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Research article

Soaking beans for 12 h reduces split percent and cooking time regardless of type of water used for cooking

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ABSTRACT

Beans are one of the most important cheap source of protein in developing countries. However, their utilisation in the diets of many people remains limited due to long cooking time, among others. Therefore, it is imperative to identify ways to enhance utilisation of beans. The aim of the current study was to assess the effects of soaking and cooking in different types of water (tap, borehole, acidulated- 1.0 percent citric acid and soda- 0.2 percent sodium bicarbonate) on cooking time (CT), split percentage (SP) and total soluble solids (TSS) in broth of different varieties of beans. Results show that soaking significantly reduced CT across eight varieties from an average CT of 109.5–84.6 min in tap water, 109.5–85.2 min in borehole water, 115.9–92.7 min in acidulated water and 82.0–51.2 min in soda water representing 22.7%, 22.1%, 20.0% and 37.6% reduction in CT, respectively. Soaking generally decreased SP and varietal differences were observed suggesting beans are less likely to break when soaking precede cooking. Although cooking in soda water significantly reduced CT, unfortunately, it increased SP. Acidulated water extended CT but reduced SP in almost all varieties. Soaking generally decreased TSS in broth from 7.0 to 6.7% in tap water, 6.1–5.8% in borehole water and 11.3–7.7% in soda water while it increased TSS in acidulated water from 18.2 to 20.6% across all the eight varieties which suggest reduction in leaching out of bean solids into cooking water which is consistent with reduced SP of soaked beans. While use of soda water reduced cooking time and therefore saved time and energy, its effect of increasing split percent may not be appealing to some consumers. This study has demonstrated that bean soaking significantly reduced cooking time and split percent and these can also be affected by type of cooking water.

1. Introduction

Common beans (*Phaseolus vulgaris*) are the most important class of legumes in the world, only second to soybeans (Xu and Chang, 2008). They are nutrient dense containing 16–33% proteins; 50–60% carbohydrates of which 14–19% is dietary fibre; 1–3% lipids; and numerous micronutrients, such as zinc, iron, magnesium, phosphorus, calcium, sodium, copper, potassium, thiamine, riboflavin, niacin, vitamin B_6, and folic acid (Wainaina et al., 2021; Hayat et al., 2014; Campos-Vega et al., 2010; Shimelis and Rakshit, 2005; Kimura and Koaze, 2000, Augustin et al., 1981). Protein-energy malnutrition is widespread affecting over 170 million preschool children and lactating women in developing African and Asian countries (Nedumaran et al., 2015; Staniak et al., 2014; Khalid and Elharadallou, 2013; Boye et al., 2010; Bhat and Karim, 2009; Van Heerden and Schönfeldt, 2004). Beans could be among strategic legume crops to combat malnutrition in these parts of the world (Maphosa and Jideani, 2017).

Normally, in eastern and southern African countries, beans are consumed alongside a staple thick porridge, usually from maize, known as *nsima* in Malawi and *ugari* in East Africa. In addition, though still uncommon, bean flour is blended with other legume and cereal flours to produce a nutritious flour blend that can be used for complementary feeding. Beans are a relatively rich source of lysine and tryptophan, but have a deficiency of the sulfur amino acids, particularly methionine.

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Maize is deficient in lysine and tryptophan but has fair amounts of sulphur-containing amino acids, i.e. methionine and cysteine. This means that the protein quality in both beans and maize is generally poor, but may complement each other when used in mixtures (Maphosa and Jideani, 2017; Asgar et al., 2010; Ejigui et al., 2007; Bressani et al., 1974; Evans and Bandemer, 1967). Despite these known benefits, some people are reluctant to incorporate beans in their diet because they generally take long to cook and they contain anti-nutritional factors (Maphosa and Jideani, 2017; Reyes-Moreno and Paredes-López, 1993). Prolonged cooking time is particularly of concern in resource-constrained communities and have other unwarranted gender and fuel-energy use implications (Cichy et al., 2015; Rehfuess, 2006). Actually, some consumers replace beans with less nutritious foods due to long cooking time (Siqueira et al., 2013). Some people are also concerned with the gaseous compounds that are produced due to indigestible carbohydrates that are consequently fermented in the colon and may cause discomfort (Maphosa and Jideani, 2017; Winham and Hutchins, 2011; Aguilera et al., 2009). Probably, efforts to reduce and or eliminate these undesirable attributes could increase consumption and utilisation of beans.

A number of strategies are used to reduce cooking time and fuel wood consumption during preparation of beans. Some of these strategies include soaking and cooking with various compounds like sodium bicarbonate (baking soda). Previous studies have reported significant reduction in cooking time when beans were soaked and or cooked using sodium bicarbonate (Schoeninger et al., 2014; Carmona-García et al., 2007; Onwuka and Opara, 2006). During soaking there is increased hydration, which results in softening of the seed coat making it easier for water to penetrate during cooking, which results in decreasing cooking time (Chigwedere et al., 2019). Soaking also accelerates starch gelatinization and protein denaturation during cooking resulting in fast cooking (Zamindar et al., 2013). Similarly, alkaline condition created by sodium bicarbonate contributes to solubilisation or weakening of seed components such as polysaccharides and polyphenols (Chigwedere et al., 2019; Carmona-García et al., 2007; Shimelis and Rakshit, 2007; Onwuka and Opara, 2006). On the contrary, the longer cooking time in beans cooked in acidulated water has been attributed to the toughening of the seed coat created by acid (Kinyanjui et al., 2015).

While these pre-cooking treatments reduce cooking time, they may hardly improve bean utilization because other important aspects of cooked beans may be negated. Besides increasing split percent, soda could produces a darker color of the seed coats, thereby affecting sensory characteristics of the product (Schoeninger et al., 2014). In view of the available findings in literature, there is a need to strike a balance among the different factors that affect cooking characteristics of beans, such as cooking time, split percent and total solids in order to ensure that cooked beans still retain the desirable sensory attributes to improve its acceptance to consumers. The main objective of the current study was to determine the effect of soaking and type of water on cooking time and split percent of beans.

2. Materials and methods

2.1. Materials

Eight varieties of common bean breeder seed (NUA35, NUA59, NUA45, SER124, SER83, Kabalabala, Kholophethe and Napilira) were grown at Chitedze Research Station fields during summer of 2019/2020 growing season. Beans were harvested and dried at the Alliance of Bioversity International and CIAT seed laboratory to a moisture level of about 12%. Four types of water, namely tap, borehole, acidulated (1% citric acid), and soda (0.2% sodium bicarbonate) water were used for soaking, as well as cooking. In addition, appropriate and relevant equipment for the execution of the study were used. Furthermore, equipment and utensils, such as hotplates, pots and buckets with same specifications were used for soaking and cooking to control extraneous variables.

2.2. Preparation of soaking and cooking water

The four types of water were prepared in adequate amounts in advance every day as per cooking schedule. Tap water, provided by Lilongwe Water Board, was drawn straight from a tap at Lilongwe University of Agriculture and Natural Resources (LUANAR), Bunda campus. Borehole water was drawn from one of the boreholes within Bunda campus. Acidulated and soda water were prepared by adding citric acid (1%) and sodium bicarbonate (0.2%) to distilled water, respectively. Prior to soaking, the hardness of each soaking water was measured.

2.3. Soaking of beans

All the eight bean varieties were sorted to remove broken, wrinkled, rotten and external matter. Each bean variety was divided into two samples; one for soaking (2400 g) and another not to be soaked (2400 g). Approximately 200 g of each bean were soaked, in each of the four different types of water, for precisely 12 h. This procedure was replicated three times ($n = 3$). Soaking beans in water for at least 12 h before cooking has been previously recommended (Wainaina et al., 2021; Abdel-Hameed and Latif, 2019). From the eight bean varieties, 200 g of the right bean variety was soaked in the right type of water until all samples, as per schedule for the respective day of cooking, were completed. Equal volume of water for soaking beans (1000 ml) was used in each soaking container. The start times for soaking the beans were staggered, i.e. at 6 pm, 9 pm, 12 am (mid night) and 5 am in the following day. Staggering was done to achieve a 12 h soaking duration since the beans were cooked at different times the following day. The volume and pH of soaking water were recorded and measured using a calibrated cylinder and pH meter, respectively, before and after 12 h of soaking.

