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QUANTIFYING THE EFFECTS OF POSTHARVEST STORAGE AND SOAKING PRETREATMENTS ON THE COOKING QUALITY OF COMMON BEANS (*PHASEOLUS VULGARIS*)

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ABSTRACT

Cooking quality of common beans greatly influences acceptability. The objective of this study was to quantify the effect of bean type, storage time, temperature and relative humidity (RH) on the cooking time of four bean types grown in Kenya. Beans were stored under different temperature (25, 35 and 45C) and RH (75 and 83%). After sampling, they were pre-soaked or not and cooked to generate cooking curves which were subjected to nonlinear regression. Significance of the different variables was evaluated using mixed model regression. Higher storage temperatures (35 and 45C), higher RH (83%) and extended time significantly increased lag phase and cooking time. Soaking pretreatments reduced cooking time. Canadian wonder and Pinto beans took long thus hard-to-cook while Rose coco and Red haricot took short cooking time, thus, easy-to-cook. This work demonstrated the critical nature of bean type, storage and pretreatment conditions in influencing bean cooking quality.

PRACTICAL APPLICATIONS

The hard-to-cook (HTC) problem in common beans is one of the main problems leading to low consumption of beans. This manuscript provides information on the easy to cook and HTC bean varieties grown in Kenya. The roles of storage temperature and relative humidity on predisposing beans to the HTC problem is discussed including the optimal storage conditions. Finally, the effect of pretreatment conditions and cooking on overall cooking time is highlighted. Soaking in distilled water and Na_2CO_3 significantly reduced the cooking time of the beans. It is hoped that this information can be translated to practical guidelines for bean breeders, stockists, processors and consumers.

INTRODUCTION

Common beans (*Phaseolus vulgaris*), also referred to as dry beans or edible beans, and represents a nutritious food providing essential nutrients such as proteins, iron, calcium, vitamins, carbohydrate and fiber. They constitute an essential part of the diet for over 700 million people in the world (Leterme and Munoz 2002). Their consumption in Eastern and Southern Africa exceeds 50 kg/person/year (Wortman *et al.* 1998). Common bean genetic breeding programs have produced cultivars with high bean yields, tolerance to pests and diseases, different sizes, colors, shapes and sheen. In addition, beans have different cooking characteristics in terms of cooking time, palatability and broth characteristics (Perina *et al.* 2014). Previous studies have shown that the per capita consumption of beans in many places has gone down mainly due to the reduced time available to prepare meals especially with the rapid urbanization (Arruda *et al.* 2012). Therefore, bean cooking quality and especially the cooking time is an essential attribute for both bean breeders and consumers (Leterme and Munoz 2002).

There are many factors that affect the cooking quality of beans such as storage time, moisture content, packaging used, temperature and relative humidity (Arruada *et al.* 2012). Storage of beans has been shown to cause changes in their taste, broth characteristics, color and cooking time, therefore, lowering their commercial value (Sawazaki *et al.* 1985, Arruda *et al.* 2012). This deterioration in cookability (ability to soften with cooking) during storage is caused by the hardening of the cotyledons, a condition described as the hard-to-cook (HTC) phenomenon (Nasar-Abbas *et al.* 2008). Several hypotheses to explain the development of the HTC defect have been proposed. Galiotou-Panayotou *et al.* (2007) developed the middle lamella–cation–phytate–phytase theory which suggests that pectates in the middle lamella are rendered insoluble upon cooking by replacement of their monovalent ions by calcium and magnesium ions. When the phytase hydrolyzes the phytate, divalent cations are released and diffuse to the middle lamella to combine with the pectates. Hincks and Stanley (1987) and Srisuma *et al.* (1989) on the other hand suggested that lignification occurs through the cross-linking of phenolics to cell wall proteins promoting hardening both as a result of increased mechanical strength from the lignin as well as a result from the prevention of water imbibition and swelling. A multiple mechanism of bean hardening which included phytate loss as a minor contributor during initial storage and phenol metabolism as a major contributor during extended storage has also been proposed (Hincks and Stanley 1986). However, the complex mechanisms have not been clearly elucidated (Liu *et al.* 1992; Njoroge *et al.* 2014).

Attempts to increase the utilization of legumes in general have employed a wide range of processing techniques such as soaking, boiling, autoclaving, radiation, cooking, roasting, dehulling, germination, fermentation, supplementation with various chemicals and enzymes and extrusion cooking (Van der Poel 1990; Gujska and Khan 1991; Bishnoi and Khetarpaul 1994; Fernandez *et al.* 1997; Alonso *et al.* 1998, 2000). Soaking and cooking of beans are two separate processes that may or may not be performed simultaneously (Taiwo *et al.* 1997). Soaking in distilled water, however, is not very effective and therefore many attempts have been made to fasten the cooking by the use of soaking solutions such as sodium bicarbonate (Abu-Ghannam and McKenna 1997).

