THE HARD TO COOK DEFECT IN COMMON BEANS: UNDERSTANDING THE EFFECT OF STORAGE CONDITIONS ON PHYSICAL, COOKING AND NUTRITIONAL PROPERTIES

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Abstract
Common beans are highly nutritious and widely consumed in Kenya. Storage of common beans under adverse conditions of high temperature (≥25°C) and high humidity (≥ 65%) renders them susceptible to the hard-to-cook (HTC) defect. This results in increased cooking time, fuel and water use. This has a negative effect on acceptability and utilization of beans. The objective of this study was to determine effects of storage temperature and relative humidity on development of the HTC defect in common beans and subsequent physical and nutritional quality changes. Rose coco and Red kidney bean varieties were obtained from Kenya Agricultural Research Institute (KARI) - Thika. The beans were subjected to combination of varying temperature (35˚ C and 45˚ C) and relative humidity (75% and85% RH). Beans from each treatment condition were sampled at an interval of zero, two, four and six months followed by analysis of physical, cooking and nutritional properties. There was a significant increase in conductivity and leached solutes. Significant decrease was observed in hydration and swelling coefficients of beans under each storage condition. Characteristic dimensions and one hundred seed weight were not significantly different among the various storage conditions. Based on the results of this study, it was concluded that adverse storage conditions of temperature (35˚ C and 45˚ C) and relative humidity (75% and85% RH) cause development of the HTC defect which in turn affects physical properties and cooking quality of common beans.

Key words: HTC defect, storage conditions, physical properties, cooking quality

1.0 Introduction

Common beans refer to food legumes of the genus Phaseolus, family Leguminosae, subfamily Papilio-noidae, tribe Phaseoleae, subtribe Phaseolinae. Beans are found from sea level up to 3000m above sea level and are cultivated either in monoculture, associations or in rotations (Broughton *et al.*, 2003). Grain legumes, especially common bean, are a staple food for people in many parts of the world (Galiotou-Panayotou *et al.*, 2008). They supply a significant amount of protein for a great part of the world population, especially in poor countries where the consumption of animal protein is relatively low (Batista *et.al*, 2010). Furthermore, their high content of p protein, carbohydrates, fibres, some minerals and vitamins make beans a superior nutrient source. Beans are generally stored at ambient temperature for varying periods of time before use for domestic consumption. The storage varies from several months up to even one year or more (Kaur and Singh 2007). Storage of beans at high temperatures may result in cumulative increases in cooking time, loss of cooking quality and reduced water uptake during cooking (Yusuf and Deeth, 2003). Further, such conditions render beans susceptible to a hardening phenomenon, also known as the hard-to-cook (HTC) defect. Beans with this defect are characterized by extended cooking times for cotyledon softening, are less acceptable to the consumer due to loss of flavour and colour, and are of lower nutritive value (Reyes Moreno, 1993). Additionally, beans with this defect undergo significant post production losses. Water absorption, soluble solids and electrolyte leaching are vital quality factors associated with the bean hardness defect (Berrios et. al., 1999). Therefore they are good indicators of the loss in bean quality during storage as are loss of colour and increase in hydration and swelling coefficients. The HTC defect can be attributed to multiple mechanisms, such as lipid oxidation, insoluble pectates formation and middle lamella lignifications (Liu, 1995). However, most researchers agree that the defect occurs at the cotyledons (Mauer, 2004).

2.0 Materials and Methods

2.1 Beans and Storage conditions

The bean varieties used were GLP 24- Red Kidney and GLP 2 -Rose Coco. These were subjected to the different storage temperature of 25⁰C, 35⁰C and 45⁰C and relative humidity of 75% and 85 %. These conditions were achieved by using storage incubators pre-conditioned to the desired temperature. The respective relative humidity was achieved using concentrated potassium chloride salt solutions. Sampling was carried out at 0, 2, 4 and 6 months.

