

Comparative study of beans from vine and bush type of vegetative growth. Effect of storage on cell wall components as factors in increasing cooking time

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SUMMARY. Four samples each of black beans representing two types of vegetative growth were collected from farmers' fields in four locations in Guatemala. Soon after collection, samples were stored at 4° and 38°C at ambient relative humidity and subsamples were withdrawn at 0, 45, 90 and 135 days of storage for determination of water absorption, cooking time and analysis of neutral- and acid detergent fiber, cellulose, hemicellulose and lignin. The fiber fraction analysis were done on samples of 0,45 and 90 days of storage. Water absorption for all 4 samples of the bush type was similar at both storage T, however the samples stored at 38°C and at 135 days absorbed more water than when stored at 4°C. The 4 vine types of beans showed different water absorption rates, with two showing patterns similar to those beans of the bush type and two which did absorbed water at a very slow rate. For both types of beans stored at 4°C, cooking time decreased from 0 to 135 days of storage. On the other hand for all bean samples of the two types cooking time increased when stored at 38°C. Analysis of variance showed highly significant effects due to plant type, days of storage, temperature and locality, and for some interactions. Analysis of variance of the fiber fractions showed high significant differences for days of storage for NDF, ADF, cellulose, hemicellulose, and lignin. Plant type gave significant differences for cellulose and hemicellulose. Highly significant differences for hemicellulose were found for the interactions of type x days, type x temperature, locality x type, and type x days x temperature. The rate of synthesis of the 5 fractions were calculated by simple regression analysis. For the bush type of beans some synthesis occurred at 4°C, but it was enhanced when stored at 38°C. For vine type of beans at 4°C relative high rates of synthesis were observed, which were higher at 38°C for NDF, hemicellulose and lignin. Cooking time and fiber fraction contents were subjected to regression analysis. The correlations at 38°C were higher than at 4°C for all fractions for both types of beans, but statistical significance was obtained only for NDF, ADF and cellulose for vine type of beans. These data show therefore that synthesis of cell wall structure fractions, and not only lignin formation, are responsible for the increase in cooking time observed upon storage at high temperature.

Key words: Beans, bush and vine type, storage, cell wall components, harvesting, cooking time.

RESUMEN. Estudio comparativo entre el frijol de crecimiento vegetativo de suelo y de enredo. Efecto de almacenamiento sobre el contenido de los componentes de la pared celular como factor en aumentar el tiempo de cocción. Cuatro muestras de frijol negro de cada uno de dos tipos de frijol de diferente crecimiento vegetativo fueron recolectados de los campos de agricultores en cuatro localidades en Guatemala. Inmediatamente después de la recolección, las muestras fueron almacenadas a 4°C y a 38°C a la humedad relativa ambiental y submuestras fueron tomadas a los 0, 45, 90 y 135 días de almacenamiento para determinaciones de absorción de agua, tiempo de cocción y los análisis de fibra neutro- y ácido detergente, celulosa, hemicelulosa y lignina. El análisis de las fracciones de la fibra se hicieron en las muestras de 0, 45 y 90 días. La absorción de agua de las 4 muestras de frijol arbustivo fue similar para las dos temperaturas de almacenamiento. Sin embargo las muestras almacenadas a 38°C y a los 135 días absorbieron más agua que las muestras almacenadas a 4°C. Las cuatro muestras de frijol de enredo mostraron diferentes tasas de absorción de agua, con dos de ellas mostrando un patrón similar a las muestras de frijol arbustivo y dos que absorbieron el agua lentamente. Para las muestras de los dos tipos de frijol almacenadas a 4°C, el tiempo de cocción disminuyó de 0 a 135 días de almacenamiento. Por el contrario todas las muestras de los dos tipos de frijol almacenadas a 38°C aumentaron en tiempo de cocción de 0 a 135 días. Análisis de varianza mostró efectos altamente significativos debido a tipo de planta, en almacenamiento, temperatura y localidad, y en algunos, interacciones. El análisis de varianza de las fracciones de la fibra mostraron diferencias altamente significativas para días de almacenamiento por NDF, ADF, celulosa, hemicelulosa y lignina. El tipo de planta mostró diferencias significativas para celulosa y hemicelulosa. Diferencias altamente significativas para hemicelulosa fueron encontradas para las interacciones de tipo planta x días, tipo de planta x temperatura, localidad x tipo de planta y tipo de planta x días x temperatura. La tasa de síntesis de las 5 fracciones de la fibra fueron calculadas por medio de regresión lineal. Una tasa baja de síntesis de las fracciones ocurrió a 4°C, que aumentó significativamente a 38°C para el frijol arbustivo. Para el frijol de enredo la síntesis a 4°C fue mayor que para el frijol arbustivo a una misma temperatura y aumentó en los frijoles de enredo almacenados a 38°C en particular para NDF, hemicelulosa y lignina. Asimismo, las fracciones de fibra y el tiempo de cocción fueron analizados por regresión lineal. Las correlaciones a 38°C fueron mayores que a 4°C de almacenamiento para todas las fracciones, pero significancia estadística sólo fue evidente para NDF, ADF y celulosa para el frijol de enredo. Los datos sugieren por consiguiente, que la síntesis de componentes de la estructura de la pared celular son responsables por el aumento en el tiempo de cocción que se observa durante el almacenamiento del frijol a la alta temperatura y no sólo lignina.

