RELATIONSHIP BETWEEN INSTRUMENTAL AND SENSORY PARAMETERS OF COOKED SWEETPOTATO TEXTURE[1]

V.D. TRUONG, W.M. WALTER, JR.[2] and D.D. HAMANN

U.S. Department of Agriculture, Agricultural Research Service
North Carolina Agricultural Research Service
Department of Food Science
North Carolina State University
Raleigh, North Carolina 27695-7624

(Manuscript received July 26, 1996; accepted for publication January 2, 1997)

ABSTRACT

This study compared two instrumental methods, namely uniaxial compression and texture profile analysis (TPA), with sensory evaluation in describing the textural properties of cooked sweetpotatoes. The steamed cooked samples (1.35 × 2.2 cm cylinder) of four cultivars and six selections were subjected to a trained texture profile panel for sensory ratings and the two instrumental methods for determination of the mechanical properties. Factor analysis indicated that the 15 sensory variables were grouped into 3 main factors, namely moistness-firmness (factor 1), particles (factor 2), and fiber (factor 3). Among the instrumental parameters, shear stress of compression and fracturability, hardness, and gumminess of TPA correlated highly (R = 0.73–0.95) with both the mouthfeel and mechanical-type sensory notes. These parameters of the two instrumental methods were linearly related ($R^2 \geqslant 0.95$) and could be converted from one to another with a high degree of reliability. Regression equations based on shear stress significantly explained ($R^2 = 0.71$–0.91) eight of the sensory notes. These instrumental parameters can be good predictors of cooked sweetpotato texture.

[1]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or North Carolina Agricultural Research Service, nor does it imply approval to the exclusion of other products that may be suitable.

[2]Corresponding author. Telephone: 919-515-2990; fax: 919-856-4361; e-mail: wmwalter@ncsu.edu. Author Truong is with the Department of Food Science, NCARS, NCSU, Raleigh, NC 27695-7624; author Walter is with USDA-ARS and NCARS, NCSU, Raleigh, NC 27695-7624; author Hamann is now deceased.

Journal of Texture Studies **28** (1997) 163–185.

INTRODUCTION

Texture is an important quality attribute of many foods, including vegetables. It is an essential factor in consumers' perception of quality and has been a subject of research for several decades. For Irish potatoes, a great deal of research has been conducted to elucidate the causes of textural differences among cultivars and processed products (Anderson *et al.* 1994; McComber *et al.* 1994; Warren and Woodman 1974). Applications of instrumental methods for evaluating potato texture and their correlations with sensory data were studied (Diehl and Hamann 1979; Hughes and Grant 1975; Le Tourneau *et al.* 1962; Leung *et al.* 1983; McComber *et al.* 1987; Nonak and Timm 1983). However, only limited research of this type has been conducted on sweetpotatoes.

Cooked sweetpotatoes, have been arbitrarily classified into two major textural types. The "moist" or "yam" type has a soft, syrupy texture. At the other extreme is the firm, mealy texture, the "dry" type. This property describes the mouthfeel characteristics (Rao *et al.* 1974) and is independent of water content (Nelson 1973). Histological studies (Sterling and Aldridge 1977) indicated that mealiness in baked roots of dry sweetpotatoes was due to whole cell separation similar to that reported for white potato. These workers found that sogginess of baked roots of moist sweetpotatoes had a different cause in that the cells did not separate but both starch and cell wall tended to break down. Walter *et al.* (1975) reported that the moistness of baked sweetpotatoes was influenced by the extent of starch degradation by α-amylase.

Assessment of textural characteristics of sweetpotatoes by instrumental methods was conducted by several researchers. Sistrunk (1971) employed a shear press to detect differences in firmness of canned sweetpotatoes. Nelson (1973) used this method to differentiate the mouthfeel characteristics of baked sweetpotatoes. Apparent viscosity was recommended by Rao *et al* (1975) as a measure of the moist mouthfeel of sweetpotato puree. Rao *et al.* (1974) applied uniaxial compression tests on raw sweetpotatoes in an attempt to measure the kinesthetic quality of baked roots. Truong and Walter (1994) found that parameters of Texture Profile Analysis (TPA) described by Bourne (1978) were correlated with sensory texture attributes of restructured products from sweetpotato puree. The TPA parameters were useful in obtaining the optimal conditions for alginate texturization of puree into simulated baked sweetpotatoes (Truong *et al.* 1995). However, no attempt has been made to compare different instrumental methods to sensory evaluation in describing textural properties of cooked sweetpotatoes.

The objectives of the present study were to: (1) determine the textural characteristics of commercial and experimental sweetpotato cultivars/selections using a fundamental test (uniaxial compression) and an imitative test (TPA), (2) determine the sensory textural properties of these materials by a texture profile panel, and (3) to establish correlations between instrumental and sensory measurements.

MATERIALS AND METHODS

Ten commercial and experimental cultivars/selections of sweetpotatoes which have a wide range of textural properties, i.e., moist (soggy) to mealy (dry), were used in the experiment. 'Beauregard,' 'Hernandez' and 'Jewel' are the moist-type sweetpotatoes which are popular in the southern United States. Oriental yam, a typical Asian sweetpotato cultivar, was purchased from two batches in an Oriental food store. The six selections with designated accession numbers 10-28, 12-5, 2-26, 15-13, 6-30, and 8-22 were developed at the Department of Horticulture, North Carolina State University (NCSU). These selections were grown during the 1994 cropping season at the Horticultural Crops Research Station at Clinton, North Carolina (NC). The roots were cured and stored at 13–16C and 80–90% relative humidity for 8–10 weeks. Root size, specific gravity and visual flesh color of these cultivars are shown in Table 1. Informal assessment of the texture of cooked samples of these cultivars by a 5-member panel indicated that selections 6-30 and 8-22 were highly mealy, while oriental yam and 10-28, 12-5, 2-26, and 15-13 were intermediate between moist-mealy texture.

