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Relating consumer preferences to textural attributes of cooked beans: Development of an industrial protocol and microstructural observations

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ABSTRACT

The effects of temperature, duration of cooking and different cooking media (salt solutions) on bean-texture attributes were evaluated by response surface methodology. Sensory evaluation and scanning electron microscopy (SEM) were also carried out to clarify the properties of cooked beans. The sensory evaluation results showed that consumers most prefer beans with a soft texture. A 2^4 full-factorial central composite design (CCD) was used to optimize the process conditions. For each response, a second-order polynomial model was developed using multiple linear regression analysis. Applying the desirability function method, the most suitable combination of process conditions to obtain the texture found most acceptable were a cooking temperature of 75 °C, a cooking time of 63 min, NaCl concentration of 1.88 g/l and $CaCl_2$ concentration of 0.12 g/l. RSM analysis indicated good correlation between experimental and predicted values. SEM studies of cooked bean tissues further confirmed that cell-wall separation was mainly the result of pectin solubilization and middle lamella dissolution. An important finding obtained in this study was determining the optimum salt concentration needed to soften the grain in a minimum period of time; this is important from an economic as well as from an industrial point of view.

1. Introduction

Food legumes are an important constituent of daily diet worldwide, especially in developing countries (Bressani, 1993). Amongst legumes, common beans (*Phaseolus vulgaris*) are the most popular because they provide a rich and relatively inexpensive source of proteins, complex carbohydrates and other bioactive components (Costa, Queiroz-Monici, Reis, & Oliveira, 2006). It is well known that bean consumption has been associated with numerous health benefits, e.g. lower glycemic index for people with diabetes, cancer prevention and reduced risk of coronary disease (Hangen & Bennink, 2002; Viswanathan et al., 1989). Legumes are prepared in many ways for human consumption. Cooking is probably the oldest known and most widely used method for consuming legumes. Thermal treatments not only inactivate some anti-nutritional substances but also tenderize the seed coat and cotyledon and develop acceptable flavor and texture (Vijayakumari, Sidduraju, Pugalenthi, & Janardhanan, 1998). In fresh beans, the majority of pectins are covalently linked to other cell-wall polymers (Stolle-Smits, Beekhuizen, Van Dijk, Voragen, & Recourt, 1997). When legumes are processed thermally, turgor and membrane integrity are gradually destroyed. Previous works have shown that softening of legumes during heating are most likely related to the degradation and solubilization of pectic polymers from the cell wall and middle lamella (Abu-Ghannam, 1998; Greve, McArdle, Gohlke, & Labavitch, 1994; Stolle-Smits et al., 1997) which lead to decreased firmness. The mechanism of cooking is not fully understood. However, a number of parameters, such as time, temperature, water imbibition, pH of soak solution, cell separation, release of divalent cations like Ca^{2+} from the middle lamellae, and phytic acid content, can affect the texture of cooked pulses (Reyes-Morenoa, Paredes-Lópeza, & Gonzalezb, 1993). Cooking time is considered as the main parameter in evaluating the quality of pulses. Shorter heating time not improves economies at an industrial scale, but also allows considerable reduction in use of fuel, particularly important where fuels are very scarce. It was reported that salt solutions reduce time because calcium (Ca^{2+}) replaces the sodium and potassium (Na^+ and K^+) (de Leon, Elias, & Bressani, 1992). Salt solutions have been reported to improve heat-transfer properties from the beans to their surroundings, and to increase

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water-absorption capacity as well as water-holding capacity (Garcia-Vela & Stanley, 1989; de Leon et al., 1992). Previous studies (Berrios, Swanson, & Cheong, 1999; de Leon et al., 1992; Nasar-Abbas et al., 2008) have shown that cooking time can be decreased by the use of different salt solutions. However, the amount and type of salts used were not optimal.

Accurate evaluation of the effects of cooking on bean texture requires focus on the precise conducting of thermal processing. A search of the literature showed that many studies have been performed on decreasing cooking time, and on the physicochemical properties of cooked beans (Berrios et al., 1999; Shimelis & Rakshit, 2005), but limited systematic information is currently known about optimum conditions for cooking beans in terms of their sensory properties and analysis of texture.

Response surface methodology (RSM) has been reported to be an effective tool for establishing models and optimizing processes in which a response of interest is influenced simultaneously by several variables (Baş & Boyaci, 2007), leading to a faster and more precise optimization. This procedure not only determines the combined effects between parameters, but also reduces the number of experimental trials, development time and overall cost (Myers & Montgomery, 2002, chap. 1). It is well documented that RSM is the most popular method for optimizing food processing.

Thus, the aim of this study was to relate consumer preferences (including sensory evaluation) to textural attributes (including force and deformation) of cooked bean. RSM analysis was employed to facilitate finding this relationship and also to optimize the bean-cooking conditions in order to determine the industrial protocol. Scanning electron microscopy (SEM) was also undertaken to observe changes at the cellular level during cooking.

