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Viscoelastic properties and changes in pasting characteristics of trifoliate yam (*Dioscorea dumetorum*) starch after harvest

Emmanuel Ohene Afoakwa*, Samuel Sefa-Dedeh

Department of Nutrition and Food Science, University of Ghana, PO Box LG 134, Legon-Accra, Ghana

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Abstract

Studies were conducted on the viscoelastic properties, as well as the changes in pasting characteristics, of trifoliate yam, *Dioscorea dumetorum*, starch during post-harvest hardening of the tubers. A 3×4 factorial experiment with blanching treatment time (0, 15 and 30 s) and storage time (0, 12, 24 and 36 h) as the respective variables was performed. The samples were evaluated for pasting temperature, viscosity at 95 °C, viscosity at 95 °C-Hold, viscosity at 50 °C and viscosity at 50 °C-Hold, as well as their changes during storage of the tubers, to determine the starch behaviour of the *D. dumetorum* tubers during the hardening phenomenon and how blanching affects the process during storage. No significant differences ($P \leqslant 0.05$) in the viscoelastic properties were observed between the means obtained for pasting temperature, viscosity at 95 °C, viscosity at 95 °C-Hold, viscosity at 50 °C and viscosity at 50 °C-Hold in the white and yellow cultivars studied. Storage caused decreases in all the Brabender Viscoamylograph indices measured. Pasting temperature decreased from 80.4 to 66.6 °C whilst peak viscosity decreased from 30 to 18 BU during the storage period. Viscosities at 95 °C and 95 °C-Hold also declined, respectively, from 30 to 20 BU and 450 to 330 BU within 36 h after harvest. Similarly, viscosities at 50 °C and 50 °C-Hold decreased, respectively, from 450 to 265 BU and 480 to 300 BU during storage of the tubers. Blanching, however, increased the pasting characteristics of the stored tubers. The viscoelastic properties of the two cultivars of *D. dumetorum* tubers studied were similar. However, the hardening phenomenon causes slight decreases in the pasting characteristics of the tubers after harvest. © 2002 Published by Elsevier Science Ltd.

Keywords: *Dioscorea dumetorum*, Viscoelastic properties, Pasting characteristics, Post-harvest changes, Starch paste

1. Introduction

Starch is the major component of the yam tuber and it determines, to a large extent, the viscoelastic and textural characteristics of the different yam species. The characteristics of starch granules and the physico-chemical properties of native starch are reflective of its plant origin and differences among the species of the plant. Varietal differences in various properties of yam starches have been reported in the literature (Afoakwa, 1999; Faboya & Asagbra, 1990; Moorty & Nair, 1989; Rasper & Coursey, 1967). Coursey (1967) noted that the factors which determine the behaviour of starches from different sources are the total starch content available, the size and shape of the starch granules, viscoelastic properties and swelling capacity.

Viscoelastic studies have been used to determine the gelatinization of suspensions from a variety of starches, as well as their pasting characteristics during heating and subsequent cooling (Eliasson, 1986; Evans & Lips, 1992; Reddy, Subramanian, Ali, & Bhattacharya, 1994; Svegmark & Hermansson, 1990; Tsai, Li, & Lii 1997). It has been shown (Tsai et al., 1997) that, upon heating, the viscosity increases suddenly after a certain temperature is reached and increases to a maximum. Further heating only leads to reduction in viscosity.

Dioscorea dumetorum is the most nutritious of the six yam species consumed in West Africa. Its starch is as digestible as corn starch (Delpeuch & Favier, 1980) and is made up of tiny polygonal or spherical granules (less than 10 μm) with a type A X-ray diffraction structure, similar to that of cereals (Afoakwa & Sefa-Dedeh, 2001b; Robin, 1976). In spite of its importance as a food source, the storability of this yam is restricted by a severe hardening phenomenon which occurs within 24 h after harvest and renders it unsuitable for human

* Corresponding author. Tel./Fax: +233-21-500389.
E-mail address: e_afoakwa@xmail.com (E.O. Afoakwa).

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consumption even after hours of cooking. Initial studies (Afoakwa & Sefa-Dedeh, 2001a) reported that the chemical compositions of the two main cultivars (white and yellow) consumed are similar, but observations (Afoakwa, 1999) are that the white cultivars harden relatively quicker than the yellow cultivars. Generally, the tubers are left in the soil and harvested as needed for food and often boiled before selling on the market.