2.4. Cooking of beans

The soaked and or unsoaked beans were placed in respective aluminium cooking pots and cooked on electric hotplates. For soaked samples, the decanted water was re-added to the respective cooking pots. The hot plate was then turned on until it turned red. The knobs on the hotplate were always turned at the same level for all cooking sessions. Time of placing the beans on hotplate and start of boiling were both recorded. Temperature at the start of boiling was similarly recorded using a thermometer. Electric kettles were used to heat the extra volume of water, which was used for filling water in the cooking beans. Caution was taken to make sure that the right type of water was heated and put in the right bean sample. Stirring was not done during cooking to avoid enhancing splitting of the beans. The beans were let to cook for 30 min, thereafter doneness test was performed by investigators every 10 min using the tactile method of pressing bean seeds between the forefinger and the thumb until a smooth and soft texture was obtained (Kinyanjui et al., 2015). Investigators were adequately trained in the tactile method. If the beans were found not done, the cooking continued. All beans used in doneness testing were accounted for and number recorded to help during split percentage calculations. In case the beans were not cooked but the cooking water was finished, extra hot water was added and the volume was recorded. A thermometer was used to measure a drop in temperature at each point of adding the water. Consistency was observed in the amount of extra water added in the cooking of the beans. When the beans were done, temperature was recorded. Beans were immediately removed from the hot plate and placed on a flat sheet for counting of all whole grains.

2.5. Determination of common beans characteristics

2.5.1. Moisture

Moisture content of beans was determined by drying an empty dish and lid in the oven at 105 °C for 3 h and transferring it to a desiccator to cool. The empty dish and lid were weighed and masses recorded. About

10.0 g of each sample was put in the dish. The sample was spread to the uniformity and placed in the oven. The samples were dried overnight at 105 °C. After drying, it was transferred with a partially covered lid to the desiccator to cool. After the sample cooled it was reweighed (the dish and its dried sample). The change in weight before and after drying was used to calculate the moisture content of the beans (AOAC, 2000). Calculation was done as following formula (1) below:

$$Moisture\ (\%) = \frac{W1 - W2}{W1} \times 100\% \quad (1)$$

where: W1 = weight (g) of sample before drying; W2 = weight (g) of sample after drying.

2.6. Ash determination

A standard method for ash determination (AOAC, 2000) was used where 2.0 g of bean powder was weighed in triplicate in dry crucible, which was placed in a desiccator for 30 min. Ashing was done in a muffle furnace (Lab technologies, India), at a temperature of 600 °C for 16 h. After 16 h, the sample was removed after the temperature had cooled to about 30 °C. The crucibles were put in a desiccator until they were completely cooled and then weighed. Ash percentage was calculated as following formula (2) below:

$$Ash\ (\%) = \frac{weight\ of\ ash}{weight\ of\ sample} \times 100\% \quad (2)$$

2.7. Determination of crude protein

Crude protein was determined using Kjeldahl method (Jiang et al., 2014; Beljkaš et al., 2010). The determination of crude protein was done in four steps, namely digestion, dilution, distillation and titration. Briefly, 1.0 g of the sample was weighed using an analytical balance on a filter paper and was put in a digestion tube. Thirty millilitres (30 mL) of 98% H_2SO4 was then added into the digestion tube together with 1 tablet of Kjeldahl catalyst. The digestion apparatus was then assembled and put in the fume hood which was turned on. Digestion of the sample was initiated at a low heat (150 °C) for 30 min, then increased to higher heat (400 °C). After the samples turned green, the digester was switched off to allow the tubes to cool down**.** The digest was then transferred to a 50 mL volumetric flask through a funnel and then top up the volume to the 50 ml mark with distilled water. An aliquot (10 mL) of the extract was then transferred into a distillation tube, which had 10 mL of 40 percent NaOH dispensed into it. Thereafter, 10 mL of 2 percent boric acid was added in an Erlenmeyer flask followed with 5 drops of mixed indicator made of methyl red and bromo-cresol green. The mixture was then steam-distilled for 4 min until the wine-red colour of the solution in the Erlenmeyer flask flashed to green. Lastly, the solution was titrated back to the original pink or wine-red colour using 0.1N HCl acid. Crude protein content was calculated using the following formula (3) below:

$$Protein\ (\%) = \frac{N \times 14.007 \times (Vs - Vb) \times 6.25 \times D] \times 1000}{W \times 1000} \quad (3)$$

where: N = Normality (0.1) of standard HCl acid (may also be 0.01, Vs = Volume of standard HCl acid used to titrate a sample, Vb = Volume of standard HCl acid used to titrate a blank, W = Weight (g) of dry sample used, D = Dilution factor (50/2).

2.8. Crude fat determination

Crude fat content was determined using Soxhlet method (Caprioli et al., 2016). Two grams (2.0 g) of the sample was weighed on an analytical balance and mass recorded as W1. The sample was folded in a filter paper and inserted in a labelled thimble. The thimble was inserted in the extractor. A round bottom quick fit flask was pre-weighed and labelled (W2) for collecting oil. The flask was filled up to two thirds of its volume with petroleum ether. The whole Soxhlet set was assembled and placed on a heating mantle for extraction for 16 h. After extraction the solvent was evaporated in the fume hood and flask was put in a desiccator for cooling and weighed as W3. All reagents used were of analytical grade purchased from MERCK, South Africa. Crude fat percentage was calculated following formula (4) below:

$$Crude\ fat\ (\%) = \frac{(W3 - W2)}{W1} \times 100\% \quad (4)$$

where: W1 = weight of sample (g); W2 = Weight of flask (g); W3 = Weight of flask after extraction (g).

2.9. Determination of iron (Fe) and zinc (Zn)

Determination of iron and zinc in bean powder was done according to a method described by Kalumbi et al. (2020) with minor modifications. Sample preparation for iron and zinc involved accurately weighing and mixing powdered bean samples in a clean silica crucible in preparation for wet oxidation digestion using elemental free HNO_3–$HClO_4$ di-acid mixture in order to release iron and zinc. Exactly, 1.0 g of the powdered bean sample was weighed on an analytical balance and 3 mL of nitric acid was added to the sample. The mixture was then placed in a 250 mL conical flask on a hot plate for 1 h at 145 °C. Thereafter, 4 mL of di-acid mixture (HNO_3 and $HClO_4$) was added and the mixture was left on the hot plate for another hour with adjusted temperature of 240 °C until the brown fumes cleared. The sample was left to cool. The digestion mixture was filtered using Whatman no 1 filter paper into 100 mLcalibrated volumetric flask and diluted up to the mark with double-distilled water. The filtrate was used for determination of zinc and iron by Atomic Absorption Spectrometry (AAS) (AA240FS Model, Agilent Technologies, Australia). The Standard solutions were prepared and every sample was tested in parallel with a blank. All the chemicals used were of analytical grade and purchased from Sigma, UK.

2.10. Determination of carbohydrates by anthrone method

Carbohydrates were determined according to the Anthrone method (Leyva et al., 2008). Exactly 100 mg of the sample was weighed into a boiling tube. Then it was hydrolysed by keeping it in boiling water bath for 3 h with 5 mL of 2.5 N–HCl and cooled to room temperature. Few solid sodium carbonate were added to neutralize the mixture until the effervescence ceased. The contents were made up to 100 mL volume and centrifuged. A volume of 0.5 mL of supernatant was collected for analysis. Standards were prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of the working standard. '0' served as a blank and made up to 1 mL in all the tubes including the sample tubes by adding distilled water. Then 4 mL of anthrone reagent was added. The mixture was heated for 8 min in a boiling water bath. Then it was cooled rapidly and read the green to dark green colour at 630 nm. A standard graph was drawn by plotting concentration of the standard on the *X*-axis versus absorbance on the *Y*-axis. Glucose was used as a standard. Calculation was done as following formula (5) below:

$$\text{Amount of carbohydrate present in 100 mg of the sample} = \frac{mg\ of\ glucose}{Volume\ of\ test\ sample} \times 100\% \quad (5)$$

2.11. Starch determination by anthrone method

Starch content was determined according to the Anthrone method (Leyva et al., 2008). A powdered bean sample of 0.10 g was weighed and homogenized in hot 80% ethanol to remove sugars. It was then centrifuged and the residues were retained. Residues were repeatedly washed with hot 80% ethanol till the washings did not give colour with anthrone

reagent. Then the residues were dried over a water bath. To the residues 5.0 mL of water and 6.5 mL of 52% perchloric acid were added, respectively. The mixture was extracted at 0 °C for 20 min then centrifuged and the supernatant saved. Extraction was repeated with fresh perchloric acid and supernatant was pooled together. The volume was made to 100 mL. Standards were prepared from glucose and anthrone reagent was added as outlined in carbohydrate method section above. Starch content was calculated by multiplying with a factor of 0.9.

