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ORIGINAL ARTICLE

Effect of line, soaking and cooking time on water absorption, texture and splitting of red kidney beans

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Abstract Dry beans are rich sources of dietary fiber and phytochemicals such as flavonoids and phenolics that exhibit good functional properties. In current study line, cooking and soaking time effects were investigated on water absorption, splitting and texture of different Iranian red kidney beans to determine the best lines and the best soaking time related to them for industrial use. D81083 line had the highest level of water absorption after 24 h soaking followed by Akhtar and KS31164 lines while Azna, Goli and Naz lines had the lowest level of water absorption ($p<0.05$). Akhtar and Sayyad had the highest level of splitting while KS31164 had the lowest level of splitting ($p<0.05$). Soaking of Akhtar line for 24 h caused the highest level of water absorption accompanied with low splitting level. 24 h soaking and longer cooking time is recommended for Sayyad, while 12 h soaking and longer cooking time is recommended for KS31164 line. 24 h soaking causes higher level of water absorption and lower level of splitting in Derakhshan line. The effects of line, cooking and soaking time on red bean texture were significant ($p<0.01$).

Keywords Red kidney beans · Soaking · Cooking · Water absorption · Splitting · Shear strength

Introduction

Dry beans (*Phaseolus* spp. L.) are the most important grain legumes for human consumption. Dry beans have been cultivating for thousands of years, and have been playing an important role in the traditional diets of many regions throughout the world (Meng and Ma 2001; Oboh et al. 1998; Rehman and Shah 2005). In spite of most developing countries dry beans are less significant in western diets. The daily per capita consumption of all bean products in Asia is 110 g compared to about 9 g in the United States (Boateng et al. 2008). Beans (*Phaseolus vulgaris L.*), are excellent sources of proteins (20–30%) and carbohydrates (50–60%) and fairly good sources of minerals and vitamins (Rehman and Shah 2004; Yin et al. 2008). Dry beans are widely known for their fiber, mineral and protein contents. The flour and protein concentrate of red bean exhibited good functional properties (Tang 2008). Resistant starch is important due to its various beneficial health properties mostly mediated by short chain fatty acids produced during its fermentation in the large intestine. Legumes contain higher amount of resistant starch in comparison to cereals and tubers (Yadav et al. 2010).

Numerous processing and cooking methods have been shown to possibly reduce antinutrients such as trypsin inhibitors and phytic acid, and increase the content of tannins, catechins and polyphenols possessing antimutagenic and antioxidant activities (Boateng et al. 2008). Antinutrients commonly found in plant foods such as saponins, tannins and phytate reduce the availability of nutrients and cause growth inhibition. Some of them contribute to flatulence production in consumers (Oboh et al. 1998). Therefore, many attempts have been made to reduce the levels of the anti-nutritional substances and improve the nutritive value (Abd El-Hady and Habiba 2003). Soaking of beans before cooking is a common practice to soften texture and hasten the cooking process. Soaking has also been suggested for reducing anti-nutritional substances and improving cooking quality (Rehman et al. 2001). In

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traditional cooking, beans are first soaked overnight to increase the availability of water in the seeds prior to cooking and, thereby accelerate chemical reactions such as starch gelatinization and protein denaturation during cooking (Bellido et al. 2006). Hydration of dry beans before cooking or canning is usually considered necessary to decrease cooking times and increase drained weight. Other beneficial effects of a soaking period include a softer drained texture, and partial removal of stachyose and raffinose, which are related to flatulence (Taiwo et al. 1998).

It has been observed by earlier workers, that different cooking methods improve the nutritional quality of food legumes and grains to various extents (Rehman and Shah 2005; Vasudeva et al. 2010). As well as being inconvenient to both consumers and producers, long soaking times can potentially increase harmful microbial proliferation. Soaking allows water to be distributed among starch and protein fractions within the legume. As soaking proceeds, water penetrates the seed coat, travelling through the cotyledons and towards the centre of the bean. Such water absorption causes the bean to become soft and uniform in texture (Gowen et al. 2007).

Very little information is available about Iranian red beans and the main aim of present work was to study the effect of different soaking and cooking time on water absorption and textural properties of red kidney beans.