Although the influence of different factors on bean cooking behavior has been described qualitatively, the specific objective of this study was to quantify the influence of storage time, storage temperature and storage relative humidity (RH) as well as soaking pretreatments on the cooking time of four bean "types" grown in Kenya, whereby bean type is defined as a bean variety grown at a certain place and time. The holistic approach used to quantify the effect of aforementioned parameters in bean cooking quality is what sets this work apart.

TABLE 1. SAMPLING PLAN OF THE STORED BEANS (* INDICATES THE SAMPLING TIME AT A GIVEN STORAGE CONDITION AND TIME)

Condition		Storage time in months						
RH (%)	Temperature (C)	0	2	4	6	8	10	12
75	25	*		*		*		*
	35	*		*		*		*
	45	*	*	*	*			
83	35	*	*	*	*			

MATERIALS AND METHODS

Storage of Common Beans

Four bean (*Phaseolus vulgaris* L.) varieties (Rose coco, Canadian wonder, Pinto and Red haricot) grown in the same place and harvested in the same season were purchased from Kenya Agricultural Research Institute (KARI), Thika Station. About 12 kg of each bean type was first conditioned for 2 weeks at 25C and 75% RH to equilibrate the moisture content in the beans. After the conditioning process, a reference sample (0 month storage) of 1 kg was taken for each bean type and stored under frozen conditions at −18C. The rest of the beans were divided into four equal lots, packaged in perforated plastic containers to allow for air circulation and stored under different conditions of temperature and relative humidity (Table 1). The samples were stored in thermostated incubation/RH-temperature controlled chambers. To ensure that the required RH was maintained at the desired levels, saturated salt solutions of NaCl and KCl were used for 75 and 83% RH, respectively. The temperature and the RH were continuously monitored using a calibrated thermometer and hygrometer, respectively. Under all storage conditions, sampling was done four times. In case of high temperature and/or high relative humidity storage conditions (45C/75% RH and 35C/83% RH), sampling was within an interval of 2 months up to a maximum storage period of 6 months, while the samples stored at 25C/75% RH and 35C/75% RH were sampled every 4 months within a maximum storage time of 12 months (Table 1). At each sampling time, 2 kg of bean seeds were sampled for each type, of which 1 kg was used for the analysis, while the rest was stored under frozen conditions at −18C for future reference. The moisture content of the beans was determined according to the AOAC method 930.15 (AOAC 2000) after each sampling. It was found to be around 10% and stable throughout the experiment. To prevent mold growth during storage, very high relative humidity values were avoided.

Soaking Pretreatments of Beans

Beans were either not soaked or soaked in different solutions to determine their subsequent cooking behavior. The solutions used for soaking included deionized water and 0.1 N Na_2CO_3. Soaking was done at 25C for 16 h in an incubator. A ratio of 1:5 was used in soaking the beans.

Cooking of Beans

About 100 seeds from each of the stored (un)soaked beans were subjected to standard cooking at 96C in a thermostated water bath (Memmert WBU-45, Germany) for varying time intervals after each sampling. The cooked samples were withdrawn from the water bath and cooled in a cold water bath for 1 min before determining the cooking status (softness/hardness [cookability]) of the beans. This was determined subjectively by pressing the cooked beans between the thumb and forefinger. The beans were classified as cooked when the cotyledons disintegrated on pressing (Vindiola *et al.* 1986; Kinyanjui *et al.* 2015). The finger pressing method was favored over the objective (cutting) test due to its speed and simplicity. The percentage of cooked beans in the batch was determined as a function of time. This was done in duplicate. These data were then used to generate cooking curves. A total of 192 curves were generated. These cooking curves define the cooking quality of the different bean samples.

Data Analysis

Statistical data analysis was performed using a Statistical Analysis System (SAS) statistical software package (SAS Enterprise Guide 4.3, The United States).

Nonlinear Regression. Since the cooking curves appeared sigmoidal in nature, a nonlinear regression with a sigmoidal model was performed for every single cooking curve according to Eq. (1). (SAS Enterprise Guide 4.3, USA)

$$y=\frac{100}{1+\exp^{(b+c*x)}} \quad (1)$$

In this equation y is the predicted value of cooked beans (%), x is the cooking time (min) and b and c are two theoretical parameters that completely describe the cooking curves. From the estimated parameters b and c, parameters with physical meaning were generated. These parameters are, the cooking rate ($-c$), the time required to cook 95% of the beans (which is a measure for the total cooking time) and the time required to cook 5% of the beans (which is a measure for the lag phase).

