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doi: 10.9016/IJFN-117/1000117.
Kwofie EM, et al. In J Food Nutri: IJFN-117.

Research Article

International Journal of Food and Nutrition

Nutrition-Sensitive Bean Processing: Analysis of Degradation Trade-Off of Softening Techniques on Some Essential Trace Elements

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Citation: Kwofie EM, Mba O, Ngadi M, Kennedy G (2019) Nutrition-Sensitive Bean Processing: Analysis of Degradation Trade-Off of Softening Techniques on Some Essential Trace Elements. In J Food Nutri: IJFN-117.

Received Date: 05 April, 2019; **Accepted Date:** 16 April, 2019; **Published Date:** 24 April, 2019

Abstract

Common beans are considered an important source of nutrients globally with a significant health benefits. The primary limitation to consumption is the prolonged cooking time and high fuel use. Softening techniques that reduce cooking are evaluated in this study. The nutritional implication of softening common beans is evaluated through selected mineral loss trade-off analysis. The minerals considered are calcium (Ca), iron (Fe) and Zinc (Zn). The results show a general decline of all mineral content during cooking up to 88%. The results also indicated that soaking beyond 8 hours resulted to 15 min gain in cooking time but led to 4-11% loss in Ca, 5-45% loss in Fe, and 1-9% loss in Zn compared to cooking without a softening technique. Cooking in a 5% potassium carbonate (K_2CO_3) solution significantly reduced the cooking time up to 115 minutes and a relatively higher mineral retention capacity.

Keywords: common beans, softening techniques, mineral degradation, trade-off analysis

Introduction

Common beans have become an essential source of food with huge health benefits. Apart from being a rich source of plant-based protein, common beans are noted for important micronutrients including iron as well as stored bioactive compounds including raffinosaccharides, phytate, and polyphenols. Raffinosaccharides are recognized as stimulants of the growth and activities of probiotics that possess anti-cancer [1], anti-oxidative [2] and anti-calcification [3] characteristics. A major challenge to fully harnessing these nutrient benefits is the hard-to-cook (HTC) nature of most beans varieties. HTC in beans has been attributed to the storage condition (temperature higher than 25⁰C and relative humidity greater than 65%) [4]. Antunes and Sgarbieri [5] observed that the average cooking time of fresh beans was 60 min. However, after six months of storage at 37ᵒC and 76% relative humidity, cooking time could reach 300 min. Certainly, the HTC flaw leads to prolonged cooking time, high energy demand as well as nutrient degradation [4].

Trace nutrients have important niche in human nutrition. Bean legumes makes important contribution in the calcium (Ca), iron (Fe) and zinc (Zn) availability in the diet [6]. Ca in the diet are plays a role in strengthening bones and teeth, regulating body activities such as blood clotting, enzyme and heart functioning, muscular contraction and relaxation, and transmission of nervous system messages. It has been established that maintaining proper level of Ca in the body throughout life time helps in preventing osteoporosis [6,7]. Fe is needed in the body for the production of the protein hemoglobin. Inadequate intake of iron is the leading cause of anemia [8]. Zn is an important component of many body enzymes. It is needed for making proteins and genetic materials. It plays major role in taste perception, wound healing, semen production and development of the fetus. Inadequacy of Zn can lead to growth impediment and increased risks of infections [6].

Considering the benefits and challenges highlighted above, different strategies have been employed to improve bean processing and utilization. Generally, these are faster beans softening techniques aimed at significantly reducing both cooking time and energy use. These techniques include but are not limited to soaking [9], addition of monovalent and divalent salts during cooking [10], cooking in alkaline solution [11] and extrusion processing [12]. While some of these softening techniques have led to significant reduction in hardness (reflected in shorter cooking times), they have been reported to be detrimental to the nutritional quality of the cooked beans. However, most of the nutritional impacts reported in literature have focused on the proximate composition [12], starch and protein digestibility [13-15], anti-nutrients [12,14], resistant starch and bioactive properties [16].

Information on the impact of these softening techniques on the minerals composition during processing is very limited and almost non-existent for cultivars native to developing countries. Improving nutrition in these regions, requires full nutrition sensitive processing data to understand the degradation of these nutrients during processing especially the processing time-nutrient trade-offs. Such information will provide basic thresholds for the various processing conditions in order to minimize severe degradation of beneficial trace nutrients.

The study was therefore formulated to (a) determine changes in calcium, iron and zinc composition due to cooking (b) evaluate the impact of softening techniques on the selected minerals during bean processing (c) assess the cooking time - mineral loss trade-off for the different softening techniques and establish optimal cooking conditions.

Materials and Methods

Materials

Two common beans cultivars harvested from Kameme in the Chitipa district of Malawi and Ipusukilo in the Luwingu district of Zambia were used for this analysis. The cultivars namely *Kabulangeti* (Zambia) and *Maine* (Malawi) were harvested during the 2016 farming season. Prior to the experiments, the seeds were carefully cleaned and sorted. Thus, extraneous materials such as stones, dry twigs, dirt and broken bean seeds were removed. Initial moisture content of the bean seeds was determined using the ASAE S352.2 DEC 97.