2.12. Hardness of cooking water

2.12.1. Determination of phosphorus

Phosphorus was determined by using Murphy-Riley Colorimetric Method (Cho and Nielsen, 2017) as described in the manual of the measuring instrument. The method involves an oxidation-reduction reaction in which phosphorus is reacted to form a chromogen-mineral complex that can be measured with a spectrophotometer at a visible wavelength. Working standard solution of phosphorus of 0 ppm, 2.5 ppm, 5 ppm, 7.5 ppm and 10 ppm, were prepared from an intermediate solution of 100 mg/L. Ten millilitres (10 mL) Mehlich 3 extractant was added and the volume was made to 100 mL using distilled water. To determine the amount of phosphorus in the water sample, 1 mL aliquot of the sample, as well as standards were taken and 9 mL Murphy Riley working solution was mixed in different vials. The solution was left to stand for 15 min for colour development. After 15 min, the solution was run at 882 nm on an ultra-visible spectrophotometer starting with standards and then samples.

2.12.2. Determination of calcium

Calcium determination followed the method as previously reported(Poirier et al., 2016) but with some modification. Water samples were filtered to less than 0.45 μm and acidified to a pH less than 2 with HNO_3 for 16 h before ICP-OES analysis. Working standard solution of calcium of 0 ppm, 0.5 ppm, 1.0 ppm, 1.5 ppm and 2.0 ppm, 2.5 ppm and 5 ppm were prepared from an intermediate solution of 100 mg/L. Four millilitres (4 mL) of strontium chloride solution was added and the volume was made to 100 mL with distilled water. The standards were run on the ICP programmed to rinse for 60 s and emission wavelength set at 317.93 nm followed by the samples. The standard 2.5 ppm was used as a quality control sample. The instrument was set to configure linearity, least square calculated intercept, curve fit algorithms for converting emission value to mg/L (ppm) concentration units. The instrument operates on a program that stops the analysis if the standard coefficient of determination is below 0.995.

2.12.3. Determination of magnesium

Magnesium was determined using Atomic Absorption Spectrophotometer (AAS) according to a method by Bisergaeva and Sirieva (2020) with some modification. Water samples were filtered to less than 0.45 μm and acidified to a pH less than 2 with HNO_3 before analysis. Working standard solution of Magnesium of 0 ppm, 0.25 ppm, 0.50ppm, 0.75 ppm and 1.0 ppm, were prepared from an intermediate solution of 100 mg/L where 4 mL of lanthanum oxide solution was added and the volume was made to 100 mL with distilled water. The samples were prepared by adding 4 ml of Lanthanum oxide to 1 mL of the samples, followed by 15 ml of distilled water. The standards were run on the AAS that was programmed to rinse after running standards and after every run of 5 samples at emission wavelength set at 285.2 nm. The standard 0.5 ppm was used as a quality control sample/standard. The instrument was set to configure linearity, least square calculated intercept, curve fit algorithms for converting emission value to mg/L (ppm) concentration units. The concentration of the samples was multiplied by 20 as a dilution factor to determine the concentration in the water sample.

2.12.4. Total soluble solids (TSS) in broth

For each bean sample, 3 g of broth (soup) were obtained and placed on the drying sheet or aluminium foil plate The weight of 3 g broth plus drying sheet were recorded. Drying was done overnight in the oven and weight of dried broth plus drying sheet was recorded. The TSS was calculated using formula (6) below:

$$TSS\ (\%) = \frac{Weight\ of\ sample + \ sheet\ before\ drying - weight\ of\ sample + sheet\ after\ drying}{Weight\ of\ sample + \ sheet\ before\ drying} \times 100\% \quad (6)$$

2.12.5. Split percent

After cooking, whole cooked beans were counted and subtracted from the total number of beans that were actually cooked. The difference between the number of beans available for cooking and number of whole cooked beans represented split beans. Therefore, split percent was calculated using formula (7) below:

$$Split\ percent\ (\%) = \frac{number\ of\ beans\ available\ for\ cooking - number\ of\ whole\ cooked\ beans}{number\ of\ beans\ available\ for\ cooking} \times 100\% \quad (7)$$

2.12.6. Data analysis

Data was analysed using one way ANOVA on SPSS version 20.0 to generate means and standard deviations. The means generated were based on bean varieties, type of soaking and or cooking water and type of precooking treatment (soaked and not soaked) on cooking time. The means were significantly different when p-value < 0.05 using Tukey's test. Data was presented in tables and graphs.

Table 1. Nutritional value of the eight varieties of beans.

Bean variety	Moisture%	Protein%	Fe (mg/100g)	Zn (mg/100g)	Ash%	Fats%	Carbohydrates%	Starch%
NUA 59	9.2 ± 0.0	26.2 ± 0.3	7.1 ± 0.8	2.0 ± 0.0	7.5 ± 0.4	4.4 ± 0.3	52.9 ± 1.3	45.3 ± 0.7
SER 83	9.3 ± 0.0	22.1 ± 0.9	5.1 ± 0.0	1.7 ± 0.0	6.3 ± 0.6	4.1 ± 0.1	59.2 ± 2.3	50.6 ± 1.7
Kabalabala	10.4 ± 0.0	21.4 ± 1.2	5.5 ± 0.1	2.3 ± 0.0	7.3 ± 0.1	2.4 ± 0.2	59.7 ± 2.2	51.0 ± 1.7
Kholophethe	9.4 ± 0.0	23.0 ± 1.5	4.7 ± 0.1	1.7 ± 0.0	6.5 ± 0.0	5.2 ± 0.0	57.5 ± 2.0	48.9 ± 1.7
Napirira	8.9 ± 0.0	20.8 ± 0.3	5.5 ± 0.2	2.0 ± 0.1	5.6 ± 0.0	3.8 ± 0.0	61.8 ± 1.2	52.8 ± 1.5
NUA 35	8.8 ± 0.0	19.4 ± 0.2	4.9 ± 0.3	1.2 ± 0.0	6.3 ± 0.0	3.2 ± 0.0	63.7 ± 2.1	54.1 ± 1.8
NUA 45	8.6 ± 0.0	20.5 ± 1.7	4.8 ± 0.1	1.8 ± 0.0	8.3 ± 0.1	4.3 ± 0.0	59.2 ± 1.0	50.6 ± 1.
SER 124	10.1 ± 0.0	24.3 ± 1.9	4.6 ± 0.1	2.1 ± 0.0	7.6 ± 0.1	3.4 ± 0.1	56.4 ± 5.1	48.0 ± 4.4

Table 2. Hardness of cooking water expressed in terms of calcium, phosphorus and magnesium (mg/L) content.

Type of water	Calcium	Phosphorus	Magnesium
Tap water	3.54 ± 0.08^{a}	0.38 ± 0.01	12.05 ± 0.03^{a}
Borehole	4.07 ± 0.40^{a}	0.38 ± 0.01	11.44 ± 0.04^{a}
Acidulated	0.19 ± 0.13^{b}	0.38 ± 0.01	5.31 ± 0.05^{b}
Soda	0.07 ± 0.02^{c}	0.36 ± 0.03	5.23 ± 0.03^{b}
Distilled water	0.06 ± 0.01^{c}	0.37 ± 0.01	5.38 ± 0.02^{b}

Means with different superscripts within a column are significantly different at $\alpha = 0.05$.

