J. F. SULLIVAN, R. P. KONSTANCE, M. J. CALHOUN, F. B. TALLEY, J. CORDING JR. and O. PANASIUK
USDA Eastern Regional Research Center, ARS, Philadelphia, PA 19118

# FLAVOR AND STORAGE STABILITY OF EXPLOSION-PUFFED POTATOES: Nonenzymatic Browning

## INTRODUCTION

NONENZYMATIC browning phenomena occur frequently during food processing and storage. In the majority of cases, this nonenzymatic browning is a distinct sign of a deterioration of the flavor and the nutritional value of the food in question (Braverman, 1963).

One of the major causes of the degeneration of flavor in dehydrated potato products is the Maillard reaction. This amino-carbonyl reaction of reducing sugars and amino acids results in the formation of 2-methylpropanal (2 MP) and 2- and 3-methylbutanal (2 + 3 MB), the Strecker degradation aldehydes, as well as many other volatile compounds.

This formation of these Strecker aldehydes in explosion-puffed potato dice is accelerated in the puffing gun where the browning precursors are exposed to favorable reaction conditions (i.e., high temperature, low moisture content). This acceleration of browning during puffing was evidenced by the characteristic browning odor (burnt and toasted) and was further substantiated by gas-liquid chromatography (Sapers et al., 1970, 1971).

The explosion puffing process relies upon steam condensation, under high pressure-high temperature conditions, to create an expanded potato piece. The energy supplied by this condensation superheats the water in the individual pieces. When the pressure is released the water within the dice is flashed and a porous structure is created (Turkot et al., 1967). This porous structure remains intact during the final dehydration step allowing rapid drying and permitting a much more rapid penetration of water upon rehydration (Eisenhardt et al., 1962).

Research done by Cording and Sullivan (1973), indicates that dilution of the superheated steam with a noncondensable gas (2:1 steam to gas) in the puffing system is effective in inhibiting the formation of the browning aldehydes during the puffing operation.

The present paper compares the relative amounts of 2 + 3 MB in potatoes under storage that have been (1) conventionally processed, (2) puffed with superheated steam alone and (3) puffed with a superheated steam/nitrogen mixture. The lack of quantitative organoleptic data in this study necessitated a second storage test.

This subsequent storage study examines the development of the Strecker aldehydes in high and low sugar potatoes by means of chromatographic analyses and organoleptic evaluations. Hexanal, which develops due to the autoxidation of potato lipids, was also found. Its development was followed throughout the storage periods because of the rancid flavor it imparts to the potato dice. The control of this off-flavor will be the subject of a later study.

**Table 1—Sugar contents of raw potatoes**

| g/100g, MFB | Kennebec | | Russet Burbank | |
|---|---|---|---|---|
| | High | Low | High | Low |
| Glucose | 2.688 | 0.380 | 3.000 | 0.800 |
| Fructose | 2.872 | 0.820 | 3.842 | 1.610 |
| Sucrose | 3.355 | 1.010 | 2.548 | 1.250 |

## EXPERIMENTAL

TYPICAL COMMERCIAL processing varieties of potatoes were used for both storage tests: (a) Test #1, Idaho Russet Burbank; (b) Test #2, Maine Kennebec and Maine Russet Burbank.

The potatoes were submerged in a 20% (by weight) caustic solution to loosen outer skins. These skins were then removed by a rotary washer with high pressure water jets. Trimming to remove rot, sunburn and other blemishes, was followed by a 1/2% sodium bisulfite, 1/2% citric acid dip to prevent enzymatic browning. This dip was applied each time a new surface of potato was exposed. The potatoes were then cut into nominal 3/8 in. cubes and traversed over a 3/16 in. shaker screen to provide a fraction of more uniform size. The dice were washed thoroughly to remove surface starch. Precooking at 71°C for 15 min and cooling (Cording et al., 1955, 1959) in cold water (< 21°C) for 10 min preceded a 15 min atmospheric steam blanch. The dice were then dipped in a 1/4% $NaHSO_3$-1/4% $Na_2SO_3$ solution for 1 min to control nonenzymatic browning during the drying cycle. The potato dice were dried to 25–30% moisture in a batch through-flow air drier at 93°C. Equilibration at 23°C for an 18–24 hr period to insure a uniform moisture distribution within and among dice was the last step before explosion puffing.

