Controlled Alpha Amylase Process for Improved Sweet Potato Puree

R. J. SZYPERSKI, D. D. HAMANN, and W. M. WALTER JR.

ABSTRACT

A process using a commercial alpha amylase was developed for producing consistent sweet potato puree independent of age or seasonal variations in the raw roots. The process includes thermal gelatinization of the puree starch, enzyme hydrolysis of a portion of the puree, and subsequent blending of the enzyme-treated portion with the untreated portion. Alcohol insoluble solids decreased as the percentage of enzyme-treated puree in the mixture was increased. Chemical and rheological differences comparing purees made from fresh and stored roots became insignificant when the proportion of enzyme-treated puree was greater than 75%. Sensory texture differences were insignificant if the proportion was greater than 50%.

INTRODUCTION

SWEET POTATOES (*Ipomoea batatas*) are a major food crop in the United States and the state of North Carolina. In 1983, North Carolina produced over 158,000 metric tons or over 33% of the nations' supply of sweet potatoes (Crop Reporting Board, 1983).

Sweet potatoes are very starchy when freshly harvested. As the roots are cured and stored, the carbohydrate composition changes. Hasselbring and Hawkins (1915) observed there was a rapid decrease in the starch content of sweet potatoes during the first 12 days of storage. After the first few weeks of storage, the decrease in starch content was more gradual. The decrease in starch content corresponded to an increase in the sugar content of the roots.

Hoover (1966) developed a process for producing sweet potato flakes from a puree using a commercial alpha-amylase to hydrolize the starch improving texture and flavor. He studied the effects of time, temperature, and enzyme concentration on the quality of flakes. It was demonstrated that the optimum enzyme activity occurred at 70°C and if too much conversion was allowed, puree viscosity was too low to produce desirable flakes on a drum dryer. Whitaker (1972) demonstrated that alpha-amylase is the major enzyme controlling viscosity in a model starch system. Beta-amylase, while causing a significant change in viscosity, does not produce the large quantitative changes caused by alpha-amylase. Walter and Purcell (1976) showed a rapid decrease in starch during the first 10 min of conversion of sweet potato puree followed by a gradual decrease over a 2 hr time interval. Along with the starch changes, they found a corresponding drop in the apparent viscosity.

Hoover (1967) developed an "enzyme activation" process for flakes. This process used the native enzyme system in the sweet potato for starch conversion. The endogenous enzyme activity of the sweet potato root varies greatly from season to season and from fresh to stored (Ikemiya and Deobald, 1966; Deobald et al., 1969, 1971) thus, making it difficult to control starch hydrolysis by the native enzyme system. A possible solution to this problem might be to continuously monitor viscosity or flow resistance in order to control the conversion process. This physical property is known to be related to storage variables and starch conversion and be highly correlated with sensory characteristics of sweet potatoes, (Hamann et al., 1980; Rao et al., 1975a, b).

In order to use viscosity as a controlling parameter, the flow properties of sweet potato puree, as influenced by starch hydrolysis, need to be documented quantitatively. Sweet potato puree exhibits pseudoplastic or shear thinning flow with a yield stress. Rao et al. (1975b) studied the flow behavior of sweet potato puree and its relationship to mouthfeel quality. This work indicated that yield stress was correlated significantly to sensory panel scores. Rao et al. (1975a) demonstrated that apparent viscosity could be used as a means of classifying sweet potatoes to predict the degree of moist mouthfeel. Rao and Graham (1982) combined rheological, chemical, and sensory data to characterize sweet potato flakes. They found that viscosity correlated significantly with both chemical properties and sensory texture panel notes.

The research presented here had four objectives: (1) measure the sensory texture properties and chemical constituents of puree made by enzymatic hydrolysis; (2) evaluate rheological properties of the purees to determine if properties such as apparent viscosity can be used to control the process and provide quality control measurements; (3) design of a process that would allow the production of a consistent sweet potato puree product that is independent of seasonal or storage time differences in the raw material; (4) provide flow data suitable for modeling the process and designing a control system.

