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Effect of salt solutions on the cooking time, nutritional and sensory characteristics of common beans (*Phaseolus vulgaris*)

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The effect of using salt solutions to soak fresh and hard-to-cook beans on cooking time and protein quality (protein efficiency ratio and digestibility) was evaluated. A sensory analysis was also carried out after soaking and cooking. It was found that by increasing the ratio of monovalent (Na^+ and K^+) to divalent ions (Ca^{2+} and Mg^{2+}) in the salt solutions, cooking time of both fresh and hard-to-cook beans decreased significantly ($p \leq 0.05$). Protein quality was lowered significantly at lower (0·30) and higher (9·80) monovalent to divalent ion ratios. Although cooked bean flavour was slightly affected by the salt treatment, taste was improved by discarding the salt solutions after soaking and cooking with water. Cost analyses showed an energy saving of more than US$0·19 per kg of beans during cooking with a ratio of 8·30 of monovalent to divalent ions of salt solution. Data obtained indicated the feasibility of implementing this process at industrial or population levels in order to decrease cooking time of both fresh and hardened beans. The most effective soaking solution evaluated had a salt composition of 0·5% $NaHCO_3$ and 2·5% K_2CO_3 (w/v) (a ratio of 8·30 of monovalent to divalent ions). Therefore, the recommended cooking method is to soak beans with this salt solution, discard the soaking solution and cook with fresh water.

Keywords: salt solutions, cooking time, nutritional characteristics, hard-to-cook beans, *Phaseolus vulgaris.*

INTRODUCTION

Common bean (*Phaseolus vulgaris*) is a staple food in the basic diet of many Latin American countries. In Central America, beans provide from 20 to 30% of the total protein in the diet (Rizo Cruz, 1981). Although beans are a highly acceptable commodity, their utilization is impaired by several factors such as low agricultural productivity, postharvest losses and limited industrial processing for different food products (Rizo Cruz, 1981).

Bean hardening is a physiological phenomenon which requires a prolonged cooking time, and has been assumed to be a direct consequence of environmental and poor storage conditions. This hardening limits bean availability and results in significant economic losses. In 1977, the Central American countries lost US$12 000 000 due to the hard-to-cook phenomenon (Mejía, 1981), making it the most important cause of postharvest losses of this basic food. Hence, attention should be paid to this physiological problem in order to develop methods to prevent hardening. It is also necessary to develop procedures to utilize the already hardened beans.

Previous studies (Rockland and Metzler, 1967; Varriano-Marston and De Omana, 1979; Moscoso, 1981) have shown that cooking time can be reduced by the use of different salt solutions. However, the amount and type of salts used were not optimal; furthermore, the effect of these salts on flavor and nutritional value of beans has not been assessed. This study was undertaken to evaluate the effect of using different ratios of monovalent (Na^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) ions on cooking time, protein quality and sensory characteristics of common beans.

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MATERIALS AND METHODS

Materials

A recently harvested and hardened Tamazulapa black bean variety (*P. vulgaris*) was used. The hard-to-cook bean was obtained by placing the fresh bean in accelerated storage conditions (45°C, 90% relative humidity and 18% moisture content) for a 12-week period. These conditions were selected to assure complete hardening of the grain in a relatively short period of time.

Soaking solutions

The soaking salt solutions were prepared based on the ratio of monovalent (Na^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) ions of the fresh (ratio 4·30) and hardened beans (ratio 4·60); i.e. in fresh bean samples the sum of monovalent ions (K^+ and Na^+) was 1525·5 mg (1486 mg K^+ + 39·5 mg Na^+) and that of divalent ions (Ca^{2+} and Mg^{2+}) was 355·7 mg (173·9 mg Ca and 181·8 mg Mg); thus the monovalent to divalent ion ratio was 4·30 (1525·5 ÷ 355·7). The same was determined for the hardened bean samples (Table 1). This was done so as to have the following ratios of monovalent to divalent ions: 0·30, 2·30, 6·30, 8·30, 8·38 and 9·80. $NaHCO_3$ and K_2CO_3 salts were used to increase Na^+ and K^+ ion content, whereas $CaCl_2$ and $MgCl_2$ were used to increase Ca^{2+} and Mg^{2+} content. Tables 2 and 3 present the amount of salts used to obtain the previously mentioned ratios for the fresh and hardened beans, respectively. Soaking salt solutions were used in a ratio of 3·1 (soaking solution/bean) for a 16 h soaking period at room temperature.

