Effect of Storage on Fructan and Fructooligosaccharide of Onion (*Allium cepa* L.)

Laura Jaime, María A. Martín-Cabrejas, Esperanza Mollá, Francisco J. López-Andréu, and Rosa M. Esteban*

Departamento de Química Agrícola, Facultad de Ciencias, Universidad Autónoma de Madrid (UAM), 28049 Madrid, Spain

The purpose of this study was a comparative examination of the fructan and fructooligosaccharide (FOS) content of different varieties of onions (*Allium cepa* L. cv. Sturon, Hysam, Durco, Grano de Oro, and Caribo) and the changes produced during their commercial storage. In fresh onions, the Grano de Oro variety presented a remarkably different behavior, showing low contents of total fructans and FOS and high levels of reducing sugars. In the other varieties, Sturon, Hysam, Durco, and Caribo, fructans were the main carbohydrates, the lowest polymerized FOS being the major oligomer. Storage period caused in these varieties important increased levels of free fructose attributed to fructan hydrolysis. Maleic hydrazide treatment had no significant effect in avoiding the hydrolysis of fructans during storage conditions for the Sturon variety. Varieties with >16% dry matter or 15% soluble solids contents could be stored for 6 months at 0 °C and 60−65% relative humidity.

Keywords: *Onion (Allium cepa L.); carbohydrates; fructans; fructooligosaccharides; storage*

INTRODUCTION

Fructans are referred to as a series of homologous oligo- and polysaccharides of fructose in which fructosyl units (F) are bound by β linkage at the position of sucrose (GF). However, several structurally different oligosaccharides have been referred to as fructooligosaccharides (FOS). Because kestose (GF_2), nystose (GF_3), and fructofuranosylnystose (GF_4) are the only fructose oligomers commercially available, it is generally accepted that FOS is a common name only for them (*1*).

Fructans occur in almost 15% of flowering plants, including such important crops as cereals, vegetables, and fruits (*2*−*5*). In plants, fructans work mainly as reserve carbohydrates, but opposite from starch behavior, they could act as osmoregulators due to their solubility in water inside the vacuole (*6*, *7*). Recent papers have published the role of fructans against hydric stress caused by drought or cold (*8*−*10*).

Fructose oligomers together with glucose, fructose, and sucrose are the main nonstructural carbohydrates in onion bulbs (*5*, *11*). Bacon (*12*) and Darbyshire and Henry (*13*1981) first investigated the content, distribution, and structure of fructooligomers in onion bulbs. At present, techniques such as HPLC with refractive index or pulse amperometric detection (*4*, *14*) and mass spectrometry (*15*) have been used to quantify fructans and fructooligosaccharides.

Nowadays, fructans and FOS are being investigated because they might be physiologically useful for improving the intestinal flora, especially the bifidobacteria intestinal conditions against pathogen agents (*16a*,*b*). Administration of FOS significantly lowered fasting glycemia and serum total cholesterol (*17*, *18*), increasing the intestinal absorption and bone density of calcium and magnesium (*19*, *20*).

Because onions are widely consumed over the whole year, they are stored to be available anytime in the market. As the commercial storage period for onions is often terminated by the initiation of root growth and sprout elongation, it is important to the onion industry to gain knowledge about which onion constituents control the storage life in the bulbs. Several workers (*21*−*25*) have considered total sugar content during storage to be an index of quality control. However, the relationship between fructan content and the degree of polymerization (DP) with the extent of fructan hydrolysis suffered by onion bulbs during storage has been scarcely investigated. In this respect, estimations of total fructans at harvest might be useful to growers of commercial onion crops as indicators of storage duration in any particular season.

The objective of the present work was to evaluate the effect of storage on total fructan and FOS (DP up to 5) content in onion varieties and to explore their relationships with total soluble solids (SS) and dry matter (DM) contents, with a view to being used as a shelf life index of stored onions.

MATERIALS AND METHODS

Materials. Five varieties of fresh mature onions (*Allium cepa* L. cv. Sturon, Hysam, Durco, Grano de Oro, and Caribo) and stored onions (at 0 °C and 60−65% relative humidity for 6 months) were provided by U.K. suppliers (British Onion Producers Association). To investigate the effects of sprout suppressant, Sturon variety onions were provided with (S) and without (NS) maleic hydrazide (Fazor). Onion suppliers sent us 10 kg of fresh onions and 25 kg of stored onions. Ten onion bulbs were taken randomly to form 10-bulb samples for each variety in triplicate and processed as follows: the top, bottom, brown dry outer skin, and outer two fleshy layers of onions were removed and the remaining inner fleshy leaves were

* Author to whom correspondence should be addressed (telephone 34-91-9373937; fax 34-91-3973830; e-mail rosa.esteban@uam.es).