3. Results and discussion

3.1. Nutrition value of the eight bean varieties

The nutritional value of all the eight varieties are presented in Table 1. Protein content ranged from 19.4% in NUA35 to 26.2% in NUA59. NUA59 had the lowest starch and carbohydrate contents of 45.3% and 52.9%, respectively, while NUA35 had the highest starch and carbohydrate contents of 54.3% and 63.7%, respectively, suggesting an inverse relationship between protein content and carbohydrate and/or starch ($R^2 = 0.9151$). This relationship has been previously reported in cereal and bean grains (Burešová et al., 2010; Shen et al., 2015). The fat contents ranged from 2.4% to 5.2%, while ash ranged from 5.6% to 8.3%. These results are consistent with previous studies in bean grains (Shen et al., 2016; Burešová et al., 2010; Reyes-Moreno and Paredes-López, 1993; Kelly and Bliss, 1975). The iron content ranged from 4.6 mg/100 g in SER124 to 7.1 mg/100 g in NUA59, while zinc content ranged from 1.25 mg/100 g in NUA35 to 2.37 mg/100 g in Kabalabala bean variety. Of all the bean varieties in this study NUA35 would provide the least amount, while NUA59 the highest amount of total iron and zinc upon consumption (Table 1). Considering that the beans were grown in the same location, the differences in the selected nutrients and minerals might be attributed to genetic differences.

3.2. Hardness of water used in bean cooking

The cooking ability of water is determined by its hardness. Hardness of water is the measured content of divalent ions mainly calcium and magnesium (Diggs and Parker, 2009). Hard water is known to increase the cooking time of beans (Uzogara et al., 1992). In natural waters, these ions are bound to bicarbonate, sulfate and chloride. The calcium content of cooking water ranged from 0.06 in distilled water to 4.01 mg/L in borehole water (Table 2). Tap water (3.54 mg/L) and borehole (4.07 mg/L) had higher values, while soda and acidulated water had very low calcium contents (Table 2), which was expected since these water samples were made from distilled water. Borehole and tap water had significantly higher ($p < 0.05$) magnesium content than other types of water. Despite these variations, all types of cooking water were classified as soft water because they were below 60 mg/L $CaCO_3$ equivalent, which is considered the upper limit for soft water (Diggs and Parker, 2009). Additionally, results on phosphorus contents revealed very low levels (0.36–0.38 mg/L) in all the types of water used in cooking (Table 2).

3.3. Effect of bean variety on cooking time

Results on cooking time as a function of bean variety are presented in Figures 1 and 2. Results showed that bean variety significantly affected cooking time depending on pre-treatment of beans - soaked or not soaked. Generally, Kabalabala and SER 83 cooked faster compared to the other bean varieties, while SER 124 generally took the longest time to cook both for soaked and not soaked beans (Figure 1). The longer cooking times imply increased fuel wood or energy consumption for the households (Wood, 2017; Adkins et al., 2010). The longer cooking times and an increase in energy consumption are deterrent attributes contributing to low utilization of beans at household level (Wood, 2017; Cichy et al., 2015; Siqueira et al., 2013; Rehfuess, 2006). Cooking time is a function of heritable traits, environmental, and storage conditions, as well as pre-cooking and cooking treatments (Wainaina et al., 2021; Wood, 2017). Previous studies done by other authors have reported that starch composition (amylose and amylopectin ratio) and protein content affect cooking time (Chigwedere et al., 2019). Others suggest that the density of the cotyledon is the determinant of cooking time, i.e. cotyledons with higher density have slower water uptake resulting in longer cooking time (Yadav et al., 2018). Further, it has been reported that higher values of minerals and chemical composition among bean varieties affect thermal behaviour and this is associated with greater hardness and lower degree of cooking (Sánchez-Arteaga et al., 2015). From the results, it is evident that the differences in chemical composition among the bean varieties might have contributed to the differences in cooking time.

3.4. Effect of soaking beans for 12 h on cooking time

Results on the effect of soaking beans on cooking time are presented in Figure 2. The results have clearly demonstrated that irrespective of bean variety and type of water used, soaking significantly reduced cooking time (Figure 2 and Table 3). The reduction in cooking time as a result of soaking was smallest in SER83 variety. Several research works on bean soaking by various researchers have shown that soaking beans prior to cooking reduces cooking time (Chigwedere et al., 2019; Schoeninger et al., 2014; Carmona-García et al., 2007; Onwuka and Opara, 2006). This has been attributed to the fact that as beans are being soaked, there is increased hydration, which results in softening of the seed coat, which makes it easier for the water to penetrate through during cooking resulting in decreasing the cooking time (Kwofie et al., 2020; Chigwedere et al., 2019; Wood, 2017). Other researchers have also reported that soaking accelerates chemical and physical reactions, such as solubilisation, starch gelatinization and polymerization, and protein denaturation during cooking and this subsequently results in reduction of cooking time (Wainaina et al., 2021; Zamindar et al., 2013). Various researchers have reported that soaking contributes to loss of some macronutrients

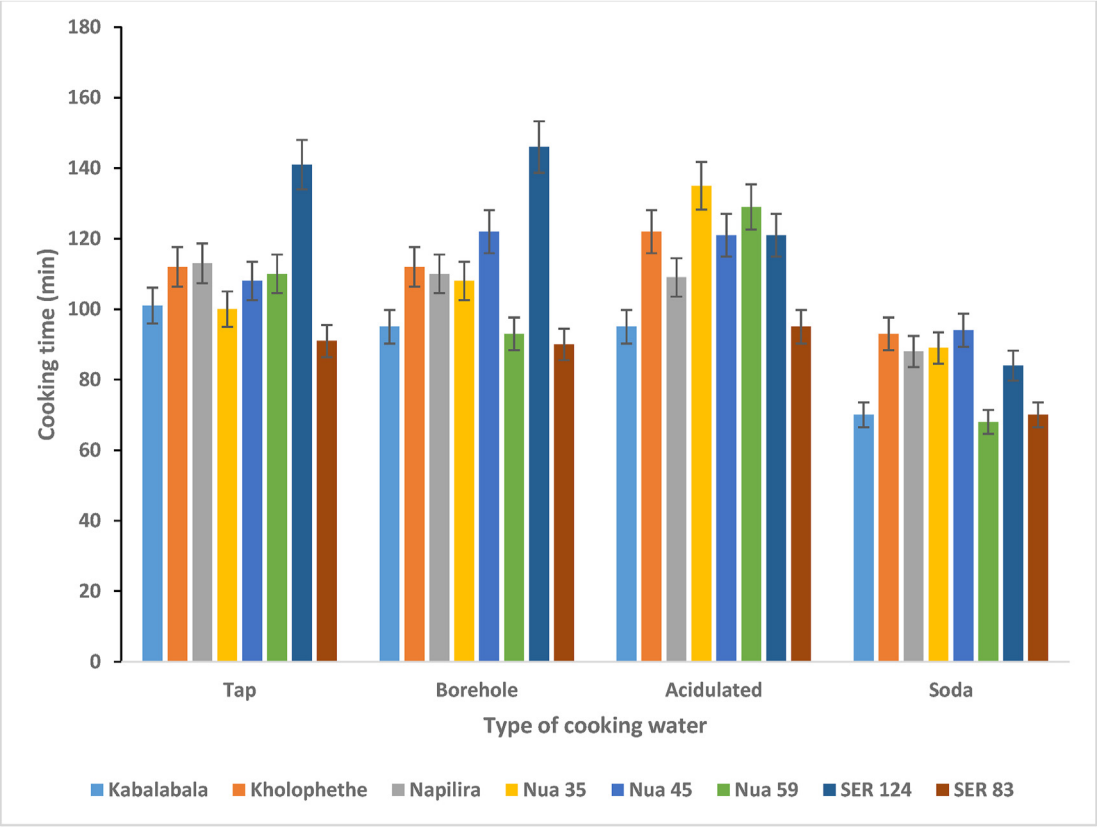

Figure 1. Relative cooking time of eight different bean varieties in four different types of cooking water (unsoaked beans).