Mixed Model Regression. For the three different physical parameters considered in this study, a mixed model was applied with fixed factors (storage relative humidity, storage temperature, storage time and soaking pretreatment), to estimate the effects of controllable factors, and a random factor (bean type), to correct for the correlation between samples coming from the same bean type. Significant differences among fixed factors were examined using the *post hoc* Tukey test at a significance level of $P \leq 0.05$ (Palmers *et al.* 2014).

Mixed model regression was used to evaluate the significance of bean type and different storage and soaking pretreatment conditions on the time required to cook 95% of the beans, the time required to cook 5% of the beans and the cooking rate. These physical parameters were derived from the two theoretical parameters obtained from the sigmoidal regression of the cooking curves. The definition of this model, built with one random factor (bean type) and four fixed factors (storage time, storage temperature, storage relative humidity and soaking pretreatments), is represented in the following equation:

$$y = \mu + \beta_t t + \beta_{RH} + \beta_T + \beta_C + \beta_v + \epsilon \quad (2)$$

where, y is 95% cooked beans, 5% cooked beans or cooking rate, μ is the intercept, β_t is the estimate of storage time, t is the storage time in months, β_{RH} is the estimate of relative humidity, β_T is the estimate of temperature, β_c is the estimate of soaking pretreatment, β_v is the estimate of bean type and ε is the estimate of error. Storage time was the only continuous (numerical) variable while the rest were considered discrete (categorical) variables. This equation was applicable when all the bean types were considered. When the influence of storage and soaking pretreatment on the physical parameters was investigated for each bean type separately, the equation was:

$$y = \mu + \beta_t t + \beta_{RH} + \beta_T + \beta_C + \epsilon \quad (3)$$

RESULTS AND DISCUSSION

General Observations

Examples of the cooking profiles generated during the cooking process of different bean types stored at different temperature and relative humidity conditions are shown in Fig. 1. For all the bean types, the time taken for the beans to be fully cooked increased with increasing storage time showing that all the bean types developed to a certain extent the HTC defect upon storage. For example (Fig. 1) in Canadian wonder the cooking time increased from 120 to 420 min at the end of six month storage at 45C/75% RH. Pre-treatments reduced the cooking time. For instance, soaking Canadian