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Table 1. Content of Nonstructural Carbohydrates in Fresh Onion Varieties[a]

variety		total fructose	total glucose	free fructose	free glucose	sucrose	total fructans
		***	***	***	***	***	
Sturon (NS)	***	$449.6 \pm 2.6^{b}_{\mathbf{a}}$	$219.5 \pm 1.6^{d}_{\mathbf{b}}$	$37.3 \pm 2.3^{d}_{\mathbf{e}}$	$75.1 \pm 1.9^{e}_{\mathbf{d}}$	$96.0 \pm 6.7^{cd}_{\mathbf{c}}$	421.5
Sturon (S)	***	$519.1 \pm 7.1^{a}_{\mathbf{a}}$	$188.6 \pm 0.6^{e}_{\mathbf{b}}$	$62.6 \pm 7.3^{c}_{\mathbf{d}}$	$34.9 \pm 4.2^{f}_{\mathbf{e}}$	$109.1 \pm 7.4^{b}_{\mathbf{c}}$	458.1
Hysam	***	$370.5 \pm 3.8^{d}_{\mathbf{a}}$	$286.4 \pm 3.5^{a}_{\mathbf{b}}$	$43.1 \pm 0.5^{c}_{\mathbf{e}}$	$163.3 \pm 6.2^{b}_{\mathbf{c}}$	$103.1 \pm 4.6^{c}_{\mathbf{d}}$	316.3
Durco	***	$390.7 \pm 3.1^{c}_{\mathbf{a}}$	$246.6 \pm 1.8^{c}_{\mathbf{b}}$	$62.2 \pm 0.4^{b}_{\mathbf{d}}$	$111.5 \pm 1.8^{d}_{\mathbf{c}}$	$112.4 \pm 4.1^{b}_{\mathbf{c}}$	319.5
Grano de Oro	***	$260.5 \pm 14.2^{f}_{\mathbf{b}}$	$279.8 \pm 13.8^{a}_{\mathbf{a}}$	$214.8 \pm 5.7^{a}_{\mathbf{d}}$	$248.6 \pm 2.8^{a}_{\mathbf{c}}$	$31.7 \pm 2.2^{e}_{\mathbf{e}}$	40.2
Caribo	***	$353.4 \pm 0.6^{e}_{\mathbf{a}}$	$267.2 \pm 12.1^{b}_{\mathbf{b}}$	$46.7 \pm 4.1^{c}_{\mathbf{e}}$	$133.5 \pm 5.2^{c}_{\mathbf{c}}$	$120.0 \pm 11.9^{a}_{\mathbf{d}}$	290.5

[a] Grams per kilogram of DM, mean ± SD ($n = 3$). Mean values of each column followed by a different superscript letter significantly differ when subjected to DMRT ($P < 0.05$). Mean values of each row followed by a different subscript letter in bold significantly differ when subjected to DMRT ($P < 0.05$). Asterisks in each column indicate statistical differences between varieties at *** $P < 0.001$. Asterisks in each row indicate statistical differences between the nonstructural carbohydrates of each variety at *** $P < 0.001$.

chopped, immediately frozen in liquid nitrogen, and stored at −20 °C. All analyses were performed on these inner fleshy layers. For fructans and FOS determination, samples were freeze-dried, ground (0.5 mm), and stored at −20 °C.

Physical Parameters. Dry matter content was evaluated according to the method of Sharma and Nath (*26*) in the 10-bulb samples. Mean thickness of fleshy layers was determined as indicated by Sinclair et al. (*25*).

Chemical Parameters. Soluble solids were determined in triplicate of each ten-bulb sample: 10 g of onion bulb was homogenized using a mortar; the homogenate was passed through a layer of muslin gauze, discarding the first drops. Soluble solids concentration (percent sucrose or degrees Brix) was determined for the juice at 20 °C using an Abbé refractometer.

Extraction of Fructans and FOS. Extraction of FOS and total fructans was carried out in the three 10-bulb samples by using the following procedure: 1.0000 ± 0.0005 g of freeze-dried and ground material was homogenized into 50 mL of 70% ethanol and immediately heated at 100 °C for 10 min. Subsequently, the residue and supernatant were centrifuged at 4000 rpm for 15 min and decanted. The residue was extracted four extra times. All supernatants were pooled and vacuum evaporated at 30−33 °C to dryness. Final residues were discarded. The concentrated sugars were redissolved into 50 mL of deionized water, and this solution was kept for further determination of soluble carbohydrates (extract I).