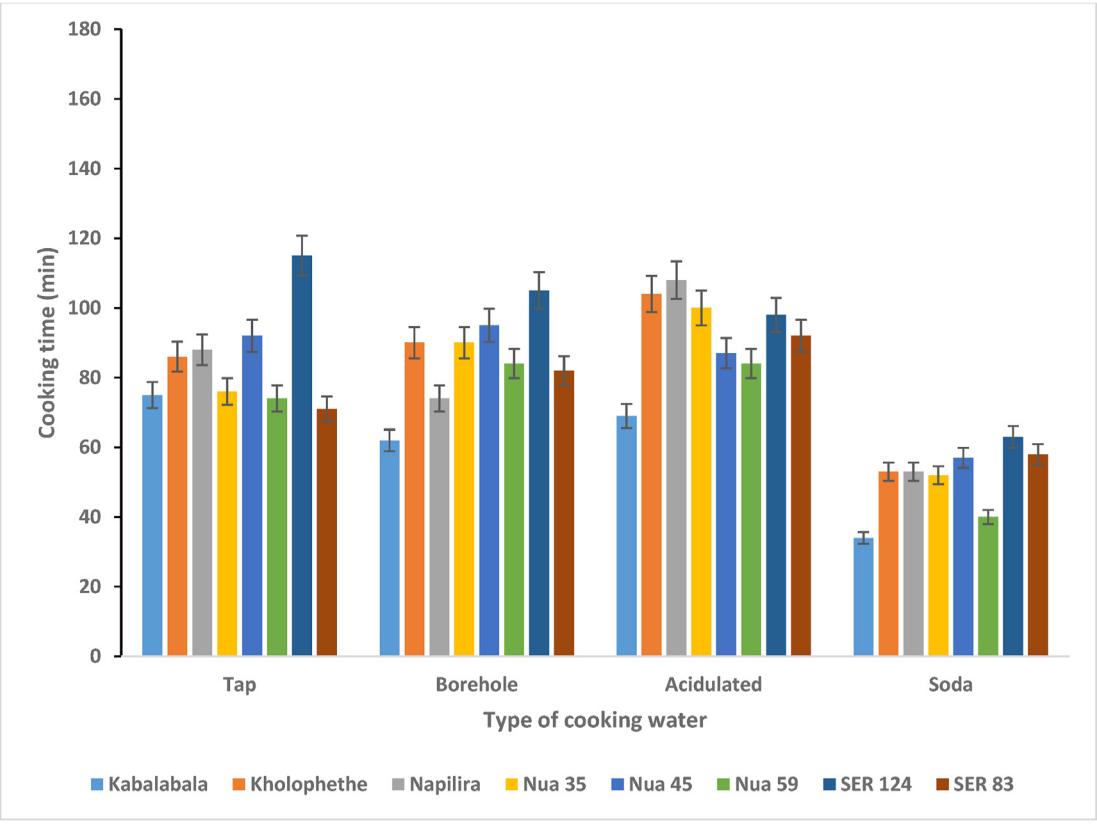

Figure 2. Relative cooking time of eight different varieties in four different cooking water after soaking followed by cooking (soaked beans).

Table 3. Summary of cooking times (minutes) for each variety in different cooking water.

Type of cooking water (pH)	Number of varieties that cooked after 60 min		Number of varieties that cooked after 100 min		Number of varieties that cooked after 120 min	
	Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked	Soaked
Tap (5.26)	8	8	5	1	1	0
Borehole (5.07)	8	8	5	1	2	0
Acidulated (1.81)	8	8	6	3	5	0
Soda (5.82)	8	1	0	0	0	0

(proteins, carbohydrates) and micronutrients (vitamins and minerals) (Shimelis and Rakshit, 2007; Vidal-Valverde et al., 1998). However, Fernandes et al. (2010) systematically demonstrated that the benefits of soaking before cooking are many and exceeds the negatives. Besides, soaking the beans significantly increases leaching out of ant-nutritional factors (phytates, phytic acid and oligosaccharides) and that partial reduction of anti-oxidants (phenolic compounds) during soaking may actually be desirable because high levels could impair digestions and protein absorption (Wainaina et al., 2021; Valdés et al., 2011; Fernandes et al., 2010).

3.5. Effect of type of water on cooking time

Results on the effect of type of water on cooking time are summarized in Table 3. The type of water used significantly influenced cooking time. Cooking time was significantly lower in soda water (alkaline water) compared to other types of water used (Figure 2 and Table 3). The cooking time taken by the different bean varieties based on whether they were soaked or not, as well as the type of water used was categorised into three as follows; *varieties that cooked after 60 min*, *varieties that cooked after 100 min* and *varieties that cooked after 120 min*. Longer cooking times were observed in acidulated water as demonstrated by high number of bean varieties that cooked after 100 min (Table 3). The longer cooking time in beans cooked in acidulated water could be attributed to the toughening effect of the acids as they alter the structural properties of starch rendering the cells resistant to water absorption and subsequent failure of adjacent cells to separate upon cooking (Kinyanjui et al., 2015; Onwuka and Okala, 2003). The longer cooking times in acidic water could also imply high fuel wood consumption, which may subsequently deter households from preparing beans for consumption. During cooking, adding food sources of acid, such as tomatoes and vinegar to the bean dishes is a great way to increase the depth of flavour. However, according to Garden-Robinson and Mcneal (2019) caution should be exercised to add the acidic ingredients when the beans are fully done because, as observed in the current study, acidity may prolong the cooking time. Several authors have previously reported a reduction in cooking time in beans cooked under alkaline conditions. Some researchers have reported that the alkaline condition contributed by sodium bicarbonate contribute to solubilization of polyphenols and this contribute to reduction in cooking time (Chigwedere et al., 2019; Carmona-García et al., 2007; Shimelis and Rakshit, 2007; Onwuka and Opara, 2006), while others have reported that sodium bicarbonate has unidentified structural weakening effect on the seed, which reduced the cooking time (Onwuka and Opara, 2006).

3.6. The effect of hardness of on cooking time

Results on hardness of water represented by concentrations of calcium, phosphorous and magnesium are presented in Table 2. From the results, the low levels of minerals in the different types of water used in cooking might have no effect on the cooking time. This was evident when the analysis of the association between hardness of water and cooking time produced no meaningful results (data not shown). This might be because all the types of water used in this study fall under the category of soft water (0–60 ppm). The highest level of calcium content was 4 mg/L, which is considerably lower compared to values permitted in bottled water (usually, even greater than 200 mg/L) (Ong et al., 2009; Morr et al., 2006). The calcium concentration was below 60 mg/L suggesting that all the four different types of cooking water used were soft. The Water Quality Association (WQA) and the United States Geological Survey (USGS) classify water hardness based on the concentration of Ca^{2+} and Mg^{2+} ion in waters. When the concentration of ions falls within 0–60 ppm, the water is classified as soft while between 61–120 ppm and 121–180 ppm, the water is classified as moderately hard and hard, respectively. Water containing more than 180 ppm is classified as very hard water (Ahn et al., 2018). It has been reported that hardness of water (>80 mg/L) affects cooking time (Uzogara et al., 1992) but the levels of different minerals such as calcium, phosphorus and magnesium were very low to have an effect on cooking time in the current study.

3.7. Effect of soaking and type of water on split percentage of cooked beans

Results on split percent of cooked beans are presented in Figure 3. Split percent was found to be dependent on variety, soaking and cooking water. In terms of variety, Kabalabala had a higher split percent than any other bean variety in this study. Generally, higher split percent were observed in beans that were not soaked except for few varieties. Cooking using soda water generally increased split percent. However, soaking in soda water before cooking generally reduced split percent (Figure 3). The higher split percent in soda water might have been attributed to the structural weakening effect of soda on the seed, which made the beans vulnerable to splitting as they were being cooked (Chigwedere et al., 2019; Carmona-García et al., 2007; Shimelis and Rakshit, 2007; Onwuka and Opara, 2006). Generally, soaking seems to have a modest reduction in split percent in cooked beans, which seem to be dependent on a variety of beans, as well as type of cooking water. Probably, this suggests that soaking beans prior to cooking reduces bean splitting, which may improve consumer appeal for the beans. Other researchers have previously reported that increased hydration of the beans as a result of soaking results in low split percentage (Zamindar et al., 2013) and this might have been the reason for the low split percent in soaked then cooked beans. However, it is critical to note that use of soda water for soaking and cooking significantly reduces overall acceptability of sensory evaluation parameters, such as colour, texture, taste and odour (Abdel--Hameed and Latif, 2019; Schoeninger et al., 2014).