MATERIALS AND METHODS

Raw materials

Two lots of Jewel cultivar sweet potatoes, each 227 kg, were obtained during the 1982 and 1983 growing seasons from a produce company in Johnston County, North Carolina. Roots from the 1982 season were harvested during October, cured for 7 days at approximately 30°C and 90% relative humidity, stored at approximately 15°C for approximately 6 months and processed. These roots were labeled stored. Roots from the 1983 season were harvested in September, and 91 kg were cured in the same manner as the 1982 crop, but processed within 7 days after curing. The other 136 kg were not cured and were processed within 7 days of harvesting. These 1983 roots (both cured and uncured) were designated as fresh representing the range of root conditions when roots are processed without storage.

Processing

A schematic of the process is depicted in Fig. 1. There was a total of five runs for each season with 45 kg sweet potatoes used for each processing run. The roots were washed in a reel type washer (A. K. Robbins and Co., Inc., Baltimore, MD) and peeled in a 10% lye solution at a temperature of 102°C for 5 min. Peel and excess lye were washed from the roots in a reel washer. Roots were trimmed to remove ends and surface defects and comminuted in a Fitz Mill (Fitzpatric Co., Chicago, IL) fitted with a 1.52 mm mesh screen. A small quantity of water was added to the puree when washing adhering puree from the mill. The puree and added water were thoroughly mixed in a large container. Puree was heated to 105°C by direct steam injection and held at this temperature for 5 min to inactivate the native enzyme system and to gelatinize the starch. Preliminary research showed that these conditions are sufficient to provide the required inactivation.

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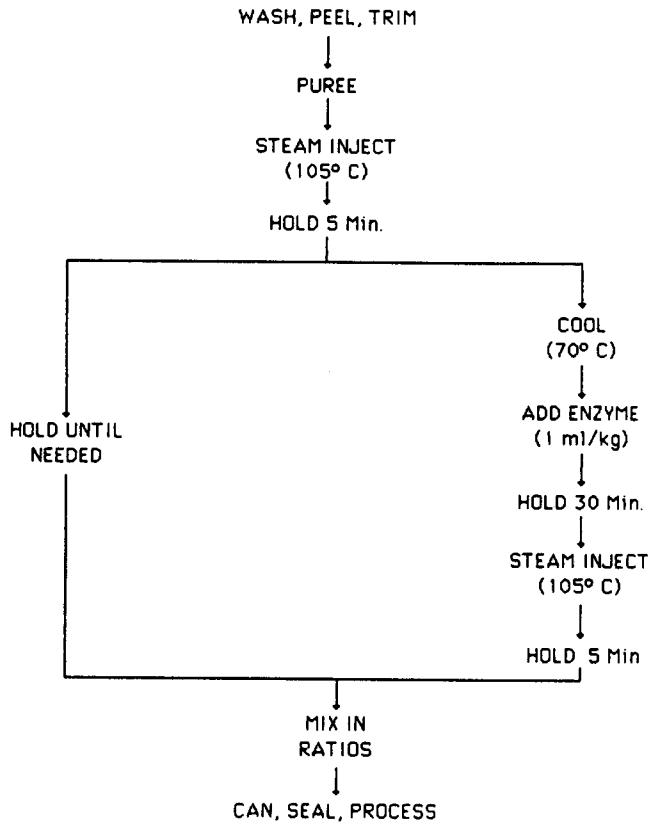

Fig. 1—Process design for production of sweet potato puree.

The puree was divided into two lots. The first lot was set aside for later proportioning with the second lot.

The second lot of puree was allowed to cool to 70°C. A commercial liquid alpha-amylase with a reported activity of 340,000 MWU/g (Tenase®, Miles Laboratories, Inc., Elkhart, IN) was then added to the puree at the rate of 1 mL per kg puree and the puree held for 30 min at approximately 70°C. This level of enzyme produced a stable low viscosity within a few minutes, but 30 minutes holding time insured maximum hydrolysis by the enzyme. The puree was reheated by direct steam injection to 105°C and held for approximately 5 min at 100°C to inactivate the added enzyme. Preliminary testing showed that no activity remained after this treatment. Enzyme-treated puree was mixed with non-enzyme-treated puree (lot #1) on a weight basis as follows: 0:100, 25:75, 50:50, 75:25, 100:0. The first number is the percentage by weight of the enzyme-treated puree. Mixed puree was then poured into 303 cans, sealed with a Dixie Can Co. hand can sealer, and retorted at 115°C for 110 min. Cans were stored at room temperature until evaluations were made.