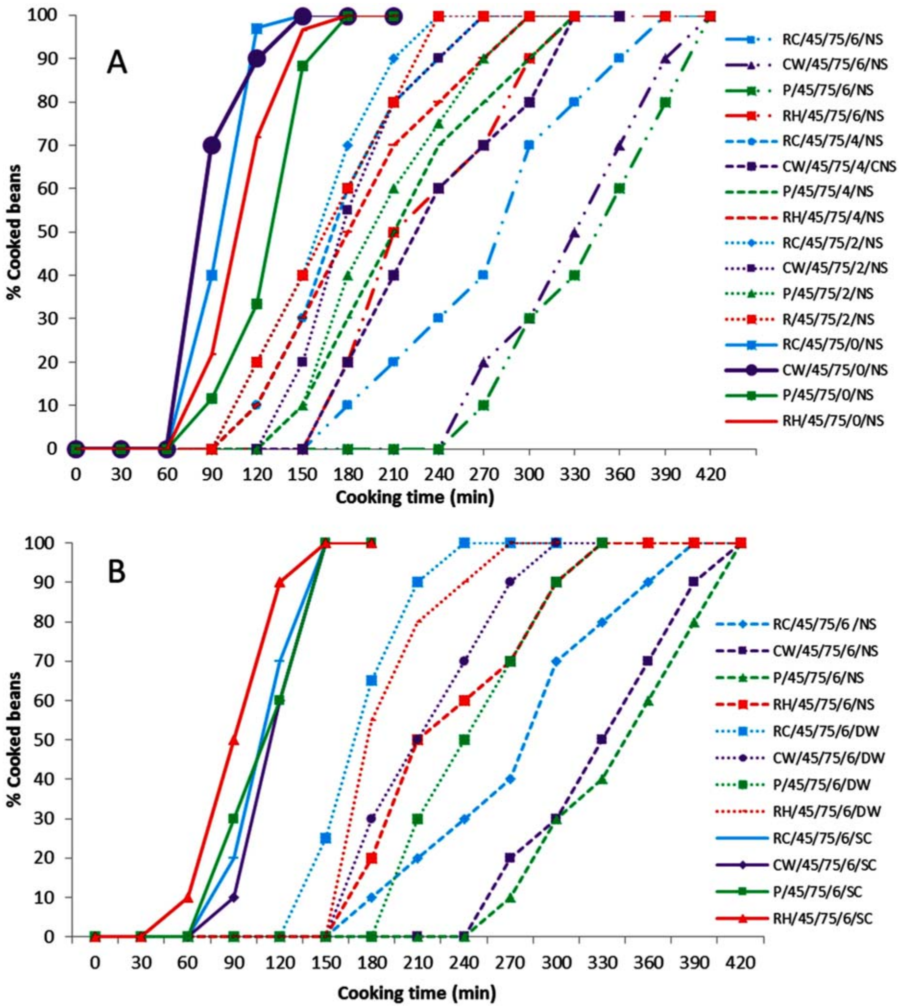

FIG. 1. THE COOKING CURVES OF FOUR DIFFERENT BEAN TYPES STORED AT 45C AND 75% RELATIVE HUMIDITY COOKED WITHOUT PRIOR SOAKING. (**A**) EFFECT OF STORAGE TIME AT 45C AND 75%; (**B**) EFFECT OF SOAKING SOLUTIONS. (RC, ROSE COCO; CW, CANADIAN WONDER; RH, RED HARICOT; P, PINTO; NS, NONSOAKED; DW, SOAKED IN DISTILLED WATER; SC, SOAKED IN SODIUM CARBONATE)

wonder beans stored for 6 months at 45C/75% RH in deionized water reduced the cooking time from 420 to 330 min (∼30% reduction in cooking time) as compared with 50% reduction in cooking time (120–60 min) at the beginning of the storage experiment. For the same Canadian wonder stored for 6 months, soaking in Na_2CO_3 reduced the cooking time from 420 to 150 min (∼64% reduction in cooking time) as compared with 80% reduction in cooking time (120–30 min) at the beginning of the storage experiment. The effects of soaking in Na_2CO_3 on the cooking time are higher than the effects of soaking in distilled water (Fig. 1).

Statistical data analysis was then used to quantify the effects of the different variables on the cooking time of the beans.

Cooking Behavior of Beans

All bean types cooked following a sigmoidal model characterized by a lag, exponential and plateau phase. The lag phase indicates the initial time before any substantial softening occurs (<5% softening), the exponential phase marks the actual softening phase while the plateau phase indicates the fully cooked state of the beans (≥95% cooked). In Fig. 2, out of the 192 cooking curves, four curves were selected and are shown as an example. Specifically, the sigmoidal regression of cooking curves for Rose coco beans stored at 45C and 75% RH for 0, 2, 4 and 6 months and soaked in distilled water before subsequent cooking at 96C is presented. From these curves it can be observed that a sigmoidal function adequately predicts the experimental data. In general, for all the 192 samples, the correlation between the predicted and experimental values for the % cooked beans was high ($R^2 = 0.99$) (Fig. 3).

Modeling the Influence of Bean Type, Storage Condition and Soaking Pretreatment on Cooking Quality of Beans

Influence of Variables on the Lag Phase of Beans. The statistical output of the selected mixed model to obtain insight into the effect of bean type, storage and

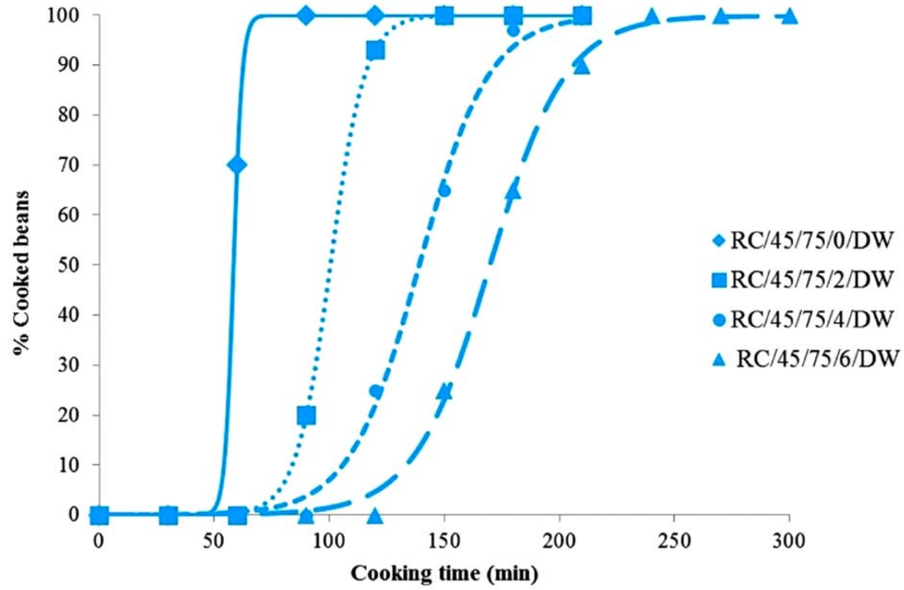

FIG. 2. SIGMOIDAL REGRESSION OF COOKING CURVES FOR ROSE COCO BEANS STORED AT 45C AND 75% RH FOR 0, 2, 4 AND 6 MONTHS AND SOAKED IN DISTILLED WATER BEFORE SUBSEQUENT COOKING AT 96C. THE MODELED COOKING CURVES ARE PRESENTED BY LINES. THE EXPERIMENTAL VALUES ARE INDICATED BY SYMBOLS. (RC, ROSE COCO; DW, SOAKED IN DISTILLED WATER