Palabras clave: Frijol, de suelo y de enredo, almacenamiento, componente de la pared celular, cosecha, tiempo de cocción.

As indicated in a previous paper, in certain areas of Latin America, farmers produce type IV bean (Vine type) as well as types II and III (bush type). Except for some differences in physical characteristics, such as 100 kernel weight, bean size distribution, seed coat percentage all higher in vine and, solids in cooking broth higher in bush type of beans, no other important differences in chemical composition and nutritive value were found (1). Farmers which produce the vine type claim that this type of bean does not become as hard upon storage as beans from the bush type. Seed hardening is an important post-harvest technology problem with grain legumes, particularly with *Phaseolus vulgaris* (2,3), which increases cooking time and consequently cost of preparation, and which may result in losses in nutritive value (4,5). The hard-to-cook problem has been studied extensively and various mechanisms have been proposed (2,3). Some researchers have attributed the defect to an increase in the adhesive proportions of components in the middle lamella (3). Several studies have suggested a possible role of lignin (6,18,19). However, Roso et al. (21) reported that acid detergent fibers, lignin and cellulose contents of bean cotyledons did not change when subjected to storage at 34°C and 80% RH or 40°C and 80% RH. Similar data was presented by Srisumo et al, 1989 (22). The chemical compounds studied are components of the cell wall which may not be static during bean storage.

In the present study, the claim by farmers that vine type of beans do not harden as fast as bush type was studied by measuring water absorption, cooking time and cell wall components of the two types of beans, when stored under different conditions.

MATERIALS AND METHODS

The bean samples used for the present study were those used previously (1). They represented 4 bean cultivars of type IV (vine type) collected in the following production areas in Guatemala. Chuarrancho, Pachalí, Parramos and Santiago Sacatepéquez. The other 4 bean cultivars representing types II and III (bush type) were collected from farmers in the same localities in the same growing season and year. All were *Phaseolus vulgaris* black seeded. A total of 15 kg of each sample were purchased in the field and placed at 4°C upon arrival to the laboratory.

Sub-samples weighing 200 g were taken for storage studies. A set of samples from each cultivar were stored at 4°C and analyzed at 0, 45, 90 and 130 days for water absorption, cooking time and fiber fractionation. Another set of samples from each cultivar were stored at 30°C with a relative humidity which varied between 55-60%. These were also analyzed as indicated above at 0, 45, 90 and 135 days of storage. Fiber fractionation was not conducted on 135 day stored samples.