Table 2. Salt concentrations used for soaking fresh beans

Ratio of monovalent to divalent ions	Salt (g/100 g beans[a])			
	$NaHCO_3$	$K_2CO_3 \cdot 1{\cdot}5H_2O$	$CaCl_2 \cdot 2H_2O$	$MgCl_2 \cdot 6H_2O$
0·30	—[b]	—	8·49	20·38
2·30	—	—	0·55	1·32
4·30	—	—	—	—
6·30	0·068	1·483	—	—
8·30	0·135	2·944	—	—
8·38	5·300	—	—	—
9·80	7·158	—	—	—

[a]In 300 ml water.
[b]No salts added.

Table 3. Salt concentrations used for soaking hard beans

Ratio of monovalent to divalent ions	Salt (g/100 g beans[a])			
	$NaHCO_3$	$K_2CO_3 \cdot 1{\cdot}5H_2O$	$CaCl_2 \cdot 2H_2O$	$MgCl_2 \cdot 6H_2O$
0·30	—	—	7·669	20·067
2·30	—	—	0·536	1·403
4·60	—	—	—	—
6·30	0·031	1·10	—	—
8·30	0·068	2·401	—	—
8·38	4·300	—	—	—
9·80	5·919	—	—	—

[a]In 300 ml water.
[b]No salts added.

Cooking procedure

Beans soaked in the different salt solutions were cooked using the Mattson bean cooker (Mattson *et al.*, 1950). Two procedures were used: in one case the beans were cooked in the same salt solution used for soaking, and in the other the soaking solution was discarded and the beans were cooked with fresh water. For the biological assays after soaking, beans were cooked in the autoclave for 15 min at 121°C and $1{\cdot}10 \times 10^5$ Pa.

Chemical analysis

Na^+, K^+, Ca^{2+} and Mg^{2+} contents were determined by atomic absorption spectrophotometry (AOAC, 1975) and ash solutions were prepared by using the AOAC method (AOAC, 1970).

Protein quality evaluation

Protein quality was determined by the protein efficiency ratio (PER) method (AOAC, 1970) and

Table 1. Mineral content (mg/100 g beans) of common beans (*P. vulgaris*)

Sample	K^+	Na^+	Ca^{2+}	Mg^{2+}	Ratio of monovalent to divalent ions
Recently harvested[a]	1486	39·5	173·9	181·8	4·30
Hard-to-cook[b]	1416	22·3	145·7	166·5	4·60

[a]Bean recently harvested, Tamazulapa variety, 1985.
[b]Hard-to-cook bean, Tamazulapa variety, submitted to accelerated storage conditions.

protein digestibility was determined according to the procedure described by Pellet and Young (1980).

Sensory evaluation

For acceptability trials, fresh and hardened beans were soaked in the salt solution with a ratio of 8·30 of monovalent of divalent ions and cooked in an open kettle for the time needed to soften the grain. The form of preparation selected was 'fried beans' which are prepared from cooked beans. The cooked beans together with their broth were milled in a blender and then fried in hot oil for 30–40 min until a semi-solid paste was obtained. This preparation is given the name of fried beans and is widely consumed in Guatemala and the rest of the Central American countries.

The evaluation was carried out with 30 'in-house' panelists using the hedonic scale described by Larmond (1977), with numerical values from 1 (dislike extremely) to 9 (like extremely).

Statistical analysis

Results obtained were statistically analyzed by analysis of variance and Tukey's test (Cochran and Cox, 1957).

RESULTS AND DISCUSSION

Selected mineral content

Table 1 shows the selected mineral content of both fresh and hard-to-cook beans. As can be seen, the ratios of monovalent (Na^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) ions are 4·30 and 4·60 for the fresh and the hardened beans, respectively. It can also be observed that there was a decrease of all minerals analyzed in the hardened beans, being more significant in the case of sodium (44% less as compared with the initial value), suggesting an association between sodium losses during inadequate storage conditions and the hardening phenomena. The relationship of Na^+ as well as of K^+, Ca^{2+} and Mg^{2+} with cooking time of beans has also been pointed out by other studies (Moscoso, 1981). Although no explanation can be offered for the data obtained in the present study, preliminary evidence has suggested the possibility that monovalent and divalent ions can migrate to the bean's surface. This migration could be possible through the water that is lost from the grain in the transportation process which occurs during storage. The hypothesis should be corroborated in further studies.