Materials and methods

Raw dry beans

Red kidney beans (*Phaseolus vulgaris*), used in this study were obtained from Khomein Agricultural Research Institute (Arak, Iran). Azna, Goli, D81083, Akhtar, Sayad, Naz, KS31164, Derakhshan lines were selected for this study. Samples were stored in hermetically sealed bags at room temperature, in a dark room (Gowen et al. 2007). These food legumes were separated from broken, small and split seeds, dust and other excessive materials, cleaned and size-graded manually. 100 g of each line of raw beans were ground to a fine powder (particle size of 0.5 mm) using a kitchen mill and were used for chemical analysis, the rest were subjected to soaking treatments prior to cooking (Rehinan et al. 2004).

Chemical analysis

Protein contents of samples were determined after digestion with concentrated sulphuric acid according to the micro-Kjeldalal method, as described in AOAC (1990). The chemicals used were reagent grade (Merck, Darmstadt, Germany). All determinations were carried out in triplicate and calculated means were compared using LSD test at $P<0.05$. Mean values are reported in Table 1.

Soaking treatment

Water uptake data were obtained by soaking 10 g seeds in 80 ml of distilled water in a beaker and maintained at room temperature (25 °C). The soaking times were 0,6,12 and 24 h. After soaking for each period, the seeds were removed from water and drained for 2 min. Soaked legumes were also cooked by boiling, keeping seed to boiling distilled water ratio of 1:5 (ordinary cooking). The legumes maintained in boiling water for 3, 5 and 10 min. Then the beans were removed from the boiling water and allowed to cool and drain. The heated beans were left while being spread over tissue paper to remove surface water, kept in closed plastic container to equilibrate with the room temperature and then weighed. In general, a total of 10–15 min were enough to bring the beans temperature to 25 °C. The weight gain was then calculated as the percentage of difference between the measured weight at a given time and the original weight. No corrections were made for the loss of solids leached into the soaking and cooking water (Taiwo et al. 1998). At this step all split and cracked beans were removed manually and weighed. Weight of damaged beans was divided to soaked cooked beans weight and multiplied by 100 to report percentage of cracked beans caused by soaking and cooking treatments. All treatments were carried out on three sets of samples.

Texture evaluation

20 g of red kidney beans of Azna, Goli, D81083, Akhtar, Sayad, KS31164, Derakhshan lines were soaked in distilled water (ratio 1:5 beans to water). Soaking times were 12 and 24 h. Soaked beans were divided into two groups, the first group were directly used for texture analysis but the second group were cooked in boiling distilled water (ratio 1:5 beans to water) for 10 min. Cooked beans were drained for about 3 min, and placed in 250 ml covered plastic

Table 1 Protein content of different raw dry red beans

Red bean lines	Protein(%)
Azna	$18.6^{h}\pm0.03$
Goli	$19.7^{g}\pm0.16$
D81083	$20.2^{f}\pm0.06$
Akhtar	$20.8^{e}\pm0.14$
Sayyad	$23.4^{b}\pm0.13$
Naz	$21.2^{d}\pm0.16$
KS31164	$21.8^{c}\pm0.04$
Derakhshsan	$23.6^{a}\pm0.13$

Mean values ± SD of triplicate determinations

Mean values within a column with different superscripts are significantly different at $P<0.05$

containers and cooled at room temperature for 0.5 h prior to texture analysis. 7 beans were selected to undergo puncture tests performed by an Instron Universal Testing Machine (model 1140). A cylindrical shape probe of 3.3 mm end diameter was used in puncture tests. An aluminum plate with dimensions of 10×10 cm^2 and thickness of 1.3 cm and a hole of 5 mm diameter in its centre, was supported on the Instron base. The cutter was lowered at the speed of 200 mmmin^{-1}. During operation, the orientation of each bean was kept uniform. Beans were placed on their side, with the hilum pointing away from the observer. Cutting the sample transversely through the centre at the hilum, the probe was allowed to cross the thickness of the bean. The probe was stopped 1 mm away from the plate. Seven legumes were chosen as a representative sample of the soaking population to undergo compression at each sampling point, since variation in texture was substantial. Red bean hardness was defined as shear strength. The shearing strength determines the degree to which the bean cells are held together.

$$S = F/\pi dt$$

Where "S" is the shearing strength gf/cm^2, "F" is shearing force (maximum force required to shear the bean, the peak of the force–deformation curve) recorded in gf per sample, "d" is the diameter of cylindical probe and "t" is the thickness of each bean (Gowen et al. 2007; Mohsenin 1986).