For water absorption two groups of 25 seeds each from each samples were weighed and placed into a beaker with 75 ml of water at room temperature. The beans were weighed

again at the end of four hours after drying external water.

Cooking time was carried out using two groups of 100 seeds from each bean sample and placed in 400 ml of water. A total of 10 seeds were withdrawn every 20 minutes and each was pressed between the fingers. Cooking time was taken when 80% of the beans were easily pressed, gave a pasty consistency, and had no granules.

Fiber fractionation. All samples were finely ground. They were analyzed for their moisture content in a vacuum oven. For fiber fractionation a 0.60 g sample was first treated with Thermamyl in a Na phosphate buffer at pH 6.0 (7). After hydrolysis the pH was taken to 7.0 with 1N NaOH and fiber fractionation was conducted by the methodology of Goering and Van Soest (8).

RESULTS AND DISCUSSION

Data on water absorption of the two types of bean samples at 0° and 38°C are shown in Table 1. The behavior for all four bean samples of the bush type was similar at both storage temperatures, however, at 135 days of storage at 38°C the samples absorbed more water than at 4°C. For vine type beans, two samples showed high water absorption at both temperature of storage, while 2 samples gave very low water absorption, which improved to some extent when the samples were stored at 38°C at 90 and 135 days of storage. The water impermeability has been described before and it has been attributed to seed structure cuticularized layer, the hilum and the micropyle (9-12). The hard shell condition has been indicated to be reversible with storage time, which is what can be observed when two samples were stored at 38°C for 90 and 135 days (13). Statistical analysis of the data showed significant effect (F01) for bean type, days of storage and for the interactions of bean type x temperature, days of storage x temperature, locality and type x locality (Table 2).

The effect of storage on cooking time up to 135 days, at 4.0° and 38°C are shown in Table 3. The dry matter content of all samples varied from 86.7 to 90%. It is of interest to point out the decrease in cooking time when beans of all types were stored at 4°C up to 135 days. This observation confirms the findings of Hentges et al. (13) recently published. On the other hand, all bean samples, whether of the bush or vine type showed an increase in cooking time, which was more evident at 135 days of storage at a T of 38°C with a relative humidity of 55-60%. At this time of storage, the vine type of beans were hard-to-cook than the bush type, however, it is not of importance since cooking times for both was quite high. The data was subjected to analysis of variance and the results are summarized in Table 2. Cooking time was significantly affected by plant type, days of storage, temperature, locality and the interactions between type of plant x days of storage, type of plant and temperature of storage, days x temperature of storage, type x locality and type x days x temperature. Some of these effects were expected, and confirm results of other

workers. Based on studies with 3 bean cultivars, Quenzer et al. (14) reported that growing site influenced cooking time more than cultivar. Similar results were published by Proctor and Watts (15) with 3 cultivars grown in different locations. Paredes-López et al. (16) found that cooking time of 2 bean cultivars grown in 2 locations differing in soil Ca and Mg content, were higher for the beans grown in Ca rich soils.

TABLE 1
Percentage of water absorption

Storage time days	Chuarrancho	Pachalí	Santiago Sacatepequez	Parramos	Ave± S.D
Bush type					
4.0°C					
0	65.0	70.0	66.0	42.0	61.0±10.9
45	77.5	76.0	80.0	67.0	75±4.9
90	89.0	72.0	70.0	79.0	77±7.4
135	87.5	71.0	70.5	78.5	77±6.9
38°C					
0	65.0	70.0	66.0	42.0	61±10.9
45	46.0	38.0	42.5	21.5	37±6.2
90	90.0	81.5	81.0	70.5	81.0±7.9
135	91.0	88.5	91.5	91.5	91.0±1.3
Vine type					
4.0°C					
0	87.5	85	-	-	86.0±1.1
			6.0	4.5	5.0±1.0
45	90.5	92.5	-	-	91.0±1.1
			11.0	7.0	9.0±2.6
90	77.5	81.5	-	-	79.5±2.0
			11.0	1.5	6.2±5.2
135	81.5	95.0	-	-	88.2±6.7
			13.0	4.0	8.5±3.9
38°C					
0	87.5	85.0	-	-	86.2±1.2
			6.0	4.5	5.2±0.2
45	70.0	65.5	-	-	67.5±2.3
			9.0	10.0	9.5±4.5
90	94.5	100.0	-	-	97.2±2.7
			28.5	34.5	31.5±3.0
135	91.0	95.5	-	-	93.2±2.2
			61.0	58.0	59.5±1.5

