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Chemical and nutritional changes associated with the development of the hard-to-cook defect in common beans

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Abstract
Four common bean (*Phaseolus vulgaris* L.) varieties, *Kawanda* (K)131, K132, NABE4 and NABE11, were evaluated for the relationship between development of the hard-to-cook (HTC) defect and changes in nutritional quality during 6-month storage under ambient conditions. All varieties developed the HTC defect, but the extent was found to vary with variety. Cooking time increased by 113% in K131, 95.3% in K132, 56.4% in NABE4 and 42.93% in NABE11 after 6 months. The development of the HTC defect was found to be associated with a reduction in phytic acid content ($r^2 = -0.802$), *in vitro* protein digestibility ($r^2 = -0.872$) and *in vitro* starch digestibility ($r^2 = -0.729$). The susceptibility to the HTC defect during storage could be attributed to a phytic acid interaction with proteins and carbohydrates, and is also associated with small seed size. Breeding for large seed size could therefore help reduce the development of the HTC defect.

Keywords: *Common beans, hard-to-cook defect, phytic acid,* in vitro *protein and starch digestibility, cooking time*

Introduction

Phaseolus beans or common beans (*Phaseolus vulgaris* L.) are the world's most important food legume (Pachico 1993). It is one of the most important crops in the agricultural sector and household economy of Uganda (Opio et al. 2001). Beans are among the three most important sources of proteins and calories in Eastern and Southern Africa (Pachico 1993). The poor also value beans because most parts of the plants can be consumed (David et al. 2000). However, beans stored at conditions of high temperature ($\geq 25^{\circ}$C) and relative humidity ($\geq 65\%$) develop the hard-to-cook (HTC) defect. The long cooking time and consequently high-energy requirements for dry bean preparation is detrimental to nutritional quality, and leads to reduced acceptability and marketability of beans (Aguilera and Stanley 1985). This study was conducted to determine the susceptibility of varieties commonly grown in Uganda to

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the development of the HTC defect and the effect of this defect on nutritional quality of the beans.

Materials and methods

Beans

Common bean samples were obtained within 2 weeks of the April 2005 harvest from farmer groups in the Lira and Kabale districts of Uganda. These districts are among the leading producers of beans and also represent the northern and southern parts of Uganda, respectively. The varieties used included: *Kawanda* (K)131, an indeterminate bush Calima type variety (Type II), characterized by small beige seeds; K132, a determinate bush Carioca seed type (Type 1), characterized by dark-red mottled, large seeds; and NABE4 and NABE11 bush varieties with large seeds. Beans were cleaned to remove extraneous matter, and then packaged in gunny bags. The beans were stored under ambient conditions (23–27°C and 63–74% RH) for 6 months.

Physico-chemical analysis

Triplicate samples were drawn from the different varieties once every month, ground in a Willey laboratory mill (Model 4; Arthur H. Thomas Co. Philadelphia, PA, USA) with a 40-μm mesh sieve and analysed for proximate composition by the official methods of the Association of Analytical Chemists (AOAC 1999). Moisture content, crude fibre (nutro-detergent fibre [NDF]) and protein content were determined by the oven method, acid hydrolysis and the Kjeldahl method, respectively. *In vitro* protein digestibility was determined using methods described by the AOAC (1999), and involved the determination of crude protein content before and after 2 h digestion with pepsin (1:3,000 IU Hog pepsin/l, pH 2.0), while *in vitro* starch digestion was carried out by the method of Dahlin and Lorenz (1993); reducing sugars were determined in the filtrate after digestion with salivary amylase diluted with an equal volume of water and pancreatic amylase from 1% solution of porcine pancreatic amylase (Grade II) in 0.1 M citrate phosphate buffer (pH 6.8). The phytic acid content was determined using the spectrophotometric method at 640 nm (AOAC 1999). The cooking time of the beans was determined using the Mattson Bar Drop Method (Jackson and Variano-Mattson 1981).

Statistical analysis

Measurements presented are averages of triplicate determinations for separate varieties. Differences between varieties and changes during storage were determined using one-way analysis of variance with the Fisher's least-significant difference at a 5% probability level. Correlation was also carried out to determine the relationships between the factors.