Table 2 Effect of red bean lines, soaking time and cooking time on water absorption and splitting (main effects)

Main effects	Water absorption (%)	Splitting(%)
Red bean lines		
Azna	$56.8^{c}\pm0.379$	$7.2^{cd}\pm0.093$
Goli	$56.7^{c}\pm0.288$	$12.2^{ab}\pm0.098$
D81083	$88.6^{a}\pm0.310$	$7.8^{bcd}\pm0.065$
Akhtar	$64.9^{b}\pm0.292$	$13.3^{a}\pm0.133$
Sayyad	$59.0^{bc}\pm0.310$	$13.2^{a}\pm0.130$
Naz	$55.9^{c}\pm0.324$	$11.8^{abc}\pm0.138$
KS31164	$64.5^{b}\pm0.373$	$5.3^{d}\pm0.096$
Derakhshsan	$60.7^{bc}\pm0.390$	$7.7^{bcd}\pm0.089$
Soaking time (h)		
0	$31.9^{d}\pm0.232$	$8.3^{b}\pm0.111$
6	$44.8^{c}\pm0.218$	$12.8^{a}\pm0.139$
12	$75.7^{b}\pm0.262$	$9.1^{b}\pm0.089$
24	$101.2^{a}\pm0.137$	$9.0^{b}\pm0.090$
Cooking time (min)		
3	$53.4^{c}\pm0.366$	$10.6^{ab}\pm0.104$
5	$61.6^{b}\pm0.349$	$11.0^{a}\pm0.125$
10	$75.2^{a}\pm0.286$	$7.8^{b}\pm0.098$

Means having the same letter within each property are not significantly different using LSD test at $P<0.05$, means are calculated as main effects

Table 3 Interactive effect of soaking and cooking time on water absorption and splitting

Soaking time × Cooking time	Water absorption (%)	Splitting (%)
0 h×3 min	$13.8^{h}\pm0.110$	$11.6^{ab}\pm0.130$
0 h×5 min	$27.5^{g}\pm0.157$	$9.5^{abc}\pm0.114$
0 h×10 min	$54.3^{e}\pm0.203$	$3.7^{c}\pm0.065$
6 h×3 min	$29.6^{g}\pm0.201$	$10.9^{ab}\pm0.124$
6 h×5 min	$44.6^{f}\pm0.189$	$13.5^{a}\pm0.165$
6 h×10 min	$60.2^{e}\pm0.148$	$14.1^{a}\pm0.129$
12 h×3 min	$78.0^{d}\pm0.203$	$9.8^{ab}\pm0.084$
12 h×5 min	$73.5^{d}\pm0.318$	$11.0^{ab}\pm0.098$
12 h×10 min	$75.7^{d}\pm0.263$	$6.4^{bc}\pm0.083$
24 h×3 min	$92.0^{c}\pm0.136$	$9.9^{ab}\pm0.074$
24 h×5 min	$101.0^{b}\pm0.121$	$10.1^{ab}\pm0.115$
24 h×10 min	$110.6^{a}\pm0.081$	$7.1^{bc}\pm0.076$

Mean values within a column with different letters are significantly different using LSD test at $P<0.05$

Experimental design

The experiment was conducted in factorial form, using a completely randomized design with three replications to study the effects of lines, soaking and cooking time on water absorption and splitting percentage. The first factor was eight different red bean lines including Azna, Goli, D81083, Akhtar, Sayad, Naz, KS31164 and Derakhshan, the second factor was soaking time (0, 6, 12 and 24 h) and the third factor was cooking time (3, 5 and 10 min). 10 g seeds were used for each replication. LSD test was performed to compare the means. The significance level 'a' for these comparisons was set to 0.05. Data were analyzed by SAS (version 8.02, SAS Institute Inc, 2001, Cary, NC).

Experimental design for texture analysis was a factorial experiment including three factors arranged in a completely randomized design with seven replications. The effect of seven red bean lines (Azna, Goli, D81083, Akhtar, Sayad, KS31164, Derakhshan), two soaking periods (12 and 24 h) and two cooking level (0 and 10 min) on texture were studied in this design.

Results and discussion

Protein contents of different lines of red bean are presented in Table 1. Derakhshan and Azna contained the highest and the lowest value of protein ($p<0.05$) respectively. Considering the protein content of red bean lines it is clear that red beans are good sources of proteins for human consumption. Soaking and thermal processing improve protein digestibility of kidney beans (Abd El-Hady and Habiba 2003; Rehman and Shah 2005), therefore soaking studied red beans before utilization will increase their nutritive value when consumed directly or as an ingredient of certain meal.