### Storage test #1

Idaho Russet Burbank potatoes were processed in this test. After initial processing (as above) the partially dried potatoes were separated into three fractions. The first fraction was conventionally air dried to 4.5% moisture. The second fraction was explosion-puffed with superheated steam alone. The third fraction was explosion-puffed in a superheated steam/nitrogen mixture (2:1 steam to $N_2$).

After puffing, the potatoes were placed in a hot air, through-flow tray drier and dried at 66°C to 3–4% moisture. All material was then packed under nitrogen (less than 2% $O_2$) or air atmospheres in 211 × 414 cans, 120g/can and stored at −18 and 23°C.

### Storage test #2

Evaluations of both high and low sugar level Maine potatoes were made in this test. Due to the low sugar level of the potatoes half was processed upon receipt. The remaining half was stored at 3°C for 12 wk to increase the sugar content. Sugar levels appear in Table 1.

The potato dice were explosion-puffed in a superheated steam/nitrogen mixture (2:1 steam to $N_2$) and dried.

Samples were packed under air and nitrogen atmospheres in 211 × 414 cans and stored at −18°C, 23°C and 38°C. Samples were analyzed by two methods concurrently: (a) gas liquid chromatography and (b) organoleptic evaluations.

### Chromatographic analyses

Head space vapor analyses by gas-liquid chromatography were used to measure the volatiles above the reconstituted product (Sapers et al., 1970). Results were recorded as ratios of the areas of 2 + 3 MB and hexanal to the area of the internal standard, ethylbutyrate. 2 MP results were not reported due to inaccuracies resulting from the coincidence of the 2 MP and acetone retention times (Sapers, 1970).

### Organoleptic evaluations

Sensory evaluations were accomplished by the use of a modified Kramer test (Kramer and Twigg, 1962) in which each sample was compared with a standard and judged accordingly. The modification consists of an additional category in the "better than standard" range. The scoring system was as follows:

(a) Less than 4, decreasingly worse than standard (i.e., score of 1, which is the lower limit, indicates the sample is "very much worse" than the standard).

(b) Equal to 4, same as standard.

(c) Greater than 4, increasingly better than standard (i.e., a score of 6, which is the upper limit, indicates the sample is "much better" than the standard).

All samples were rehydrated until tender and riced to minimize textural differences. They were served in small, odor free, aluminum dishes and presented to a trained panel averaging 15 members. Colored lights were used during tasting to mask any color difference in the samples. The data were treated statistically by an analysis of variance and a multiple range test (Duncan, 1955).

### Product acceptability

Potatoes were prepared with a bland cream

Table 2—Storage test #1: Idaho Russet Burbank air and $N_2$ pack

| Time (Months) | °C Temp | Comp. | Air | | | $N_2$ | | |
|---|---|---|---|---|---|---|---|---|
| | | | Processing condition | | | | | |
| | | | Conv. | Steam Puff | Steam/$N_2$ Puff | Conv. | Steam Puff | Steam/$N_2$ Puff |
| | | | Mean peak area ratio[a] | | | | | |
| 1 | −18°C | 2 + 3 MB | 0.092 | 0.519 | 0.226 | 0.080 | 0.483 | 0.236 |
| | | Hexanal | 0.075 | 0.097 | 0.113 | 0.095 | 0.112 | 0.087 |
| | 23°C | 2 + 3 MB | 0.118 | 0.524 | 0.235 | 0.117 | 0.507 | 0.220 |
| | | Hexanal | 0.083 | 0.130 | 0.085 | 0.074 | 0.086 | 0.089 |
| 8 | −18°C | 2 + 3 MB | 0.100 | 0.519 | 0.191 | 0.090 | 0.513 | 0.164 |
| | | Hexanal | 0.119 | 0.393 | 0.202 | 0.052 | 0.210 | 0.058 |
| | 23°C | 2 + 3 MB | 0.124 | 0.622 | 0.260 | 0.108 | 0.583 | 0.238 |
| | | Hexanal | 0.718 | 1.690 | 1.370 | – | 0.067 | 0.105 |

[a] Mean peak area ratio—area aldehyde peak/area internal standard peak

sauce and rated by a minimum of 45 untrained tasters. The samples were presented as a single stimulus and scored on a standard 9-point hedonic scale (Peryam and Pilgrim, 1957).