The aim of this study was to investigate the viscoelastic properties of the white and yellow cultivars mostly consumed in West Africa as well as the changes in pasting characteristics of the white cultivars during the hardening phenomenon of *D. dumetorum* starch after harvest.

2. Materials and methods

2.1. Materials

Two cultivars (white and yellow) of trifoliate yam *D. dumetorum* tubers were randomly harvested (matured) from a farm at Obomeng in the eastern region of Ghana, washed thoroughly with water and kept in two ice-packed ice chest box containers. One of the boxes (Box 1) contained both white and yellow cultivars for viscoelastic analyses whilst the other box (Box 2) contained only white cultivars for the analysis of the pasting characteristics of the tubers during the hardening process. The samples were then transported immediately (within 3 h) to the laboratory for analyses.

2.2. Sample preparation for viscoelastic analyses

At the laboratory, the white and yellow cultivars (in Box 1) were prepared for viscoelastic analysis. For each cultivar, the samples were washed, peeled and cut into cubes. Afterwards, 100 ml of CO_2-free distilled water was added to 300 g of freshly cut cubes and blended at high speed for 5 min using a Waring Blender, into a smooth paste. The paste was then subjected to viscoelastic analyses using Brabender Viscoamylograph. The Brabender Viscoamylograph cycle was monitored and the various viscosity profile indices recorded.

2.3. Sample preparation for the analyses of the pasting characteristics

The white cultivars (in Box 2) were grouped into three portions. The first group of tubers was blanched in hot water at 100 °C for 15 s, and the second group blanched for 30 s. The third group was left unblanched to serve as control. The three groups were then stored under tropical ambient temperature conditions (28 °C) for 36 h and samples taken from each group after 0, 12, 24 and 36 h of storage for analyses. Samples were prepared for pasting characteristics, using the method described in Section 2.2.

2.4. Experimental design

A 3×4 factorial design was used and the principal factors investigated were:

1. Blanching time: 0, 15 and 30 s.
2. Storage period: 0, 12, 24 and 36 h.

2.5. Methods

The viscoelastic properties, as well as the pasting characteristics, of an 8% slurry (dry matter basis), of blended samples were determined by the use of Brabender Viscoamylograph (Brabender Instrument Inc. Duisburg, West Germany) equipped with a 700 cmg sensitivity cartridge. The weighed sample was then mixed with water and made up to 500 ml in a volumetric flask. The suspension was heated from 25 °C at a rate of 1.5 °C/min to 95 °C, held at this temperature for 30 min, cooled at 1.5 °C/min to 50 °C and held at this temperature for 20 min. The viscosity profile indices recorded included the following: pasting temperature, peak viscosity, viscosity at 95 °C, viscosity after 30 min hold at 95 °C (95 °C-Hold), viscosity at 50 °C and viscosity after 20 min hold at 50 °C (50 °C-Hold).

2.6. Statistical analyses

The data obtained from the viscoelastic properties and pasting characteristics were statistically analyzed using Statgraphics (Graphics Software System, STCC, USA). Comparisons between sample treatments and the indices were done using analysis of variance (ANOVA) and significance of differences was defined at $P \leqslant 0.05$.

3. Results and discussion

3.1. Viscoelastic properties of D. dumetorum starch

The Brabender Viscoamylograph yields useful information on the hot and cold paste viscosity characteristics of starch-based foods. The pasting temperatures of

Table 1
Viscoelastic properties of *Dioscorea dumetorum* starch[a]

Index	*D. dumetorum*		Literature value
	White	Yellow	
Pasting temperature (°C)	80.4	80.2	80.0
Peak viscosity	30	32	25
Viscosity at 95 °C	30	33	25
Viscosity at 95 °C-Hold	450	460	425
Viscosity at 50 °C	460	472	–
Viscosity at 50 °C-Hold	480	488	–

[a] Viscosity data in Brabender Units (BU).

the two cultivars of *D. dumetorum* starches studied were similar, with the white and yellow cultivars having 80.4 and 80.2 °C, respectively (Table 1). Similar results were reported by Coursey (1967) who classified *D. dumetorum* starch as having high pasting temperatures between 80 and 82 °C. These temperatures are slightly higher than the 76–79 °C reported for various *Dioscorea rotundata* and *Dioscorea esculenta* yam starches but lower than the 85 °C reported for *Dioscorea alata* starch (Rasper & Coursey, 1967). This means that *D. dumetorum* starch would take a longer time to gelatinize during processing than *D. rotundata* and *D. esculenta* starches but a shorter time to gelatinize than *D. alata* starch.