The effects of line, soaking and cooking time on water absorption were significant at $p<0.01$. Interactions of line and cooking time, line and soaking time, soaking and cooking time and interaction of line, soaking time and cooking time on water absorption were significant at $p<0.01$. The effect of line and soaking time on splitting were significant at $p<0.01$ and $p<0.05$, respectively. The effects of other factors and their interactions on splitting were not significant.

Table 2 summarizes the main effects of lines, soaking time and cooking time on water absorption and splitting. Means presented for red bean lines show the comparison of red bean lines means averaged over all levels of soaking and cooking periods. As shown in Table 2, D81083 line had the highest level of water absorption followed by Akhtar and KS31164 lines while Azna, Goli and Naz ones showed the lowest level of water absorption ($p<0.05$). Significant variations were noticed in splitting of the studied lines in Table 2. KS3116 line had the lowest level of splitting while Akhtar and Sayyad had the highest level of splitting ($p<0.05$). Considering water absorption and splitting level, D81083 and KS31164 lines are recommended for industrial use as they had high level of water uptake and low level of splitting. Results presented for soaking time show the comparison of soaking time levels averaged

Table 4 Interaction of red bean lines × soaking time and red bean lines × cooking time on water absorption and splitting

Line × soaking time	Water absorption (%)	Splitting (%)	Line × cooking time	Water absorption (%)	Splitting (%)
Azna×24 h	$97.3^{bc}\pm0.128$	$4.7^{fgh}\pm0.056$	Azna×10 min	$62.1^{fghi}\pm0.321$	$4.7^{ed}\pm0.072$
Azna×12 h	$83.8^{d}\pm0.206$	$11.9^{bcdefg}\pm0.060$	Azna×5 min	$55.8^{hijk}\pm0.422$	$5.2^{cde}\pm0.069$
Azna×6 h	$25.5^{mn}\pm0.192$	$6.0^{defgh}\pm0.091$	Azna×3 min	$52.7^{ijk}\pm0.414$	$11.7^{abcde}\pm0.119$
Azna×0 h	$20.8^{n}\pm0.096$	$6.3^{defgh}\pm0.139$			
Goli×24 h	$86.6^{cd}\pm0.213$	$6.4^{defgh}\pm0.062$	Goli×10 min	$71.0^{def}\pm0.246$	$9.0^{abcde}\pm0.080$
Goli×12 h	$62.3^{fg}\pm0.229$	$12.7^{bcdef}\pm0.120$	Goli×5 min	$57.6^{ghijk}\pm0.284$	$13.5^{abc}\pm0.104$
Goli×6 h	$43.4^{hij}\pm0.186$	$14.3^{bcdef}\pm0.095$	Goli×3 min	$41.7^{l}\pm0.257$	$14.1^{ab}\pm0.107$
Goli×0 h	$34.8^{jklm}\pm0.229$	$15.5^{bcd}\pm0.094$			
D81083×24 h	$114.7^{a}\pm0.050$	$5.8^{defgh}\pm0.024$	D81083×10 min	$97.3^{a}\pm0.233$	$6.8^{bcde}\pm0.037$