TABLE 1.
PHYSICAL PROPERTIES AND COOKING TIME OF SWEETPOTATO CULTIVARS

Texture type/cultivars	Flesh color	Root size: Weight (g)	Root size: Diameter (cm)	Cylindrical samples: Specific gravity	Cylindrical samples: Cooking time (min)
Moist (soggy)					
Beauregard	Orange	430-747	7.3-9.8	1.071-1.086	19
Hernandez	Orange	566-605	6.4-8.1	1.071-1.086	18
Jewel	Orange	327-593	5.7-8.5	1.071-1.086	20
Intermediate					
Oriental sweetpotato	Yellow	396-686	6.3-9.0	1.116-1.132	18
Acc. 10-28	Purple	258-628	5.8-9.3	1.116-1.148	17
Acc. 12-5	Orange	321-775	5.7-8.8	1.101-1.116	16
Acc. 2-26	Light yellow	205-420	6.8-8.9	1.101-1.132	13
Acc. 15-13	Yellow	376-742	7.8-10.7	1.101-1.116	17
Mealy (dry)					
Acc. 6-30	Yellow with purple streaks	394-695	6.8-11.2	1.132-1.164	16
Acc 8-22	White	141-435	5.4-8.6	1.116-1.158	12.5

Sample Preparation

A middle portion of each raw root was cut transversely to the long axis into a 3.5 cm thick slab. Using a no. 10 cork borer, five cylindrical samples (1.35 cm diameter) were taken from each slab and trimmed to a height of 2.2 cm. Samples were taken at the inner tissue of the roots at about $\leq$ 1 cm from the root skin. From each root, one cylinder was used for specific gravity determination, one for compression test, one for TPA, and two for sensory evaluation. Specific gravity was determined by immersion of the cylindrical samples in brine solutions. Preliminary experiments indicated that the values of instrumental parameters between different roots of the same cultivars normally exceeded the variability within the same root. For each cultivar, 25 roots were sampled per replication.

The cylindrical samples were washed with tap water to remove adhered starch and steamed in a kitchen-type food steamer (100C, atmospheric pressure). The cooking time for each cultivar is shown in Table 1. Steaming resulted in less sloughing (breakdown) than boiling. The cooked samples were kept in a closed container to avoid moisture losses and subjected to a uniaxial compression test, TPA and sensory evaluation on the day of preparation.

Sensory Evaluation

Sensory texture profiles were assessed by a six-member panel previously trained in profile methods of descriptive texture analysis (Brandt *et al.* 1963). The panel has been evaluating texture and flavor of various foods, including sweetpotatoes, during the last ten years. The panelists were trained specifically on steamed sweetpotatoes, following established guidelines (Civille and Szczesniak 1973) in three, 3-h training sessions on three consecutive days. The panel established texture notes and definitions (Table 2). Panelists practiced using the structured rating scale to quantify tested attributes and were provided feedback on their ratings. Scores for texture notes, except chewiness, were based on a 14-point descriptive intensity scale, with 1 indicating the lowest and 14 the highest score of an attribute. Panelists were provided water and unsalted crackers for rinsing and palate cleaning. All sessions were conducted in a climate-controlled sensory analysis laboratory.

The experiment was replicated two times in a randomized block design. Each panelist received 8 cylinders (1.35 $\times$ 3.5 cm) of steamed samples (40–50 g) per cultivar. Samples were presented in small plastic cups labeled with 3-digit random numbers. At each session, panelists evaluated two samples in random order. Samples of Oriental yam cultivar, prepared as described, was used as the reference standard.

TABLE 2.
TEXTURE PROFILE PANEL NOTES, PROCEDURE, AND DESCRIPTION FOR COOKED SWEETPOTATOES

I. Initial perception:
Lightly press the end of the sample to the lips and evaluate for: *Moistness (I-MOIST)* — degree to which the sample is moist
Press the sample between the lips and evaluate for: *Springiness (I-SPRIN)* — degree to which the sample returns to its original shape after deformation
Cohesiveness (I-COH) — degree to which the sample deforms before rupture

II. First bite:
Use a half of a sample, press the end to the roof of the mouth, using the tongue, and evaluate for:
Adhesiveness to palate (B-ADP) — the force required to remove the sample from the palate with the tongue
Bite with the front teeth and evaluate for:
Hardness (B-HARD) — amount of force necessary to bite completely through the sample
Denseness (B-DNS) — degree to which the sample is solid, compactness of the cross section
Moistness (B-MOIST) — degree to which the sample is moist

III. Mastication:
Chew at a constant rate of one chew per second and evaluate for:
Chewiness (M-CHEW) — number of chews required to prepare the sample for swallowing
Adhesiveness of the mass (M-ADHE) — degree to which the sample adheres or sticks to any of the mouth surfaces such as teeth, gums, palate
Moistness of mass (M-MOIST) — amount of moisture/wetness perceived in the mass
Fibers (M-FIBER) — amount of stringy fibers perceived

IV. Swallow-Residual:
At the time of and immediately after swallow evaluate for:
Ease of swallow (SEOS) — ease with which the sample is gatherred up and swallowed
Mouth coating (S-MCT) — amount of sample remaining in the mouth after swallow
Fibers (S-FIBER) — amount of stringy fibers perceived
Chalkiness (S-CHLK) — degree to which the mouth feels chalky; very fine particles, if present, often perceived on the roof of the mouth

Instrumental Tests

Uniaxial compression tests and TPA were performed using an Instron Universal Testing Machine (model 1122, Instron Inc., Canton, MA) fitted with a 500 N load cell with a plunger having a 5.7-cm diameter compression plate. The compression was along the longitudinal axis of the cylindrical specimen. All the tests were conducted at 25C and with a crosshead speed of 10 cm/min. Data collection and calculation were done with the aid of the TestWorks computer program (MTS Sintech Inc., NC). Mechanical parameters measured in uniaxial compression were compressive stress at failure, shear strain and shear stress at failure (Hamann 1983). For TPA, samples were compressed twice to 75% of their initial height. Fracturability, hardness, adhesiveness, cohesiveness, and gumminess were determined as described by Bourne (1978). Springiness is the recovered height of the sample after the compressive force is removed (Bourne 1978), and was calculated as the proportion of the compression distance recovered between the first and second compression (Montejano *et al.* 1985).

Chemical Analyses

After taking cylindrical samples for instrumental and sensory tests, the remaining tissue of the sweetpotato slabs without skin were cut into small pieces for chemical analyses. One half of the material was steam-cooked as indicated above. The other half was uncooked and used for dry matter determination. Dry matter, alcohol-insoluble solids (AIS), and sugars were measured as described in the previous report (Walter and Schwartz 1993).