Total Fructan Determination. The method for total fructan determination is based on inulinase enzymatic treatment (*27*) with Novozym 230, generously provided by Novo (Nordisk, Bagsvaerd, Denmark). The diluted inulinase solution (0.1 mL; Novozym 230, enzyme activity = 330 units g^{-1} of inuline) was added to an aliquot of extract I (0.9 mL). The solution was mixed and incubated at 57.5 °C for 30 min, and total released glucose and fructose was determined by HPLC. In addition, free glucose, free fructose, and sucrose were also directly identified in an aliquot from extract I (without previous inulinase hydrolysis). The HPLC method is based on the use of an Aminex HPX-42C column (cationic ion exchanger, 0.78 × 30 cm, Bio-Rad, Hercules, CA) and refractive index detector. The column temperature was maintained at 85 °C, and deionized water was used as mobile phase at a 0.5 mL min^{-1} flow rate. Appropriate dilutions of a solution containing glucose, fructose, and sucrose (Sigma, St. Louis, MO) were used as calibration standards. The concentration of total fructans was calculated according to the method of Hoebregs (*28*):

$$G = G_T - (S/1.9) - G_F$$

$$F = F_T - (S/1.9) - F_F$$

where G = glucose from fructans, G_T = total glucose, $S/1.9$ = glucose of fructose from sucrose (S), G_F = free glucose, F = fructose from fructans, F_T = total fructose, and F_F = free fructose.

The total fructan content is the sum of G and F, corrected for the water loss during hydrolysis:

$$\text{total fructans} = k(G + F)$$

where $k = 0.925$ (for fructose oligomers)

FOS Determination in Onion Tissues. The main FOS, kestose, nystose, and fructofuranosylnystose, were directly identified in an aliquot from extract I by the above HPLC method. Appropriate dilutions of a solution containing 1F-fructofuranosylnystose, nystose, and 1-kestose (Wako Pure Chemical Industries, Ltd., Osaka, Japan), were used as calibration standards.

Fructan Hydrolysis. Fructan hydrolysis percentage was calculated as follows:

$$(\text{fructan}_{\text{fresh onions}} - \text{fructan}_{\text{stored onions}}) \times 100/\text{fructan}_{\text{fresh onions}}$$

Sprouted Bulb Onions. The percentage of sprouted onions after storage was calculated as the number of sprouted onions per 100 bulbs analyzed.

Statistical Analysis. Results were analyzed using Duncan's multiple-range test (DMRT) (*29*). Differences were considered to be significant at $P \leq 0.05$. Linear regression analysis and correlation matrices between variates over all varieties were carried out using StatGraphics v. 3.1.

RESULTS AND DISCUSSION

The nonstructural carbohydrate content (as the sum of free fructose, free glucose, sucrose, and fructan levels) of the various onion varieties analyzed showed no drastic differences among them, the values ranging from 535 to 665 g kg^{-1} in DM, according to Darbyshire and Henry (*6*), Nilsson (*30*), Rutherford and Whittle (*22*), and Salama et al. (*24*) results. The study of the nonstructural carbohydrate profile of fresh bulbs from different onion varieties (Table 1) revealed that fructans were the main carbohydrate fraction, except for Grano de Oro. This variety contained high levels of free glucose and fructose. Free fructose was the minor sugar in every onion variety, except for Grano de Oro and Sturon (S). Total fructans content comprised up to 70% of total nonstructural carbohydrates in the Sturon variety; Hysam, Durco, and Caribo showed lower contents of fructans (49, 47, and 51%, respectively), whereas in Grano de Oro fructans accounted for only 8% of total carbohydrates. This variety also showed a low content of sucrose. Several authors (*11*, *13*, *31*) have suggested that carbohydrate supply, in the form of sucrose, may play a central role and control the ability of the plant to synthesize fructan; according to this, all varieties showed similar contents of sucrose, higher than free fructose, except Grano de Oro, which showed the lowest contents of sucrose and fructans. These results made clear significant differences between onion varieties as potential sources of fructans.

With regard to FOS content and composition (Table 2), the results showed that the total content of FOS as the sum of GF_2, GF_3, and GF_4 varied considerably depending on the onion variety. However, in general the

Table 2. Content of FOS in Fresh Onion Varieties[a]

variety		kestose (GF_2)	nystose (GF_3)	fructofuranosylnystose (GF_4)	total
		***	***	***	
Sturon (NS)	***	$73.2 \pm 1.8^{a}{}_{\mathbf{a}}$	$55.4 \pm 2.9^{a}{}_{\mathbf{b}}$	$12.2 \pm 1.9^{ab}{}_{\mathbf{c}}$	140.8
Sturon (S)	***	$76.9 \pm 4.4^{a}{}_{\mathbf{a}}$	$49.9 \pm 0.9^{ab}{}_{\mathbf{b}}$	$15.1 \pm 1.8^{a}{}_{\mathbf{c}}$	141.9
Hysam	***	$74.7 \pm 5.5^{a}{}_{\mathbf{a}}$	$54.2 \pm 5.4^{a}{}_{\mathbf{b}}$	$9.8 \pm 1.3^{b}{}_{\mathbf{c}}$	138.7
Durco	***	$61.2 \pm 4.6^{c}{}_{\mathbf{a}}$	$28.5 \pm 1.6^{c}{}_{\mathbf{b}}$	$7.2 \pm 0.7^{bc}{}_{\mathbf{c}}$	96.8
Grano de Oro	***	$10.4 \pm 1.2^{d}{}_{\mathbf{b}}$	$12.8 \pm 1.1^{d}{}_{\mathbf{a}}$	ND[b]	23.3
Caribo	***	$67.3 \pm 1.9^{b}{}_{\mathbf{a}}$	$33.4 \pm 4.3^{c}{}_{\mathbf{b}}$	$2.9 \pm 0.2^{d}{}_{\mathbf{c}}$	103.5