Fiber fractionation data for bush bean samples at 4°C and 38°C of storage are given in Tables 4 and 5, while Tables 6 and 7 show the same data for vine type of beans stored up to 90 days. As indicated previously, samples at 135 days of storage were not analyzed. The fiber fractions of all bush bean samples stored at 4°C were similar (Table 4), therefore, average values were used for interpretation. NDF, ADF, cellulose and ligning showed an increase from 0 to 45 days and a decrease from 45 days to 90 days.

TABLE 2
Analysis of variance. Results

Source of variation	Water absorpt		Cook time		NDF		ADF		Cellulose		Hemi-cellulose		Lignin	
	F05	F01	F05	F01	F05	F01	F05	F01	F05	F01	F05	F01	F05	F01
Plant type	**		**			*			**		**			
Days storage	**		**		**		**		**		**		**	**
Type x days	*		**	*				*		*		**	**	**
Temperature			**						*		*			
Type x Temp	**		**									**	*	
Days x Temp	**		**											**
Type x Days x Temp			**				**		**		**	**	*	
Locality	**		**	*								**		
Type x Locality	**		**											**
Type x Days x Local														
Temp x Local												*		
Type x Temp x Local												*	*	
Type x Days x Temp x Local														

* Significant 0.05
** Significant 0.01

TABLE 3
Cooking time - minutes

Storage time days	Chuarrancho	Pachalí	Santiago Sacatepequez	Parramos	Ave± S.D
Bush type					
4.0°C					
0	145	125	120	140	132±10.3
45	140	130	110	140	130±12.2
90	110	115	105	110	110±3.5
135	95	95	100	105	99±4.1
38°C					
0	145	125	120	140	132±10.3
45	170	170	160	170	167±4.3
90	170	160	140	160	157±10.9
135	420	410	370	420	405±20.6
Vine type					
4.0°C					
0	115	145	145	150	139±3.8
45	120	130	140	140	132±8.3
90	110	115	115	125	119±6.1
135	107	110	102	110	107±3.5
38°C					
0	115	145	145	150	139±13.8
45	150	170	180	180	170±12.2
90	155	170	170	170	166±6.5
135	480	480	480	480	480±0

TABLE 4
Fiber fractions of bush bean samples stored at
4°C from 0 to 90 days

Storage time & temp.	Fiber fraction %	Parramos	Pachalí	Santiago Sacatepequez	Chuarrancho	Average ± S.D.
0 days	NDF	15.01	16.44	16.46	12.91	15.20±1.45
	ADF	6.02	6.66	7.60	6.45	6.68±0.58
	Hcel	8.99	9.78	8.86	6.46	8.52±1.74
	Cel	5.45	6.12	6.80	6.03	6.10±0.48
	Lignin	0.56	0.54	0.80	0.42	0.58±0.14
45 days	NDF	17.00	18.24	15.25	16.18	16.67±1.10
	ADF	9.51	9.20	9.36	10.51	9.64±0.51
	Hcel	7.49	9.04	5.89	5.67	7.02±1.36
	Cel	7.51	7.14	7.38	8.81	7.71±0.65
	Lignin	1.99	2.07	1.98	1.70	1.93±0.14
90 days	NDF	15.50	16.16	15.28	13.95	15.22±0.80
	ADF	7.28	7.99	7.54	7.34	7.54±0.53
	Hcel	8.22	8.17	7.74	6.61	7.56±0.67
	Cel	6.93	7.68	6.80	6.76	7.04±0.37
	Lignin	0.35	0.31	0.74	0.58	0.49±0.17

Hcel = NDF - ADF
ADF = Cel + Lig.