soaking pretreatments on the time required to cook 5% of the beans is shown in Table 2. All the tested variables had a significant influence on the lag phase of the cooking curves of all the bean types. An increase in storage time, RH and temperature led to an extension of the lag phase of the beans cooking curves. Soaking in distilled water and Na_2CO_3 reduced the lag phase of the cooking curves. Soaking in Na_2CO_3 had the largest effect on the lag phase reducing it by more than one hour (76 min). Storage for long time significantly extended the lag phase, e.g., storage for 12 months extended the lag phase by 74 min when compared with the fresh beans (Fig. 2). The effect of temperature on the lag phase was higher than the effect of RH in the range of temperatures and RH used in this study.

Considering the estimates for the random effect, origin, a classification among the bean types according to the lag phase of the cooking curves can be made. Canadian wonder

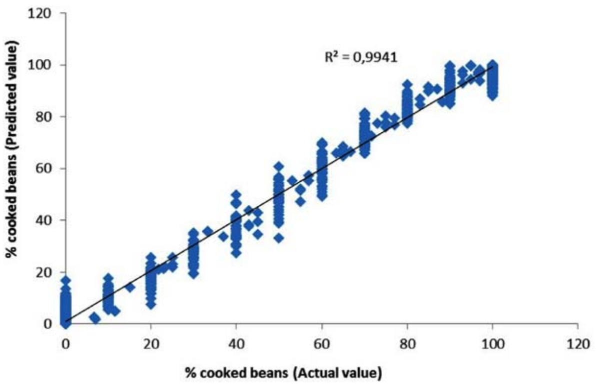

FIG. 3. CORRELATIONS BETWEEN THE PREDICTED AND EXPERIMENTAL VALUES OF % COOKED BEANS

and Pinto beans used in this study had a longer lag phase thus were HTC while Rose coco and Red haricot beans had a shorter lag phase thus were ETC. To demonstrate the effect of bean type on the lag phase, the cooking curves of the beans stored for 6 months at 45C and 75% RH are shown in Fig. 4. It can be observed that the lag time is bean type specific.

The influence of storage and soaking pretreatment conditions on the lag phase was also investigated for each bean type separately (Table 3). The effect of RH (75 and 83%) and temperature (35 and 45C) on the lag phase were not significant anymore for Canadian wonder and Rose coco beans. This showed that there were considerable differences between the individual bean types in the effect of RH and temperature on the lag phase of the cooking curves. In particular, the effect of RH was found to be significant for Pinto and Red haricot and not significant for Canadian wonder and Rose coco. Soaking in Na_2CO_3 still had the largest effect on the lag phase of the cooking curves when considering each bean type separately and the effect was largest on the lag phase of Pinto beans. Finally, the magnitude of the influence of storage time on the lag phase was also dependent on the bean type.

Influence of Variables on the Total Cooking Time of Beans. The statistical output of the model used to obtain insight into the effect of bean type and storage and soaking pretreatment conditions on the time required to cook 95% (total cooking time) of the beans is shown in Table 4. All the investigated parameters significantly ($P \leq 0.05$) influenced the total cooking time of beans. An increase in storage time, RH, and temperature led to a longer cooking time of the beans. This is similar to the results

TABLE 2. THE INFLUENCE OF THE FIXED AND RANDOM EFFECTS ON THE TIME REQUIRED TO COOK 5% OF THE BEANS WHEN ALL BEAN VARIETIES WERE CONSIDERED

	Effect	RH (%)	Temp. (C)	S-pre.	Estimate	Standard error	*t* value	Pr > |t|
Fixed effects	Intercept				44.7591	7.7073	5.81	0.0102
	S-time				6.1482	0.5004	12.29	<0.0001
	RH	75			−16.2316	5.2515	−3.09	0.0023
	RH	83			0			
	Temp.		25		−24.2289	5.2581	−4.61	<0.0001
	Temp.		35		−22.4967	5.2515	−4.28	<0.0001
	Temp.		45		0			
	S-pre.			NS	76.1069	4.3481	17.5	<0.0001
	S-pre.			DW	31.0966	4.3642	7.13	<0.0001
	S-pre.			SC	0			
Random effect	Type	Canadian wonder			6.1342			
	Type	Pinto			4.4634			
	Type	Rose coco			−0.8774			
	Type	Red haricot			−9.7202			