2.2 Physical Properties

2.2.1 Characteristic Dimension of Seeds

This was carried out using a vernier calliper where length and width of each variety was assessed using a representative sample of five seeds from each variety.

2.2.2 One Hundred Seed WeIght

The weight of a hundred seeds was recorded in triplicate for each of the two bean varieties. Weight measurement was in grams.

2.2.3 True Seed Density

True seed density was calculated by recording the weight of twenty seeds in triplicate for each bean variety. The weight of a 100 ml volumetric flask was then recorded and also its weight with water filled up to the mark. Each of the twenty seeds was then placed into the volumetric flask and water added up to the mark and this weight recorded. The mass of the displaced water was the balance reading with the submerged seeds minus the mass of the volumetric flask and water.

The seed volume (V) was estimated by dividing the mass of the displaced water (g) by the density of water (g/cm^3) Seed density was calculated from the values obtained for weight (g) of twenty seeds and volume (g/ml). Seed density = weight of seeds in grams/ Volume of Water.

2.2.4 Bulk Seed Density

Bulk density (BD) was determined using the method of Wang and Kinsella (1976). Seed material of common bean was placed in a 250 ml graduated cylinder and packed by gentle tapping of the cylinder on a bench top ten times from a height of 5–8 cm. The final volume of the test material will be recorded and expressed as g/ml. (Narayana and Narasinga, 1984)

BD= weight of seeds/ Volume of bulk seed.

2.2.5 Seed Porosity

This is the property of the grain which depends on its bulk and true densities. It was calculated as: P= 1- Pb/Pt × 100

Where Pb is bulk density (g/cm3) and Pt is seed density (g/cm3)

2.2.6 Hydration Coefficient

Twenty seeds of each variety were weighed in triplicate and stored at 25^oC in deionized water for 16 hours. A ratio of 1: 5 (bean weight to water ratio) was used to assess how much deionized water would be used for soaking the seeds. These beans were then cut in half along the fissure. The testa and cotyledon were then separated. The free water was removed using a blotting paper. These were reweighed. Hydration coefficient = Weight of beans after soaking ⁄ weight before soaking × 100

2.2.7 Swelling Coefficient

Twenty seeds of each variety were soaked at 25^oC in deionized water for 16 hours. A ratio of 1:5 (bean weight to water ratio) was used to assess how much deionized water would be used for soaking the seeds. The volume of raw bean seeds before and after soaking in deionized water was determined by water volume displaced in a graduated cylinder and expressed as the swelling coefficient swelling coefficient = Volume of beans after soaking ⁄ volume of beans before soaking × 100.

2.2.8 Electrolytes and Solutes Leaching

Twenty seeds of each variety were soaked at 25^oC in deionized water for 16 hours. The soak water was then collected and leached electrolytes were quantified by assessing conductivity with a digital conductivity meter (S isabata model SC - 179). The solutes leached from beans were evaluated by evaporating the soak water and then drying in a hot air oven at 105^oC, cooling was then done in a desiccator and weighing followed. Results were expressed as mg/g dry weight of beans.

2.2.9 Grain colour

A Colorimeter (Minolta chromameter- CR-200b) was used to take colour measurements. The instrument assesses colour in Hunter ($L^* a^* b^*$) form; Hunter L-values, (whiteness/lightness, Hunter-a value (redness) and Hunter-b value (yellowness). The instrument was first calibrated using standard white plate with transparent paper placed over the standard plate. After calibration, colour measurements were taken at random in triplicates.

2.3 Cooking Properties

The cooking profile for beans subjected to storage hardening was obtained by cooking at 96.5^o C in a water bath (water bath shaker sha-c). Cooking was determined by subjective method which included pressing the bean seeds with fingers. Cooking occurred when the bean cotyledon disintegrated.

2.4 Statistical Analysis Differences between varieties and various treatments was determined using two way analysis of variance. The least significant difference (LSD) at 5% probability level was used for mean separation.