Normal cooking experiments

One hundred dry bean seeds were used in for each cooking experiment. The raw bean samples in 300-mL glass containers filled with 200 mL distilled water were cooked in a water bath (Grant Instruments Ltd, Cambridge, UK) at 96^{o}C. A predetermined average compression force of 3.75± 0.88 N measured with TA-HD Plus texture analyzer (Stable Micro Systems Ltd, Surrey, UK) was used to define fully cooked beans. The samples were then dried in an air oven at 40^{o}C for 18h and milled prior to mineral content determination.

Softening techniques

Another set of experiments were conducted to evaluate the effect of softening techniques on the loss of the selected minerals during bean processing. The two most common practices namely, soaking and salt addition were evaluated. Soaking is the most widely used softening technique among bean consumers. In this study, the impact of soaking on changes in the minerals composition was carried out using 100g seeds randomly selected from the beans cultivars studied. The seeds were soaked in 200 mL distilled water at room temperature for 8, 12, and 16 hours. At the end of each experimental run, the water was drained and the surface of the samples dabbed with paper towel. The samples were then cooked in a 300-mL glass container filled with 200 mL distilled water in a water bath (Grant Instruments Ltd, Cambridge, UK) at 96^{o}C. The samples were finally dried in an air oven at 40^{o}C for 18h and milled prior to mineral content determination.

The effect of two salts commonly used in beans cooking were next considered. These were common salt (NaCl) and carbonate of potash (K_2CO_3). The dry beans were cooked without prior soaking. The impact of these salts on both softening of beans and the mineral composition were evaluated. One hundred gram each of *Kabulangeti* and *Maine* cultivars were cooked in 200 mL of 5% salt (NaCl and K_2CO_3) solution. The control samples were cooked in 200 mL distilled water. The beans were considered cooked when the predetermined cooked bean hardness (softness) for a cultivar was attained.

Cooking time determination

In all the experiments, the cooking time was determined as the time to reach the predetermined average compression force of 2.75 ± 0.88 N. Changes in bean hardness was monitored using the TA-HD Plus texture analyzer (Stable Micro Systems Ltd, Surrey, UK). A return-to-start (RTS), measuring force under compression using a 2-mm cylindrical stainless-steel probe (P2) mode was used. The probe punctured the bean sample axially to 75% of their original height applying a cross head speed of 1.0mm/s and a pre-test and post-test speed of 1 mm/s. Due to significant variation of individual bean hardness, ten (10) bean seeds were randomly chosen from each treatment batch. For consistency, the orientation of the seeds on the texture analyzer platform were kept uniform.

Chemical properties

Proximate Analysis

Proximate analysis of the dried pulverized bean samples were conducted. The Dumas combustion method was used to determine the total nitrogen content of bean powders from which the crude protein was estimated using a conversion factor of 6.25 in accordance with AOAC method 968.06 [17]. Using the hot air oven method (AOAC Method 925.09 [17], the moisture content of samples was measured. Crude fats was determined by petroleum ether extraction method (AOAC method 963.15) using solvent extractor (SER 148/6, VELP Scientifica, Usmate, Italy).

Mineral content Analysis

The quadrupole inductively coupled plasma mass spectrometer (ICP-MS) used in this work was Varian 820 MS with collision reaction interface (CRI) system (Analytik Jena AG, Jena, Germany). The argon gas utilized was of spectral purity (99.9998%). The instrumental settings and operative conditions are shown in Table 1.

Beans samples were digested using 70% nitric acid (HNO3). Two mL of HNO3 was added to accurately weighed 0.1600 g of milled beans samples in Pyrex glass digestion tubes. The samples in the acid were first left in a heating block (Tecator Co., Hoganas, Sweden) overnight at room temperature. The following day, the temperature of the heating block was gradually increased, beginning from 50oC and increasing up to 120oC. The digestion was completed in 5 h as indicated by the appearance of colorless solution. The solution was transferred to 50 mL volumetric tubes and brought to volume with ultra-pure deionized H2O, labelled accurately and used for the analysis. Trace metals and major cations were determined in each sample after dilution by a factor of 4 and standards were prepared in a similar matrix. The CRM (NIST 1547 Peach leaves) was part of the quality assurance program. Furthermore, ultrapure deionized water blanks were frequently analyzed alongside samples to check for any loss or cross contamination. The capability of the method for routine analysis was estimated by determining the limits of detection for every element studied. The limits of detection (LOD) and limits of quantification (LOQ) were calculated with three and ten times the standard deviation of the blank divided by the slope of the analytical curve, respectively [18]. For each batch of samples, duplicates and quality controls were used and measured values had to be within 10%.