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

obtained for the lag phase of the cooking curves. Soaking in Na_2CO_3 had a significantly large influence on the total cooking time as shown in Fig. 5 which presents the cooking curves of Canadian wonder (stored for 6 months at 45C and 75% RH), cooked unsoaked, soaked in distilled water and soaked in Na_2CO_3. Increased storage time was also shown to increase the total cooking time, e.g., after storage for 12 months at 25C and 75% RH, the beans required 199 min more to cook when compared with the fresh beans. Similar to the effect on the lag phase, the effect of storage temperature was higher than the effect of RH on the total cooking time within the temperatures and relative humidity ranges studied in this work. Finally, from the estimates of the random effect, bean type, it was observed that Canadian wonder and Pinto required more cooking time while Rose coco and Red haricot required less cooking time. Canadian wonder and Pinto beans are, thus, HTC while the Rose coco and Red haricot beans are easy-to-cook (ETC). This is in agreement with the earlier findings in which the Rose coco and Red haricot beans were classified as ETC and Canadian wonder and Pinto were classified as HTC (Kinyanjui *et al.* 2015). However, it should be clear from the previous observations that the development of the HTC defect in beans is not only dependent on bean type but also on the storage and pretreatment conditions before cooking.

The effect of the storage and soaking pretreatment conditions on the cooking time of the beans was also investigated for each bean type separately as shown by the statistical

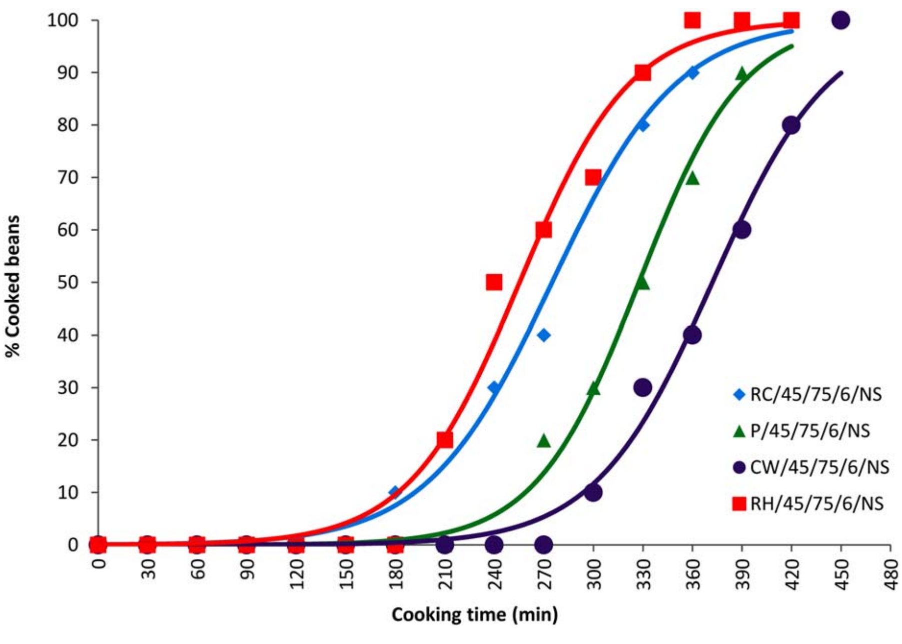

FIG. 4. SIGMOIDAL REGRESSION OF COOKING CURVES OF ALL THE BEAN ORIGINS STORED AT 45C AND 75% RH FOR 6 MONTHS AND COOKED WITHOUT SOAKING. THE MODELED COOKING CURVES ARE PRESENTED BY LINES. THE EXPERIMENTAL VALUES ARE INDICATED BY SYMBOLS. (RC, ROSECOCO; CW, CANADIAN WONDER; P, PINTO; RH, RED HARICOT; NS, NONSOAKED

TABLE 3. THE INFLUENCE OF THE FIXED EFFECTS ON THE REQUIRED TIME TO COOK 5% OF THE BEANS FOR THE INDIVIDUAL BEAN TYPES

				Rose coco		Canadian wonder		Pinto		Red haricot	
Effect	RH	Temp	S-pre.	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|
Intercept				32.342	0.0028	43.142	0.003	59.696	0.0009	44.221	<0.0001
S-time				5.537	<0.0001	7.891	<0.0001	6.665	<0.0001	4.462	<0.0001
RH	75			−3.146	0.6971	−10.523	0.3353	−30.671	0.024	−20.771	0.0141
RH	85			0		0		0		0	
Temp		25		−22.669	0.0073	−43.763	0.0002	−17.034	0.2004	−13.344	0.107
Temp		35		−10.341	0.2048	−21.684	0.0512	−37.613	0.0064	−20.536	0.0151
Temp		45		0		0		0		0	
S-pre.			NS	69.134	<0.0001	75.514	<0.0001	93.626	<0.0001	65.933	<0.0001
S-pre.			DW	31.322	<0.0001	35.800	0.0003	27.708	0.0145	29.556	<0.0001
S-pre.			SC	0		0		0		0	

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

output in Table 5. Some of the investigated parameters were not significant anymore after the separation of the bean type's analysis. An increase in RH (in the range investigated in this study) did not result in a significant increase in the total cooking time of the individual bean types. This contrasts with the effect of storage RH on the lag phase as RH was shown to significantly influence the lag phase of Pinto and Red haricot. The difference in cooking time of beans stored at 35 and 45C was not significant anymore for Canadian wonder and Rose coco. These results clearly indicate that the effect of storage and soaking pretreatment is bean type dependent.