3.0 Results and Discussion

3.1 Effect of Storage Conditions on Physical Properties

Physical property differences that occurred in both bean varieties across the six month storage period were substantial and these confirmed the development of the HTC defect. Outstanding differences were observed in colour changes, electrical conductivity, leached solutes, hydration and swelling coefficients. The colour readings were determined in terms of Hunter -L values (whiteness), Hunter- values (redness) and Hunter-b values (yellowness) and this are tabulated in Table 1. Hunter- L values for both varieties decreased indicating darkening which is associated with hardening of the bean. Hunter- a values increased indicating an increase in redness. These was in agreement with the findings of Uebersax and Bedford(1980) who observed that Hunter L values decreased with increased relative humidity, storage time and temperature. Similarly, Hellevang and Henson (2000) found that Hunter-a and b values increased with increased relative humidity, temperature and storage time. These dramatic differences showed decrease in colour quality which is a hallmark for bean hardening. Hydration and swelling coefficients reflect the capacity to imbibe water in a reasonable amount of time (Abbas, 2008).For both bean varieties, hydration and swelling coefficients decreased as is indicated in Table 1. After 12 hours soaking at 25^{o}C, the hydration coefficients were lower in samples stored under accelerated storage conditions of temperature and humidity compared to those stored at ambient temperature and humidity conditions. Similarly the swelling coefficient reduced as it mainly depends on the amount of water absorbed. Electrical conductivity and amount of leached solutes increased with increased storage temperature and humidity across both bean varieties. After 12 hours soaking the loss of solids and electrolytes from beans at accelerated storage conditions was high as compared to that at ambient conditions and this was an indication of the hard to cook defect. Evidently, a link between hydration and swelling coefficients can be drawn from this. The reduced hydration coefficient was partially due to solutes leached from the cotyledons during water imbibitions and this was greater in beans stored for 6months which were harder. Jones and Boulter (1983) state that leached solids may affect hydration rate of beans in two ways. The leached solids in the soaking water increase the concentration of the solution which in turn affects water absorption rate. Additionally, solute leakage may reduce water affinity and water holding capacity as is stipulated by osmotic principles.

3.2 Effect of Storage Conditions on Cooking Properties

The cooking profile for 45^{o}C /75% RH indicated in Figure 1 shows an increase in cooking time across the six month storage period in both bean varieties. Similarly the cooking profile for 35^{o}C/85%RH in figure 2 shows an increase in cooking time at each storage period in comparison to cooking time at the start of the experiment. Beans at the start of the experiment demonstrated shorter cooking times than beans stored at accelerated storage conditions. This consequently indicated that storage conditions of the beans have a vital role in the hardening process of beans stored for long periods of time (Berrios *et al.*, 1999). Similar results were reported by Henteges *et al.* (1991), Morris (1963) and Muneta (1964)

3.3 Effect of Storage Conditions on Moisture uptake during Cooking

Figure 3 shows the moisture uptake curve for 45^{o}C /75% RH and figure 4 shows that of 35^{o}C/85%RH. The fresh beans at 0month showed faster moisture uptake as compared to subsequent moisture uptake across the 2, 4 and 6 months storage times. In both storage conditions, Rose coco bean had higher moisture uptake rates as compared to the Red kidney bean. At 0month, the uptake differs only slightly but the differences become dramatic with increase in storage time. Burr *et al.* (1968), Jackson and Varriano-Marston (1981) also reported faster initial water absorption rate for fresh beans when compared to the initial water absorption rate for HTC beans. Generally, the faster initial water/moisture uptake and shorter cooking time exhibited by the beans at 0month compared to the beans in the subsequent months may be due to microstructural differences of the stored bean (Berrios *et.al.*, 1999).