Moisture determination

Triplicate 2-g samples were weighed to 0.1 mg, dried for 18 hr at 75°C in a forced-air oven, removed, allowed to cool for 5 min in a desiccator, and again weighed.

Flow properties

Viscosity measurements were made with a Haake Rotovisco Model RV-1 viscometer (Haake Buchler Instruments, Inc., Saddle Brook, NJ) using the SV II-P system. The system has a cup diameter of 23.1 mm, and bob dimensions of 20.2 mm diameter and 19.6 mm height. Both cup and bob are fluted in order to minimize separation of suspended particles. A ZG-10, 10:1 gear reducer was used to provide rotational rates from 0.36 to 58.32 RPM.

Eight-gram samples were weighted into the cup and torque was measured for each of the 10 speeds. Temperature of the cup was maintained at 25 ± 0.1°C. One sample from each of two cans was evaluated by increasing speeds from lowest to highest while a duplicate sample was evaluated decreasing speeds from highest to lowest. This gave four samples tested per mixture for each processing run.

Purees made from fresh roots and not containing any added enzyme treated material were too viscous for measurement with a rotational viscometer so an extrusion viscometer was used. A model 1122 Instron Universal Machine (Instron Corp.), equipped with a 500 kg load cell, was fitted with the extrusion viscometer described in Kawanari et al. (1981). The cylinder of the device was filled with puree taking care not to incorporate air in the mixture. Force necessary to extrude the material through the extrusion tube at each of 8 crosshead speeds was recorded. A long tube and a short tube were used and differences in force and tube length made it possible to neglect friction, entrance effects and exit effects in the system.

Viscometric data were fit to the 2-parameter Casson model (Casson, 1959):

$$\tau^{1/2} = C\,\dot{\gamma}^{1/2} + \tau_y^{1/2} \qquad (1)$$

where τ = shear stress (Pa), τ_y = yield stress (Pa), $\dot{\gamma}$ = shear strain rate (s^{-1}), and C is a constant. The advantage of this equation is that τ_y is easily obtained from an intercept of the $\tau^{1/2}$ vs $\dot{\gamma}^{1/2}$ plot. Shear strain rates for the rotational concentric cylinder data were obtained using the procedure of Krieger and Elrod (1953). In the case of the extrusion data the procedure of Rabinowitsch (1929) and Mooney (1931) was used. Details on the viscometer and method of data analysis are given in Kawanari et al. (1981) and in Szyperski (1984). In addition to Casson model representation, equations for viscosity assuming Newtonian flow were used to calculate what will be termed apparent viscosities.

Chemical constituents

Sugars. Ten gram samples were blended with 50 mL 95% ethanol and 8 mL H_2O for 1 min. The mixture was transferred to a 100 mL volumetric flask and held for 1 wk at room temperature. Sugars (glucose, fructose, sucrose and maltose) were measured by gas liquid chromatography (Walter and Hoover, 1984).

Alcohol insoluble solids. Twenty-five gram samples were blended with 125 mL 95% ethanol for 1 min. The solution was clarified by centrifugation and the liquid phase discarded. A boiling solution of 80% ethanol — 20% water (125 mL) was added, blended 0.5 min, cooled, centrifuged, and the liquid discarded. The step was repeated. The residue was removed, put into a tared weighing dish, and air dried overnight. The samples were then held at 65°C for 18 hr, followed by 95°C for 4 hr in a forced draft oven. They were then cooled and reweighed. The alcohol insoluble solids (AIS) were calculated as a percentage of the sample dry matter.

Sensory evaluation

Flavor evaluations will not be reported for this work since a second enzyme (e.g. Beta amylase) would normally be used for flavor development. The present work is concerned with texture.