[a] Grams per kilogram of DM. Mean ± SD ($n = 3$). Mean values of each column followed by a different superscript letter differ significantly when subjected to DMRT ($P < 0.05$). Mean values of each row followed by a different subscript letter in bold significantly differ when subjected to DMRT ($P < 0.05$). Asterisks in each column indicate statistical differences between varieties at *** $P < 0.001$. Asterisks in each row indicate statistical differences between the FOS of each variety at *** $P < 0.001$. [b] ND, not detected.

Table 3. DM, SS, and Mean Thickness of Fleshy Layers of Fresh and Stored Onion Varieties[a]

variety	DM[b] (%)			SS[c] (%)			mean thickness of fleshy layers (mm)	
	fresh		stored	fresh		stored	fresh	stored
	***		***	***		***		
Sturon (NS)	16.6 ± 1.3^{a}	NS[d]	15.4 ± 0.5^{a}	15.8 ± 0.3×bb	*	14.0 ± 0.8^{a}	4.7	5.7
Sturon (S)	16.3 ± 0.9^{a}	NS	14.9 ± 0.7^{a}	15.2 ± 0.3^{a}	*	14.0 ± 0.5^{a}	4.7	5.4
Hysam	12.8 ± 0.3^{b}	*	11.9 ± 0.8^{b}	11.8 ± 0.3^{b}	NS	11.3 ± 0.5^{b}	4.4	4.7
Durco	12.0 ± 0.6^{c}	*	10.0 ± 0.6^{c}	9.5 ± 0.0^{c}	NS	9.6 ± 0.4^{c}	4.5	4.5
Grano de Oro	8.8 ± 0.6^{d}	NS	8.8 ± 1.4^{d}	7.2 ± 0.3^{d}	*	8.6 ± 0.7^{d}	4.0	4.1
Caribo	12.1 ± 1.1^{c}	NS	10.6 ± 0.6^{c}	11.5 ± 0.0^{b}	*	9.9 ± 0.7^{c}	4.3	4.8

[a] Mean values of each column followed by a different letter significantly differ when subjected to DMRT ($P < 0.05$). Asterisks in each column indicate statistical differences between varieties at *** $P < 0.001$. [b] Mean ± SD ($n = 3$). [c] Mean ± SD ($n = 9$). [d] NS or * indicates no statistical differences or $P < 0.05$ statistical differences between fresh and stored contents.

prevalence of the lowest polymerized FOS (GF_2) was observed, accounting for 50−65% of the total FOS except for the Grano de Oro variety, whereas GF_4 showed minimum percentages ranging from not detected values in the Grano de Oro variety to 11% in Sturon (S) variety. The proportion of GF_3 was ∼35% of total carbohydrates in most varieties, except Grano de Oro. The results are in concordance with the trends observed by Darbyshire and Henry (*6*), Loo et al. (*3*), Campbell et al. (*4*), and Wang et al. (*32*) and opposite that of Stahl et al. (*15*), who found that GF_4 seemed to be the more abundant oligomer.

Remarkable differences were detected in the proportion of FOS compounds related to total fructans. Total FOS accounted for 30−60% of total fructans, depending on variety, which indicated a great content of fructose oligomers with a DP > 5. The level of these compounds, estimated by difference between total fructan and FOS contents, ranged from 17 to 316 g kg^{-1} of DM. The minimum value was observed in Grano de Oro, the variety with the lowest content of total fructans, whereas the onion varieties with higher fructan content showed greater proportions of high molecular weight compounds.

Many varietal differences regarding to DM content were observed in fresh onions (Table 3), the levels ranging from 16.6% in Sturon (NS) to 8.8% in Grano de Oro variety. Bulb DM content is an important quality parameter to the onion dehydration industry because it impacts directly on the energy required for drying (*33*). Several other quality attributes, such as pungency (*34*) and storage life (*23*), are related to DM content. Sinclair et al. (*25*) classified 49 onion varieties on the basis of their DM content. Varieties for the fresh market showed DM content ranging from 7.4 to 14.7%, whereas that of dehydrating varieties ranged from 15.9 to 21.5%. Therefore, the onion varieties studied in the present work should be mainly classified as "fresh market" types. Only the Sturon variety could be a "dehydrating" type. Likewise, a higher content of DM facilitates a better storage and transport (*35*).