The peak viscosities and the viscosities at 95 °C of the white and yellow cultivars investigated were similar with their respective values ranging between 30 and 33 BU for the white and yellow cultivars, respectively. These are very low compared to values for other yam tubers, including *D. rotundata* (630 BU), *D. alata* (200 BU) and *D. esculenta* (55 BU) which were noted for their peak viscosities and viscosities on attaining 95 °C (Rasper & Coursey, 1967). *D. rotundata* starches have significantly higher viscosities than the other yam species and their gel strengths are also moderately high. However, after holding at 95 °C for 30 min, the viscosities of both cultivars increased markedly to 450 and 460 BU, respectively, for the white and yellow cultivars.

The mean viscosities at 50 °C and 50 °C-Hold of the *D. dumetorum* starches were found to range between 460 and 480 BU and 472 and 488 BU for the white and yellow cultivars, respectively (Table 1). These observations reveal that the cooled paste viscosities of the white and yellow cultivars of *D. dumetorum* starches studied are high compared to their respective hot paste viscosities. These drastic increases in viscosities during cooling of the paste might have resulted from the high retrogradation property of yam starch during cooling, which is brought about by the high degree of association between the starch–water systems and their high ability to re-crystallize, resulting in progressively higher viscosities during cooling of yam starches. Ayernor (1985) reported that the rate at which the development of rigidity occurs in yam starches is dependent on the degree of starch-water binding which can be effected through processes that influence the interaction between the starch particles and water.

Analysis of variance conducted on the data showed no significant difference ($P \leqslant 0.05$) between the viscoelastic properties of white and yellow cultivars of *D. dumetorum* starch.

3.2. Changes in pasting characteristics of D. dumetorum starch

The practical importance of the Brabender Viscoamylograph viscosity changes during the pasting cycle is underlined by the various viscosity indices recorded during the cycle. The indices recorded for each sample during the pasting cycle were pasting temperature, peak viscosity, viscosity at 95 °C and after holding for 30 min (95 °C-Hold) and viscosity at 50 °C and after holding for 20 min (50 °C-Hold; Table 2).

Pasting temperature is indicated by the temperature at which the first detectable viscosity is measured by the amylograph. This index is characterized by initial change in viscosity due to the swelling properties of the starches. Generally, pasting temperature was observed to decrease with increasing storage time of the tubers. Similar trends were observed for the tubers blanched for 15 and 30 s prior to storage (Fig. 1). The pasting temperatures of the unblanched tubers decreased from 80.4 to 66.6 °C during the storage period, whereas those of

Table 2
ANOVA summary of *F*-values showing the pasting characteristics of *Dioscorea dumetorum* starch

Process variables	Tuber treatment	Storage time
Pasting temperature	2.602[a]	1000.000[a]
Peak viscosity	9.341[a]	2.884
Viscosity at 95 °C	4.368[a]	1.473
Viscosity at 95 °C-Hold	3.974[a]	0.761
Viscosity at 50 °C	3.955	0.791
Viscosity at 95 °C-Hold	3.677[a]	0.831

[a] Significant *F*-ratios at $P \leqslant 0.05$.

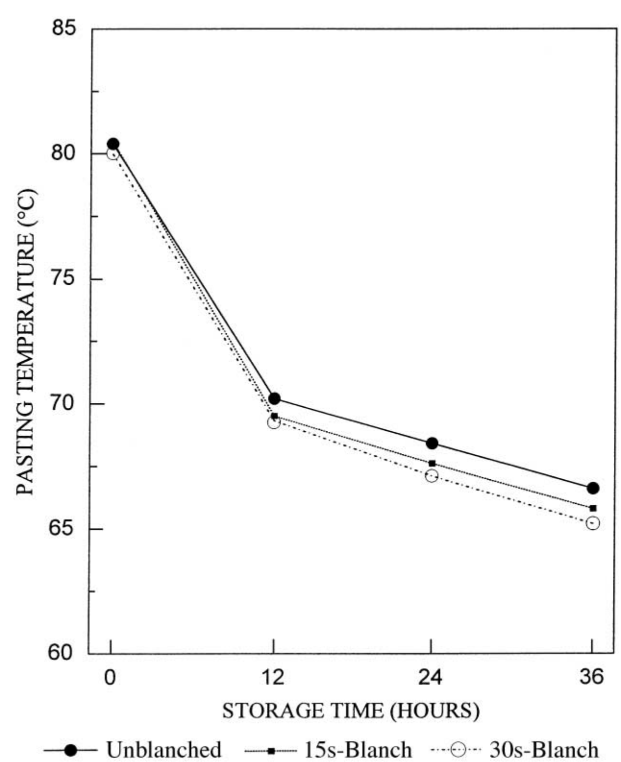

Fig. 1. Changes in pasting temperature (°C) during storage of *Dioscorea dumetorum* starch.