Texture profiling (Szczesniak, 1963; Brandt et al., 1963) was performed by a trained texture profile panel as described by Civille and Liska (1975) and Civille and Szczesniak (1973). The panel was composed of seven or eight individuals for each session. Sensory parameters were based on a descriptive intensity (not hedonic) scale that was converted to a 1-14 numerical scale for purposes of statistical analysis. The reference standard was a puree of rehydrated commercial sweet potato flakes (moisture content of 75%), from a specific lot (Bruce Foods, Wilson, NC). Notes considered most important to the basic texture of sweet potato puree were: Denseness — the degree to which the sample is solid or thick; Moistness — the degree to which the sample is moist; and Gumminess of Mass — the amount of energy required to prepare the sample for swallowing.

Sensory evaluations were made about 9:00–10:00 AM and consisted of evaluating all five mixtures of one processing run. Mixtures were coded and order of presentation randomized so that the identity of the mixture was unknown to the panelists. All samples were served at a temperature of 25°C.

Statistical design

Raw data were subjected to analysis of variance in a split plot design with years as a whole plot treatment and enzyme treatment as the sub plot treatments. After initial analysis, the data was subjected to one-way analysis of variance to evaluate yearly differences. Calculations were made using the SAS PROC ANOVA procedure (SAS Institute, Inc., Cary, NC).

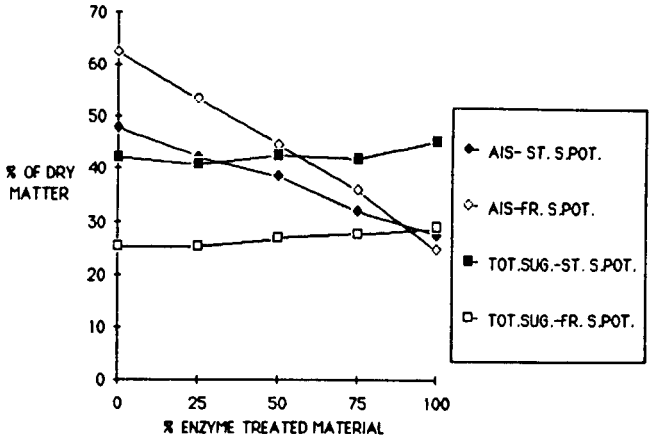

Fig. 2—Alcohol insoluble solids and total sugars as dependent on % enzyme treated puree.

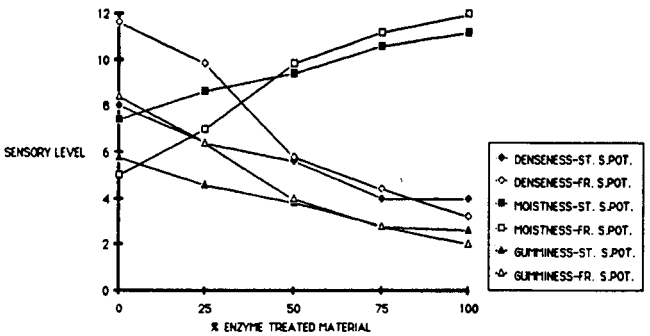

Fig. 3—Sensory texture note magnitudes as dependent on % enzyme treated puree; larger values indicate a greater sensation.