Spectrometer	**Varian 820 MS (Analytik Jena AG, Jena, Germany)**
Nebulizer	Sea Spray
Spray chamber	Glass
Interface	Collision Reaction Interface (CRI) (for Cr, Fe, As & Se)
Mass analyzator (quadrupole)	Hydrogen gas
RF power (kW)	1.35
Gas Used	Argon
Gas flow rate (LPM)	17.5
Plasma	1.5
Auxiliary	Hydrogen when using CRI
Nebulizer flow	0.75
Scanning mode	Peak hopping
Scanning time	1134 msec
Dilution factor	4
Dwell time (min or sec)	10000 µs
Sweeps/reading	30
Number of replicates/sample	5
Certified Reference Material (CRM)	NIST 1547 (Peach leaves)
Isotopes:	Ca^{43}, Fe^{56}, and Zn^{66}
Isotopes:	
Major elements	Ca^{43}, K^{39}, Na^{23}
Trace elements	Cr^{52}, Cu^{65}, Fe^{56}, Mn^{55}, Se^{78}, Zn^{66}, Ni^{60}, Mg^{26}, Al^{27}, Ag^{107}
Toxic heavy elements	Pb^{208}, Rb^{88}, Cd^{111}, As^{75}, Ba^{135}, Sr^{86}, Ce^{140}

Table1: ICP-MS operating conditions and measurement parameters

Statistical Analysis

Statistical analyses were made with the JMP Pro (version 13.0) software package for Windows (SAS Institute Inc., Cary, NC, 1989-2016). Significance differences among samples was separated using the Least Significant Difference (LSD) at a 5% probability level. Comparison of means was done using the Turkey-Kramer HSD model.

Results and discussions

Chemical properties

Proximate Analysis

The proximate analysis of the selected cultivars is shown in Table 2. Like most pulses, the protein content varied from 25.27 to 28.53% and the carbohydrates varied from 57.2 to 61.7%. The *Kabulangeti* and *Maine* cultivars studied had very low fats content (<1.5%). The result shows the studied bean cultivars have relatively high protein content compared to other common bean cultivars and other pulses reported in the literature such as, chickpeas (17-22%) [19] and lentils (20-21%) [20]. The inclusion of these local beans varieties into the daily diet would benefit from this higher protein content. It will also translate to enrichment of the heavily carbohydrate based diets of corn and rice. Thus, more nutritious meals can be provided for the households.

Bean Cultivar	**Protein (%)**	**Ash (%)**	**Moisture (%)**	**Fat (%)**	**Carbohydrate (%)**	**Gross Energy (kJ/100 g)**
Kabulangeti	26.90 ± 1.63^{a}	3.46 ± 0.09^{a}	9.25 ± 0.01^{a}	1.26 ± 0.00^{a}	59.13	1484.20
Maine	28.41 ± 0.12^{a}	3.35 ± 0.03^{a}	9.56 ± 0.11^{b}	1.48 ± 0.00^{b}	57.20	1485.48

Table 2: Chemical composition of common beans (d.b)

Mineral composition

The mineral composition of raw common bean samples is shown in Table 3. The result shows the presence of both micro and macro minerals (classified based on amount needed by an adult human body). Among the micro-minerals (< 100 mg required per day) analyzed, the beans were rich in Mg (range: 188.09-206.13 mg/100g), Fe (range: 8.22-12.19 mg/100g), Zn (range: 3.84 -4.48 mg/100g) and Mn (range: 2.00-3.34 mg/100g). Comparatively, the Malawian cultivar (Maine) was richer in all the key micro-minerals than the Zambian Kabulangeti. The analysis of the macro-minerals (> 100 mg per day) showed that very high amounts are present in both cultivars. Significantly higher levels were found for K (range: 1578-1745 mg/100g), P (range: 315.86-349.06 mg/100g), Ca (range: 154.33-218.49 mg/100g) in both cultivars. Relatively lower levels of Na were found (range: 2.01-2.56 mg/100g). The results suggest that the cultivars under study are remarkable sources of K, Ca, Fe, Zn, and Mg. The results show that overall, the individual mineral composition vary significantly ($p<0.05$) among the selected cultivars. Mean comparison of the mineral composition showed considerable variation. For instance, up to 11.2, 11.7, 29.4 and 48.2% variation were found for Fe, Mg, Zn, and K, respectively.