Another important quality factor is the content of SS. The results obtained (Table 3) showed significant differences in SS percentage among the onion varieties analyzed. Grano de Oro was the variety that exhibited the lowest SS content and Sturon (with and without sprout suppressant) the maximal. These results showed a trend similar to the DM results, exhibiting a strong positive correlation between them ($r = 0.982$); thus, measurement of SS by refractometry can give valuable information of the DM content of onion bulbs. These results corroborate the studies carried out by Nieuwhof et al. (*35*) and Sinclair et al. (*7*), who found a good correlation between these parameters.

Correlations between different variates over all fresh onion varieties are shown in Table 4. A strong linear relationship was exhibited between total fructan content and DM content and a lesser relationship between total nonstructural carbohydrates content and DM. In addition, a negative correlation between DM and reducing sugars (sum of free glucose and free fructose contents) was observed, due to the relationship between glucose and DM content, whereas there was no significant correlation between fructose content and DM. Therefore, total nonstructural carbohydrates were shown to increase as DM content increased due to the presence of fructans. The proportion of high molecular weight compounds increased as DM increased, as evidenced by the strong positive correlation between DM and fructans with a DP > 5, because the polymerization of nonstructural carbohydrates reduces their osmotic activity and enables the accumulation of carbohydrates, increasing DM content. These results confirmed the osmoregulator role attributed to fructans.

According to Darbyshire and Henry (*6*) the profile of fructan distribution in onion bulbs suggests that these compounds have been hydrolyzed to fructose in low dry weight varieties (e.g., Grano de Oro) to facilitate osmo-

Table 4. Correlation Matrices for Different Varieties on Fresh Onion Bulbs[a]

	DM	total Fr	RS	carboh	Fr>5	FOS	Scr	Frc	Glc	SS	thick	Hyd	sprout
DM	1.000												
total fructans (total Fr)	0.941**	1.000											
reducing sugars (RS)	−0.879*	−0.981***	1.000										
nonstruct carbohydrates (carboh)	0.908*	0.961**	−0.905*	1.000									
fructans DP > 5 (Fr > 5)	0.934**	0.989***	−0.973***	0.935**	1.000								
FOS	0.883*	0.944**	−0.921**	0.942**	0.886*	1.000							
sucrose (Scr)	0.578	0.804	−0.891*	0.721	0.782	0.788	1.000						
fructose (Frc)	−0.722	−0.873*	0.930**	−0.790	−0.824*	−0.913*	−0.937*	1.000					
glucose (Glc)	−0.915*	−0.960**	0.942**	−0.900	−0.989***	−0.816*	−0.740	0.751	1.000				
SS	0.982***	0.901*	−0.843*	0.868*	0.879*	0.881*	0.557	−0.715	−0.857*	1.000			
mean thickness of fleshy layers (thick)	0.951***	0.970***	−0.928**	0.928**	0.977***	0.876*	0.677	−0.775	−0.955**	0.881*	1.000		
fructan hydrolysis (Hyd) (after storage)	−0.980*	−0.917*	0.889*	−0.750	−0.840*	−0.777	0.555	0.198	0.784	−0.993*	−0.807	1.000	
sprouted onions (sprout) (after storage)	−0.872	−0.950	0.963	−0.856	−0.980	−0.805	−0.813*	0.808	0.987***	−0.816*	−0.931***	0.322	1.000

[a] Significant values ($P < 0.05$) are in italic type. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

regulation as the bulb takes up water and expands during bulb developing, and water content is therefore higher than in high dry weight cultivars where fructans are not hydrolyzed because of their genetically controlled inability to take up water, either from their inability to hydrolyze fructan to free fructose or from the behavior of the cells of high dry weight cultivars that may have restricted water uptake. The reasoning that fructans would be hydrolyzed during ripening in low dry weight cultivars contrasts with the authors who found an intense conversion of free sugars to fructan polymers during bulbing as reserve carbohydrates (*13*, *30*, *36*). More than an inability to hydrolyze fructans, it could be possible that high dry weight varieties are genetically or environmentally forced to polymerize fructans with a high DP so they could have higher levels of nonstructural carbohydrates without water uptake. Furthermore, Nilsson (*30*) suggests that this might be the reason for bulb thickening during storage, because after the bulbs have reached their physiological ripeness, the water content is determined by the level of free fructose and other osmotically active compounds, suggesting that DM and total fructan content were also positively correlated with SS; this clear tendency seems to limit the rise in the osmotic potential when SS increased in bulbs, as observed by Darbyshire and Henry (*6*). In the present study, the results showed a correlation coefficient (r) of 0.982 between SS and DM across the full range of onion varieties, the correlation equation being $y = 0.8779x + 2.7112$, where DM constitutes the dependent variable. According to Sinclair et al. (*7*) the equations relating SS and DM imply that the proportion of SS in bulb DM increases as DM increases. This fact would suggest that high DM varieties might be more efficient in their storage of photosynthates as nonstructural carbohydrate than low DM varieties. However, Darbyshire and Henry (*6*) found no drastic changes in the proportions of nonstructural carbohydrates of the bulb DM when those compounds were analyzed directly in low, medium, and high dry weight onion varieties. These authors suggested that differences in dry matter are more properly assigned to changes in water content, which is in agreement with our study. Differences of 89% in DM content of onion varieties involve much smaller changes (∼18%) in the proportions of nonstructural carbohydrates of the dry weight; however, water uptake seems to depend more on total fructan content that showed differences of 91% between the varieties studied.