Statistical Analysis

A completely randomized design was used. Data were analyzed using the Statistical Analysis System (SAS Institute 1988). Analysis of variance and means separations were calculated by the General Linear Models Procedure. Data on adhesiveness, cohesiveness, springiness, and chewiness were transformed into square root of $y + ½$ before being analyzed, where y is the measured value (Steel and Torrie 1980). Differences ($P \leqslant 0.05$) between treatment variables were evaluated by Least Square Means Procedures. Pearson correlation coefficients and canonical correlation analysis were performed using PROC CORR and PROC CANCORR, respectively. Factor analysis (PROC FACTOR) with varimax orthogonal rotation was used to determine the grouping of sensory variables. Multiple regression (PROC REG) was used to develop the second order equations of the full model which had linear, quadratic, and interaction terms of the independent variables. The terms which were found significant at $P \leqslant 0.05$ in the full model were retained in the reduced model. The final reduced model was one that was not significantly different from the full model at $P \leqslant 0.05$ as determined by the F-statistic (Neter *et al.* 1990).

RESULTS AND DISCUSSION

Changes in Firmness with Cooking Time

It was observed that the cooking time varied among cultivars/selections. In order to avoid overcooking of the material, cooking time for each was determined. Figure 1 shows the firmness changes, expressed as compressive force, occurring in cylindrical samples of cultivars 12-5 and 'Beauregard' during steaming. The firmness-steaming time curves of other cultivars had similar pattern. They all exhibited two distinct phases of firmness reduction in sweetpotato tissues during cooking. All samples were "cooked" at the end of phase 1. Our observations are in agreement with other reports on firmness loss of potato and carrots upon cooking (Mittal 1994; Nonaka 1980). In the subsequent experiments, the cooking time for a given sweetpotato cultivar was defined as the time corresponding to the inflection point of its firmness-steaming time curve. As indicated in Table 1, the cooking time appears to be longer for moist-type sweetpotatoes than for mealy cultivars.

Chemical Composition

Water evaporation during steaming resulted in a slight increase in dry matter content of the cooked samples of all cultivars/selections (Table 3). In general, the soggy cultivars, i.e. Beauregard, Hernandez and Jewel, had lower specific gravity, dry matter, AIS, and starch content than the mealy ones. Sugar composition varied significantly among the cultivars/selections. However, there was no apparent relationship between the sugar composition and textural properties.

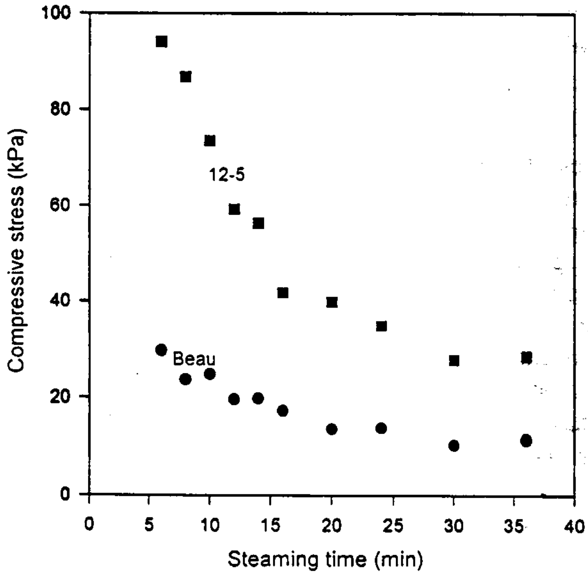

FIG. 1. EFFECT OF STEAMING TIME ON COMPRESSIVE STRESS OF SWEETPOTATO TISSUES (CULTIVARS BEAUREGARD AND 12-5)

TABLE 3.
CHEMICAL COMPOSITION (g/100 g FRESH WEIGHT) OF SWEETPOTATO CULTIVARS[a]

	Raw samples	Cooked samples					
Cultivar	Dry matter	Dry matter	AIS	Glucose	Fructose	Sucrose	Maltose
Moist (soggy)							
Beauregard	18.59G	18.91G	9.21H	1.28B	0.73B	1.29G	4.61E
Hernandez	21.08F	22.05F	10.94G	1.91A	0.97A	1.90EF	5.54D
Jewel	20.57F	21.53F	10.33G	0.76C	0.44C	3.12A	5.49DE
Intermediate							
Oriental SP	27.98C	28.66C	15.73D	0.49EF	0.48C	1.96E	8.50A
Acc. 10-28	26.65D	27.20D	14.36E	0.55DEF	0.50C	2.06EF	8.37A
Acc. 12-5	24.62E	25.02E	11.90F	0.62DE	0.44C	2.72B	7.43B
Acc. 2-26	29.90B	29.59B	18.09C	0.30G	0.22D	2.42CD	6.53C
Acc. 15-13	27.65C	26.94D	18.80B	0.68CD	0.46C	1.88F	4.14E
Mealy (dry)							
Acc. 6-30	30.63A	32.01A	18.17BC	0.37FG	0.25D	2.18DE	8.81A
Acc. 8-22	30.03AB	30.03B	25.58A	0.46F	0.46C	2.51BC	ND[b]
Coefficient of variability (CV,%)	1.9	2.1	3.0	12.3	10.7	9.3	10.4

[a]Means in the same column with a common letter are not significantly different (P <0.05).
[b]ND = not detectable.

It is interesting to note that no maltose was detected when selection 8-22 was cooked, indicating the absence of amylase activity (Takahata *et al.* 1994). Dry matter content was highly associated with AIS (r = 0.83). The results are in agreement with previous reports on sweetpotatoes (Truong and Nagahama 1994) and potatoes (Warren and Woodman 1974). However, chemical composition alone may not be sufficient to describe moistness or mealiness. For Irish potatoes, contradictory results on relationships between mealiness and specific gravity and dry matter content were reported (Anderson *et al.* 1994). Potato cultivars can differ in mealiness, even though their specific gravities are nearly equal (McComber *et al.* 1988; Nonaka and Timm 1983).

Compressive Strain and Stress

Under the uniaxial compression, we observed that the structural failure of raw sweetpotatoes was solely the shear fracture type (along 45° plane) for all cultivars/selections. Diehl and Hamann (1979) noted the same type of fracture upon com-

TABLE 4.
UNIAXIAL COMPRESSION PARAMETERS OF RAW AND COOKED SWEETPOTATOES[a]

	Raw samples		Cooked samples	
Cultivar	Strain	Stress (kPa)	Strain	Stress (kPa)
Moist (soggy)				
Beauregard	0.34B	1063.0D	0.25A	7.35E
Hernandez	0.34B	1317.9B	0.23BC	10.45D
Jewel	0.20E	824.9E	0.19EF	11.11D
Intermediate				
Oriental SP	0.25D	893.8E	0.20DE	20.39C
Acc. 10-28	0.29C	822.7E	0.23BC	19.36C
Acc. 12-5	0.33B	1152.9BC	0.25AB	27.60B
Acc. 2-26	0.42A	1301.6B	0.22CD	27.20B
Acc. 15-13	0.36B	1176.7C	0.20DE	25.84B
Mealy (dry)				
Acc. 6-30	0.29C	1419.5A	0.25AB	35.23A
Acc. 8-22	0.27CD	984.1D	0.18F	37.69A
CV (%)	17.7	13.7	15.9	23.6

[a]Means in the same column with a common letter are not significantly different ($P \leq 0.05$).

pression of raw Irish potatoes. This was also the fracture type for the cooked samples, especially the mealy selections studied. For the moist and intermediate cultivars/selections, aside from the shear fracture type being the main type of structure breakdown, a few samples exhibited a combination of shear and compression type fracture.