Bean Cultivar	Unit	Kabulangeti	Maine
Major minerals			
Calcium (Ca)	mg/100g	154.33	218.49
Phosphorus (P)	mg/100g	349.06	315.86
Potassium (K)	mg/100g	1744.77	1578.16
Sodium (Na)	mg/100g	2.01	2.56
Minor Minerals (Trace Element)			
Chromium (Cr)	µg/100g	19.34	12.77
Copper (Cu)	mg/100g	1.09	1.67
Iron (Fe)	mg/100g	8.22	12.19
Manganese (Mn)	mg/100g	2.00	3.34
Selenium (Se)	µg/100g	4.23	3.06
Zinc (Zn)	mg/100g	3.84	4.48
Cobalt (Co)	µg/100g	70.39	107.57
Nickel (Ni)	mg/100g	0.15	0.16
Magnesium	mg/100g	188.09	206.13

Table 3: Average mineral composition of common beans

A comparative assessment of calcium, iron and zinc in the selected cultivars is shown in Table 4. It is evident from this results that both cultivars can immensely contribute these minerals when included in the daily diet. The mineral composition data obtained from the selected cultivars are comparable and, in some instances, higher than other common beans and pulses. It is also clear that the mineral composition was much higher than those reported for primary cereals such as corn, rice and wheat. For instance, the *Kabulangeti* cultivar has 17 times, 22 times and 4.5 times more Ca than rice, corn and wheat, respectively. Similarly, Maine cultivar has 15 times, 4.5 times and 3.5 times higher Fe content than rice, corn and wheat, respectively. It is evident from these results that augmenting a typical cereal meal which is known to be limited in these minerals, with *Kabulangeti* or *Maine* will boost Ca or Fe intake significantly among the households. Overall, the inclusion of common beans in daily diet should be promoted to enhance the nutrient density of the meals.

Food item	Ca	Fe	Zn	Reference
Common Beans				
Kabulangeti	154	8.22	3.84	This study
Maine	218	12.19	4.48	This study
Pinto	117	8.62	2.48	[21]
Red Kidney	84	10.96	2.88	[21]
Other pulses				
Black eye beans	91	7.94	3.41	[21]
Mung beans*	42	15.62	3.19	[22]
Chickpea	178	4.48	3.53	[23]
Cereals				
Rice	9	0.8	1.16	[24]
Corn	7	2.71	2.21	[24]
Wheat	34	3.52	4.16	[24]

*average of four cultivars

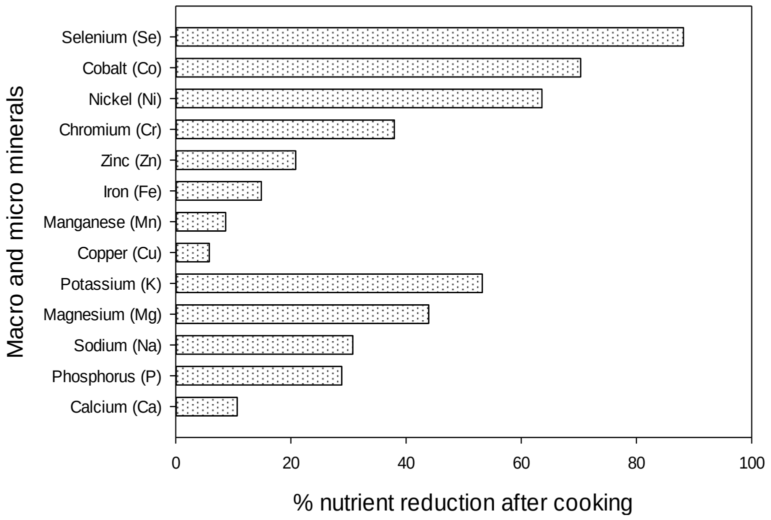
Table 4: Comparison of mineral composition with other pulses and cereal (mg/100g)

Effect of cooking on mineral composition

The result presented in the previous section demonstrated the superior nutritive capacity of common beans in comparison to other pulses and major cereals. However, it is essential to evaluate how much of these nutrients will still be available in cooked beans since it is consumed after cooking and the cooking time is much longer than for cereals. Therefore, the impact of cooking on the mineral composition of the studied cultivars is presented in this section. Fig 1 presents the variation in mineral content after cooking. The horizontal bar chart clearly shows that cooking of common beans significantly alters the mineral composition. Macro-minerals degradation observed were found to be in the range 6.8-28.2% for P, 10.7-14.8% for Ca and 45.8-53.2% for K. Among the micro-minerals, higher percent losses were recorded for Se (88%), Co (70.3%), Ni (63%) and Mg (43%) when the *Kabulangeti* cultivar was cooked. Similarly, cooking of the *Maine* cultivar also resulted in higher losses of Ni (74 %), Fe (42%), and Mg (31%). These higher mineral losses may be attributed to leaching of minerals. Cooking of *Kabulangeti* and *Maine* cultivars require 200 and 180 minutes, respectively to achieve the pre-determined hardness (fully cooked).

It is important to note that even after cooking of the selected beans cultivars, their mineral composition is still superior to those of cereal. For instance, Ca composition after cooking these cultivars is at least 15.2, 19.6 and 4.0 times higher than in uncooked rice, corn and wheat, respectively. Similarly, their Fe component after cooking is at least 8.7, 2.5 and 2 times higher than that of rice, corn and wheat, respectively.