SS is closely correlated with the thickness of the layers (Table 4). Thus, Grano de Oro, the variety with the lowest SS content, showed the lowest mean thickness of layers and, to the contrary, the varieties with the highest SS levels showed the thicker layers. Over all varieties, mean thickness of fleshy layers was positively correlated with DM, total fructans, sucrose, and SS and negatively correlated with reducing sugars and glucose content, in contrast to the results of Sinclair et al. (*7*).

The content of nonstructural carbohydrates in stored onions is shown in Table 5. In contrast to fresh onions, free sugars comprised the main fraction of carbohydrates in stored onions, where free fructose content was similar to that of free glucose, except for the Sturon variety. This variety contained a high level of total fructans (55% of total nonstructural carbohydrates), which is in concordance with its high content of DM

Table 5. Content of Nonstructural Carbohydrates in Stored Onion Varieties[a]

variety		total fructose	total glucose	free fructose	free glucose	sucrose	total fructans
		***	***	***	***	***	
Sturon (NS)	***	$475.9 \pm 35.5^{b}_{\mathbf{a}}$	$191.7 \pm 9.4^{e}_{\mathbf{b}}$	$137.9 \pm 3.7^{d}_{\mathbf{c}}$	$51.5 \pm 0.3^{e}_{\mathbf{e}}$	$92.0 \pm 1.0^{c}_{\mathbf{d}}$	352.8
Sturon (S)	***	$527.5 \pm 29.3^{a}_{\mathbf{a}}$	$210.4 \pm 7.7^{d}_{\mathbf{b}}$	$147.1 \pm 6.8^{c}_{\mathbf{c}}$	$47.2 \pm 0.7^{f}_{\mathbf{e}}$	$130.6 \pm 0.9^{a}_{\mathbf{d}}$	375.8
Hysam	***	$306.9 \pm 28.3^{c}_{\mathbf{a}}$	$191.3 \pm 18.4^{d}_{\mathbf{b}}$	$141.5 \pm 10.2^{c}_{\mathbf{c}}$	$124.9 \pm 16.4^{b}_{\mathbf{d}}$	$122.2 \pm 19.7^{a}_{\mathbf{d}}$	95.4
Durco	***	$324.8 \pm 8.1^{c}_{\mathbf{a}}$	$265.8 \pm 2.9^{b}_{\mathbf{b}}$	$186.0 \pm 4.1^{b}_{\mathbf{c}}$	$191.3 \pm 5.4^{b}_{\mathbf{c}}$	$130.0 \pm 10.6^{a}_{\mathbf{d}}$	70.7
Grano de Oro	***	$294.1 \pm 11.0^{d}_{\mathbf{a}}$	$283.1 \pm 2.0^{a}_{\mathbf{b}}$	$214.7 \pm 3.0^{a}_{\mathbf{c}}$	$263.8 \pm 8.1^{a}_{\mathbf{b}}$	$27.3 \pm 1.6^{d}_{\mathbf{d}}$	64.8
Caribo	***	$313.4 \pm 17.2^{c}_{\mathbf{a}}$	$223.0 \pm 5.8^{c}_{\mathbf{b}}$	$148.5 \pm 3.8^{c}_{\mathbf{c}}$	$153.6 \pm 1.1^{c}_{\mathbf{c}}$	$105.2 \pm 0.2^{b}_{\mathbf{d}}$	114.4

[a] Grams per kilogram of DM. Mean ± SD ($n = 3$). Mean values of each column followed by a different superscript letter significantly differ when subjected to DMRT ($P < 0.05$). Mean values of each row followed by a different subscript letter in bold significantly differ when subjected to DMRT ($P < 0.05$). Asterisks in each column indicate statistical differences between varieties at *** $P < 0.001$. Asterisks in each row indicate statistical differences between the nonstructural carbohydrates of each variety at *** $P < 0.001$.