3.8. Effect of cooking water and variety on total soluble solids (TSS) of cooked bean broth

Results show that both variety and cooking water affected the TSS in cooked bean broth (Figure 4). There was generally higher TSS in beans soaked and cooked in acidulated water while the least TSS was observed in borehole water. All the bean varieties cooked in acidulated water had TSS above 11%, while those cooked in tap and borehole waters had TSS below 11%. For all the varieties, beans cooked with soda water had higher TSS in beans that were not soaked, ranging from 8.9% in NUA45 to 14.2% in Kabalabala compared to soaked beans ranging from 4.7% in NUA59 to 11.8% in Kholophethe. While differences were evident between the different types of cooking water, an observation was made on the inconsistent effects between soaked and unsoaked beans across

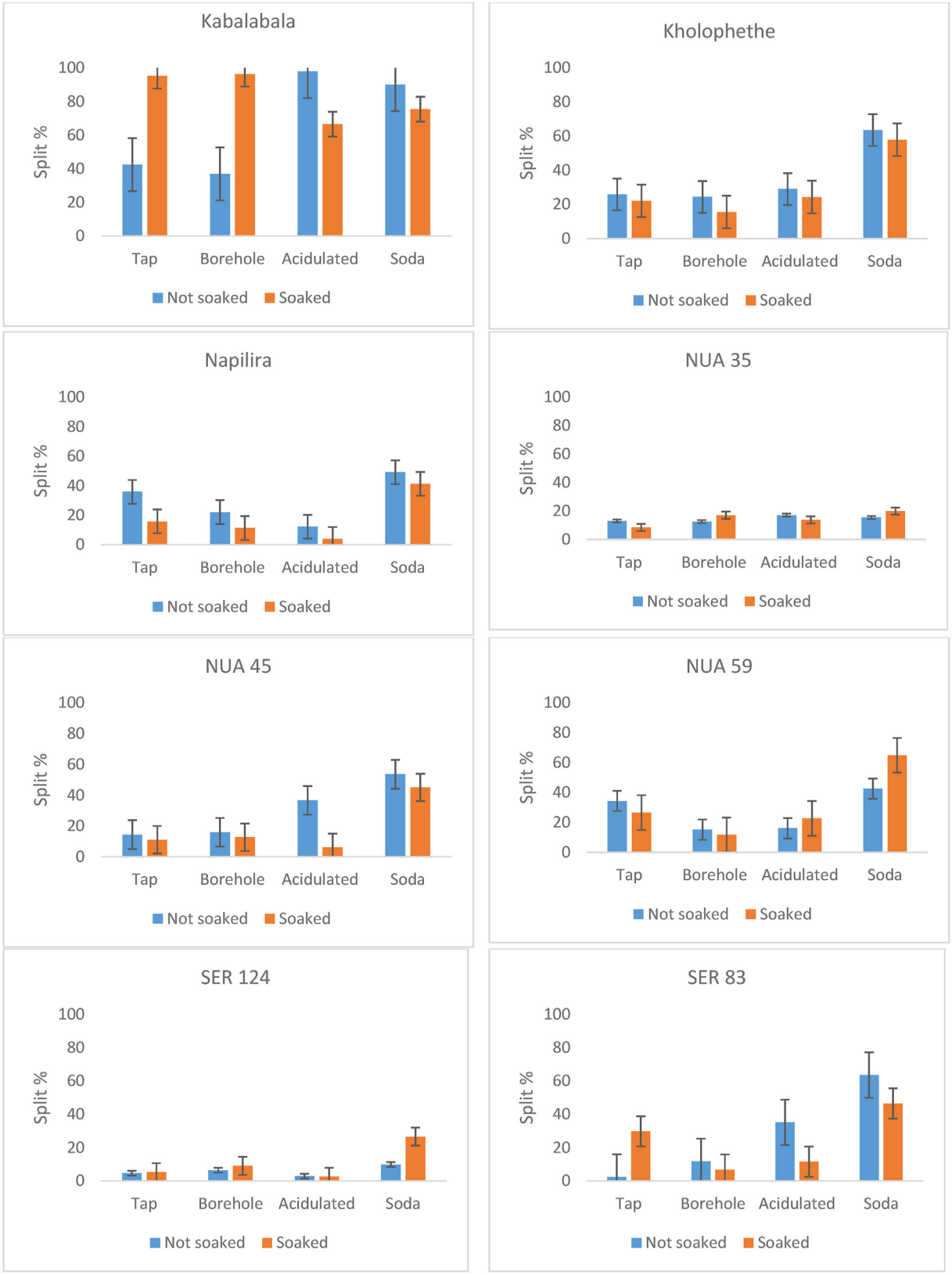

Figure 3. Effect of soaking and/or cooking water on split percent of cooked beans.

varieties implying probably that TSS could be better explained by type of cooking water than variety. The higher TSS in acidulated water was unexpected as these beans had comparatively lower split percent than soda water (Figure 3). During cooking of beans, there is leaching out of solids from grains into cooking water. Therefore, it is expected that the more the bean contents leach out into cooking water, the higher the TSS in the broth. The expectation was that beans that had high split percent (soaked and cooked in soda water) were more likely to result in leaching