(a)



(b)

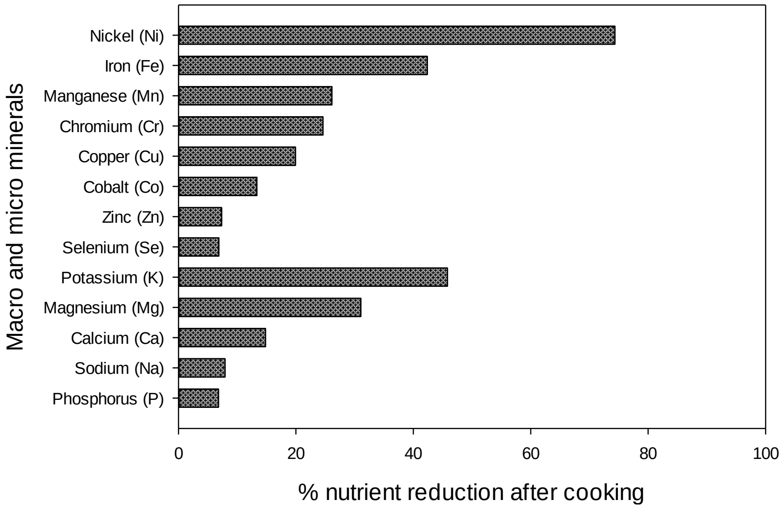


Figure 1: Mineral content variation due to cooking of common beans (a) *Kabulangeti* (b) *Maine.*

The mineral composition variation due to softening and the time trade-off

Softening and its time effect

Softening techniques are generally used to reduce the cooking time and energy use during bean processing. Fig 2 shows the time gain by the various softening techniques. The results show cooking in a 5% K_2CO_3 gave the shortest cooking time of 75±15 min representing a total time gain of 115±5 min. When the beans were cooked with NaCl salt, no softening effect was observed. The result was a longer cooking time of 210 min for both cultivars. This represented an extension of the cooking time by 20±10 min. The extension of cooking time can be attributed to bonds formation due to cross-linking of sodium ions and pectin which led to resistance water absorption by the cells and subsequent failure to separate adjacent cells during cooking [4]. Kinyanjui et al. [11] also reported a similar effect of sodium salt when added to the cooking of hard-to-cook bean cultivars.

Soaking, the primary softening technique among beans consumers was found to gain 80±10, 95±5 and 97.5±7.5 min for common beans soaked for 8, 12 and 16 h, respectively. During soaking, bean seeds absorbs water which causes cell wall softening and enhances the breakdown of the middle lamella of the cotyledon. This implies the longer the bean is soaked the higher the amount of water absorbed and consequently the softer it becomes. The mean comparison of the time saved shows no significant difference between soaking for 12 and 16 h for both cultivars considered in this study. This implies that from a time saving point of view, soaking beyond 12 hours would not yield any significant time gain.

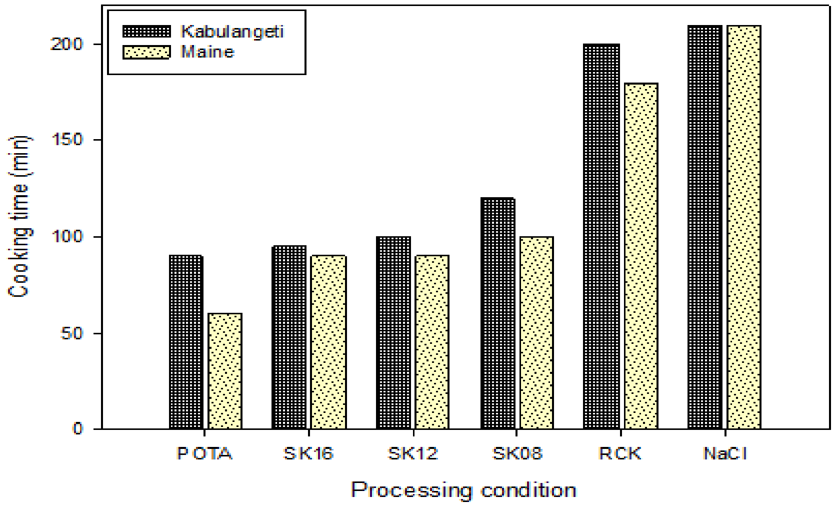
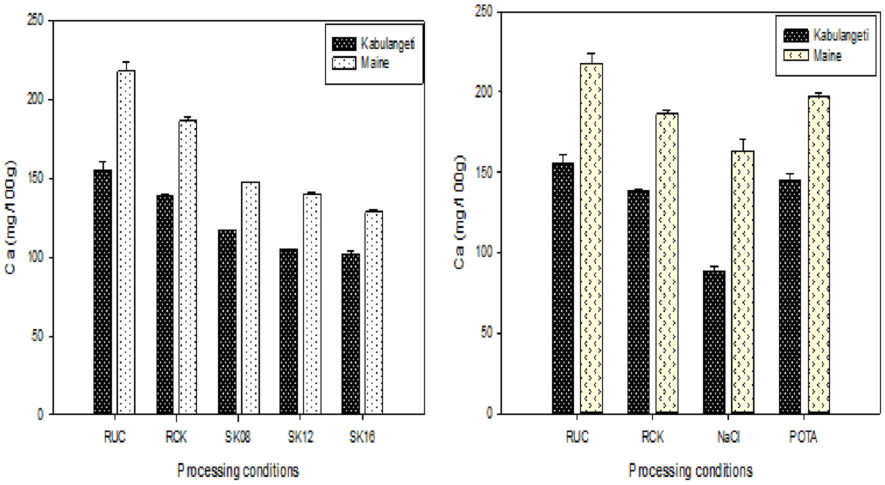