Table 6. Content of FOS in Stored Onion Varieties[a]

variety		kestose (GF_2)	nystose (GF_3)	fructofuranosylnystose (GF_4)	total
		***	***	***	
Sturon (NS)	***	$84.8 \pm 9.5^{b}_{\mathbf{a}}$	$57.2 \pm 8.8^{a}_{\mathbf{b}}$	$15.8 \pm 0.8^{a}_{\mathbf{c}}$	157.9
Sturon (S)	***	$98.3 \pm 8.1^{a}_{\mathbf{a}}$	$43.2 \pm 6.5^{b}_{\mathbf{b}}$	$13.4 \pm 1.8^{ab}_{\mathbf{c}}$	154.9
Hysam	***	$58.8 \pm 7.9^{c}_{\mathbf{a}}$	$7.4 \pm 0.6^{e}_{\mathbf{b}}$	$6.5 \pm 0.0^{d}_{\mathbf{c}}$	72.7
Durco	***	$42.0 \pm 2.9^{d}_{\mathbf{a}}$	$10.0 \pm 0.1^{d}_{\mathbf{b}}$	$4.5 \pm 1.2^{e}_{\mathbf{c}}$	56.5
Grano de Oro	***	ND	$23.5 \pm 1.0^{c}_{\mathbf{a}}$	$8.1 \pm 0.5^{c}_{\mathbf{b}}$	31.5
Caribo	***	$41.0 \pm 0.0^{d}_{\mathbf{a}}$	$3.7 \pm 0.4^{f}_{\mathbf{c}}$	$8.0 \pm 0.4^{c}_{\mathbf{b}}$	52.7

[a] Grams per kilogram of DM. Mean ± SD ($n = 3$). Mean values of each column followed by a different superscript letter significantly differ when subjected to DMRT ($P < 0.05$). Mean values of each row followed by a different subscript letter in bold significantly differ when subjected to DMRT ($P < 0.05$). Asterisks in each column indicate statistical differences between varieties at *** $P < 0.001$. Asterisks in each row indicate statistical differences between the nonstructural carbohydrates of each variety at *** $P < 0.001$.

Table 7. Hydrolysis of Fructans and Sprouted Bulbs during Storage

variety	hydrolysis (%)			sprouted bulbs (%)
	total fructans	FOS	fructans DP > 5	
Sturon (NS)	16		31	8
Sturon (S)	18		30	5
Hysam	68	48	83	19
Durco	78	42	94	11
Grano de Oro				30
Caribo	61	49	67	13

(Table 3). The increased levels of free fructose in stored onions, except for Grano de Oro, were attributed to hydrolysis of fructans during the storage period at low temperature. The sucrose content of stored onions was higher than in fresh bulbs, due to fructan hydrolysis to yield sucrose aside from fructose, except for the Caribo and Grano de Oro varieties. In the former, hydrolysis of sucrose to reducing sugars was observed, whereas in Grano de Oro a slight increase of fructan level was detected at the expense of sucrose. Sturon was the variety that showed a lower hydrolysis of fructans (17% of reduction in total fructan content), whereas Caribo, Hysam, and Durco underwent a pronounced hydrolysis, ranging from 61 to 78% of reduction. It is worth mentioning that in onion bulbs treated with sprout suppressant [Sturon (S)] the extent of fructan hydrolysis was similar to that of untreated bulbs [Sturon (NS)]; hence, it can be concluded that maleic hydrazide treatment had no significant effect in avoiding the hydrolysis of fructans during storage conditions for the Sturon variety, which agrees with the results obtained by Salama et al. (*24*) in the Sentinel variety.

Grano de Oro showed high percentages of sprouted onions (Table 7); Hysam, Durco, and Caribo showed lesser percentages, whereas Sturon was the only variety that showed a percentage of sprouted onions <10% (Table 7); this low percentage of sprouted onions allows the commercialization of Sturon bulbs after storage.

Several authors (*3*, *5*, *22*, *24*) reported similar results for onions stored at different temperatures, indicating that the main change observed in storage was the hydrolysis of fructose oligomers to reducing sugars, where the highest hydrolysis were observed at higher temperatures (25−35 °C). Moreover, Ernst et al. (*5*) reported higher decreases of fructan contents in sprouted onions. During sprouting it would cause a hydrolysis of fructans to free fructose and glucose, which achieves osmotic adjustment and nutrients as the bulb cells expand; thus, the metabolism of sugars was closely related to bulb dormancy and sprouting, and the changes in sugar amounts during storage might reveal any effects of growing conditions on the biochemistry and subsequently storage life of bulbs.

The content of FOS (GF_2, GF_3, and GF_4) in stored onions is shown in Table 6; as in fresh onion total contents of FOS varied considerably depending on onion variety. Wtih regard to the profile of distribution of FOS, the GF_2 fraction represents the main FOS in all cases, ranging from 54% in Sturon (NS) to 81% in Hysam, with the exception of Grano de Oro, in which it was not detected. GF_3 showed higher contents than the GF_4 fraction in most varieties. The highest contents of FOS were found in the Sturon variety.