Cooking time

Tables 4 and 5 show the effect of using different soaking salt solutions on the cooking time of fresh and hard-to-cook beans, respectively. The data obtained clearly show that by increasing the ratio of monovalent to divalent ions there is a significant decrease in cooking time for both samples, either cooked in water or in the same soaking salt solutions. A negative relationship was found between cooking time and the ratio of monovalent to divalent ions for the fresh ($r = -0{\cdot}96$) as well as for

Table 4. Cooking time of fresh beans soaked with salt solutions with different ratios of monovalent to divalent ions

Ratio of monovalent to divalent ions	Ions in solution	Cooking time (min)†	
		Soaked and cooked with salt solutions‡	Soaked with salt solutions and cooked with water‡
0·30	Ca^{2+}, Mg^{2+}	>240 a	>240 a
2·30	Ca^{2+}, Mg^{2+}	>240 a	>240 a
4·30	—	150 b	110 e
6·30	Na^+, K^+	47 f	95 d
8·30	Na^+, K^+	41·5 f	61 c
8·38	Na^+	27·0 h,i	33 g,h
9·80	Na^+	22·5 i	33 g,h

†Average of two replicates.
‡Statistical differences were found ($p \leq 0{\cdot}05$) between salt solutions and cooking procedures. Means not followed by the same letter are significantly different ($p \leq 0{\cdot}05$).

Table 5. Cooking time of hard beans soaked with different ratios of monovalent to divalent ions

Ratio of monovalent to divalent ions	Ions in solution	Cooking time (min)†	
		Soaked and cooked with salt solutions‡	Soaked with salt solutions and cooked with water‡
0·30	Ca^{2+}, Mg^{2+}	>450 a	>450 a
2·30	Ca^{2+}, Mg^{2+}	>450 a	>450 a
4·60	—	>360 c	>360 c
6·30	Na^+, K^+	307 d	>420 b
8·30	Na^+, K^+	64·5 f	105 e
8·38	Na^+	35·5 h	43·5 g
9·80	Na^+	24·0 i	29·5 i

†Average of two replicates.
‡Statistical differences were found ($p \leq 0{\cdot}05$) between salt solutions and cooking procedures. Means not followed by the same letter are significantly different ($p \leq 0{\cdot}05$).

the hardened ($r = -0.94$) beans. It is clear that the most significant improvement in cooking time was obtained from the ratio of 6·30 of monovalent (N^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) ion solution. Statistical analyses showed significant differences between salt solutions and cooking procedures ($p \leq 0.05$). The data obtained confirm the beneficial effect of Na^+ and K^+ in decreasing cooking time of both fresh and hardened beans, corroborating previous results with other salt solutions (Rockland & Metzler, 1967; Varriano-Marston & De Omana, 1979).

Several mechanisms could be involved during the soaking and cooking process of the beans in the saline solutions, among them an ionic interchange. Generally Na^+ tends to migrate into the bean and the Mg^{2+} and K^+ tend to leave the bean (De León, 1987). On the other hand, saline solutions improve heat transfer properties from the beans to its surroundings (diffusivity and thermal conductivity) (Coyoy Gonzalez, 1987). There is also evidence that saline solutions increase water absorption capacity (De León, 1987) as well as water holding capacity (García-Vela & Stanley, 1989). These mechanisms, alone or working together, could be responsible for the decrease in bean cooking time.

Table 6. Protein efficiency ratio (PER) and protein digestibility of fresh beans soaked with different ratios of monovalent to divalent ions