Results and discussion

The bean samples collected had a moisture content ranging between 13.3% and 15.6% (Figure 1). This was the moisture content before commencement of the storage study (month 0). There was a significant reduction in the moisture content of

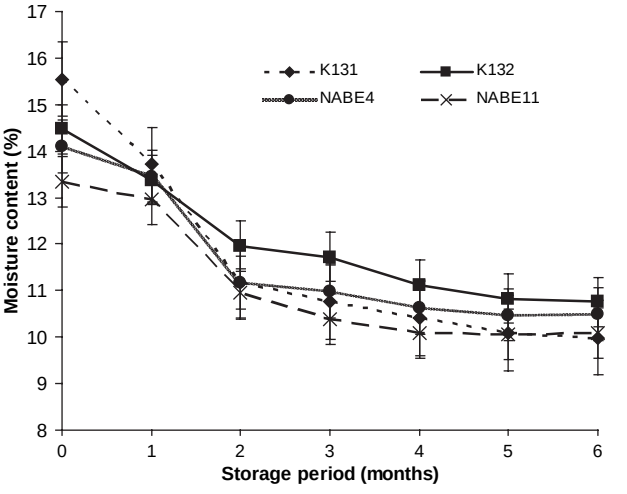

Figure 1. Changes in the moisture content of common bean varieties during storage at ambient conditions.

the beans with the storage period for all varieties. The highest reduction over the 6-month storage period occurred in K131 (35.56%) and the lowest in NABE11 (24.4%). The reduction in moisture content suggested a loss of moisture during storage. The final moisture content is important in determining the changes in other attributes of the beans. Beans with a moisture content above 13% significantly deteriorate in texture and flavour within 6 months (Reyes-Moreno and Paredes-Lòpez 1993).

The cooking time for the different bean varieties after 6 months of storage ranged between 84 and 126 min. The cooking time was in the order K131 >K132 > NABE4 >NABE11. Storage under ambient conditions significantly increased the cooking time of the beans. The highest increase was observed in K131 (113%) and the lowest in NABE 11 (42.93%) over the 6-month storage period (Figure 2).

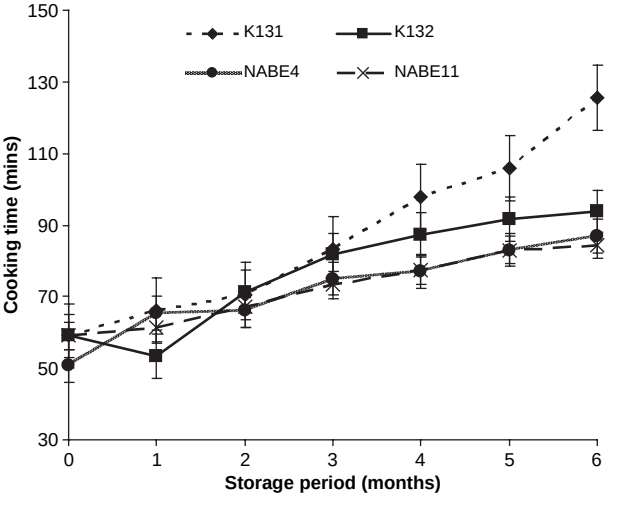

Figure 2. Changes in the cooking time of common bean varieties during storage at ambient conditions.

The results for the change in cooking time with the storage period suggest that all the bean varieties studied developed the HTC defect. The HTC defect in common beans has been attributed to many factors, including: activation of phytases, phytate degradation during storage (as observed in Figure 3), release of cations (Ca^{2+} and Mg^{2+}) and eventual cross-linking with pectin by formation of Ca^{2+} and Mg^{2+} pectinates, which render the cells resistant to water absorption, and the subsequent failure of adjacent cells to separate upon cooking (Bressani 1993; Kilmer et al. 1994). The small size of K131 probably leads to high water loss during storage and this leads to a greater extent of the HTC defect due to the higher surface area to volume ratio than in bigger seeds (K132, NABE4 and NABE11). Stanley et al. (1989) reported that the amount of water absorbed by common beans following storage was related to the seed volume and hilium area. Small seeds take in more water due to the low cultivar seed volume and hilium area.

The different bean varieties had phytic acid contents ranging from 2.44% to 2.65% at month 0, and the levels reduced to 1.98–2.2% after storage for 6 months (Figure 3). The phytic acid content of bean varieties was not significantly different before storage.

An inverse relationship was observed between changes in cooking time and the phytic acid content of common beans (Figure 4). This suggests the contribution of phytic acid to the hardening process in beans during storage. Reduction in phytic acid levels has been related to the reduction in cookability and the development of the HTC phenomena in legumes (Bhatty 1990). The varieties with a slower reduction in phytic acid (K131 and K132) were observed to exhibit a greater increase in cooking time. A strong negative correlation ($r^2 = -0.802$) was observed between the phytic acid content and the cooking time of the beans, confirming that reduction in phytic acid content affects the cookability of beans.

