Proceedings of the Concluding Plenary Meeting of EURESTA;* Asp, N.-G., van Amelsvoort, J. M. M., Hautvast, J. G. A. J., Eds.: EURESTA: Wageningen, The Netherlands, 1994; pp 110−112.

Holm, J.; Björck, I.; Asp, N.-G.; Sjöberg, L.-B.; Lundquist, I. Starch availability in vitro and in vivo after flaking, steam-cooking and popping of wheat. *J. Cereal Sci.* **1985**, *3*, 193−206.

Holm, J.; Björck, I.; Drews, A.; Asp, N.-G. A rapid method for the analysis of starch. *Starch/Staerke* **1986**, *38*, 224−226.

Melito, C.; Contreras, L.; Levy-Benshimol, A.; Tovar, J. Enzymic availability of legume starches is affected by the isolation procedure and phytohaemagglutinin. In *Proceedings of the Concluding Plenary Meeting of EURESTA;* Asp, N.-G., van Amelsvoort, J. M. M., Hautvast, J. G. A. J., Eds.: EURESTA: Wageningen, The Netherlands, 1994; pp 134−138.

Sathe, S. K.; Rangnekar, S. S.; Deshpande, S. S.; Salunkhe, D. K. Isolation and partial characterization of black gram (*Phaseolus mungo* L) starch. *J. Food Sci.* **1982**, *47*, 1524−1527.

Schweizer, T. F.; Andersson, H., Langkilde, A. M.; Reiman, S.; Torsdottir, I. Nutrients excreted in ileostomy effluents after consumption of mixed diets with beans or potatoes. II: Starch, dietary fibre and sugars. *Eur. J. Clin. Nutr.* **1990**, *44*, 567−575.

Siljeström, M.; Björck, I.; Westerlund, E. Transglycosidation reactions following heat treatment of starch—effects on enzymic digestibility. *Starch/Staerke* **1989**, *41*, 95−100.

Sosulski, F.; Waczkowski, W.; Hoover, R. Chemical and enzymatic modifications of the pasting properties of legume starches. *Starch/Staerke* **1989**, *41*, 135−140.

Tovar, J. Bioavailability of carbohydrates in legumes. Digestible and indigestible fractions. *Arch. Latinoam. Nutr.* **1994a**, *44* (Suppl. 4), 36S−40S.

Tovar, J. Natural and man-made resistant starch. *AgroFood Industry Hi-Tech*. **1994b**, *5* (6), 23−25.

Tovar, J.; Velasco, Z. Available and resistant starch content in some venezuelan foods. *Acta Cient. Venez.* **1995**, *46*, 208−209.

Tovar, J.; Björck, I.; Asp, N.-G. Analytical and nutritional implications of limited enzymic availability of starch in cooked red kidney beans. *J. Agric. Food Chem.* **1990a**, *38*, 488−493.

Tovar, J.; Björck, I.; Asp, N.-G. Starch content and α-amylolysis rate in precooked legume flours. *J. Agric. Food Chem.* **1990b**, *38*, 1818−1823.

Tovar, J.; Björck, I.; Asp, N.-G. Incomplete digestion of legume starches in rats: a study of precooked flours containing retrograded and physically inaccessible starch fractions. *J. Nutr.* **1992a**, *122*, 1500−1507.

Tovar, J.; Granfeldt, Y.; Björck, I. Effect of processing on blood glucose and insulin responses to starch in legumes. *J. Agric. Food Chem.* **1992b**, *40*, 1846−1851.

Received for review December 19, 1995. Revised manuscript received June 20, 1996. Accepted June 26, 1996.[⊗] This work was supported by The International Foundation for Science, Stockholm (Grant E-2009-1), Consejo de Desarrollo Científico y Humanístico de la Universidad Central de Venezuela (03-10-0107/93), and Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICIT S1-2761).

JF950824D

[⊗] Abstract published in *Advance ACS Abstracts*, August 15, 1996.