Ratio of monovalent to divalent ions	Ions in solution	PER†,‡		Digestibility†,§	
		Soaked and cooked with salt solution	Soaked with salt solution and cooked with water	Soaked and cooked with salt solution	Soaked with salt solution and cooked
0·30	Ca^{2+}, Mg^{2+}	—	0·30 ± 0·16 d,e	—	60·32 ± 3·48
2·30	Ca^{2+}, Mg^{2+}	1·04 ± 0·18 a	1·02 ± 0·26 a	67·12 ± 2·25	71·83 ± 1·92
4·30	—	0·47 ± 0·22 c,d	0·94 ± 0·20 a,b	64·02 ± 7·15	70·69 ± 5·63
6·30	Na^+, K^+	0·68 ± 0·33 b,c	0·98 ± 0·29 a,b	68·42 ± 1·81	69·54 ± 5·89
8·30	Na^+, K^+	0·75 ± 0·21 a,b	0·99 ± 0·26 a,b	68·68 ± 6·31	68·10 ± 1·88
8·38	Na^+	0·75 ± 0·22 b	0·75 ± 0·20 b	69·34 ± 4·68	68·32 ± 4·11
9·80	Na^+	0·08 ± 0·04 e,f	0·48 ± 0·19 c,d	68·40 ± 8·19	69·70 ± 3·88
Casein		2·51 ± 0·22		93·06 ± 1·01	

† Average of eight replicates.
‡ Statistical differences were found ($p \leq 0.05$) between salt solutions and cooking procedures. Means in the vertical columns not followed by the same letter are significantly different ($p \leq 0.05$)
§ No statistical differences were found ($p \leq 0.05$) between salt solutions or cooking procedures.

Table 7. Protein efficiency ratio (PER) and protein digestibility of hard beans soaked with different ratios of monovalent to divalent ions

Ratio of monovalent to divalent ions	Ions in solution	PER†,‡		Digestibility†,§	
		Soaked and cooked with salt solution	Soaked with salt solution and cooked with water	Soaked and cooked with salt solution	Soaked with salt solution and cooked with water
0·30	Ca^{2+}, Mg^{2+}	—	1·01 ± 0·27 b,c	—	78·36 ± 1·31
2·30	Ca^{2+}, Mg^{2+}	1·30 ± 0·11 a	1·16 ± 0·25 a,b	75·50 ± 2·23	75·20 ± 1·74
4·60	—	0·74 ± 0·18 d,e	1·01 ± 0·13 b,c	76·17 ± 3·39	76·12 ± 2·77
6·30	Na^+, K^+	1·11 ± 0·13 a,b,c	0·88 ± 0·14 c,d	76·48 ± 2·83	77·90 ± 3·06
8·30	Na^+, K^+	0·35 ± 0·24 f	0·86 ± 0·14 c,d	74·90 ± 2·45	74·10 ± 2·71
8·38	Na^+	0·65 ± 0·33 d,e	0·82 ± 0·25 c,d	75·63 ± 5·03	74·39 ± 3·48
9·80	Na^+	0·07 ± 0·08 g	0·55 ± 0·19 e,f	77·61 ± 2·06	75·74 ± 2·54
Casein		3·02 ± 0·18		93·25 ± 1·05	

† Average of eight replicates.
‡ Statistical differences were found ($p \leq 0.05$) between salt solutions and cooking procedures. Means in the vertical columns not followed by the same letter are significantly different ($p \leq 0.05$)
§ No statistical differences were found ($p \leq 0.05$) between salt solutions or cooking procedures.

However, an important finding obtained in this study refers to the optimum ion concentration needed to soften the grain in a minimum period of time; this is important from an economic as well as from a practical point of view.

Nutritional properties

Protein quality and digestibility of beans cooked under different processes are shown in Tables 6 and 7 for fresh and hardened beans, respectively. As indicated, protein quality (PER) is affected by the treatments used; statistical differences were found in the PER values between treatments with salt solutions and between cooking procedures. In general, beans cooked in water showed higher values of PER compared to beans cooked in the soaking salt solutions. Previous results (Elías *et al.*, 1976; Elías *et al.*, 1979) in our laboratory have also shown an increase in protein quality of fresh beans when soaking water was discarded and new water was used during the cooking process.