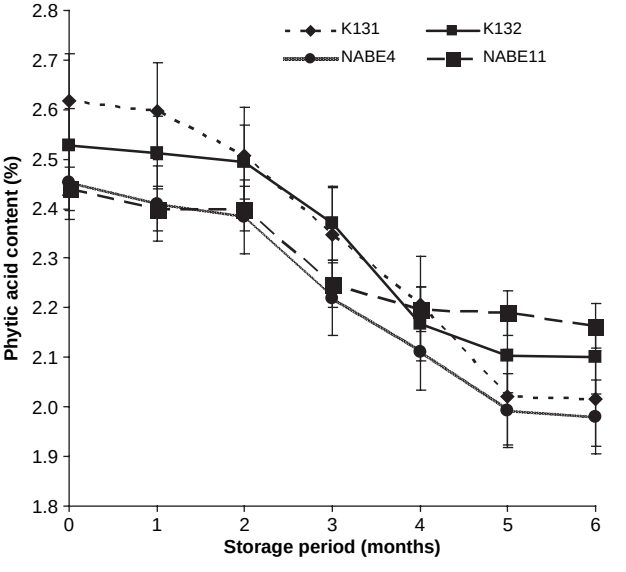

Figure 3. Changes in the phytic acid content of common bean varieties during storage at ambient conditions.

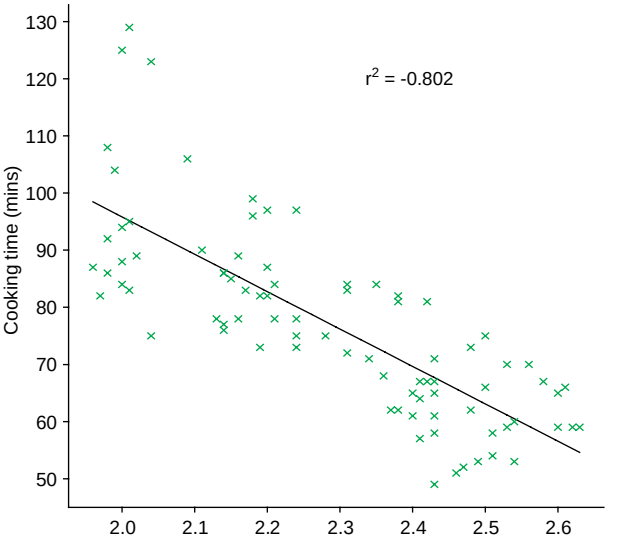

Figure 4. Fitted and observed relationship between the cooking time and phytic acid content of common beans.

The crude protein content of the different bean varieties was between 19.8% and 23.2%. The highest was 23.2% observed in NABE4, followed by K131 (21.5%), and K132 (20.5%), and the lowest was 19.8% in NABE11. The crude protein content was significantly different among the four varieties. The storage period did not have any significant effect on crude protein content.

The NDF content of the bean varieties was in the range 16.4–18.6%, with K131 having the highest and NABE4, which exhibited the lowest cooking times, having the lowest NDF levels (Figure 5). The storage period had no significant effect on the content of NDF. Therefore, an increase in cooking time does not seem to be related to changes in the NDF content of beans during storage.

In vitro *protein and starch digestibility*

Legumes have lower protein digestibility than proteins of animal origin. This is attributed to the presence of antinutritional factors such as trypsin inhibitors, polyphenols and phytic acid (Jood et al. 1998). *In vitro* protein digestibility of the raw bean varieties was found to be in the range 25–29%. These results were within the range (25–60%) reported by Reyes-Moreno and Paredes-Lòpez (1993) for common beans.

In vitro protein digestibility decreased with storage for all varieties. The highest reduction occurred in K131 (24.4%), the variety that exhibited the greatest increase in cooking time. The lowest decrease in protein digestibility was in NABE11 (9.4%), the variety that also exhibited the lowest increase in cooking time (Figure 6). According to Nielson (1991), protein digestibility in common beans is inhibited by changes in the structure of the proteins and complexing of the protein with starch, hemicelluloses, minerals and other proteins, which occurs during storage. This implies that the factors that control protein digestibility are similar to those that cause an increase in cooking time. According to Khatoon and Prakash (2004), a reduction in protein digestibility

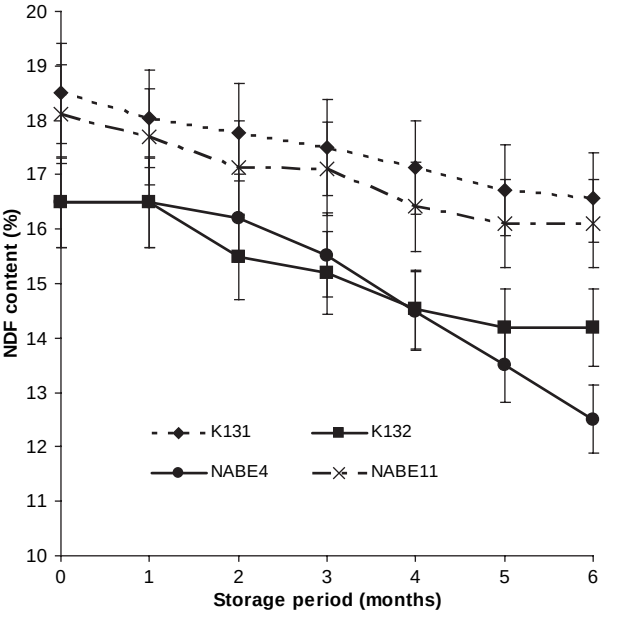

Figure 5. Variation in the nutro-detergent fibre of common bean varieties with storage at ambient conditions.

could also be related to the possible build-up of disulphide bonds between sulphur-containing amino acids, which are highly resistant to hydrolytic action of the digestive enzymes used and could cause protein–protein folding, thus hindering action of enzymes.