TABLE 6
Fiber fractions of vine bean samples stored at
4°C from 0 to 90 days

Storage time & temp.	Fiber fraction %	Parramos	Pachalí	Santiago Sacatepequez	Chuarrancho	Average ± S.D.
0 days	NDF	12.11	14.97	13.90	14.50	13.87±1.08
	ADF	6.59	7.02	7.36	6.94	7.04±0.38
	Hcel	5.52	7.95	6.54	7.56	6.89±0.94
	Cel	6.02	6.38	6.52	6.22	6.28±0.20
	Lignin	0.59	0.64	0.84	0.72	0.69±0.10
45 days	NDF	13.12	18.75	15.94	14.73	15.63±2.06
	ADF	8.42	9.20	7.87	8.34	8.46±0.48
	Hcel	4.70	9.55	8.07	6.39	7.18±1.81
	Cel	8.00	8.40	7.40	7.70	7.87±0.37
	Lignin	0.42	0.80	0.47	0.64	0.58±0.15
90 days	NDF	20.58	18.74	18.09	18.46	18.97±0.96
	ADF	8.35	10.11	9.28	9.24	9.24±0.62
	Hcel	12.23	8.63	8.81	9.22	9.72±1.46
	Cel	7.62	8.90	7.78	8.25	8.14±0.50
	Lignin	0.73	1.21	1.50	0.99	1.10±0.28

Hcel = NDF - ADF
ADF = Cel + Lig.

TABLE 5
Fiber fractions of bush bean samples stored
at 38°C from 0 to 90 days

Storage time & temp.	Fiber fraction %	Parramos	Pachalí	Santiago Sacatepequez	Chuarrancho	Average ± S.D.
0 days	NDF	15.01	16.44	16.46	12.91	15.20±1.45
	ADF	6.02	6.66	7.60	6.45	6.68±0.58
	Hcel	8.99	9.78	8.86	6.46	8.52±1.74
	Cel	5.45	6.12	6.80	6.03	6.10±0.48
	Lignin	0.56	0.54	0.80	0.42	0.58±0.14
38°C 45 days	NDF	16.20	20.63	16.50	16.23	17.39±1.87
	ADF	8.14	7.18	6.48	9.90	7.92±1.28
	Hcel	8.06	13.45	10.02	6.33	9.46±2.64
	Cel	7.41	7.04	6.40	7.89	7.18±0.54
	Lignin	0.73	0.14	0.08	2.01	0.74±0.77
38°C 90 days	NDF	19.20	22.64	19.61	19.02	20.12±1.47
	ADF	8.58	10.10	8.90	10.04	9.40±0.67
	Hcel	10.62	12.54	10.71	8.98	10.7±1.26
	Cel	7.68	8.02	8.16	8.65	8.13±0.35
	Lignin	0.90	2.08	0.74	1.39	1.38±0.52

Hcel = NDF - ADF
ADF = Cel + Lig.