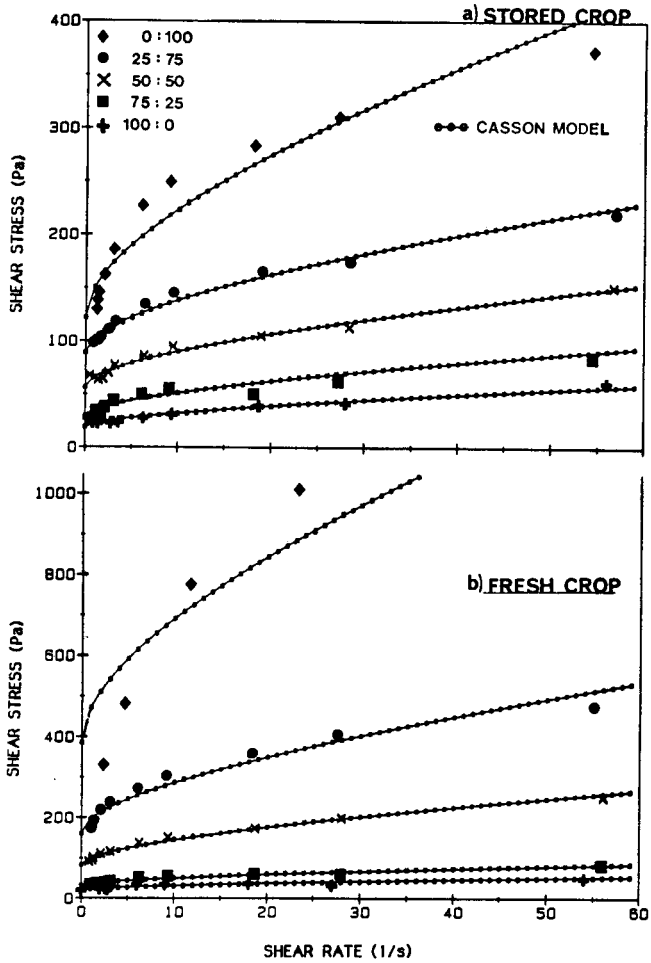

Fig. 4—Shear stress as influenced by shear strain rate for the various purees; lines are those produced by the Casson models.

RESULTS & DISCUSSION

Chemical data

Some variation in percent dry matter in the purees occurred due to storage and processing variables in the study. Percent dry matter averaged 21.1% for the 1982 stored crop purees and 21.8% for the 1983 fresh crop purees. This difference was assumed small enough not to have an important influence on the other variables measured.

Figure 2 shows the chemical changes from the enzymatic hydrolysis and blending. Alcohol insoluble solids decreased as the proportion of enzyme-treated material increased indicating that the starch was being broken down into dextrins (Deobald et al., 1969; Walter and Purcell, 1976). This breakdown was not to simple sugars since the level of total sugars for each group stayed nearly constant. The difference between the fresh crop total sugar content and the stored crop sugar content can be explained by the fact that the sugar levels increase during storage (Walter and Hoover, 1984).

An important result shown in Fig. 2 is that the AIS content of the 0% enzyme treatment for fresh and cured roots was very different. However, as the proportion of enzyme-treated material increased, this difference decreased until, at the 75% level, the difference in AIS content of the purees was barely significant ($P > 0.05$). Thus, even though the carbohydrate makeup of the fresh and stored crops was different, the difference diminished as the proportion of enzyme-treated material increased.

Sensory texture properties

Results of sensory texture analysis are depicted in Fig. 3. As with the chemical data, the sensory data indicated that even though the texture notes at the 0% enzyme-treatment level showed large differences between fresh and stored roots, these differences became smaller until after the 50% enzyme-treatment level there were no statistically significant ($P > 0.05$) differences (Szyperski, 1984). As the proportion of enzyme-treated material increased, a decrease in denseness and gumminess of mass was observed along with a corresponding increase in moistness. These results are consistent with a decreased starch level as reflected in the decrease in AIS content.

Flow properties

Casson model flow curves for typical processing runs are shown in Fig. 4. Puree flow curves for processed stored roots are shown in Fig. 4a while Fig. 4b depicts curves for the fresh roots. The yield stress, at the 75% and 100% levels of hydrolyzed puree, was a major component of the shear stress value at all shear rates. It is important to note the similarity of the flow curves for fresh roots and stored roots at the 75% and 100% levels.