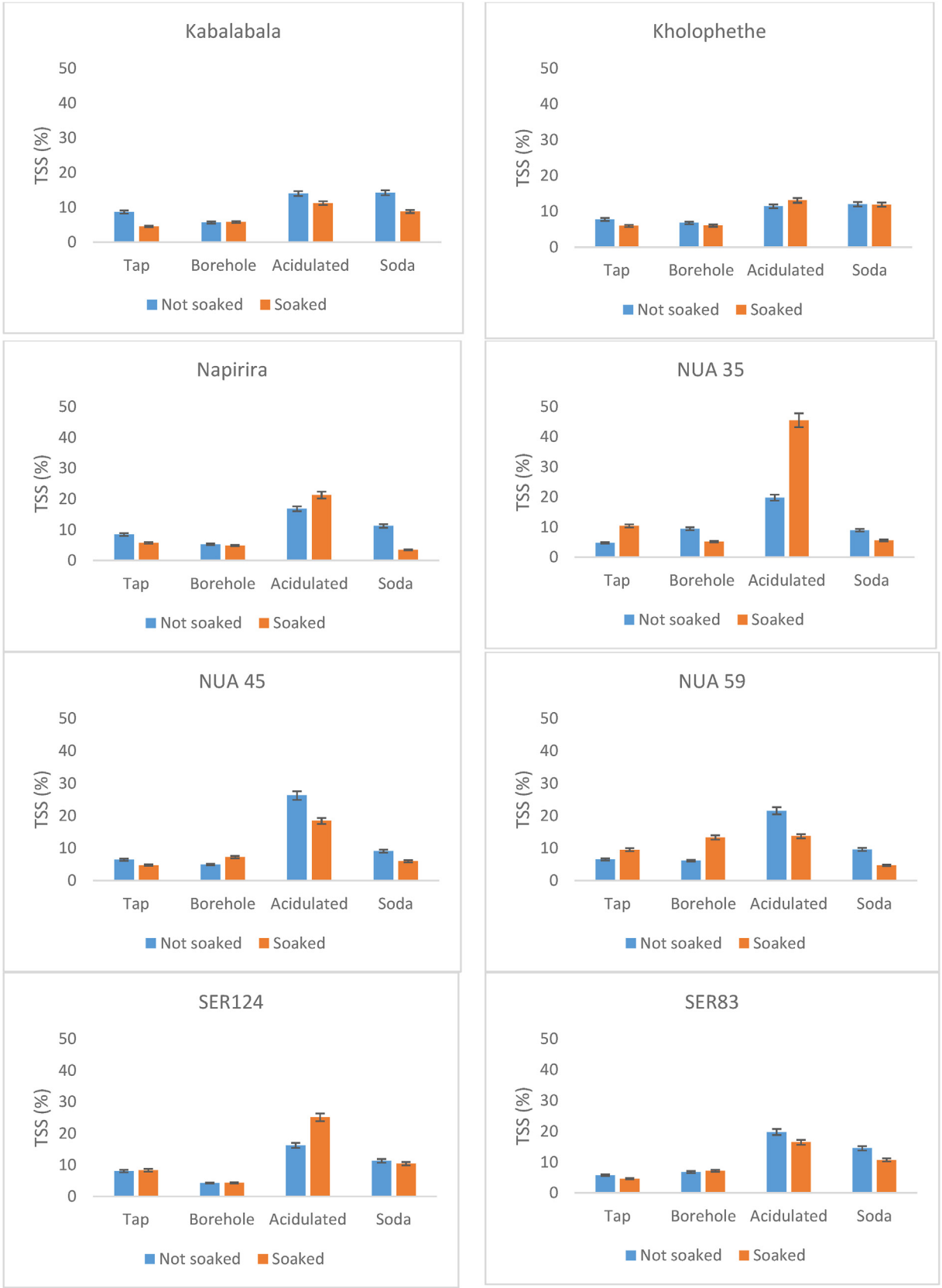

Figure 4. Effect of variety and/or cooking water on total soluble solids (TSS) of bean broth.

more solids into cooking water due to the disrupted barrier (testa) as the beans split. Surprisingly, in this study, it was observed that the beans that had higher split percent had lower TSS in broth. Consistent with this observation, Kabalabala, which had the highest split percent (Figure 3) had low TSS (Figure 4). We hypothesize that splitting *perse* did not increase TSS in broth possibly due to the fact that the endosperm and its

contents remained intact (did not leach out into broth) despite the seed coat splitting. This hypothesis needs to be explored further to ascertain the cause of high TSS in broth soaked and/or cooked in acidulated water, which had low split percent. TSS in broth may increase the viscosity of the broth. It was also observed that beans that had higher TSS produced a more viscous broth and this could affect consumers' choice.

4. Conclusion

The study has expanded existing knowledge that soaking beans prior to cooking significantly reduces cooking time irrespective of the variety of beans and type of water used for cooking. Most importantly, soaking generally alleviated splitting or breakage of beans indicating that soaking beans before cooking not only reduces cooking time but also reduces splitting of beans during cooking. The reduction in cooking time due to use of soda water may sometimes come at a cost since it increases the split percent. Further, in general, soaking and use of soda may affect the sensory properties of the beans as previous studies have shown. Therefore, a compromise to accept split beans in order to save time and energy, especially at household level should be reached. However, reducing splitting of beans could be a goal for processors, especially those producing tinned beans or other related products.

Declarations

Author contribution statement

Justice Munthali: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Drafted and reviewed the manuscript.

Smith G. Nkhata: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Darfted and reviewed the manuscript.

Kingsley Masamba: Conceived and designed the experiments; Performed the experiments; Reviewed the manuscript.

Timothy Mguntha: Analyzed and interpreted the data.

Robert Fungo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Rowland Chirwa: Supervised the experiment..

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Abdel-Hameed, S.M., Latif, S.S., 2019. Effect of soaking and cooking on nutritional and quality properties of faba bean. J. Food Dairy Sci. 10, 389–395.

Adkins, E., Tyler, E., Wang, J., Siriri, D., Modi, V., 2010. Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. Energy Sustainable Dev. 14, 172–185.

Aguilera, Y., Martın-Cabrejas, M.A., Benıtez, V., Molla, E., Lopez-Andreu, F.J., Esteban, R.M., 2009. Changes in carbohydrate fraction during dehydration process of common legumes. J. Food Compos. Anal. 22, 678–683.

Ahn, M.K., Chilakala, R., Han, C., Thenepalli, T., 2018. Removal of hardness from water samples by a carbonation process with a closed pressure reactor. Water 10 (1), 54.

AOAC, 2000. Official Methods of Analysis. The Association of Official Analytical Chemist, Gaithersburg, MD, USA.

Asgar, M.A., Fazilah, A., Huda, N., Bhat, R., Karim, A.A., 2010. Nonmeat protein alternatives as meat extenders and meat analogs. Compr. Rev. Food Sci. Food Saf. 9, 513–529.

Augustin, J., Beck, C., Kalbfleish, G., Kagel, L., Matthews, R., 1981. Variation in the vitamin and mineral content of raw and cooked commercial Phaseolus vulgaris classes. J. Food Sci. 46, 1701–1706.

Beljkaš, B., Matić, J., Milovanović, I., Jovanov, P., Mišan, A., Šarić, L., 2010. Rapid method for determination of protein content in cereals and oilseeds: validation, measurement uncertainty and comparison with the Kjeldahl method. Accred Qual. Assur. 15, 555–561.

Bhat, R., Karim, A.A., 2009. Exploring the nutritional potential of wild and underutilized legumes. Compr. Rev. Food Sci. Food Saf. 8, 305–331.

Bisergaeva, R.A., Sirieva, Y.N., 2020. Determination of calcium and magnesium by atomic absorption spectroscopy and flame photometry. J. Phys.: Conf. Ser. 1691 012055.

Boye, J., Zarefatemeh, F., Pletch, Z., 2010. Pulse proteins: processing, characterization, functional properties and applications in food and feed. Food Res. Int. 43, 414–431.

Bressani, R., Murillo, B., Elias, L.G., 1974. Whole soybeans as a means of increasing protein and calories in maize-based diets. Food Sci. (N. Y.) 39, 577–580.

Burešová, I., Sedláčková, I., Faměra, O., Lipavský, J., 2010. Effect of growing conditions on starch and protein content in triticale grain and amylose content in starch. Plant Soil 56, 99–104.

Campos-Vega, R., Loarca-Piña, G., Oomah, B.D., 2010. Minor components of pulses and their potential impact on human health. Food Res. Int. 43, 461–482.

Caprioli, G., Giusti, F., Ballini, R., Sagratini, G., Vila-Donat, P., Vittori, S., Fiorini, D., 2016. Lipid nutritional value of legumes: evaluation of different extraction methods and determination of fatty acid composition. Food Chem. 192, 965–971.

Carmona-García, R., Osorio-Díaz, P., Agama-Acevedo, E., Tovar, J., Bello-Pérez, L.A., 2007. Composition and effect of soaking on starch digestibility of Phaseolus vulgaris (L.) cv. 'Mayocoba. Int. J. Food Sci. Technol. 42, 296–302.

Chigwedere, C.M., Njoroge, D.M., Loey, A.M.V., Hendrickx, M.E., 2019. Understanding the relations among the storage, soaking, and cooking behavior of pulses: a scientific basis for innovations in sustainable foods for the future. Compr. Rev. Food Sci. Food Saf. 18.

Cho, Y.-H., Nielsen, S.S., 2017. Phosphorus determination by Murphy-Riley method. In: Food Analysis Laboratory Manual. Springer.

Cichy, K.A., Wiesinger, J.A., Mendoza, F.A., 2015. Genetic diversity and genome-wide association analysis of cooking time in dry bean (Phaseolus vulgaris L.). Theor. Appl. Genet. 128, 1555–1567.

Diggs, H.E., Parker, J.M., 2009. Aquatic facilities. In: Planning and Designing Research Animal Facilities. Academic Press.

Ejigui, J., Savoie, L., Marin, J., Desrosiers, T., 2007. Improvement of the nutritional quality of a traditional complementary porridge made of fermented yellow maize (Zea mays): effect of maize–legume combinations and traditional processing methods. Food Nutr. Bull. 28.

Evans, R.J., Bandemer, S.L., 1967. Nutritive value of legume seed proteins. J. Agric. Food Chem. 15, 439–443.