D81083×12 h	$113.7^{a}\pm0.041$	$7.7^{cdefgh}\pm0.020$	D81083×5 min	$89.3^{ab}\pm0.288$	$9.8^{abcde}\pm0.098$
D81083×6 h	$76.8^{ed}\pm0.092$	$7.6^{cdefgh}\pm0.038$	D81083×3 min	$79.3^{bcd}\pm0.388$	$6.8^{bcde}\pm0.044$
D81083×0 h	$49.4^{hi}\pm0.268$	$9.9^{bcdefg}\pm0.123$			
Akhtar×24 h	$97.7^{bc}\pm0.063$	$7.7^{cdefgh}\pm0.078$	Akhtar×10 min	$78.2^{cd}\pm0.219$	$16.7^{a}\pm0.140$
Akhtar×12 h	$77.9^{ed}\pm0.155$	$10.2^{bcdefg}\pm0.101$	Akhtar×5 min	$59.2^{ghij}\pm0.281$	$13.3^{abc}\pm0.135$
Akhtar×6 h	$49.3^{hi}\pm0.161$	$26.0^{a}\pm0.147$	Akhtar×3 min	$57.3^{ghijk}\pm0.340$	$9.8^{abcde}\pm0.119$
Akhtar×0 h	$34.6^{jklm}\pm0.220$	$9.1^{cdefgh}\pm0.110$			
Sayyad×24 h	$100.4^{b}\pm0.119$	$14.6^{bcde}\pm0.122$	Sayyad×10 min	$65.0^{efgh}\pm0.288$	$9.5^{abcde}\pm0.115$
Sayyad×12 h	$62.8^{fg}\pm0.161$	$10.1^{bcdefg}\pm0.118$	Sayyad×5 min	$63.4^{fgh}\pm0.350$	$15.0^{ab}\pm0.169$
Sayyad×6 h	$40.2^{ijkl}\pm0.194$	$19.7^{ab}\pm0.156$	Sayyad×3 min	$48.5^{kl}\pm0.298$	$15.1^{ab}\pm0.097$
Sayyad×0 h	$32.5^{jklmn}\pm0.174$	$8.4^{cdefgh}\pm0.108$			
Naz×24 h	$100.3^{b}\pm0.121$	$11.8^{bcdefg}\pm0.128$	Naz×10 min	$70.3^{def}\pm0.306$	$8.8^{abcde}\pm0.115$
Naz×12 h	$52.9^{gh}\pm0.177$	$9.7^{cdefgh}\pm0.104$	Naz×5 min	$49.5^{jkl}\pm0.318$	$14.2^{ab}\pm0.178$
Naz×6 h	$42.0^{hij}\pm0.203$	$16.3^{abc}\pm0.184$	Naz×3 min	$48.0^{kl}\pm0.323$	$12.5^{abcd}\pm0.118$
Naz×0 h	$28.5^{lmn}\pm0.206$	$9.6^{cdefgh}\pm0.107$			
KS31164×24 h	$104.5^{ab}\pm0.089$	$13.2^{bcdef}\pm0.109$	KS31164×10 min	$74.7^{cde}\pm0.270$	$3.3^{e}\pm0.077$
KS31164×12 h	$82.1^{ed}\pm0.226$	$2.4^{gh}\pm0.073$	KS31164×5 min	$67.2^{efg}\pm0.391$	$8.0^{bcde}\pm0.122$
KS31164×6 h	$41.6^{hijk}\pm0.184$	$5.4^{efgh}\pm0.108$	KS31164×3 min	$51.6^{ijkl}\pm0.432$	$4.6^{ed}\pm0.084$
KS31164×0 h	$29.8^{klmn}\pm0.327$	$0.00^{h}\pm0.000$			
Derakhshan×24 h	$108.0^{ab}\pm0.082$	$8.0^{cdefgh}\pm0.069$	Derakhshan×10 min	$83.0^{bc}\pm0.321$	$3.9^{e}\pm0.063$
Derakhshan×12 h	$70.5^{ef}\pm0.326$	$8.0^{cdefgh}\pm0.066$	Derakhshan×5 min	$51.1^{jkl}\pm0.368$	$9.1^{abcde}\pm0.079$
Derakhshan×6 h	$39.6^{ijkl}\pm0.189$	$7.5^{cdefgh}\pm0.132$	Derakhshan×3 min	$48.1^{kl}\pm0.406$	$9.9^{abcde}\pm0.112$
Derakhshan×0 h	$24.8^{mn}\pm0.246$	$7.2^{cdefgh}\pm0.089$			

Mean values within a column with different letters are significantly different using LSD test at $P<0.05$

Table 5 Interaction of red bean lines with soaking time and cooking time on water absorption and splitting