Figure 2: Cooking time gain due to softening.

RCK = Raw beans cooked in distilled water; SK08 = Bean samples soaked for 8h before cooking; SK12 = Bean samples soaked for 12h before cooking; SK16 = Bean samples soaked for 16h before cooking; NaCl = Raw samples cooked in 5% NaCl solution; POTA = Raw samples cooked in 5% K_2CO_3 solution.

Impact of softening on Calcium (Ca) content

Calcium content variation due to softening is shown in Fig 3. The results show that the softening techniques led to a decline in the Ca content. The result showed that the common practice of soaking for 8 hours prior to cooking resulted in some 17.1±1.4% decrease in Ca content depending on the cultivar. Additional 4 hours of soaking (12 h soaking) further reduced the Ca content by another 5.95±1.85 %. The softening technique of cooking the bean cultivars with salted water also led to Ca content variation as shown in Fig 3b. The results show that the addition of NaCl salt reduced the content of Ca by 32.65±8.35%. This reduction is however not significantly ($p < 0.05$) different from the Ca losses due to soaking for 12 or 16 hours but significantly higher than normal cooking without salt or soaking for 8 hours prior to cooking. The higher reduction in Ca may be attributed to the longer cooking time resulting in more leaching out of Ca. Figure 3b also shows a relatively higher average Ca content (196mg/100g) when the beans were cooked in 5% K_2CO_3.



(a) (b)

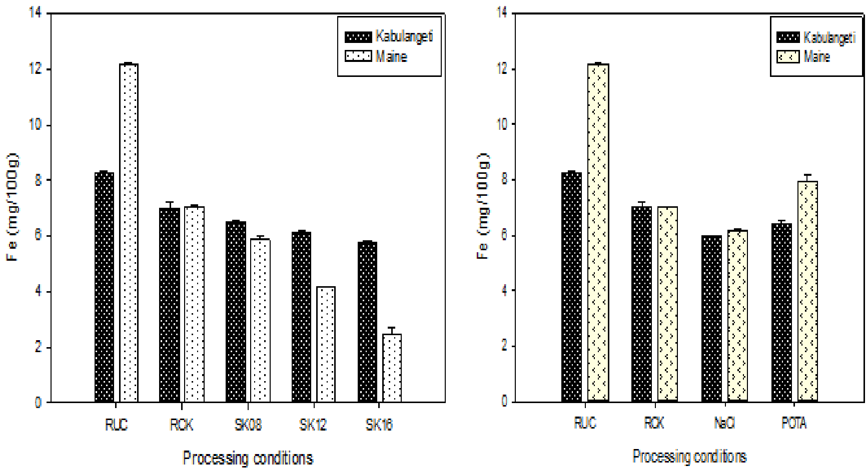
Figure 3: Calcium content variation of *Kabulangeti* and *Maine* beans due to softening (a) Soaking (b) salt addition

RUC = Raw uncooked beans; RCK = Raw beans cooked in distilled water; SK08 = Bean samples soaked for 8h before cooking; SK12 = Bean samples soaked for 12h before cooking; SK16 = Bean samples soaked for 16h before cooking; NaCl = Raw samples cooked in 5% NaCl solution; POTA = Raw samples cooked in 5% K_2CO_3 solution.