the blanched tubers decreased from 80.5 and 80.0 °C to 65.8 and 65.3 °C for the tubers blanched for 15 and 30 s, respectively. The implication is that the stored tubers which have relatively lower pasting temperatures would be easier to cook and would require less heat for gelatinization to start. The pasting temperatures of the tubers investigated were slightly higher than the mean range of 77.7–79.8 °C reported for cocoyam (Sackey, 1998).

Peak viscosity is linked to the ease of cooking of sample analysed. It is measured as the highest value of viscosity attained by the paste during the heating cycle (25–95 °C). Generally, wide variations in peak viscosities were observed during the storage period as well as with the various tuber treatments. However, the peak viscosities of the unblanched tubers showed no significant variations with storage time (Fig. 2). Contrary to this trend, the peak viscosities of the blanched tubers were observed to increase with storage time. Tubers blanched for 15 s increased from 42 to 140 BU whereas those blanched for 30 s increased from 55 to 170 BU during the storage period. These increases observed in the blanched tubers suggest that the high temperature treatment given to the tuber prior to storage, deactivated the constituent amylases such that they could not hydrolyse the starch (70.5 g/100 g) in the tubers during storage. This could also be due to the formation of cross-links between the hydroxyl groups of the different molecules within the starch granules as a result of the blanching treatment, thereby increasing the peak viscosities of the blanched samples during storage of the tubers.

The viscosities of the untreated samples at 95 °C showed no significant variation during the storage period. Similar trends were observed for the samples blanched for 15 s (Fig. 3). However, at 95 °C the samples blanched for 30 s increased from 92 to 280 BU during the storage period. This implies that the blanching treatment given to the tubers after harvesting considerably increased the viscosity of the paste of the stored samples during the cooking cycle. This is because the amylase enzymes in the tubers, which hydrolyse the starch molecules, were probably deactivated by the heat treatment and hence could not hydrolyze the starch molecules in the tubers, which would have led to subsequent lowering of paste viscosities.

The viscosity attained by a sample after holding the temperature constant at 95 °C for 30 min gave an indication of the ease of breakdown of the cooked paste. This illustrates the stability of the paste during cooking. During the study, the fresh samples were observed to decrease with storage time, whereas the blanched samples increased with increasing storage time (Fig. 4). This implies that the cooked paste of the samples blanched before storage can better withstand shear at high temperatures during cooking, whereas the fresh tubers would exhibit less cooked paste stability during storage.

The viscosity after cooling the paste to 50 °C reflects the retrogradation tendency or setback viscosity of the

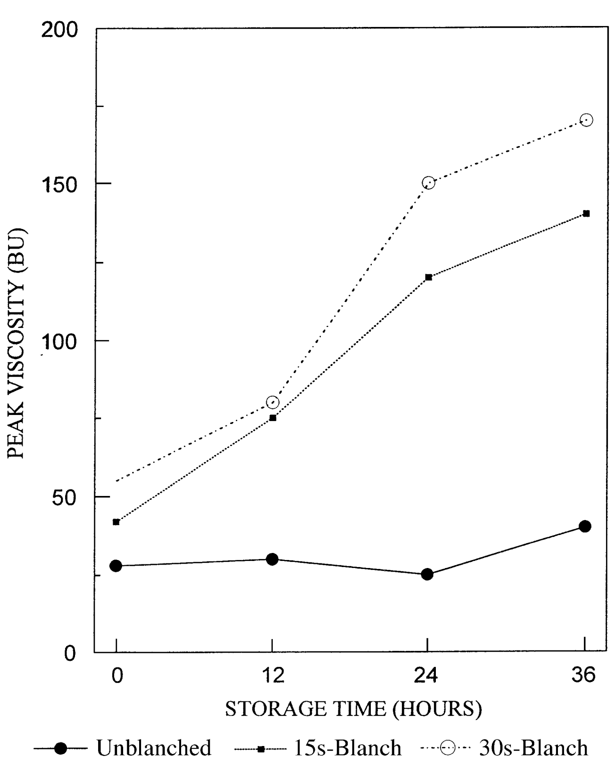

Fig. 2. Changes in peak viscosity (BU) during storage of *Dioscorea dumetorum* starch.