Influence of Variables on the Cooking Rate of Beans. The statistical output showing the significance of bean type, storage and soaking pretreatments on the cooking rates of the beans is shown in Table 6. All the tested parameters had a significant influence ($P \leq 0.05$) on the cooking rate of the beans. An increase in storage time, RH and temperature resulted in a decrease in cooking rate while soaking in distilled water, and in Na_2CO_3, increased the cooking rate (Fig. 5). A high cooking rate is related to a high uniformity in softening of the beans while a low cooking rate points at a high heterogeneity in softening of the beans. Storage time and soaking pretreatments had the largest influence on the cooking rate of beans. The effect of the random variable (bean type) was very small probably since all the beans change to a certain extent from ETC to HTC during storage therefore displaying a larger heterogeneity in softening. Canadian wonder and Rose coco beans had a slightly higher cooking rate while Pinto and Red haricot beans had a slightly lower cooking rate. This shows that the rate of hardening and subsequent softening during cooking was more homogeneous for the Canadian wonder and Rose coco bean types.

The influence of the storage and soaking pretreatment conditions on cooking rate of individual bean types is

TABLE 4. THE INFLUENCE OF FIXED AND RANDOM EFFECTS ON THE TIME REQUIRED TO COOK 95% OF THE BEANS WHEN ALL BEAN TYPES WERE CONSIDERED

	Effect	RH (%)	Temp. (C)	S-pre.	Estimate	Standard error	*t* value	Pr > |t|
Fixed effects	Intercept				88.39	13.044	6.78	0.0066
	S-time				16.55	0.8506	19.46	<0.0001
	RH	75			−24.92	8.8801	−2.81	0.0056
	RH	83			0			
	Temp.		25		−51.79	8.8801	−5.83	<0.0001
	Temp.		35		−43.53	8.8801	−4.9	<0.0001
	Temp.		45		0			
	S-pre.			NS	148.73	7.3661	20.19	<0.0001
	S-pre.			DW	50.59	7.3661	6.87	<0.0001
	S-pre.			SC	0			
Random effect	Type	Canadian wonder			10.70			
	Type	Pinto			8.84			
	Type	Rose coco			−4.82			
	Type	Red haricot			−14.72			

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

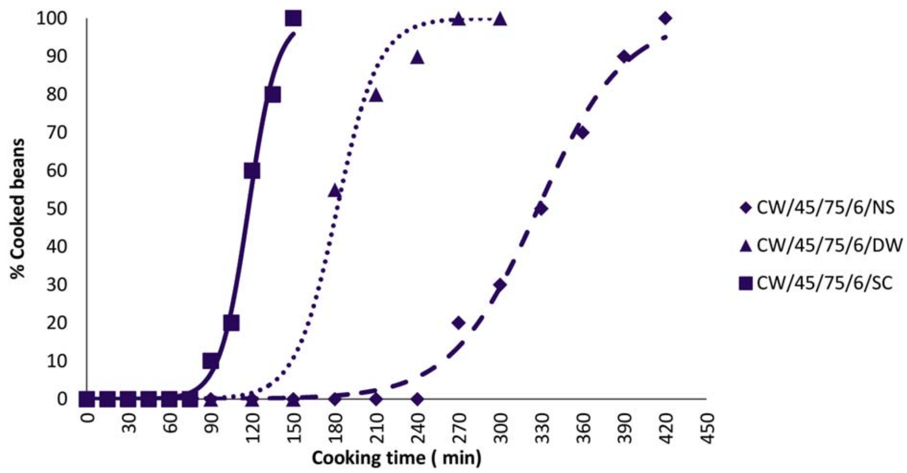

FIG. 5. SIGMOIDAL REGRESSION FOR COOKING CURVES OF CANADIAN WONDER BEAN TYPE STORED AT 45C AND 75% RH FOR 6 MONTHS AND SOAKED IN DISTILLED WATER/NA_2CO_3 AND COOKED WITHOUT SOAKING. THE MODELED COOKING CURVES ARE PRESENTED BY LINES. THE EXPERIMENTAL VALUES ARE INDICATED BY SYMBOLS. (CW, CANADIAN WONDER; NS, NO SOAKING; DW, SOAKED IN DISTILLED WATER; SC, SOAKED IN SODIUM CARBONATE)