TABLE 7
Fiber fractions of vine bean samples stored
at 38°C from 0 to 90 days

Storage time & temp.	Fiber fraction %	Parramos	Pachalí	Santiago Sacatepequez	Chuarrancho	Average ± S.D.
0 days	NDF	12.11	14.97	13.90	14.50	13.87±1.08
	ADF	6.59	7.02	7.36	6.94	7.04±0.38
	Hcel	5.52	7.95	6.54	7.56	6.89±0.94
	Cel	6.02	6.38	6.52	6.22	6.28±0.20
	Lignin	0.57	0.64	0.84	0.72	0.69±0.10
45 days	NDF	17.28	14.12	16.54	14.24	15.54±1.39
	ADF	13.38	11.14	11.98	8.42	11.23±1.81
	Hcel	3.90	2.98	4.56	5.82	4.31±1.03
	Cel	13.06	10.60	11.20	7.55	10.60±1.85
	Lignin	0.32	0.54	0.78	0.87	0.63±0.21
90 days	NDF	19.53	20.53	18.49	18.62	19.29±0.82
	ADF	9.27	9.66	8.61	8.44	9.00±0.49
	Hcel	10.26	10.87	9.88	10.18	10.30±0.36
	Cel	8.20	6.93	7.48	6.52	7.28±0.63
	Lignin	1.07	2.73	1.13	1.92	1.71±0.68

Hcel = NDF - ADF
ADF = Cel + Lig.

Hemicellulose on the other hand, decreased from 0 to 45 days and increased slightly from 45 to 90 days. When this group of samples were stored at 38°C (Table 5), NDF, ADF, hemicellulose, cellulose and lignin increased from 0 to 90 days of storage. The fiber fractions of the vine beans stored at

4°C (Table 6) increased with time of storage, as did also in the samples stored at 38°C over 90 days of storage (Table 7). Analysis of variance of the fiber fractionation data is shown in Table 2. NDF showed highly significant differences due to days of storage (F01) and significant differences for the interaction type of beans x days of storage and for locality (F05). ADF was affected in a highly significant way by days of storage and the interaction of days of storage and the interaction of days of storage x type of bean and temperature. Plant type gave significant differences for ADF. With respect to cellulose, highly significant differences were found for plant type, days of storage and the interaction of type x days x temperature. The interaction of type of beans x days of storage and temperature were significant (F05). Hemicellulose content appeared to be more affected by the variables of the study. Highly significant differences were obtained for plant type, days of storage, locality and the interactions of type x days, type x temperature, type x days x temperature, and type x locality. For lignin, days of storage gave highly significant differences, as well as the interaction of days x type and days x temperature.

The synthesis of the various fractions was calculated using linear regression analysis. These values are shown in Table 8. NDF formation under storage at 4°C for vine type of beans was 56.64 mg/day, while at 38°C it was 60.25 mg/day; ADF formation was 25.20 mg/day at 4°C, and 22.42 mg/day at 38°C, while lignin formation was 4.61 mg/day at 4°C of storage and 11.33 mg/day at 38°C. The rate of synthesis for H.C. at 4°C was 31.44 mg/day and increased to 37.83 mg/day at 38°C, however, cellulose rate of synthesis was 20.58 mg/day at 4°C and 11.11 mg/day at 38°C.

TABLE 8
Rate of synthesis of fiber fractions over time of storage (mg/day)

Bean type	Fiber fraction	Storage Temperature	
		4°C	38°C
Bush	NDF	0.194	54.58
	ADF	9.50	30.25
	Hcel	-9.30	24.33
	Cel	10.47	22.78
	Lignin	-0.94	7.75
Vine	NDF	56.64	60.25
	ADF	25.20	22.42
	Hcel	31.44	37.83
	Cel	20.58	11.11
	Lignin	4.61	11.33

Using the same approach (Table 8), NDF formation under storage at 4°C for bush type of beans was 0.194 mg/day, while at 38°C it was 54.58 mg/day; ADF formation was 9.5 mg/day at 4°C and 30.25 mg/day at 38°C. Lignin formation was -0.94 mg/day at 4°C and 7.75 mg/day at 38°C. Both cellulose and