In vitro starch digestibility of the different bean varieties was between 58.3% and 64.2% at month 0. There was a significant difference in the starch digestibility of the

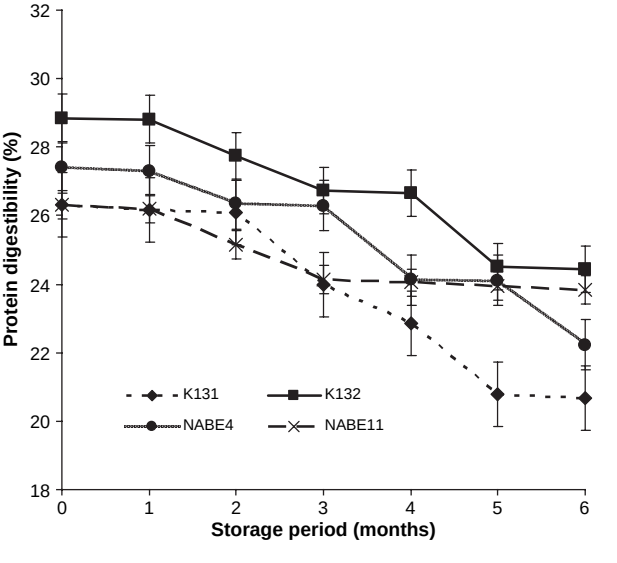

Figure 6. Changes in the protein digestibility of common bean varieties with storage at ambient conditions.

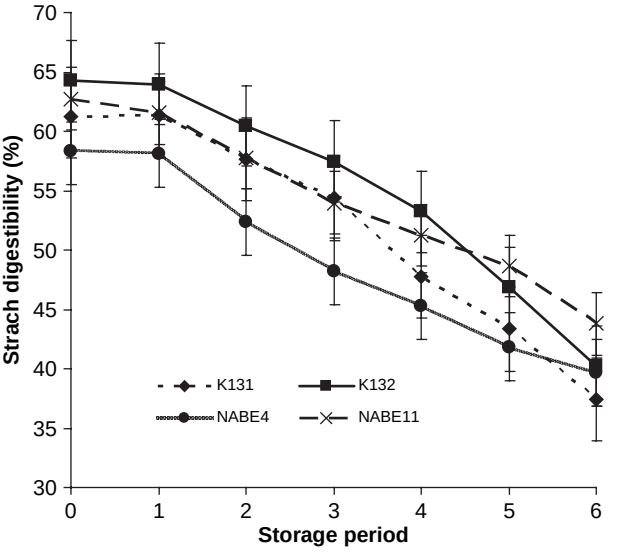

Figure 7. Changes in the starch digestibility of common bean varieties with storage at ambient conditions.

different varieties. The highest and lowest starch digestibilities were those for K132 and NABE4 varieties, respectively (Figure 7). These values dropped to between 37.3% and 43.8% after 6 months storage under ambient conditions.

The highest reduction in starch digestibility was observed in K131 (38.94%) and the lowest in NABE4 (28.6%), suggesting samples that are more prone to the HTC defect experience a higher decrease in starch digestibility. This low starch digestibility may be the result of the high amount of dietary fibre found in beans, and also of the presence of amylase inhibitors in the raw beans (Bressani 1989). Water penetration into the cell is essential for gelatinization of starch. If the cell is not well hydrated, starch will not gelatinize, resulting in low digestibility. Beans that experienced the highest increase in cooking time (K131 and K132) seemed to experience a higher reduction in starch digestibility. This is in agreement with Reyes-Moreno and Paredes-Lòpez (1993) that the HTC defect is associated with a reduction in starch digestibility.

Conclusion

The HTC defect was observed among common bean varieties grown in Uganda even during storage at ambient storage conditions. The results of this study indicate that development of the HTC defect is associated with a decrease in protein and starch digestibility; thus leading to loss of nutritional value. This suggests that susceptibility to the HTC defect during storage could be attributed to phytic acid interaction with proteins and carbohydrates. The small seeded variety K131 was affected by hardening more than large seeded varieties, probably due to faster loss of water in K131 due to the high surface area to volume ratio of the seeds. To address the problem of the HTC defect in beans, it may be necessary to breed or select large-seeded beans that do not easily develop the defect.

Acknowledgement

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