Table 1: Physical property changes for 45^oC / 75% RH

		Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney
Storage conditions	Storage time in months	100 seed weight (g)		Length (mm)		Width (mm)		Hydration coefficient %		Swelling coefficient %	
45/75	0	48.9 ± 0.6	31.3± 0.4	15.4 ± 0.1	13.7 ± 0.5	7.7 ± 0.5	6.8 ± 0.7	211.3 ± 0.99	205.6 ± 0.7	267.8 ± 13.5	266.7 ± 14.4
	2	49.0 ± 1.6	31.7 ± 1.4	15.3 ± 0.5	14.0 ± 1.1	7.6 ± 0.2	7.2 ± 0.4	203.7 ± 2.7	201.9 ± 6.1	259.4 ± 4.4	242.4 ± 16.5
	4	47.9 ± 0.4	30.5 ± 0.7	15.5 ± 0.5	12.4 ± 0.2	7.4 ± 0.3	7.03 ± 0.8	196.6 ± 1.1	190.2 ± 0.4	252.2 ± 12.9	225.0 ± 7.1
	6	47.1 ± 1.3	30.8 ± 0.8	14.8 ± 0.4	13.3 ± 0.2	7.3 ± 0.3	6.8 ± 0.6	191.7 ± 1.4	184.9 ± 3.2	203.7 ± 12.8	224.4 ± 13.5
		Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney
Storage conditions	Storage time in months	Bulk seed density (g/cm3)		Seed porosity %		True seed density (g/cm3)		Conductivity (mmh/cm)		Leached solute s%	
45/75	0	1.0 ± 0.0	1.0 ± 0.0	16.4 ± 0.8	17.4 ± 0.6	1.23 ± 0.0	1.3± 0.0	1.8 ± 0.1	2.7 ± 0.4	0.03 ± 0.0	0.04 ± 0.0
	2	1.0± 0.0	1.1 ± 0.0	19.1 ± 0.8	18.3 ± 1.8	1.3 ± 0.0	1.3 ± 0.0	2.6 ± 0.4	4.1 ± 0.5	0.1 ± 0.0	0.1 ± 0.0
	4	1.0 ± 0.0	1.1± 0.0	17.2 ± 1.0	15.2 ± 0.5	1.2 ± 0.0	1.3 ± 0.0	3.4 ± 0.2	5.1 ± 0.4	0.1 ± 0.0	0.1 ± 0.0
	6	1.0 ± 0.0	1.1 ± 0.0	17.1 ± 1.8	15.9 ± 1.6	1.2 ± 0.0	1.3 ± 0.0	5.5 ± 0.8	7.5 ± 0.7	0.1 ± 0.0	0.1 ± 0.1
		Rose coco			Red kidney						
		Colour			Colour						
		L	a	b	L	a	b				
Storage conditions	Storage time in months										
45/75	0	46.9 ± 2.4	11.8 ± 0.5	4.6 ± 1.1	43.8 ± 0.6	4.9 ± 0.6	1.8 ± 0.3				
	2	45.9 ± 2.4	9.1 ± 0.3	3.9 ± 0.4	41.4 ± 1.7	3.9 ± 0.3	0.3 ± 0.2				
	4	40.4 ± 2.7	11.2 ± 1.3	3.8 ± 2.5	41.8 ± 3.7	5.8 ± 0.5	0.8 ± 0.7				
	6	27.9 ± 5.4	15.7 ± 1.0	12.3 ± 0.5	23.9 ±1.3	13.3 ± 2.2	4.2 ± 1.6				

Values = Mean ± SD. Each value is a mean of 3 replicates. S.D (standard deviation)