HC rate of formation increased with storage temperature. These data show for most fiber fractions an increased rate of synthesis at the higher storage T, but the data suggest that this effect is different for both bean types. For the vine type, synthesis of NDF, hemicellulose and lignin was higher at 38°C of storage. These beans had a higher crude fiber content, of a higher seed coat percentage and had a higher initial cooking time than bush type of beans (1). Furthermore two of the four vine samples showed a very low water absorption. A factor which must be taken into consideration is the method of analysis. NDF contains cellulose, hemicellulose and lignin, while ADF is mainly cellulose and lignin. The difference between the two, gives hemicellulose. Therefore, errors in analysis could very well influence the calculation of the rate of synthesis. Lignification has been indicated to be a factor in the hard-to-cook problem (6) and the data from this study show high values of synthesis at 38°C, although not as high as those from NDF which contains lignin.

Regression equations of the influence of all fiber fractions on cooking time were also estimated, as shown in Table 9. NDF influenced cooking time for both types of beans, however, it was more evident for the vine type. The same can be observed for ADF for all bean types but particularly for the vine type. On the other hand, hemicellulose had only a small effect for both types of beans. The effect of cellulose was significant in increasing cooking time for all bean types but particularly for the vine type. Finally, lignin had some influence for the vine type, more so than hemicellulose.

TABLE 9
Correlations between changes in fiber fractions and cooking time

Bean type	Fiber fraction	Storage Temperature		
		4°C	38°C	
Vine	NDF	-0.63*	+0.60*	
		Bush	+0.04	+0.33
		All	-0.35	+0.37
Vine	ADF	-0.63*	+0.80**	
		Bush	+0.07	+0.47
		All	-0.21	+0.67**
Vine	HC	-0.48	-0.06	
		Bush	-0.04	+0.09
		All	-0.28	-0.10
Vine	Cellulose	-0.71**	+0.70**	
		Bush	-0.09	+0.21
		All	-0.26	+0.61**
Vine	Lignin	-0.68*	+0.13	
		Bush	+0.24	+0.29
		All	-0.05	+0.22

Various workers have suggested that the increase in cooking time of beans on storage is due to the lignification of the cell wall (3, 6).

At the storage T of 4°C, cooking time for all bean samples whether of the bush or vine type decreased, however, at 38°C cooking time increased over time of storage. At the same time, the rate of fiber fraction synthesis behaved differently. NDF rate of synthesis was higher for all beans at 38°C, as well as hemicellulose and lignin rate of synthesis, while ADF rate of synthesis was higher at 4°C of storage for vine beans. Statistical analysis showed that all fiber fractions had some influence on cooking time, which was significant in two instances at 38°C, but higher in all other cases than at 4°C. This suggests that the changes in fiber fractions, particularly in cellulose, have a role to play in increasing cooking time, although other factors are also probably involved. The role of lignin has already been described (1) and there is agreement that the hard-to-cook problem in beans is best explained on the basis of a multiple mechanism (3).

From the results of the present research it may be suggested that cellulose formation during storage is responsible to a very large extent for the increase in cooking time, probably more than lignin formation. The fiber fractions such as NDF and ADF which are made up of cellulose, hemicellulose and lignin and of cellulose and lignin respectively, resulted in significant positive correlations to cooking time as well as cellulose, while only small non-significant correlations were observed for hemicellulose and lignin, more so for the latter. At 38°C the rate of synthesis of the various fiber fractions was high, suggesting cell wall differentiation. Although the hard-to-cook condition in beans has been shown to be induced by various methods of treating the seeds, the most common has been storage at a high relative humidity with high temperature, with beans with relative high moisture content (18%), as well as high RH with high T with beans at lower moisture levels (12-14%). The first situation may lead to an aborted germination where degradation of complex organic compounds and rearrangement reactions of the products may take place, while the second, more applicable to the present study, the reactions taking place are more towards cell wall differentiation.

In future studies the changes in the cell wall components such as pectins and glycoproteins should be monitored. Likewise, the studies should be done on the cotyledon which would eliminate the interference of compounds present in the seed coat, even though it represents only about 10% of the weight of beans.

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