Impact of softening on iron (Fe)

Iron content variation of *Kabulangeti* and *Maine* beans due to softening is shown in Fig 4. A general decline of Fe content is observed for all softening techniques in both cultivars although it was more pronounced in the *Maine* cultivar. Soaking for 8 hours prior to cooking further depreciated the Fe content by 8.01±1.93% implying a total decline of 52.3% for *Maine* cultivar and 20.9% for *Kabulangeti*. Quinteros, Farré, and Lagarda [25] observed the total soluble iron in common beans was in the range of 6.17±0.13 mg/100g. They reported the ferrous Fe (II) state constitutes 27.7% in the common beans. The authors also observed that during processing up to 46% of the soluble Fe (II) is lost. It is therefore important to limit processes that increase Fe loss. The soaking experiments clearly point out that beyond the minimum 8 h soaking time, the rate of Fe content loss increased significantly at an average rate of 1.11% for *Kabulangeti* and 3.29% for *Maine* for every additional hour of soaking reaching a maximum loss of 78.8% during 16 h of soaking. This is in agreement with the total Fe decline when bean are cooked as reported by Quinteros et al. [25]. This higher rate of Fe loss may be attributed to the formation of some iron salts with increased solubility that possible led to some loss of Fe in water at the higher cooking temperature. A Turkey-Kramer HSD comparison of the mean Fe contents indicates that the impact of soaking at the selected times were significant ($p < 0.05$) for both *Kabulangeti* and *Maine*.

Fig 4b shows that cooking beans in a NaCl solution further reduced Fe content by 7.2±0.1% compared to normal cooking in distilled water. However, cooking in K_2CO_3 does show superiority in the retention of Fe depending on the cultivar. For instance, the *Maine* cultivar does retain Fe up to 6.1% compared to normal bean cooking. The superior mineral retention ability could be attributed the reduced cooking time when K_2CO_3 is used as softener hence reducing the total Fe leached out during the cooking process.



(a) (b)

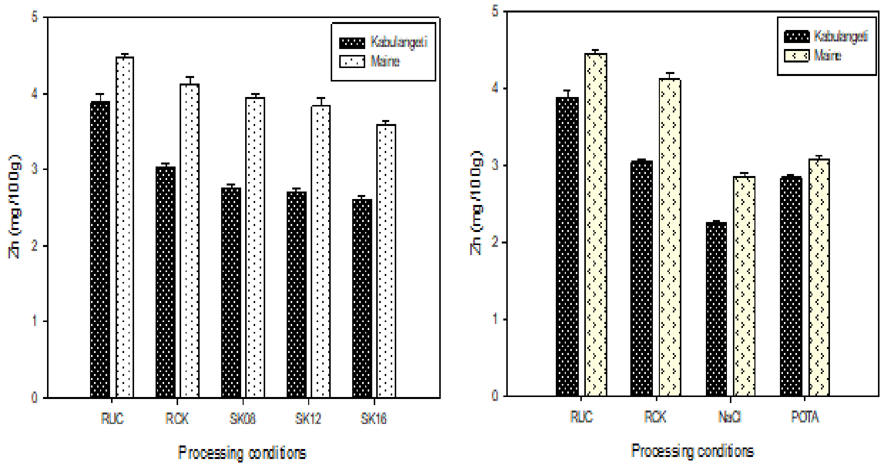
Figure 4: Fe content variation of *Kabulangeti* and *Maine* beans due to softening (a) Soaking (b) salt addition

RUC = Raw uncooked beans; RCK = Raw beans cooked in distilled water; SK08 = Bean samples soaked for 8h before cooking; SK12 = Bean samples soaked for 12h before cooking; SK16 = Bean samples soaked for 16h before cooking; NaCl = Raw samples cooked in 5% NaCl solution; POTA = Raw samples cooked in 5% K_2CO_3 solution.

Impact of softening on Zinc (Zn)

Variation in Zn content due to the applied softening procedures is shown in Fig 5. The result shows a decline in Zn content for all the softening methods evaluated. Zn content declined a further 5.55±1.75 mg/100 g for both cultivars after soaking for 8 h. This represents a total decline of 19.65±8.45%. The results also show that 12 and 16h of soaking led to 0.8 and 3.4% variation in Zn content, respectively. Comparing Zn loss to Ca and Fe, it is clear that Zn shows only minimal loss during soaking and cooking. The lower solubility of Zn in water may be responsible for it being retained most during soaking.

Cooking in salts, on the other hand, showed higher Zn loss in both cultivars in comparison to soaking. It is important to note that these losses varied significantly among the cultivars under study. Zn loss due to NaCl were lower in *Kabulangeti* (5.32±0.9%) than in *Maine* (29.2±1.3). Cooking in K_2CO_3 again showed Zn retention capacity (up to 19.2%) compared to the other softening techniques largely due to the shorter cooking time.



(a) (b)

Figure 5: Zn content variation of *Kabulangeti* and *Maine* beans due to softening (a) Soaking (b) salt addition

RUC = Raw uncooked beans; RCK = Raw beans cooked in distilled water; SK08 = Bean samples soaked for 8h before cooking; SK12 = Bean samples soaked for 12h before cooking; SK16 = Bean samples soaked for 16h before cooking; NaCl = Raw samples cooked in 5% NaCl solution; POTA = Raw samples cooked in 5% K_2CO_3 solution.