Table 2: Physical property changes for 35^oC / 85% RH

		Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney
Storage conditions	Storage time in months	100 seed weight (g)		Length (mm)		Width (mm)		Hydration coefficient %		Swelling coefficient %	
35/85	0	48.9 ± 0.6	31.3± 0.4	15.4 ± 0.1	13.7 ± 0.5	7.7 ± 0.5	6.8 ± 0.7	211.3 ± 0.99	205.6 ± 0.7	267.8 ± 13.5	266.7 ± 14.4
	2	49.8 ± 0.1	31.2 ± 0.9	15.1 ± 0.3	13.7 ± 0.9	7.6 ± 0.5	6.9 ± 0.5	211.8 ± 0.8	195.8 ± 0.9	256.7 ± 0.6	246.7 ± 5.8
	4	47.6 ± 0.6	31.2 ± 0.7	15.2 ± 0.1	14.1 ± 0.5	7.5 ± 0.2	7.5 ±0.6	197.0 ±1.7	191. ± 7.2	234.4 ± 4.4	222.5 ± 3.5
	6	45.4 ± 1.2	30.4 ± 0.9	15.4 ± 0.3	13.9 ± 0.4	8.4 ± 0.4	7.0 ± 0.4	189.4 ± 0.2	188.3 ± 1.03	229.9 ± 10.8	219 ± 1.4
Storage conditions	Storage time in months	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney	Rose coco	Red kidney
35/85		Bulk seed density (g/cm3)		Seed porosity %		True seed density (g/cm3)		Conductivity (mmh/cm)		Leached solutes %	
	0	1.0 ± 0.0	1.0 ± 0.0	16.4 ± 0.8	17.4 ± 0.6	1.2 ± 0.0	1.3 ± 0.0	1.8 ± 0.1	2.7 ± 0.4	0.03 ± 0.0	0.04 ± 0.0
	2	1.0 ± 0.0	1.0 ± 0.0	17.2 ± 0.9	17.6 ± 0.3	1.2 ± 0.0	1.2 ±0.0	2.9 ± 0.3	5.3 ± 0.2	0.1 ± 0.0	0.1 ± 0.0
	4	1.0 ± 0.0	1.0 ± 0.0	17.3 ± 0.7	17.2 ± 1.8	1.2 ± 0.0	1.3 ± 0.0	4.2 ± 0.3	5.6 ± 0.5	0.1 ± 0.0	0.1 ± 0.0
	6	1.0 ± 0.0	1.0 ± 0.0	15.1 ± 0.5	17.4 ± 0.6	1.2 ± 0.0	1.4 ± 0.1	4.1 ± 0.5	6.8 ± 0.8	0.1 ± 0.0	0.1 ± 0.0
		Rose coco			Red kidney						
		Colour			Colour						
		L	a	b	L	a	b				
Storage conditions	Storage time in months										
35/85	0	46.9 ± 2.4	11.8 ± 0.5	4.6 ± 1.1	43.8 ± 0.6	4.9 ± 0.6	1.2 ± 0.3				
	2	48.2 ± 4.6	10.4 ± 2.4	4.2 ± 1.7	44.1 ± 0.4	4.7 ± 0.7	1.2 ± 0.1				
	4	43.1 ± 2.7	10.7 ± 0.8	3.6 ± 0.6	40.2 ± 2.6	5.3 ± 1.4	1.1 ± 0.5				
	6	37.4 ± 1.9	17.0 ± 2.4	13.4 ± 2.9	23.4 ± 3.8	8.3 ± 0.7	1.2 ± 0.3				

Values = Mean ± SD. Each value is a mean of 3 replicates. S.D (standard deviation)