Line × soaking time × cooking time	Water absorption (%)	Splitting (%)	Line × soaking time × cooking time	Water absorption (%)	Splitting (%)	Line × soaking time × cooking time	Water absorption (%)	Splitting (%)
Azna×24 h×10 min	107.3±0.079	0.00±0.000	Akhtar×24 h×10 min	101.6±0.085	11.1±0.104	KS31164×24 h×10 min	113.5±0.022	5.6±0.097
Azna×24 h×5 min	89.9±0.183	7.0±0.061	Akhtar×24 h×5 min	97.3±0.053	8.0±0.070	KS31164×24 h×5 min	104.8±0.063	23.1±0.070
Azna×24 h×3 min	94.8±0.037	7.0±0.061	Akhtar×24 h×3 min	94.3±0.046	4.0±0.070	KS31164×24 h×3 min	95.4±0.055	10.9±0.096
Azna×12 h×10 min	63.3±0.243	7.7±0.067	Akhtar×12 h×10 min	89.3±0.020	14.1±0.124	KS31164×12 h×10 min	60.6±0.139	0.00±0.000
Azna×12 h×5 min	99.3±0.047	13.8±0.054	Akhtar×12 h×5 min	61.8±0.162	12.4±0.109	KS31164×12 h×5 min	97.1±0.275	0.00±0.000
Azna×12 h×3 min	88.7±0.083	14.1±0.055	Akhtar×12 h×3 min	82.2±0.085	4.1±0.071	KS31164×12 h×3 min	88.6±0.026	7.3±0.126
Azna×6 h×10 min	48.2±0.048	11.1±0.100	Akhtar×6 h×10 min	63.5±0.172	33.2±0.055	KS31164×6 h×10 min	59.8±0.080	7.5±0.130
Azna×6 h×5 min	14.6±0.137	0.00±0.000	Akhtar×6 h×5 min	51.0±0.007	26.4±0.184	KS31164×6 h×5 min	43.6±0.096	8.8±0.153
Azna×6 h×3 min	13.5±0.093	6.7±0.116	Akhtar×6 h×3 min	33.6±0.082	18.3±0.182	KS31164×6 h×3 min	21.4±0.094	0.00±0.000
Azna×0 h×10 min	29.5±0.068	0.00±0.000	Akhtar×0 h×10 min	57.9±0.175	8.2±0.143	KS31164×0 h×10 min	65.3±0.276	0.00±0.000
Azna×0 h×5 min	19.2±0.099	0.00±0.000	Akhtar×0 h×5 min	26.8±0.134	6.4±0.111	KS31164×0 h×5 min	23.2±0.176	0.00±0.000
Azna×0 h×3 min	13.6±0.057	18.9±0.204	Akhtar×0 h×3 min	19.1±0.133	12.7±0.112	KS31164×0 h×3 min	0.94±0.006	0.00±0.000
Goli×24 h×10 min	107.0±0.066	7.5±0.065	Sayyad×24 h×10 min	104.4±0.087	11.8±0.128	Derakhshan×24 h×10 min	116.8±0.056	7.8±0.089
Goli×24 h×5 min	86.9±0.170	3.0±0.052	Sayyad×24 h×5 min	110.3±0.048	14.5±0.181	Derakhshan×24 h×5 min	107.7±0.036	6.7±0.060
Goli×24 h×3 min	65.9±0.147	8.6±0.075	Sayyad×24 h×3 min	86.4±0.017	17.5±0.088	Derakhshan×24 h×3 min	99.5±0.003	9.4±0.084
Goli×12 h×10 min	55.2±0.249	0.00±0.000	Sayyad×12 h×10 min	59.5±0.121	8.9±0.154	Derakhshan×12 h×10 min	105.5±0.219	7.9±0.069
Goli×12 h×5 min	66.3±0.320	17.2±0.109	Sayyad×12 h×5 min	71.5±0.157	14.4±0.154	Derakhshan×12 h×5 min	36.4±0.098	7.5±0.067
Goli×12 h×3 min	65.3±0.182	20.8±0.094	Sayyad×12 h×3 min	57.6±0.219	7.1±0.061	Derakhshan×12 h×3 min	69.4±0.105	8.6±0.090
Goli×6 h×10 min	59.4±0.016	18.3±0.071	Sayyad×6 h×10 min	51.8±0.246	13.8±0.140	Derakhshan×6 h×10 min	54.6±0.077	0.00±0.000
Goli×6 h×5 min	48.7±0.126	19.2±0.066	Sayyad×6 h×5 min	38.0±0.140	22.7±0.252	Derakhshan×6 h×5 min	46.8±0.062	10.0±0.102
Goli×6 h×3 min	22.0±0.103	5.4±0.094	Sayyad×6 h×3 min	30.7±0.190	22.5±0.084	Derakhshan×6 h×3 min	17.3±0.129	12.4±0.215
Goli×0 h×10 min	62.5±0.058	10.3±0.017	Sayyad×0 h×10 min	44.3±0.114	3.3±0.058	Derakhshan×0 h×10 min	55.2±0.155	0.00±0.000
Goli×0 h×5 min	28.4±0.127	14.7±0.132	Sayyad×0 h×5 min	33.8±0.240	8.6±0.148	Derakhshan×0 h×5 min	13.5±0.045	12.3±0.114
Goli×0 h×3 min	13.4±0.013	21.6±0.091	Sayyad×0 h×3 min	19.4±0.054	13.2±0.118	Derakhshan×0 h×3 min	5.9±0.074	9.4±0.081
D81083×24 h×10 min	120.5±0.030	6.3±0.028	Naz×24 h×10 min	113.9±0.030	6.7±0.062			
D81083×24 h×5 min	112.0±0.036	4.9±0.031	Naz×24 h×5 min	98.8±0.054	13.3±0.230			
D81083×24 h×3 min	111.6±0.005	6.2±0.018	Naz×24 h×3 min	88.3±0.069	15.3±0.055			
D81083×12 h×10 min	112.4±0.029	8.4±0.019	Naz×12 h×10 min	59.6±0.174	4.3±0.075			
D81083×12 h×5 min	117.6±0.024	7.1±0.012	Naz×12 h×5 min	37.8±0.137	15.5±0.148			
D81083×12 h×3 min	111.1±0.041	7.6±0.031	Naz×12 h×3 min	61.3±0.158	9.1±0.079			
D81083×6 h×10 min	83.2±0.078	9.4±0.014	Naz×6 h×10 min	60.9±0.148	19.4±0.183			
D81083×6 h×5 min	75.9±0.106	4.3±0.030	Naz×6 h×5 min	37.9±0.164	17.0±0.294			
D81083×6 h×3 min	71.4±0.076	9.2±0.047	Naz×6 h×3 min	27.2±0.166	12.4±0.108			
D81083×0 h×10 min	73.1±0.242	3.0±0.052	Naz×0 h×10 min	47.0±0.256	4.6±0.079			
D81083×0 h×5 min	51.8±0.089	22.7±0.127	Naz×0 h×5 min	23.4±0.041	11.0±0.096			
D81083×0 h×3 min	23.3±0.181	4.0±0.070	Naz×0 h×3 min	15.0±0.140	13.3±0.231			