The results for compressive strain and stress at failure for raw and cooked sweetpotato samples are shown in Table 4. The values were significantly different between cultivars/selections. Steaming generally resulted in reduction in both shear strain and stress values of all cultivars. It is noted that the cultivars/selections seem to maintain their relative ranking for raw and cooked samples with regard to strain values, but not for stress values. A cultivar/selection with a high stress value in its raw form might fall into the low stress value group after cooking, and vice versa. This could be explained by the varietal differences in the magnitude of degradation of starch and cell wall substances during cooking. It is supported by a wide cultivar variation in the concentrations of maltose (Table 3), a product of starch hydrolysis during cooking of sweetpotatoes. Varietal differences in carbohydrate degradation during cooking which led to different textural properties among sweetpotato cultivars have been reported (Shen and Sterling 1981; Walter *et al.* 1975). Compression measurements on raw samples, therefore, may not be useful in predicting textural characteristics of cooked sweetpotatoes. As indicated in Table 4, there is no apparent relationship between the compression parameters of raw samples and moistness/mealiness of the sweetpotato cultivars. We are not in agreement with Rao *et al.* (1974), who reported correlation coefficients of 0.65–0.82 between maximal failure force upon compression of raw samples and mealiness sensory score of the purees made from baked roots of 8 sweetpotato cultivars. The sampling and sensory methods probably accounted for the discrepancy. In the study of Rao *et al.* (1974), sampling was limited to sweetpotato roots of approximately the same size (two roots per cultivar for each replication), and an untrained panel was used to evaluate the purees and the baked and ground material. In our study, we used 25 randomly selected roots per cultivar for each replication, and sensory tests were performed by a trained panel on the intact tissue of the cooked samples. In potatoes, mechanical properties of raw tubers did not provide satisfactory prediction of texture of the cooked products (Le Tourneau *et al.* 1962).

On the other hand, a strong association between stress values and moistness or mealiness of the cooked sweetpotatoes was noted (Table 4). The stress values of the cooked samples exhibited a distinct grouping of cultivars in association with their mealy and moist texture. The moist (Beauregard, Hernandez and Jewel) and mealy (6-30 and 8-22) cultivars are respectively grouped together at the bottom (low stress) and top (high stress) of the scale, while the intermediate cultivars are at the middle. In contrast, strain values did not reflect any differences between the three types, while within any one type, a significant difference in strain values existed (Table 4), indicating that other mechanical properties may be involved. Nevertheless, this texture scale could be useful in comparing the textural characteristics of sweetpotato cultivars or processed products with a reference cultivar or product.

Instrumental TPA

All TPA curves of the cooked samples of the ten sweetpotato cultivars exhibited distinct fracturability and hardness peaks which are similar to the TPA curves of baked sweetpotato roots reported previously (Truong and Walter 1994). The profiles were characterized by low adhesiveness, cohesiveness, springiness, and gumminess (Table 5). There were significant differences ($p \leq 0.05$) in all TPA parameters among the cultivars. Adhesiveness, cohesiveness and springiness seemed not to be associated with mealiness of the cultivars. However, fracturability, hardness and gumminess did appear to be related to mealiness. Mean values of these parameters increased with the increasing order in mealiness of the materials, from the moist cultivars, namely, Beauregard, Hernandez and Jewel, to the very mealy selections such as 6-30 and 8-22. These results are in agreement with shear stress of compression tests (Table 4) and sensory ratings of the taste panel (Table 6).

Sensory Texture Profile

The mean scores of texture notes evaluated by the trained panel are shown in Table 6. As indicated, the sweetpotato cultivars/selections selected for this study covered a wide range of textural parameter values. With regard to moistness, the panel ratings are in accordance with our preliminary grouping of the cultivars mentioned above. The moist cultivars (Beauregard, Hernandez and Jewel) were scored highest on moistness notes. The mealy selections such as 6-30 and 8-22

TABLE 5.
MEAN VALUES OF INSTRUMENTAL TEXTURE PROFILE PARAMETERS[a]

Cultivar	Fracturability (N)	Hardness (N)	Adhesiveness (mJ)	Cohesiveness (none)	Springiness (none)	Gumminess (N)
Moist (soggy)						
Beauregard	1.75F	3.08D	0.58A	0.04B	0.08C	0.12FG
Hernandez	2.37F	3.60D	0.56AB	0.06AB	0.14B	0.22EG
Jewel	2.30F	2.92D	0.59A	0.04B	0.15B	0.11FG
Intermediate						
Oriental SP	4.96E	5.91C	0.39C	0.04B	0.08C	0.26EG
Acc. 10-28	4.67E	6.33C	0.53AC	0.08A	0.12C	0.51BD
Acc. 12-5	5.90D	6.99BC	0.50AC	0.04B	0.11C	0.27DFE
Acc. 2-26	7.20C	8.09B	0.55AD	0.07A	0.20A	0.57ABC
Acc. 15-13	6.58CD	7.81B	0.49AC	0.06B	0.15B	0.45CDE
Mealy (dry)						
Acc. 6-30	9.48B	11.59A	0.44CB	0.06B	0.17AB	0.64ABC
Acc. 8-22	11.28A	11.39A	0.13E	0.08A	0.17AB	0.94A
CV (%)	12.2	13.7	13.1	9.5	6.0	9.1

[a]Means in the same column with a common letter are not significantly different ($P \leq 0.05$).