Storage period caused an important decrease of FOS in several varieties (Hysam, Durco, and Caribo), except for Sturon and Grano de Oro varieties (Table 7). The increases of FOS in the Sturon variety could be attributable to a hydrolysis of fructans with a DP > 5 to yield fructooligosaccharides, whereas in the Grano de Oro variety changes in the profile of distribution of FOS could be observed.

Total FOS accounted for 40−80% of total fructans, depending on variety. These percentages were higher than in fresh onions, making it clear that storage time caused a higher hydrolysis of fructans with DP > 5 than FOS; Sturon onions showed the lowest hydrolysis of higher fructans to yield FOS, whereas in Hysam, Durco, and Caribo varieties it caused a strong hydrolysis of fructans with DP > 5 and FOS to yield fructose.

The changes in DM content of stored onion were statistically significant in Hysam and Durco varieties,

Table 8. Correlation Matrices for Different Varieties of Stored Onion Bulbs[a]

	DM	total Fr	RS	carboh	Fr > 5	FOS	Scr	Frc	Glc	SS	thick
DM	1.000										
total fructans (total Fr)	_0.962_**	1.000									
reducing sugars (RS)	_−0.932_**	_−0.833_*	1.000								
nonstructural carbohydrates (carboh)	0.652	0.808	−0.406	1.000							
fructans DP > 5 (Fr > 5)	_0.932_**	_0.994_***	−0.796	_0.819_*	1.000						
FOS	_0.985_***	_0.983_***	_−0.872_*	0.767	_0.957_**	1.000					
sucrose (Scr)	0.427	0.286	_−0.642_	0.088	0.221	0.384	1.000				
fructose (Frc)	−0.773	−0.622	_0.941_**	−0.083	−0.585	−0.665	−0.645	1.000			
glucose (Glc)	_−0.962_**	_−0.885_*	_0.993_***	−0.510	_−0.849_*	_−0.921_**	−0.623	_0.894_*	1.000		
SS	_0.997_***	_0.964_**	_−0.924_**	0.675	_0.934_*	_0.987_***	0.440	−0.756	_−0.958_**	1.000	
mean thickness of fleshy layers (thick)	_0.970_***	_0.934_**	_−0.934_**	0.597	_0.907_*	_0.952_**	0.436	−0.803	_−0.955_**	_0.952_**	1.000

[a] Significant values ($P < 0.05$) have been italicized. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

whereas no significant changes were observed in the rest of the varieties. With regard to SS content, storage caused a slight decrease in most varieties (Table 3). Correlations between all variates of stored onions showed some differences with those corresponding to the fresh counterparts (Table 8). DM content of stored onions exhibited positive correlation with total fructans, SS, fructans with DP > 5, FOS, and mean thickness of fleshy layers and negative correlation with reducing sugars and glucose contents as in fresh onions. Both of them, fresh and stored onions, showed the strongest correlation between SS content and DM, the correlation equation being $y = 1.1607x - 1.1054$ for stored onions. Moreover, a better positive correlation between SS and mean thickness of layers has been found in stored bulbs than in the fresh ones.

The percentage of fructan hydrolysis caused by storage period showed a negative correlation with the content of total fructans of onions bulbs and, more specifically, with the content of fructose oligomers with a DP > 5. Moreover, the percentage of sprouted onions showed a strong negative correlation with total fructans, especially with fructans with a DP > 5. Thus, it is suggested that fructan having a high DP operated as a protective factor of fructan hydrolysis against the sprouting process.

As fructan content is positively correlated with DM and SS contents, varieties with high DM or SS contents are usually chosen for long storage periods. SS content exhibited the strongest correlation with percentage of fructan hydrolysis, so it could be used as a very useful and convenient tool to know the keeping quality characteristics of each variety depending on its SS content.

In this study it is suggested that there are important differences between the varieties studied that allow us to distinguish three different patterns of behavior in onion varieties: (1) varieties with high fructans, DM, and SS contents, with lesser amounts of fructan hydrolysis and sprouted onions after 6 months of storage (Grano de Oro); (2) varieties with medium fructans, DM, and SS contents, with higher percentage of fructan hydrolysis and higher amounts of sprouted onions after storage (Hysam, Durco, and Caribo); (3) varieties with low fructans, DM, and SS contents, which bring about a drastic onion sprouting (Sturon). Therefore, varieties with >16% DM or >15% SS contents could be stored for 6 months at 0 °C and 60−65% relative humidity.

ABBREVIATIONS USED

DM, dry matter; DP, degree of polymerization; FOS, fructooligosaccharides; SS, soluble solid.

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