Mean values are presented in (%), LSD values are 0.2099 and 0.171 for water absorption and splitting respectively ($P<0.05$)

Table 6 Interaction of red bean lines × soaking time and red bean lines × cooking time and soaking time × cooking time on texture of red beans

Line × cooking time	Shear strength (gf/cm^2)	Line × soaking time	Shear strength (gf/cm^2)	Soaking time × Cooking time	Shear strength (gf/cm^2)
Azna × uncooked	38041.9[a]±5860.47	Azna×12 h	27148.5[de]±7799.86	12 h×uncooked	31836.7[a]±5061.85
Azna × cooked	21408.3[e]±2423.09	Azna×24 h	32301.7[a]±10679.86	12 h×cooked	23280.0[b]±4512.13
Goli × uncooked	39022.7[a]±2035.15	Goli×12 h	31245.9[ab]±9614.00	24 h×uncooked	31688.6[a]±6535.33
Goli × cooked	21909.4[a]±4228.57	Goli×24 h	29686.1[bc]±9272.58	24 h×cooked	20220.8[c]±4236.03
D81083×uncooked	29827.6[b]±2101.73	D81083×12 h	26922.3[def]±4446.72		
D81083×cooked	23420.7[de]±2620.29	D81083×24 h	26326.0[ef]±3663.56		
Akhtar × uncooked	26390.0[c]±1689.23	Akhtar×12 h	24518.5[f]±4937.69		
Akhtar × cooked	18542.2[f]±5725.47	Akhtar×24 h	20413.8[g]±5945.08		
Sayyad × uncooked	31388.3[b]±4907.03	Sayyad×12 h	28917.2[bcd]±5539.72		
Sayyad × cooked	25013.3[cd]±5039.25	Sayyad×24 h	27484.4[cde]±6289.86		
KS31164 × uncooked	30552.2[b]±2897.54	KS31164×12 h	28959.3[bcd]±3822.55		
KS31164 × cooked	23505.4[de]±3487.19	KS31164×24 h	25098.4[ef]±4965.50		
Derakhshan × uncooked	27116.1[c]±3846.02	Derakhshan×12 h	25196.9[ef]±5452.11		
Derakhshan × cooked	18453.5[f]±4169.01	Derakhshan×24 h	20372.7[g]±5506.47		