TABLE 5. THE INFLUENCE OF THE FIXED EFFECTS ON THE TIME REQUIRED TO COOK 95% OF THE BEANS FOR THE INDIVIDUAL BEAN TYPES

				Rose coco		Canadian wonder		Pinto		Red haricot	
Effect	RH	Temp	S-pre.	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|
Intercept				82.25	0.0009	84.32	0.0012	101.14	0.0001	85.85	<0.0001
S-time				17.01	<0.0001	19.61	<0.0001	16.49	<0.0001	13.09	<0.0001
RH	75			−32.66	0.0785	−34.79	0.0751	−16.17	0.3949	−16.04	0.2685
RH	85			0		0		0		0	
Temp		25		−48.72	0.0102	−43.46	0.0278	−65.33	0.0012	−49.64	0.0012
Temp		35		−29.08	0.1158	−27.71	0.1534	−64.74	0.0013	−52.55	0.0007
Temp		45		0		0		0		0	
S-pre.			NS	146.91	<0.0001	146.19	<0.0001	161.32	<0.0001	140.50	<0.0001
S-pre.			DW	40.59	0.0099	55.07	0.0012	54.96	0.0011	51.74	<0.0001
S-pre.			SC	0		0				0	

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

TABLE 6. THE INFLUENCE OF THE FIXED AND RANDOM EFFECTS ON THE COOKING RATE OF THE BEANS WHEN ALL BEAN TYPES WERE CONSIDERED

	Effect	RH (%)	Temp. (C)	S-pre	Estimate	standard error	*t* value	Pr > |t|
Fixed effects	Intercept				0.3479	0.06665	5.22	0.0137
	S-time				−0.04498	0.00504	−8.93	<0.0001
	RH	75			0.1173	0.0526	2.23	0.027
	RH	83			0	.	.	.
	Temp.		25		0.1317	0.0526	2.5	0.0132
	Temp.		35		0.1254	0.0526	2.38	0.0182
	Temp.		45		0	.	.	.
	S-pre.			NS	−0.2735	0.04364	−6.27	<0.0001
	S-pre.			DW	−0.1737	0.04364	−3.98	<0.0001
Random effect	S-pre.			SC	0	.	.	.
	Type	Canadian wonder			0.01592			
	Type	Pinto			−0.01797			
	Type	Rose coco			0.03441			
	Type	Red haricot			−0.03236			

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

TABLE 7. THE INFLUENCE OF THE FIXED EFFECTS ON THE COOKING RATE OF THE BEANS FOR THE INDIVIDUAL BEAN TYPES

				Rose coco		Canadian wonder		Pinto		Red haricot	
Effect	RH	Temp	S-pre.	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|	Estimate	Pr > |t|
Intercept				0.227	0.0068	0.382	0.0161	0.386	0.0157	0.395	0.013
S-time				−0.035	<0.0001	−0.041	0.0008	−0.050	<0.0001	−0.052	<0.0001
RH	75			0.101	0.1154	0.116	0.3392	0.1252	0.3069	0.127	0.2986
RH	85			0	.	0	.	0	.	0	.
Temp		25		0.100	0.1185	0.109	0.3686	0.156	0.2027	0.161	0.1888
Temp		35		0.090	0.1569	0.109	0.3678	0.147	0.2304	0.154	0.2073
Temp		45		0	.	0	.	0	.	0	.
S-pre.			NS	−0.155	0.0048	−0.299	0.0046	−0.316	0.003	−0.324	0.0024
S-pre.			DW	−0.031	0.5491	−0.288	0.0062	−0.196	0.0581	−0.179	0.0793
S-pre.			SC	0	.	0	.	0	.	0	.

S-time, storage time; S-pre, soaking pretreatment; RH, relative humidity; NS, nonsoaked; DW, soaked in distilled water; SC, soaked in sodium carbonate.

shown in Table 7. Only storage time and soaking in Na_2CO_3 had a significant effect on the cooking rates of the individual bean types. Within the range used, storage temperature and RH had no significant influence on the cooking rates of the individual bean types. Soaking beans in Na_2CO_3 or using beans stored for limited time periods can result in quick cooking beans. The considerably lower response of Rose coco beans to Na_2CO_3soaking confirms that the cooking rate of the beans is bean type dependent.

CONCLUSIONS

Storage of beans at higher temperatures (35 and 45C), higher RH (83%) and for longer time periods was shown to significantly increase the cooking time of the beans. In general, the influence of storage time was larger than the influence of storage temperature, while RH had the least impact in the ranges tested in this study. Soaking in both Na_2CO_3 and distilled water (pretreatments) were shown to very significantly reduce the lag phase and the total cooking time thus can be applied to reverse the HTC defect that develops upon storage. In addition, soaking in Na_2CO_3 increased the cooking rate thereby increasing the uniformity in the softening of the bean samples. The obtained results demonstrated the critical nature of pretreatments, storage temperature and relative humidity in influencing the cooking quality of beans.

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