There is the possibility that excessive minerals and antinutritional substances such as polyphenols and hemaglutinins, extracted during the soaking process, may be eliminated when soaking water is discarded. PER values indicated that lower (0·30) and higher (9·80) ratios of monovalent to divalent ions significantly affected protein quality as compared to the natural ratio occurring in beans (4·30). This effect was observed both in the fresh and in the hard-to-cook samples when they were soaked and cooked with salt solutions. This effect is probably due to the higher concentrations of Ca^{2+} and Mg^{2+} (ratio of 0·30) and Na^{+} ions (ratio of 9·80) which induced physiological disturbances in the rats fed with these diets. Patience *et al.* (1986) evaluated the effect of Na^{+} and K^{+} the acid–base status and protein quality in swine and found that, although changes in the acid–base status in the blood were not significant, the implications of a renal compensation cannot be ignored. High K^{+} concentrations reduced digestible energy and the addition of Na^{+} and K^{+} did not improve absorption of amino acids such as lysine and tryptophan (Patience *et al.*, 1986). Furthermore, it is possible that the procedures used with different salt solutions could affect protein quality because of changes in pH and in protein solubility. On the other hand, these procedures (mainly alkaline) plus the boiling process could result in racemization of some amino acids to the DL form and affect the protein quality. In addition, alkaline pH could also reduce the amount and availability of the sulfur amino acids, which are limiting in the bean protein, reducing protein quality even more. Intermediate ratios also gave intermediate and acceptability PER values as compared to the control sample for the fresh (ratio of 4·30) and for the hardened beans (ratio of 4·60).

Protein digestibility values are also shown in Tables 6 and 7 for the fresh and hard-to-cook beans, respectively, showing that it is not affected by the use of salt solutions either during soaking or cooking. No statistical differences were found ($p > 0{\cdot}05$) between salt solution or cooking procedures.

Sensory and economic evaluation

A sensory evaluation was also carried out with the hardened beans soaked and cooked in the salt solution with a ratio of 8·30 of monovalent to divalent ions. The form of preparation selected was 'fried beans', which were compared to a sample without salt treatment. Results are presented in Table 8. Preference was determined by a hedonic scale method (1 = least accepted; 9 = most accepted sample). The average score given by the panelists to the hard-to-cook beans treated with the salt solution (ratio of 8·30) was approximately 6, as compared to the approximate score of 7 for the control sample. However, when beans were soaked in the salt solution and cooked with water, sensory properties were significantly improved as compared with beans soaked and cooked in the same salt solution. Furthermore, no statistical differences were found between the control sample and beans soaked with salt solution and cooked with water.

Table 9 shows a preliminary economic evaluation of the use of salt solutions to decrease cook-

Table 8. Sensory evaluation† of fried beans prepared from hard-to-cook beans treated with salt solution

Treatment	Acceptability‡ $\bar{x} \pm$ SD
Soaked and cooked without salt solution	7·04 ± 1·5 a§
Soaked and cooked with salt solution of Na^{+} K^{+}	6·06 ± 2·5 b
Soaked with salt solution and cooked with water	7·55 ± 0·8 a

†Average of 30 'in-house' panelists.
‡1 = least accepted; 9 = most accepted; $\bar{x}$ = mean; SD = standard deviation.
§Means in the vertical columns not followed by the same letter are significantly different ($p \leq 0{\cdot}05$).

Table 9. Costs[a] and economic benefits by the use of salt solutions to decrease cooking time of the hard-to-cook beans

Ratio of monovalent to divalent ions	Ions in solution	Cost of salt (Q/kg beans)		Electricity cost (Q/kg beans)	Saving (Q/kg beans)	
		Reagent grade salts	Industrial grade salts		Reagent grade salts	Industrial grade salts
0·30	Ca^{2+}, Mg^{2+}	3·07	—	—	—	—
2·30	Ca^{2+}, Mg^{2+}	0·21	—	—	—	—
4·60	—	0·00	0·00	0·73	—	—
6·30	Na^{+}, K^{+}	0·09	0·07	0·50	0·14	0·16
8·30	Na^{+}, K^{+}	0·19	0·15	0·10	0·44	0·48
8·38	Na^{+}	2·69	0·14	0·06	—	0·53
9·80	Na^{+}	3·70	0·20	0·04	—	0·49

[a] Kilowatts × time × energy cost = energy expense, in quetzales (1Q = US$0·40).

ing time of hardened beans. Cost analyses indicate an attractive economic benefit due to saving of electric energy costs during the cooking process. As can be seen from this Table, in the case of beans soaked with salt solutions of Na^{+} and K^{+} with a ratio of 8·30, there is an energy cost saving of 0·48 Quetzal (1Q = US$0·40) per kg of beans.

Data obtained indicate the feasibility of implementing this process at industrial or consumer levels in order to decrease cooking time of both fresh and hardened beans and to reduce the postharvest losses of this legume food, which is extensively consumed by our population.

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