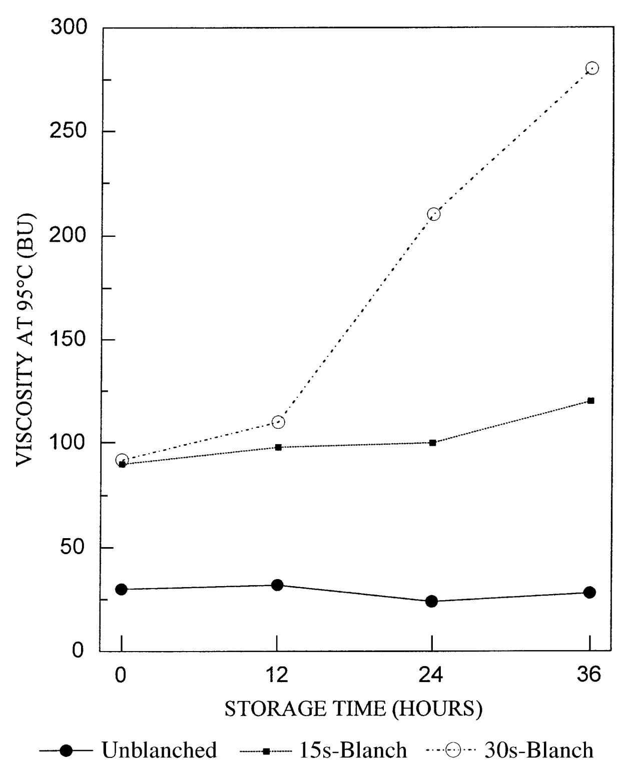

Fig. 3. Changes in viscosity at 95 °C (BU) during storage of *Dioscorea dumetorum* starch.

cooked pastes. This property is of considerable importance to the food processor. During storage, the viscosity at 50 °C of the unblanched samples, decreased from 450 to 230 BU (Fig. 5). Contrary to this trend, samples blanched for 15 s thickened considerably from 450 to 560 BU, but to a greater extent for the tubers blanched for 30 s which increased from 420 to 1040 BU during the storage period. This high retrogradation property of the pastes of the blanched tubers during storage can be ascribed to a high degree of association of starch molecules caused by a strong tendency for hydrogen bond formation between hydroxyl groups on adjacent starch molecules due to the inability of the constituent amylases to hydrolyse the starch molecules. Textural changes leading to undesirable properties such as staling in bread, skin formation, paste gelling and loss of clarity, in prepared starch pastes, have been associated with retrogradation (Sackey, 1998).

The viscosities of the pastes, after keeping the temperatures constant at 50 °C for 20 min (50 °C-Hold), were measured. This measures the stability of paste as it might be used. During the holding period, the viscosities of the unblanched samples were observed to decrease with increasing storage time, whereas those for the blanched samples increased with storage time (Fig. 6).

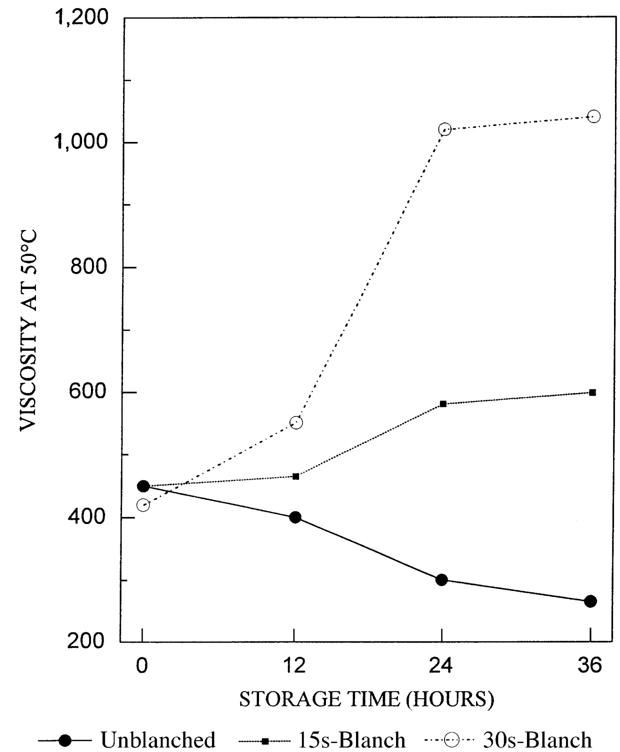

Fig. 5. Changes in viscosity at 50 °C (BU) during storage of *Dioscorea dumetorum* starch.