Figure 5 shows enzyme influence on the Casson model slope, C, and yield stress. It can be readily seen that when the proportion of enzyme-treated puree was above 50%, the differences between purees for fresh and stored roots were small. Results of a statistical analysis of this data are given in Szyperski (1984). Szyperski (1984) after determining the Casson yield stress, also used the three parameter Herschel-Bulkley model (power law with a yield stress) (Herschel and Buckley, 1926) to represent the data. Statistical analysis of the Herschel-Bulkley flow behavior index (power law exponent) demonstrated no difference between the fresh and stored crop. All

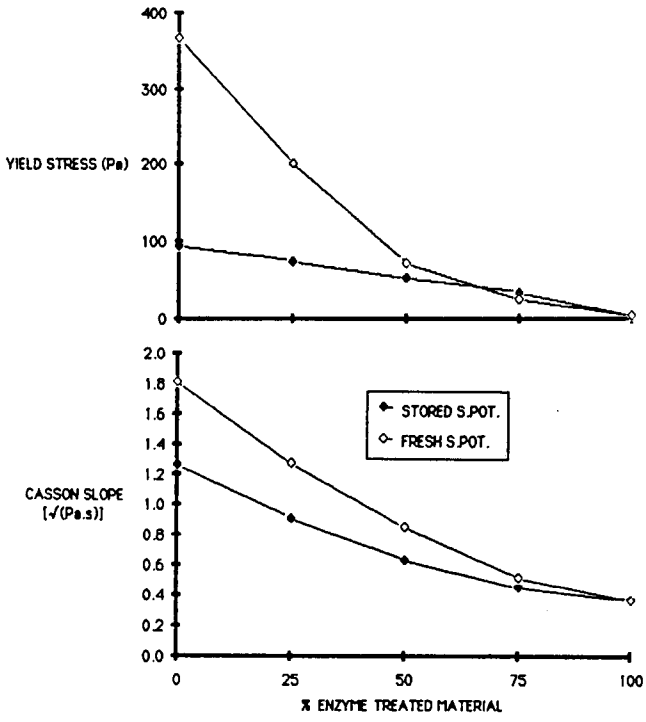

Fig. 5—Casson model constants as influenced by enzyme treatment.

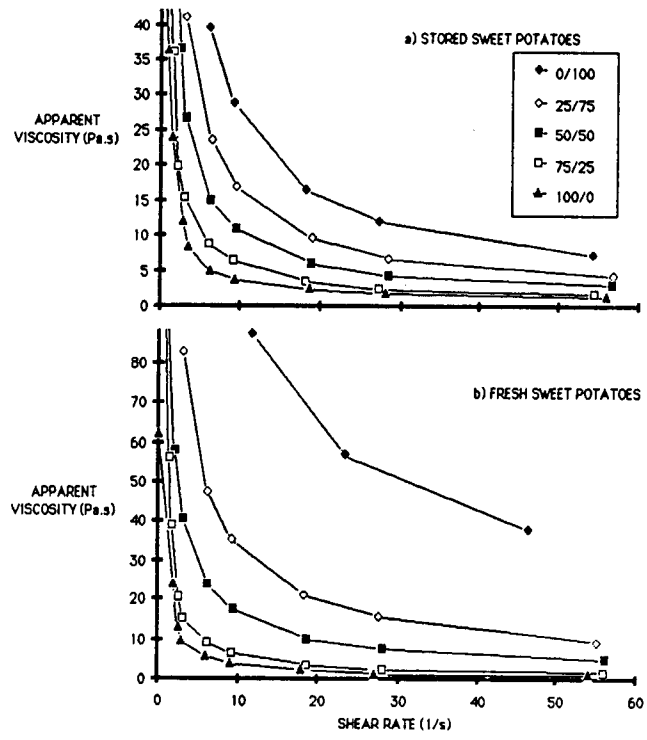

Fig. 6—Typical apparent viscosity versus shear rate graphs for the purees; ratios given are % enzyme treated puree over % untreated puree.

enzyme levels except the 100% level also produced the same exponent values indicating that this index could be considered approximately constant for these purees. In effect, this reduced the three parameter model to a two parameter model and it had no statistical advantage over the Casson model in representing the data. Figure 5 and the statistical analysis indicated that at the 75% and 100% levels of enzyme hydrolyzed puree very similar purees can be produced from stored or fresh roots. It should be possible to control the process by sensing apparent viscosity and, when there is a departure from the desired level, to adjust the percentage of enzyme-treated puree. Apparent viscosity has been shown to correlate with sensory texture parameters (Rao et al., 1975b).