TABLE 6.
MEAN VALUES OF SENSORY TEXTURE NOTES FOR COOKED SWEETPOTATOES[a]

Sensory note	Beau-regard	Her-nandez	Jewel	Orien-tal SP	Acc. 10-28	Acc. 12-5	Acc. 2-26	Acc. 15-13	Acc. 6-30	Acc. 8-22	CV (%)
Initial perception											
I-MOIST	9.8A	8.6B	7.0C	4.9D	4.43DF	5.3D	4.6DF	3.7EF	3.8EF	2.5G	13.9
I-SPRIN	1.2C	1.6AB	1.3BC	1.0C	1.0C	1.2C	1.7A	1.0C	1.0C	1.0C	26.9
I-COH	8.3AB	9.4A	9.0A	7.4BC	5.3DE	6.3CD	6.0DE	4.7E	5.0DE	2.5F	19.2
First bite											
B-ADP	3.7E	4.1DE	4.5AC	5.9AC	5.9AC	5.5BCD	6.1ABF	6.1ABF	7.2A	4.7CEF	24.4
B-HARD	3.8D	4.1D	3.8D	5.9C	7.0B	7.5AB	7.9AB	7.7AB	8.3A	7.2AB	16.1
B-DNS	5.5E	6.4E	6.3E	8.1BD	8.7BC	7.5D	9.0B	8.7BC	10.2A	7.9CD	11.0
B-MOIST	9.7A	8.4B	9.5A	6.3C	5.7CE	6.2C	5.0DE	4.1D	4.5D	2.8F	14.8
Mastication											
M-CHEW	13.9E	15.1E	14.6E	19.1D	22.0BD	19.8CD	22.4BC	23.0BC	25.2AB	27.8A	14.8
M-ADHE	5.3E	7.6C	6.3D	8.4BC	8.3BC	6.7D	8.9B	9.1AB	9.0B	10.0A	10.0
M-MOIST	10.9A	9.1B	9.6B	6.9D	6.9D	7.9C	5.6E	5.3E	5.6E	3.4F	12.4
M-FIBER	3.5DEF	5.3A	4.8AB	4.0BCDF	3.0F	4.7AC	4.1BCDF	3.4F	3.8BCDF	4.2BCD	23.6
Swallow/Residual											
S-EOS	9.7A	8.9B	8.7B	7.1C	7.0C	7.4C	6.0E	5.0D	5.2DE	4.7D	10.3
S-MCT	6.3E	7.1DE	7.1DE	7.9CD	7.7CD	7.0CE	9.3B	9.4B	9.8AB	10.5A	10.0
S-FIBER	3.7B	5.3A	4.2AB	3.7B	3.6B	4.7AB	4.6AB	3.9B	4.0AB	4.7AB	24.5
S-CHLK	2.7EF	3.6DF	2.8EFG	4.0CDG	4.6BCD	3.17DE	4.6BCD	5.3AB	4.8BC	6.5A	25.8

[a]Means in the same row with a common letter are not significantly different ($P \leq 0.05$).

were scored lowest. The panel moistness scores of all cultivars/selections, except 15-13, associate very well with shear stress of the cooked samples (Table 4), and TPA fracturability and hardness values (Table 5). Panelists noted the variability in the color and texture among the 15-13 samples. This may explain the discrepancy in sensory moistness scores and instrumental values of this experimental cultivar.

It is noticeable that the scores for firmness, denseness, and chewiness notes (B-HARD, B-DNS, M-CHEW) were opposite to those for moistness (Table 6). The moist sweetpotatoes were soft, less dense and required fewer chews than the mealy selections. In contrast, the cohesiveness (I-COH) scores increased with increasing moistness, indicating the moist cultivars deformed more before rupture. This trend, however, was not detectable in compressive strain values (Table 4) which measure deformation of material at failure. The mealy samples deformed less and tended to break into small particles, which adhered to the mouth surface such as teeth, gums, and palate. This accounts for an increase in scores for adhesiveness notes (B-ADP, M-ADP) and chalkiness (S-CHLK) associated with increasing mealiness of the cultivars. It appears that the adhesiveness perceived by the panelists is not measuring the same properties as is the TPA adhesiveness. In fact, TPA adhesiveness values seem to decrease from the moist to mealy cultivars (Table 4).

Correlation Analysis

Sensory texture parameters having significant correlation coefficients among themselves are shown in Table 7. Most of the texture notes were highly correlated with others ($r \geqslant 0.90$), indicting that they do not vary independently. There are some common attributes which these values measure, and, as a result, they could be good predictors of each other. It should be possible to predict mouthfeel notes such as moistness by knowing the magnitude of mechanical-type parameters from sensory evaluation (I-COH, B-ADP, B-HARD, B-DNS, M-CHEW, M-ADHE) or instrumental measurements.

Factor analysis indicated that these sensory notes could be represented by four factors which accounted for 71.8% of data variance (Table 8). The rotated factor loadings pattern showed that factor 1 (F1) explained 32.2% of the variance in the data with moistness (I-MOIST, B-MOIST, M-MOIST) and firmness notes (B-HARD, B-DNS, M-CHEW) having the greatest absolute loadings. F1 may be named "moistness and firmness" factor. It is noted that moistness evaluated at different stages (initial perception, first-bite, mastication, and swallow) were closely related to each other. The panel scored this texture note consistently, regardless of the stage. Factor 2 (F2) explained 17.5% of the variance and encompassed measures on mastication adhesiveness, ease of swallow, mouth coating,

TABLE 7.

CORRELATION COEFFICIENTS AMONG SENSORY TEXTURE ATTRIBUTES[a]

	I-MOIST	I-COH	B-ADP	B-HARD	B-DNS	B-MOIST	M-CHEW	M-ADHE	M-MOIST	S-EOS	S-MCT
I-MOIST											
I-COH	0.88										
B-ADP	-0.72	-									
B-HARD	-0.86	-0.82	0.85								
B-DNS	-0.82	-0.67	0.96	0.9							
B-MOIST	0.94	0.94	-0.66	-0.90	-0.80						
M-CHEW	-0.93	-0.96	0.64	0.88	0.8	-0.98					
M-ADHE	-0.87	-0.78	-	0.72	0.78	-0.91	0.88				
M-MOIST	0.95	0.91	-	-0.83	-0.78	0.98	-0.97	-0.95			
S-EOS	0.95	0.91	-0.72	-0.88	-0.84	0.97	-0.96	-0.91	0.97		
S-MCT	-0.84	-0.83	-	0.73	0.74	-0.89	0.91	0.93	-0.94	-0.95	
S-CHLK	-0.84	-0.89	-	0.68	0.65	-0.92	0.92	0.95	-0.95	-0.91	0.93

[a]Correlation coefficients >0.78 are significant at P ≤0.01; coefficients >0.64 are significant at P ≤0.05; - = not significant.