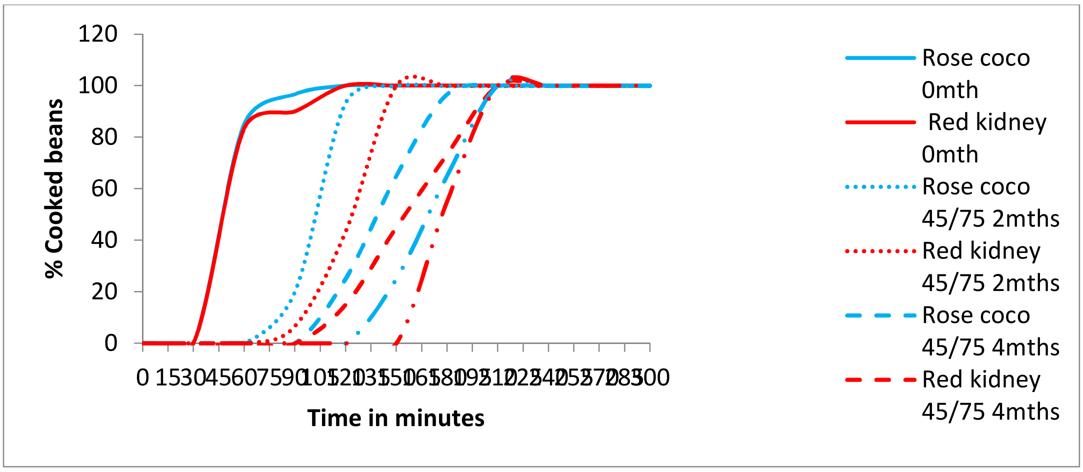

Figure 1: Cooking profile for 45°C / 75% RH

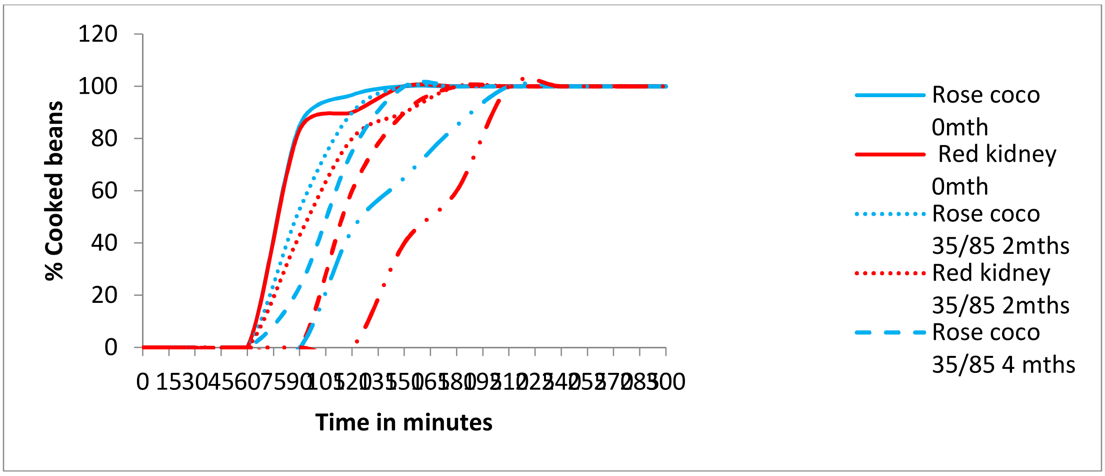

Figure 2: Cooking profile for 35°C / 85% RH

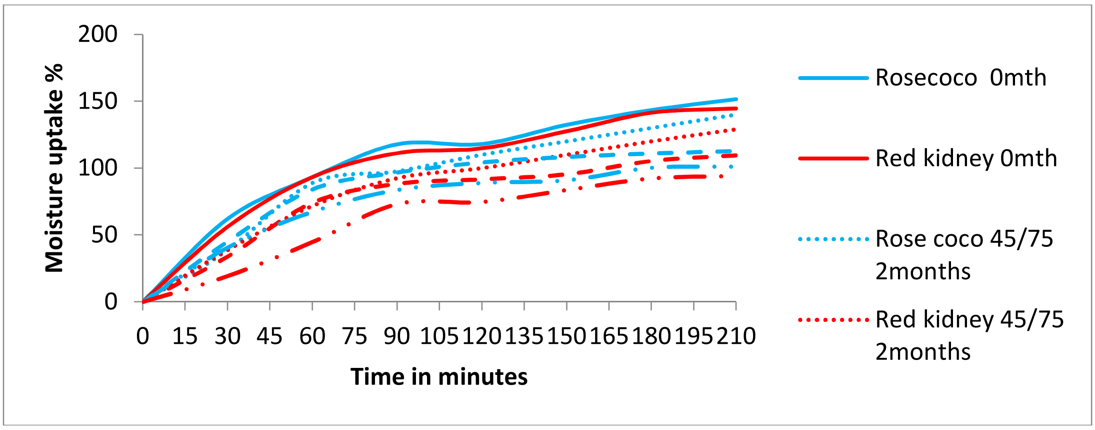

Figure 3: Moisture uptake curve for 45°C / 75% RH

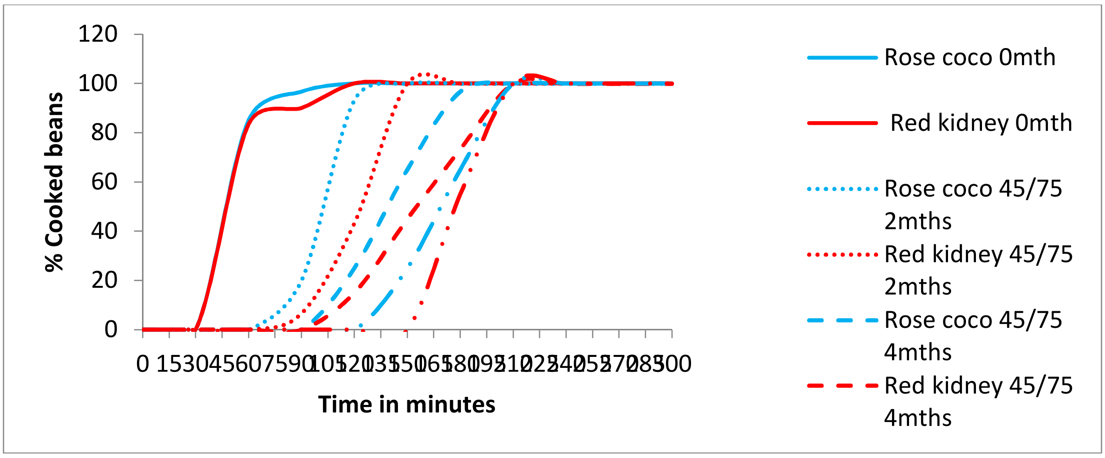

Figure 4: Moisture uptake curve for 35°C / 85% RH

4. 0 Conclusion

From the research carried out it was evident that the accelerated storage conditions of 45°C /75% RH and 35°C / 85% RH cause the development of the hard to cook defect in common beans. In this particular study the HTC defect developed in the Rose coco bean which is classified as an easy to cook bean. In similar fashion the defect was observed in the Red kidney bean which is classified as initially easy to cook but subsequently develops the defect to a high degree in comparison to Rose coco. The conclusion that there was HTC defect development was supported by the results from physical characteristics, cooking profiles and moisture uptake during cooking. The physical characteristics under study were; 100 seed weight, length, width, bulk density, true density, seed porosity, leached solutes, conductivity, colour, swelling coefficients and hydration coefficients. Substantial changes in colour, leached solutes, conductivity, hydration and swelling coefficients confirmed the HTC defect. Cooking profiles showed increased cooking time for both bean varieties across the six month storage period and especially so in the Red kidney bean. Moisture uptake capacity reduced in both varieties across the storage period with the greatest reduction observed in the Red kidney bean. Common beans should thus be stored at ambient conditions of cool temperatures and low relative humidity so as to maintain both physical and cooking qualities. A better knowledge of physical, physicochemical, functional, chemical and structural differences between different bean varieties with high and low proneness to develop the hard to cook phenomenon might be useful in breeding and genetic programs to improve bean grain quality and also generate materials less prone to the hardening.

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