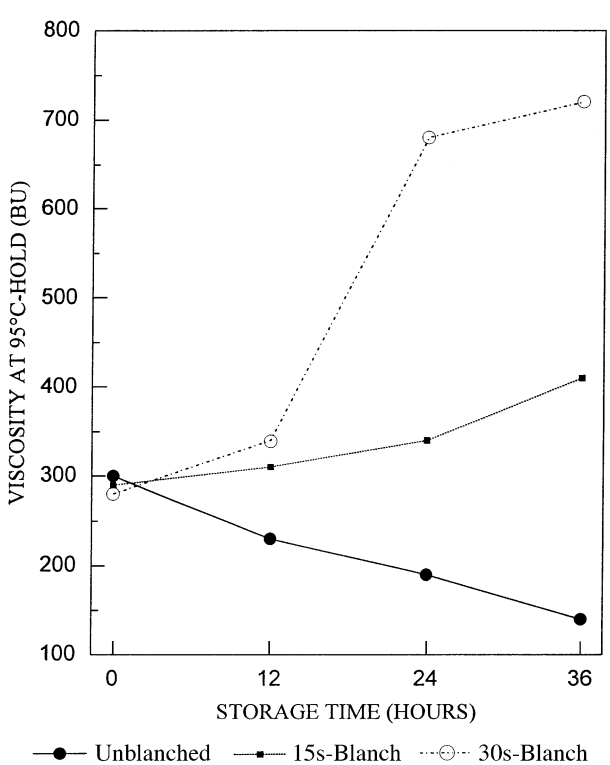

Fig. 4. Changes in viscosity at 95 °C-Hold (BU) during storage of *Dioscorea dumetorum* starch.

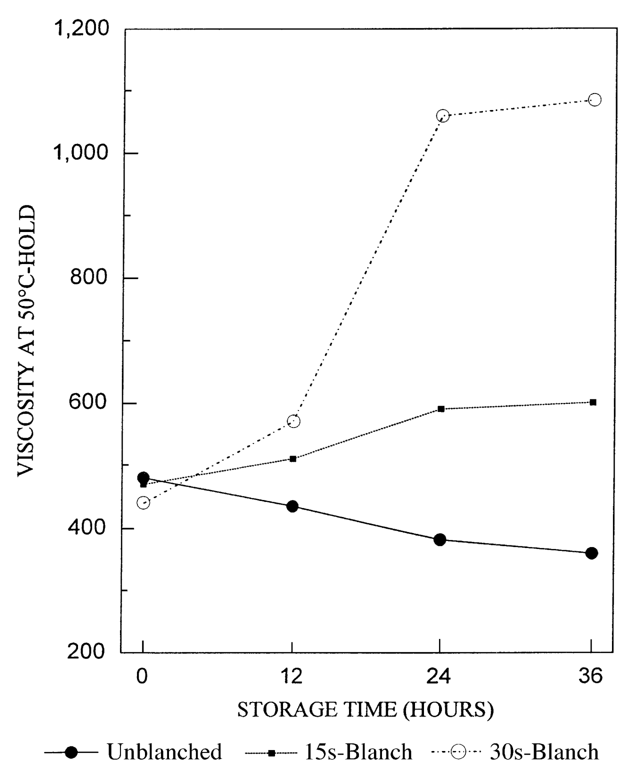

Fig. 6. Changes in viscosity at 50 °C-Hold (BU) during storage of *Dioscorea dumetorum* starch.

4. Conclusions

The viscoelastic properties of the white and yellow cultivars of *D. dumetorum* starches were similar with little variation in their paste viscosities. The pasting characteristics of the white tubers showed no significant changes during the post-harvest hardening process with the exception of pasting temperature, which decreased significantly during hardening. However, the tubers blanched prior to storage exhibited tremendous increases in viscosities during storage. Blanching *D. dumetorum* tubers, in boiling water (100 °C) for 15–30 s, therefore deactivates the action of amylases on the tubers and subsequently increases the paste characteristics of *D. dumetorum* starch after harvest.

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