TABLE 8.
ROTATED FACTOR LOADINGS OF THE SENSORY TEXTURE NOTES

	Factor			
Sensory note	F1	F2	F3	F4
Initial perception				
I-MOIST	0.78	-[b]	-	-
I-SPRN	-	-	-	-
ICOH	0.57	-	-	0.80
First-bite				
B-ADP	-0.45	-	-	-
B-HARD	-0.78	-	-	-
B-DNS	-0.67	-	-	-
B-MOIST	0.79	-0.41	-	-
Mastication				
M-Chew	-0.63	-	-	-0.40
M-ADHE	-0.46	0.75	-	-
M-MOIST	0.72	-0.59	-	-
M-FIBER	-	-	0.78	-
Swallow/Residual				
S-EOS	0.74	-0.50	-	-
S-MCT	-	0.76	-	-
S-FIBER	-	-	0.95	-
S-CHALK	-	0.53	-	-
Variance	4.83	2.62	1.75	1.58
CPVAP[a] (%)	32.2	49.7	61.3	71.8

[a]Cumulative proportion of variance accounted for = $\sum_{j=1}^{r} \lambda_j/p$, λ_j = unweighted variance of jth component, r = retained components, p = number of varibles.

[b]Loadings with absolute values less than 0.4 are not listed.

and chalkiness. These sensory notes described the fine particles which resulted from disintegration of cooked sweetpotato tissue during mastication and swallowing. F2 may be called "particles" factor. In factor 3 (F3), called "fiber" factor, fiber was the sole variable defining the factor, which accounted for 11.7% of the variance. It appears that fiber is not associated with other sensory characteristics of cooked sweetpotatoes. Factor 4 (F4) explained 10.5% of the variance. The I-COH and M-CHEW variables which define this factor were also correlated with moistness and firmness variables in F1.

The above pattern of interdependency of sensory texture notes is in accordance with that of baked sweetpotatoes reported by Syarief *et al.* (1985). The close interrelationships among sensory texture notes of fish, meat and egg white gels have also been reported (Hamann and Webb 1979; Montejano *et al.* 1985). In an earlier study, Henry *et al.* (1971) found some degree of redundancy among the 15 sensory texture attributes of semi-solid foods. They suggested that the attributes could be adequately represented by 4 factors, accounting for more than 90% of the original variance.

M-FIBER and S-FIBER were not correlated with shear stress at failure in uniaxial compression and TPA parameters (data not shown). Apparently, the fiber does not significantly contribute to the texture of cooked sweetpotatoes.

The relationships between the instrumental texture parameters, as indicated by their correlation coefficients, are shown in Table 9. Among the TPA parameters, cohesiveness and springiness were not correlated with the remaining parameters, and apparently are independent. Fracturability, hardness and chewiness were highly correlated ($r \geq 0.92$) with each other. It is interesting that these TPA parameters also correlated strongly with sensory notes (Table 10). This is in accordance with our previous report on instrumental and sensory evaluation of textural properties of sweetpotato puree texturized with cellulose gelling agents (Truong and Walter 1994). Woodman and Warren (1972) likewise reported a correlation of instrumental extrusive force and mealiness of canned potatoes. Leung

TABLE 9.

CORRELATION COEFFICIENTS AMONG INSTRUMENTAL PARAMETERS[a]

	Fracturability	Hardness	Adhesiveness	Cohesiveness	Springiness	Gumminess
Fracturability						
Hardness	0.99					
Adhesiveness	-0.77	-0.68				
Cohesiveness	-	-	-			
Springiness	-	-	-	-		
Gumminess	0.93	0.92	-0.7	0.8	0.63	
Shear strain	-	-	-	-	-	-
Shear stress	0.98	0.98	-0.69	-	-	0.87

[a]Correlation coefficients >0.847 are significant at $P \leq 0.01$; coefficients >0.63 are significant at $P \leq 0.05$; - = not significant.

et al. (1983) found a high correlation between TPA hardness or fracturability with sensory firmness, but not with mealiness scores of boiled potatoes (Leung *et al.* 1983). They postulated that hardness and mealiness are two independent attributes of potato texture.

TPA adhesivness and springiness were not highly correlated with sensory attributes (Table 10. Therefore, of the six TPA parameters, only fracturability, hardness and gumminess were highly correlated with sensory attributes. This also includes cohesiveness, since gumminess is, by definition, the product of cohesiveness and hardness (Bourne 1978).

Strain was not correlated with any TPA parameters (Table 9) nor sensory notes. This is not surprising because uniaxial compression measurements are based on deformation at failure, i.e. small strain, while mastication during sensory evaluation usually causes structural breakdown (Bourne 1975; Hamann and Diehl 1978). In contrast, stress was highly correlated with TPA fracturability, hardness and gumminess. It had a significant correlation with adhesiveness, but no correlation with cohesiveness and springiness of TPA (Table 9). It is interesting that stress had high correlation coefficients with most of the sensory texture notes including moistness (Table 10). The correlation coefficients for shear stress and sensory moistness during initial perception, first bite and mastication (r = 0.90–0.93)

TABLE 10.

CORRELATION COEFFICIENTS BETWEEN INSTRUMENTAL AND SENSORY TEXTURE PARAMETERS[a]

Sensory note	Fracturability	Hardness	Adhesiveness	Cohesiveness	Springiness	Gumminess	Shear stress
I-MOIST	-0.87	-0.86	0.64	-	-	-0.84	-0.90
I-COH	-0.91	-0.90	0.71	-0.63	-	-0.92	-0.89
B-ADP	-	0.67	-	-	-	-	0.66
B-HARD	0.83	0.87	-	-	-	0.77	0.89
B-DNS	0.73	0.80	-	-	-	0.71	0.77
B-MOIST	-0.93	-0.93	0.68	-0.64	-	-0.92	-0.93
M-CHEW	0.96	0.96	-0.70	0.66	-	0.96	0.95
M-ADHE	0.83	0.81	-0.65	0.74	-	0.88	0.78
M-MOIST	-0.93	-0.91	0.72	-0.67	-	-0.93	-0.91
S-EOS	-0.93	-0.93	-	-	-	-0.89	-0.93
S-MOIST	0.92	0.90	-0.65	-	0.75	-	0.86
S-CHLK	0.86	0.84	-0.75	0.79	-	0.94	0.79

[a]Correlation coefficients >0.63 are significant at P ≤0.05; coefficients >0.77 are significant at P ≤0.01; - = not significant.

were higher than the value (r = 0.75) for shear stress and mouthfeel scores of puree from baked sweetpotatoes reported by Nelson (1973).