Mean values within a column with different letters are significantly different using LSD test at $P<0.05$

over all red bean lines and cooking time levels. Water absorption of 31.9% and splitting of 8.3% are the means for 0 h soaking. These means are averages of water absorption and splitting for all lines that have not been soaked but have been cooked 3, 5 or 10 min, so one can conclude this amount of water absorption and splitting at 0 h soaking are results of cooking periods. Since red bean lines and levels of cooking time are exactly repeated in other levels of soaking time (6, 12 and 24 h), when means of soaking time are compared just the main effect of soaking time is considered. Results given in Table 2 showed that longer soaking and cooking time increased water absorption significantly ($p<0.05$). Heating in boiling water for 10 min was not enough to soften the texture of red beans, more than 20 min were needed for this purpose. To determine the best lines and the best soaking and cooking time related to them that give maximum water absorption and minimum splitting, interactions will be discussed.

Interactions of soaking and cooking time on water absorption and splitting are shown in Table 3. Interaction of 6 h soaking and 5 or 10 min cooking showed the highest level of splitting because the surface and center of beans were not homogenously hydrated. Interactions of line and soaking time on water absorption and splitting are shown in Table 4 and interactions of line, soaking time and cooking time on water absorption and splitting are shown in Table 5. Considering level of water absorption and splitting, one can conclude for Azna 24 h soaking and longer cooking time cause higher water absorption and lower splitting level. Goli line is not recommended for industrial use since its water absorption was low even after 24 h soaking. As it is clear in Table 5, longer cooking time caused higher level of water absorption for Goli. D81083 line obtained a suitable water absorption level after 12 h soaking that was not significantly different from water absorption level after 24 h, but soaking for 24 h decreased the level of splitting after cooking (Table 4). As shorter soaking time is more economical and causes less microbial growth, this line is highly recommended for industrial use. In Akhtar line, soaking for 24 h caused the highest level of water absorption with low splitting, while soaking for 6 h caused the highest splitting level. In this line longer cooking time caused significant increase in water absorption but did not increase splitting significantly. For Sayyad line, 24 h soaking and longer cooking time is recommended. According to Table 5, it is clear that in Sayyad line 24 h soaking and 3 min cooking caused lower water absorption than 24 h soaking and 5 min cooking. Naz line is not applicable for industrial use because its color changes to grey after water absorption. If KS31164 line was soaked for 24 h, its water absorption would get significantly higher than 12 h soaking but splitting level would also be higher (Table 4). So 12 h soaking and longer cooking time is recommended for this line. In the case of Derakhshan line, increasing soaking time caused more water absorption but did not change the level of splitting significantly (Table 4). In Derakhshan the increase in cooking time resulted in more water absorption and decreased splitting significantly. Hence in Derakhshan line 24 h soaking time and longer cooking time is recommended.

Vasudeva and Vishwanathan (2010) reported that slow hydration may be due to hemicellulose and pentosans in the seed coat which hinder the penetration of water while the middle lamella in legumes without seed coat may absorb the moisture fast.

Texture of soaked beans

The effect of line and cooking on red bean texture were significant at $p<0.01$ and effect of soaking on texture was significant at $p<0.001$. Interactive effects of these factors on red bean texture are shown in Table 6. For all studied soaked red beans (except Azna), the force required to shear across the beans decreased with increase in soaking time and these results were in agreement with the findings of other researchers (Abu-Ghannam 1998). In fact, soil, climate, collection time and botanical variety difference are factors which might be responsible for the difference observed in the case of Azna.

As the cooking process continues the pectic substances decompose and the connection between the cells weakens and the shearing strength decreases. The seed coat and microstructure of seeds may be responsible for facilitating a rapid softening of seeds during soaking (Taiwo et al. 1998). Results in Table 6 (interactions of soaking and cooking time) indicate that when beans are not cooked, 12 h soaking is not significantly different from 24 h soaking, but force required to shear across the cooked beans which had been soaked for 12 h was significantly higher than those cooked beans which had been soaked for 24 h ($p<0.05$). For Azna line 12 h soaking time got better results than 24 h soaking, that is less force was required to shear across the beans (Table 6), but the results in Table 4 showed that water absorption at 12 h soaking was low and so this line is not suitable for industrial use. Goli had a hard texture and the force required to shear across the beans was very high even after 24 h soaking. Therefore this line is not recommended for industrial use.

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