The shear rate influence on apparent viscosity is shown in Fig. 6. This information is needed for designing a control system. The curves indicate that apparent viscosity follows a typical pseudoplastic form. Shear rates below 10 s^{-1} appear to produce very measurable differences in puree viscosity and a process control viscometer shearing puree at a rate in or near this range would be expected to be a good sensing device.

Chemical, rheological and sensory differences between stored crop and fresh crop purees were significant ($P < 0.05$) for purees containing less than 50% enzyme-treated puree. From a practical standpoint this means that for a standard product to be produced that would not be influenced by whether the raw material was fresh or stored, the product would have to be based on puree containing 50% or more enzyme-treated puree.

CONCLUSIONS

THE COMPOSITION of the unhydrolyzed puree made from fresh crop sweet potatoes was different than unhydrolyzed puree from the stored crop. Decrease in alcohol insoluble solids showed that enzyme hydrolysis of the puree had an effect on the starch in both products. The difference in alcohol insoluble solids between the fresh crop and the stored crop became less as the percent of enzyme treated puree increased until the difference disappeared at about 75% hydrolyzed puree. The enzyme did not break the starch material into simple sugars.

Apparent viscosity was very sensitive to the variables of this study and should be useful for process control. Yield stress and apparent viscosity were much higher for unhydrolyzed fresh crop puree than for the unhydrolyzed stored crop. The flow properties of fresh and stored crop purees became similar as the amount of enzyme-treated material was increased and there were no differences at levels of enzyme-treated puree of 75% or higher.

Sensory data showed the textural properties of the fresh crop puree and stored crop puree were different but became similar as the percent of enzyme-treated puree was increased. At 50% or greater enzyme-treated material, the fresh crop and stored crop purees were indistinguishable.

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would seem that the probability of binding of negative ions to this protein would be less than for vicilin. This, in turn, would account for the more dramatic destabilizing response observed for vicilin in the presence of these salts.

With $CaCl_2$, the situation was different, as there was no indication of distinct responses for the two fababean proteins. In fact, only a single endotherm was observed until the protein was completely denatured (Fig. 4). There was, however, a change of only 4°C (94 to 90) in the Td value observed up to the addition of 2.0M $CaCl_2$. Beyond this concentration, no endotherm was observed. This relatively small change in Td values observed for the isolate, and hence a relatively minimal amount of destabilization, may not have been sufficient to give a detectable differential response for vicilin and legumin. Alternately, the binding of the divalent calcium cation may not have been different for the two proteins, despite their different electrostatic profiles.

Overall, structural variations in legumin and vicilin have contributed to their different responses in various salt and sucrose environments. In terms of food applications, this has some interesting implications. In products requiring heat treatments, elevated denaturation temperatures in the presence of some salts and sucrose would have to be considered if protein denaturation were a desired result. However, because of the separation of Td values for the two proteins, it would also be possible to denature only the vicilin protein by careful control of heating temperature. This could be an advantage if a partially denatured product were desired. Conversely, if a totally denatured protein were required, the heating temperature should be greater than the Td values of both legumin and vicilin in the environment present in the food system.

CONCLUSIONS

THE CONFORMATIONAL RESPONSES of the two major storage proteins in a fababean protein isolate varied with identity and concentration of the salt environment. Two different modes of interactions between salt and protein (possible electrostatic and lyotropic) were evident by the biphasic linear relationship between Td and μ for the stabilizing salts. With sucrose, on the other hand, the increase in stability was directly proportional to concentration. This was attributed to a single stabilization mechanism, possibly preferential hydration, being primarily responsible for the stabilization phenomenon. Ranking of various salts in terms of their relative stabilization potential was similar for the two proteins and, in fact, corresponded to the lyotropic series originally described by Hofmeister, plus that obtained in a study with isolated vicilin (Ismond, 1984). In some environments, the response of these two proteins, legumin and vicilin, were different; it was only in the presence of $CaCl_2$ and some concentrations of $Na_3C_6H_5O_7$ that a single endotherm was detected. This behavior has been related to the differences in responses to water availability as well as electrostatic profiles for the two proteins.

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ALPHA AMYLASE PROCESS FOR SWEET POTATO. . .From page 363

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