High correlations between instrumental firmness parameters (fracturability, hardness, shear stress) and sensory cohesiveness (I-COH) which characterizes the disintegration of cooked sweetpotatoes in the mouth (Table 2) suggest that the predominant factor in firmness is how strongly the tissue is held together. This tends to support the measurement of compressive strength as an indicator of cell separation which is related to mealiness and sloughing of potato (Hughes and Grant 1975), tropical yam (Onayemi *et al.* 1987) and cassava (Eggleston and Asiedu 1994). However, according to Sterling and Aldridge (1977), starch and cell rupture rather than cell separation were observed in the moist-type sweetpotatoes after baking. Further studies on microstructure in relation to compressive strength and viscoelastic properties of cooked sweetpotatoes will be required to resolve this issue.

It appears that many sensory texture notes of cooked sweetpotatoes could be predicted by a few instrumental parameters, e.g. fracturability and gumminess of TPA or shear stress of uniaxial compression. Uniaxial compression with two parameters seems to be as good as TPA with six parameters. This is attested to by the high canonical correlation coefficients (adjusted $R^2 = 0.99$) among parameters from uniaxial compression, TPA and sensory evaluation. Canonical correlation analysis has been used to assess the overall relationship between two sets of parameters from two different types of tests. It is an exploratory tool to summarize the complex relationships of two sets of parameters in terms of a few variables (Johnson and Wichern 1992).

Regression Equations

Multiple regression analyses were performed to determine how well each parameter from one test could be predicted by one or more parameters from another test. The best selected regression equations ($R^2 \geqslant 0.70$) for instrumental and sensory parameters are presented in Table 11. Square root or logarithmic transformation of stress values were a contributory term only in the equations for moistness and ease of swallow.

As indicated by the results of the correlation analysis, no significant relationship could be established between shear strain and TPA parameters or sensory notes. In contrast, shear stress and TPA firmness parameters (fracturability, hardness and gumminess) were linearly related ($R^2 = 0.95$–0.99). The gumminess term appeared only in the stress-fracturability equation. Although TPA cohesiveness, by itself, did not appear in the equation, it contributed to the compression stress-TPA fracturability relationship via the gumminess term. Thus, we have demonstrated that parameters of TPA imitative test can be converted

TABLE 11.

BEST SELECTED REGRESSION EQUATIONS FOR INSTRUMENTAL AND INSTRUMENTAL PARAMETERS

Equation	R^2
Stress = -0.17 + 4.76 (fracturability) + 0.06 (gumminess) - 1.5 (fracturability) (gumminess)	0.99
Stress = 0.13 + 3.26 (hardness)	0.95
I-MOIST = 17.20 - 9.10 (log stress)	0.89
I-COH = 10.50 - 0.18 (stress)	0.78
B-ADP = 1.43 + 0.34 (stress) - 0.01 $(\text{stress})^2$	0.71
B-HARD = 0.32 + 0.45 (stress) - 0.01 $(\text{stress})^2$	0.91
B-MOIST = 17.95 - 9.10 (log stress)	0.89
M-CHEW = 3.18 + 3.76 $(\sqrt{stress})$	0.90
M-MOIST = 18.40 - 8.75 (log stress)	0.85
S-EOS = 13.34 - 1.40 $(\sqrt{stress})$	0.88

to fundamental parameters of uniaxial compression with a high degree of reliability.

Linear relationships were obtained between stress and eight sensory attributes including mechanical-type notes (hardness, chewiness, cohesiveness) and mouthfeel notes (moistness, ease of swallow). High R^2 values of the equations indicated that stress can account for most of the observed variability. Therefore, it is clear that shear stress of uniaxial compression appears to be a good predictor of sensory texture notes of cooked sweetpotatoes. Shear stress at failure in torsion was also found to be a good predictor of sensory texture of brittle materials such as fresh fruits and vegetables (Diehl and Hamman 1979). However, shear stress played a lesser role than shear strain in predicting the textural characteristics of viscoelastic protein gels (Montejano *et al.* 1985).

CONCLUSIONS

The sweetpotato cultivars selected for this study covered a wide range of textural properties. There was a significant variation in the chemical composition among the cultivars. Mealy cultivars tended to have higher dry matter, and AIS content than the moist ones. There was no apparent relationship between sugar composition and texture.

Sensory texture notes of cooked sweetpotatoes were interrelated and grouped into three main factors, namely moistness-firmness, particles and fiber. These attributes, including both the mouthfeel (moistness, ease of swallow, chalkiness) and mechanical-type notes (cohesiveness, hardness, denseness, chewiness, adhesiveness), were highly correlated (r = 0.73–0.95) with shear stress of uniaxial compression, as well as fracturability, hardness and gumminess of TPA. These instrumental parameters were linearly related and could be converted from one to another with a high degree of reliability. Regression equations based on shear stress significantly explained ($R^2 \geqslant 0.71$) eight of the sensory attributes. Apparently, these instrumental parameters can be used as a good predictor of the textural properties of cooked sweetpotatoes.

ACKNOWLEDGMENTS

We express our appreciation to Dr. Francis G. Giesbrecht, Dr. John Monahan, and Ms. Sandra B. Donaghy, Department of Statistics, for statistical advice and assistance in use of Statistical Analysis System. We also thank Ms. Michele D. Keziah for her help in sensory evaluation and Ms. Karina E. Sylvia for her technical assistance.

REFERENCES

ANDERSON, A., GEKAS, V., LIND, I., OLIVERIA, F. and OSTE, R. 1994. Effect of preheating on potato texture. Crit. Rev. Food Sci. Nutr. *34*(2), 229-251.

BOURNE, M.C. 1975. Texture measurements in vegetables. In *Theory, Determination and Control of Physical Properties of Food Materials*, (C.K. Rha, ed.) pp. 131–162. D. Reidel, Boston, MA.

BOURNE, M.C. 1978. Texture profile analysis. Food Technol. *32*, 62, 72.

BRANDT, M.A., SKINNER, E.Z. and COLEMAN, J.A. 1963. Texture profile method. J. Food Sci. *28*, 404–409.

CIVILLE, G.V. and SZCZESNIAK, A.S. 1973. Guidelines to training a texture profile panel. J. Texture Studies *4*, 204–223.

DIEHL, K.C. and HAMANN, D.D. 1979. Relationships between sensory profile parameters and fundamental mechanical parameters for raw potatoes, melons and apples. J. Texture Studies *10*, 401–420.

EGGLESTON, G. and ASIEDU, R. 1994. Effects of boiling on the texture of cassava clones: a comparison of compressive strength, intercellular adhesion and physicochemical composition of the tuberous roots. Trop. Sci. *34*, 259–273.