2. Materials and methods

2.1. Experimental design

Sensory evaluation (conducted by human panelists) was related to textural attributes of cooked beans. In second step of this study, to determine optimum cooking conditions, a total of 30 experimental runs with different combinations of cooking temperature, cooking time and concentrations of NaCl and $CaCl_2$ were conducted by 2^4 full-factorial central composite design (CCD). Firmness (rupture force) and deformation were taken as the responses for the combination of the variables (Table 1). The city of Karaj is about 1185 m above sea level, so water boils at 95 °C; this prevented trials carried out with water temperatures above 95 °C.

2.2. Preparation of samples and cooking

Commercially available pinto bean seeds were obtained from the local market in Karaj (located in the west of Iran's capital, Tehran). The seeds were cleaned and freed from dust, dirt and chaff as well as immature and broken seeds, placed in polyethylene bags and stored at 4 °C until they were used. The seeds were soaked for 8 h in distilled water (1:3 dried seed–water ratio, w/v) at room temperature. After the soaking water was drained and discarded, the beans were cooked.

Water was heated to the desired temperature in a temperature-controlled beaker (made in faculty of agriculture, University of Tehran, Iran) on a hotplate. Beans were occasionally stirred. Temperature fluctuations in the liquid were reduced by wrapping cooking beakers with aluminum foil. Eighty grams of prepared soaked beans were added to beakers containing 1.2 l boiling water each, with different concentrations of the two salts (NaCl and

Table 1
Coded levels and actual values of the independent variables in central composite design and experimental results for force and deformation.

Run	Coded variables[b]				Uncoded variables				Textural properties	
	X1	X2	X3	X4	Cooking temp (°C)	Cooking time (min)	NaCl conc. (g/l)	$CaCl_2$ conc. (g/l)	Force[a] (N)	Deformation[a] (mm)
1	−1	−1	−1	−1	60	60	1.82	0.06	22.58 ± 2.39	1.70 ± 0.30
2	1	−1	−1	−1	90	60	1.82	0.06	9.03 ± 1.54	2.09 ± 0.29
3	−1	1	−1	−1	60	120	1.82	0.06	52.09 ± 4.88	2.39 ± 0.21
4	1	1	−1	−1	90	120	1.82	0.06	4.03 ± 1.82	1.56 ± 0.12
5	−1	−1	1	−1	60	60	1.94	0.06	41.41 ± 3.22	1.38 ± 0.05
6	1	−1	1	−1	90	60	1.94	0.06	10.36 ± 0.56	2.17 ± 0.31
7	−1	1	1	−1	60	120	1.94	0.06	31.77 ± 2.03	2.87 ± 0.41
8	1	1	1	−1	90	120	1.94	0.06	2.27 ± 0.24	2.07 ± 0.38
9	−1	−1	−1	1	60	60	1.82	0.18	24.43 ± 1.53	2.72 ± 0.29
10	1	−1	−1	1	90	60	1.82	0.18	11.08 ± 1.29	2.27 ± 0.26
11	−1	1	−1	1	60	120	1.82	0.18	45.74 ± 2.33	3.06 ± 0.52
12	1	1	−1	1	90	120	1.82	0.18	7.91 ± 1.12	1.80 ± 0.32
13	−1	−1	1	1	60	60	1.94	0.18	25.66 ± 3.01	2.42 ± 0.18
14	1	−1	1	1	90	60	1.94	0.18	24.45 ± 1.66	2.10 ± 0.17
15	−1	1	1	1	60	120	1.94	0.18	25.59 ± 1.41	3.00 ± 0.51
16	1	1	1	1	90	120	1.94	0.18	11.64 ± 0.54	2.18 ± 0.19
17	−2	0	0	0	45	90	1.88	0.12	72.42 ± 5.21	2.67 ± 0.24
18	2	0	0	0	95	90	1.88	0.12	8.51 ± 0.21	2.21 ± 0.42
19	0	−2	0	0	75	30	1.88	0.12	9.73 ± 0.76	1.84 ± 0.23
20	0	2	0	0	75	150	1.88	0.12	6.85 ± 0.12	2.36 ± 0.28
21	0	0	−2	0	75	90	1.76	0.12	25.07 ± 1.42	2.15 ± 0.33
22	0	0	2	0	75	90	2.00	0.12	28.01 ± 1.09	2.53 ± 0.24
23	0	0	0	−2	75	90	1.88	0.00	8.37 ± 0.64	1.59 ± 0.32
24	0	0	0	2	75	90	1.88	0.24	27.32 ± 1.02	2.59 ± 0.18
25	0	0	0	0	75	90	1.88	0.12	16.40 ± 1.23	2.02 ± 0.29
26	0	0	0	0	75	90	1.88	0.12	13.33 ± 0.87	1.94 ± 0.09
27	0	0	0	0	75	90	1.88	0.12	23.70 ± 1.23	2.30 ± 0.47
28	0	0	0	0	75	90	1.88	0.12	24.13 ± 1.44	2.15 ± 0.22
29	0	0	0	0	75	90	1.88	0.12	23.12 ± 0.99	1.89 ± 0.13
30	0	0	0	0	75	90	1.88	0.12	20.13 ± 0.77	1.98 ± 0.19

[a] Values are mean ± SD of three replications.
[b] X_1:Cooking temperature; X_2: Cooking time; X_3: Concentration of NaCl; X_4: Concentration of $CaCl_2$.