Time-mineral loss trade-off analysis

The mineral content trade-off analysis for the selected minerals are shown in Table 5. The losses have been estimated as percent of mineral content of cooked beans. The results demonstrate that softening techniques generally result in cooking time savings up to 115 min. However, there are nutritional implication for applying these techniques, especially the longer soaking times. It is important to analyze gains in cooking time against mineral loss and establish the specific trade-offs. From the Table, it is evident that soaking for 8 hours save 80 min with a corresponding 14-20% loss of Ca compared to normal cooked beans. However, extending soaking time to 12 and 16 hours resulted in additional gain of 10-25 min and extra Ca loss of 4.8-8.8% and 9.7-11.7%, respectively. Thus, it is recommended that pre-cooking soaking of beans should not exceed 8 h to avoid higher loss of Ca. Cooking beans in 5% K_2CO_3 salt water appear to be a better softening technique. The cooking time was reduced by more than half and the Ca content increased by 2.9-5.4%. It is important to note that the increase in Ca is only relative to cooking without prior softening.

The Fe loss trade-off analysis also presented in Table 5 suggest that although Fe may be lost during cooking, the degree of loss can significantly be reduced at shorter cooking times. Cooking in potash solution, for instance, reduced cooking time by 115±5 min and prevented the loss of 0.88 mg/100g Fe. The results also show soaking for more than 8 hours results in some gain in cooking time up to 15 min, however, this time gain may not be worth the 5.6-23.8% and 10.4-45.8% loss in Fe content for a 12 and 16 hours soaking, respectively. Therefore, households are better of nutritionally when soaking is limited to 8 hours or less.

Similarly, the trade-off analysis plot for Zn shown in Table 5 demonstrate soaking for 8 hours gives the minimum Zn loss of less than 10% compared to normal cooked beans without any softening techniques. Extending soaking time to 12 and 16 hours gives a 10-15 min gain in cooking time but a trade-off loss less than 2% for 12 hours and 5.3-9.2 % additional loss of Fe. Considering that the body has no reserve system for Zn in cellular processes [26], it is important to regularly supply Zn in daily food to avoid impaired immune function as well as retarded growth [27]. Therefore, processors and consumers must endeavor to prioritize nutrient retention over cooking time gain especially if it's marginal.

Cooking condition	**Actual cooking time**		**Time gained**		**%Ca loss**		**% Fe loss**		**% Zn loss**	
	KB	MN	KG	MN	KG	MN	KG	MN	KG	MN
RCK	200	180	0	0	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{a}	0.00^{a}
SK08	120	100	80	80	15.42^{b}	20.57^{c}	7.14^{b}	16.65^{c}	8.99^{b}	4.28^{ab}
SK12	100	90	100	90	24.10^{c}	25.04^{cd}	12.67^{c}	41.06^{d}	10.96^{bc}	7.11^{b}
SK16	95	90	105	90	26.51^{c}	30.95^{d}	17.57^{d}	64.90^{e}	14.04^{c}	12.69^{c}
NaCl	210	210	-10	-30	35.90^{d}	12.34^{b}	15.00^{cd}	12.72^{c}	25.88^{d}	30.64^{e}
POTA	90	60	110	120	-4.82^{a}	-5.90^{a}	8.57^{b}	-12.30^{a}	6.47^{b}	25.14^{d}

Table 5: Mineral content trade-off analysis

Time gained and % losses are estimated relative to cooking without softening technique; KG = Kabulangeti bean cultivar; MN = Maine bean cultivar; SK08 = Bean samples soaked for 8h before cooking; SK12 = Bean samples soaked for 12h before cooking; SK16 = Bean samples soaked for 16h before cooking; NaCl = Raw samples cooked in 5% NaCl solution; POTA = Raw samples cooked in 5% K_2CO_3 solution.

Conclusion

In this study, the effect of the bean softening techniques on mineral composition was evaluated and a nutrient-time trade off estimated. It was established that *Kabulangati* and *Maine* bean varieties are important sources of plant-based protein and essential minerals such as Calcium (Ca), Iron (Fe), and Zinc (Zn). Considerable amount of these minerals is lost during processing of common beans regardless of the method employed. However, the degree of mineral loss is largely dependent on the technique used. The results obtained indicates the degree of mineral loss is dictated by the duration of soaking and cooking. Thus, beans requiring longer cooking time stands the highest risk of mineral loss. Longer soaking time resulted in shorter cooking time but higher mineral loss. Soaking beyond 8 hours led to marginal gains in cooking time. However, these gains have a price tag, unnecessary further loss of minerals. Therefore, our results comparing five processing methods, suggest 8-hour soaking prior to cooking yields the best combination of shorter cooking and least mineral loss. Cooking in NaCl solution increased the cooking time and consequently resulted in higher mineral loss. Conversely, cooking in a 5% K_2CO_3 solution significantly reduced the cooking time with a relatively higher mineral retention capacity.

Acknowledgements

The authors gratefully acknowledge the International Fund for Agricultural Development (IFAD) for providing financial assistance through IFAD project grant 2000000974.

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