HAMMAN, D.D. and WEBB, N.B. 1979. Sensory and instrumental evaluation of material properties of fish gels. J. Texture Studies *10*, 117–130.

HAMANN, D.D. 1983. Structural failure in solid foods. In *Physical Properties of Foods* (M. Peleg, E.B. Bagley, eds.) pp. 351–383, AVI, Van Nostrand Reinhold/New York.

HENRY, W.F., KATZ, M.H., PILGRIM, F.J. and MAY, A.T. 1971. Texture of semi-solid foods: sensory and physical correlates. J. Food Sci. *36*, 155–161.

HUGHES, J.C. and GRANT, A. 1975. Texture of cooked potatoes. 4. Comparison of texture measured by compressive strength and a retained weight method. Potato Res. *18*, 237–242.

JOHNSON, R.A. and WICHERN, D.W. 1992. *Applied Multivariate Statistical Analysis*, 3rd ed., p. 459, Prentice Hall, Englewood Cliffs, NJ.

LE TOURNEAU, D., ZACHRINGER, M.V. and POTTER, A.L. 1962. Textural quality of potatoes. 2. An objective method for evaluating texture. Food Technol. *16*(10), 135–138.

LEUNG, H.K., BARRON, F.H. and DAVIS, D.C. 1983. Textural and rheological properties of cooked potatoes. J. Food Sci. *48*, 1470–1474, 1496.

MCCOMBER, D.R., HORNER, H.T., CHAMBERLIN, M.A. and COX, D.F. 1994. Potato cultivar differences associated with mealiness. J. Agric. Food Chem. *42*, 2433–2439.

MCCOMBER, D.R., LOHNES, R.A. and OSMAN, E.M. 1987. Double direct shear test for potato texture. J. Food Sci. *52*, 1302–1304, 1307.

MCCOMBER, D.R., OSMAN, E.M. and LOHNES, R.A. 1988. Factors related to potato mealiness. J. Food Sci. *53*, 1423–1426.

MITTAL, G.S. 1994. Thermal softening of potatoes and carrots. Lebensm. Wiss. Technol. *27*, 253–258.

MONTEJANO, J.G., HAMANN, D.D. and LANIER, T.C. 1985. Comparison of two instrumental methods with sensory texture of protein gels. J. Texture Studies *16*, 403–424.

NELSON, A.M. 1973. Shear press testing to define mouthfeel characteristics of baked sweetpotatoes. M.S. Thesis, North Carolina State University, Raleigh.

NETER, J., WASSERMAN, W. and KUTNER, M.H. 1990. *Applied Linear Statistical Models*, 3rd Ed., pp. 225–308, R.D. Irwin, Boston, MA.

NONAKA, M. 1980. The textural quality of cooked potatoes. 1. The relationship of cooking time to the separation and rupture of potato cells. Amer. Pot. J. *57*, 141–149.

NONAKA, M. and TIMM, H. 1983. Textural quality of cooked potatoes. 2. Relationship of steam cooking time to cellular strength of cultivars with similar and differing solids. Amer. Pot. J. *60*, 685-692.

ONAYEMI, O., BABALOLA, R.O. and BADANGA, A. 1987. Textural properties of cooked tropical yam (*Dioscorea* spp). J. Texture Studies *18*, 17–29.

RAO, V.N.M., HAMANN, D.D. and HUMPHRIES, E.G. 1974. Mechanical testing as a measure of kinesthetic quality of raw and baked sweetpotatoes. Trans. ASAE *17*(6), 1187–1190.

RAO, V.N.M., HAMANN, D.D. and HUMPHRIES, E.G. 1975. Apparent viscosity as a measure of moist mouthfeel of sweetpotatoes. J. Food Sci. *40*, 97–100.

SAS INSTITUTE, INC. 1988. SAS/STAT User's Guide. SAS Institute, Inc., Cary, NC.

SHEN, M.C. and STERLING, C. 1981. Changes in starch and other carbohydrates in baking *Ipomoea batatas*. Starch *33*, 261–268.

SISTRUNK, W.A. 1971. Carbohydrate transformations, color and firmness of canned sweetpotatoes as influenced by variety, storage, pH and treatment. J. Food Sci. *36*, 39–42.

STEEL, R.G.D. and TORRIE, J.H. 1980. *Principles and Procedures of Statistics*, 2nd Ed., pp. 235, 459, McGraw-Hill, New York.

STERLING, C. and ALDRIDGE, M.L. 1977. Mealiness and sogginess in sweetpotato. Food Chem. 2, 71–76.

SYARIEF, H., HAMANN, D.D., GIESBRECHT, F.G. and MONROE, R.J. 1985. Interdependency and underlying dimensions of sensory textural characteristics of selected foods. J. Texture Studies *16*, 29–52.

TAKAHATA, Y., NODA, T. and NAGATA, T. 1994. Effect of beta-amylase stability and starch gelatinization during heating on varietal differences in maltose content in sweetpotatoes. J. Agric. Food Chem. *42*, 2564–2569.

TRUONG, V.D. and NAGAHAMA, T. 1994. Evaluation of sweetpotato varieties for food uses in the tropics. In *Postharvest Biochemistry of Plant Food Materials in the Tropics*. (I. Uritani, V.V. Garcia and E.M.T. Mendoza, eds.) pp. 223–240, Japan Scientific Societies Press, Tokyo, Japan.

TRUONG, V.D. and WALTER, JR., W.M. 1994. Physical and sensory properties of sweetpotato puree texturized with cellulose derivatives. J. Food Sci. *59*, 1175–1180.

TRUONG, V.D., WALTER, JR., W.M. and GIESBRECHT, F.G. 1995. Texturization of sweetpotato puree with alginate: effects of tetrasodium pyrophosphate and calcium sulfate. J. Food Sci. *60*, 1054–1059, 1074.

WALTER, JR., W.M., PURCELL, A.E. and NELSON, A.M. 1975. Effects of amylolytic enzymes on "moistness" and carbohydrate changes of baked sweetpotato cultivars. J. Food Sci. *40*, 793–796.

WALTER, JR., W.M. and SCHWARTZ, S.J. 1993. Controlled heat processing of "Jewel" sweetpotatoes for puree production. J. Food Quality *16*, 71–80.

WARREN, D.S. and WOODMAN, J.S. 1974. The texture of cooked potatoes: a review. J. Sci. Food Agric. *25*, 129–138.

WOODMAN, J.S. and WARREN, D.S. 1972. Texture of canned potatoes: use of new objective methods to separate the attributes of mouthfeel and breakdown. J. Sci. Food Agric. *23*, 1067–1077.