Fernandes, A.C., Nishida, W., Da Costa Proença, R.P., 2010. Influence of soaking on the nutritional quality of common beans (Phaseolus vulgaris L.) cooked with or without the soaking water: a review. Int. J. Food Sci. Technol. 45, 2209–2218.

Garden-Robinson, J., Mcneal, K., 2019. All about Beans: nutrition, health benefits, preparation and use in menus. Red 112, 0.4.

Hayat, I., Ahmad, A., Masud, T., Ahmed, A., Bashir, S., 2014. Nutritional and health perspectives of beans (Phaseolus vulgaris L.): an overview. Crit. Rev. Food Sci. Nutr. 54, 580–592.

Jiang, B., Tsao, R., Li, Y., Miao, M., 2014. Food safety: food analysis technologies/techniques. Encycl. Agric. Food Syst. 273–288.

Kalumbi, M.H., Likongwe, M.C., Mponda, J., Zimba, B.L., Phiri, O., Lipenga, T., Mguntha, T., Kumphanda, J., 2020. Bacterial and heavy metal contamination in selected commonly sold herbal medicine in Blantyre, Malawi. Malawi Med. J. 32 (3), 153–159.

Kelly, J.D., Bliss, F.A., 1975. Heritability estimates of percentage seed protein and available methionine and correlations with yield in dry beans. Crop Sci. 15, 753.

Khalid, I.I., Elharadallou, S.B., 2013. Functional properties of Cowpea (Vigna unguiculata L. Walp), and Lupin (Lupinus termis) flour and protein isolates. J. Nutr. Food Sci. 3, 1.

Kimura, T., Koaze, H., 2000. Composition, soaking and softening characteristics of some Kenyan beans (Phaseolus vulgaris L.). Food Sci. Technol. Res. 6, 12–18.

Kinyanjui, P.K., Njoroge, D.M., Makokha, A.O., Christiaens, S., Ndaka, D.S., Hendrickx, M., 2015. Hydration properties and texture fingerprints of easy- and hard-to-cook bean varieties. Food Sci. Nutr. 3, 39–47.

Kwofie, E.M., Mba, O.I., Ngadi, M., 2020. Classification, force deformation characteristics and cooking kinetics of common beans. Processes 8.

Leyva, A., Quintana, A., Sánchez, M., Rodríguez, E.N., Cremata, J., Sánchez, J.C., 2008. Rapid and sensitive anthrone–sulfuric acid assay in microplate format to quantify carbohydrate in biopharmaceutical products: method development and validation. Biologicals 36, 134–141.

Maphosa, Y., Jideani, V.A., 2017. The role of legumes in human nutrition. In: Functional food-improve health through adequate food, vol. 1, p. 13.

Morr, S., Cuartas, E., Alwattar, B., Lane, J.M., 2006. How much calcium is in your drinking water? A survey of calcium concentrations in bottled and tap water and their significance for medical treatment and drug administration. HSS J. 2, 130–135.
Nedumaran, S., Abinaya, P., Jyosthnaa, P., Shraavya, B., Rao, P., Bantilan, C., 2015. Grain Legumes Production, Consumption and Trade Trends in Developing Countries. In: Working Paper Series No. 60.
Ong, C.N., Grandjean, A., Heaney, R., 2009. The mineral composition of water and its contribution to calcium and magnesium intake. Calcium Magnes. Drink.-water 37.
Onwuka, G.I., Opara, H.O., 2006. Evaluation of the effect of chemical treatment and soaking on the cooking time of african yam bean seed (Sphenostylis stenocarpa). Bio-Research 4, 10–13.
Onwuka, U., Okala, O., 2003. Effects of Selected Salts on the Cooking Time, Protein Content and Sensory Properties of African Yam Beans and Cowpeas. Wiley Online Library.
Poirier, L., Nelson, J., Leong, D., Berhane, L., Hajdu, P., Lopez-Linares, F., 2016. Application of ICP-MS and ICP-OES on the determination of nickel, vanadium, iron, and calcium in petroleum crude oils via direct dilution. Energy Fuels 30 (5), 3783–3790.
Rehfuess, E., 2006. Fuel for Life: Household Energy and Health. World Health Organization, Geneva, Switzerland.
Reyes-Moreno, C., Paredes-López, O., 1993. Hard-to-Cook phenomenon in common beans — a review. Crit. Rev. Food Sci. Nutr. 33, 227–286.
Sánchez-Arteaga, H.M., Urias-Silvas, J.E., Espinosa-Andrews, H., García-Márquez, E., 2015. Effect of chemical composition and thermal properties on the cooking quality of common beans (Phaseolus vulgaris). CyTA - J. Food 13, 385–391.
Schoeninger, V., Coelho, S.R.M., Christ, D., Sampaio, S.C., 2014. Processing parameter optimization for obtaining dry beans with reduced cooking time. Food Sci. Technol. 56, 49–57.
Shen, S., Hou, H., Ding, C., Bing, D.J., Lu, Z.X., 2016. Protein content correlates with starch morphology, composition and physicochemical properties in field peas. Can. J. Plant Sci. 96, 404–412.
Shimelis, E.A., Rakshit, S.K., 2005. Proximate composition and physico-chemical properties of improved dry bean (Phaseolus vulgaris L.) varieties grown in Ethiopia. LWT–Food Sci. Technol. 38, 331–338.
Shimelis, E.A., Rakshit, S.K., 2007. Effect of processing on antinutrients and in vitro protein digestibility of kidney bean (Phaseolus vulgaris L.) varieties grown in East Africa. Food Chem. 103, 161–172.
Siqueira, B.D.S., Vianello, R.P., Fernandes, K.F., Bassinello, P.Z., 2013. Hardness of carioca beans (Phaseolus vulgaris L.) as affected by cooking methods. Food Sci. Technol. 54, 13–17.
Staniak, M., Księżak, J., Bojarszczuk, J., 2014. Mixtures of legumes with cereals as a source of feed for animals. Org. Agric. Towards Sustain. 123–145.
Uzogara, S.G., Morton, I.D., Daniel, J.W., 1992. Effect of water hardness on cooking characteristics of cowpea (Vigna unguiculata L. Walp) seeds. Int. J. Food Sci. Techonol. 27, 49–55.
Valdés, S.T., Coelho, C.M.M., Michelluti, D.J., Tramonte, V.L.C.G., 2011. Association of genotype and preparation methods on the antioxidant activity, and antinutrients in common beans (Phaseolus vulgaris L.). LWT–Food Sci. Technol. 44, 2104–2111.
Van Heerden, S.M., Schönfeldt, H.C., 2004. The need for food composition tables for southern africa. J. Food Compos. Anal. 17, 531–537.
Vidal-Valverde, C., Frias, J., Sotomayor, C., Diaz-Pollan, C., Fernandez, M., Urbano, G., 1998. Nutrients and antinutritional factors in faba beans as affected by processing. Z. Lebensm. Unters. Forsch. A 207, 140–145.
Wainaina, I., Wafula, E., Sila, D., Kyomugasho, C., Grauwet, T., Van Loey, A., Hendrickx, M., 2021. Thermal treatment of common beans (Phaseolus vulgaris L.): factors determining cooking time and its consequences for sensory and nutritional quality. Compr. Rev. Food Sci. Food Saf.
Winham, D.M., Hutchins, A.M., 2011. Perceptions of flatulence from bean consumption among adults in 3 feeding studies. Nutr. J. 10.
Wood, J.A., 2017. Evaluation of cooking time in pulses: a review. Cereal Chem. 94, 32–48.
Xu, B.J., Chang, S., 2008. Total phenolic content and antioxidant properties of eclipse black beans (Phaseolus vulgaris L.) as affected by processing methods. J. Food Sci. 73, H19–H27.
Yadav, U., Singh, N., Kaur, A., Thakur, S., 2018. Physico-chemical, hydration, cooking, textural and pasting properties of different adzuki bean (Vigna angularis) accessions. J. Food Sci. Technol. 55, 802–810.
Zamindar, N., Baghekhandan, M.S., Nasirpour, A., Sheikhzeinoddin, M., 2013. Effect of line, soaking and cooking time on water absorption, texture and splitting of red kidney beans. J. Food Sci. Technol. 50, 108–114.