## RESULTS & DISCUSSION

### Storage test #1

In this test, chromatographic measurements of the development of 2 + 3 MB and hexanal were made for potato dice processed under three different techniques: (a) Conventional processing; (b) Explosion puffing (steam only); and (c) Explosion puffing (steam/$N_2$ mixture).

Examination of the initial formation of the Strecker aldehydes (see Table 2—1 month) revealed that the conventionally processed material had the least amount of 2 + 3 MB. In order of increasing aldehyde formation the processes are conventional, explosion puff (steam/$N_2$) and finally explosion puff (steam only).

It should be noted that under the storage conditions set, there is no significant increase in the browning aldehydes with respect to time.

In air packed samples (Table 2), however, the aldehyde, hexanal, resulting from the autoxidation of potato lipids, increased rapidly when stored at 23°C with all processing techniques.

There was a substantial decrease in the initial formation of 2 + 3 MB when a steam/$N_2$ mixture was employed during puffing rather than steam alone. This decrease is meaningful only if the off-flavor imparted by these components is below the taste threshold level and remains so for a reasonable period of time in storage.

Taste evaluations of the samples were made monthly. The browning off-flavor was detected in the steam-puffed product by 75% of a group of 10—15 judges while the material puffed in a steam/$N_2$ mixture had no detectable browning flavor during the 8-month storage. A rancid flavor, which can be attributed to the formation of hexanal, was noted in the 23°C air-pack samples within the first 3 months of storage.

These taste evaluations cannot be presented as quantitative data because panel membership and training had not been completed. Training sessions were held in preparation for the second storage test.

### Storage test #2

In order to substantiate the "below threshold levels" of the browning in steam/$N_2$ puffed potato dice, a second storage test was initiated. In addition to chromatographic analyses, organoleptic evaluations were made monthly by 15 trained taste panelists. Maine Kennebecs and Maine Russet Burbanks were studied at both high and low sugar levels. All samples were compared to a control which was stored at −18°C under a nitrogen atmosphere. Under these conditions, potato dice remained stable with regard to browning and autoxidation throughout the storage period (see Tables 3—6).

### Analytical results

**High sugar.** Samples of both varieties stored at 23°C under air or nitrogen atmospheres remained stable with regard to 2 + 3 MB throughout their respective storage periods (see Tables 3 and 4). An increase in hexanal was noted in the air-packed samples almost immediately. The increase of this component was dramatic after only 2 months storage (Table 3).

Samples stored at 38°C were canned in a nitrogen atmosphere. Significant increases in 2 + 3 MB were seen after storage for 1 month (see Tables 3 and 4).

**Low sugar.** Under all storage conditions, low sugar samples exhibit lower initial levels of 2 + 3 MB than their high sugar counterparts. The Strecker degradation aldehyde remains stable throughout the storage period regardless of storage

Table 3—Maine Kennebec high sugar

| Storage condition | Comp. | Time in storage (months) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 2 | 3 | 5 | 12 |
| | | Mean peak area ratio[a] | | | | |
| −18°C, $N_2$ | 2 + 3 MB | 0.210 | 0.216 | 0.194 | 0.270 | – |
| | Hexanal | 0.027 | 0.028 | 0.026 | 0.082 | – |
| | Taste[b] | 4.00 | 3.93 | 4.00 | 4.21 | 3.87 |
| 23°C, $N_2$ | 2 + 3 MB | 0.210 | 0.244 | 0.292 | 0.296 | – |
| | Hexanal | 0.027 | 0.030 | 0.033 | 0.100 | – |
| | Taste[b] | 4.00 | 4.15 | – | 4.08 | 3.87 |
| 23°C, Air | 2 + 3 MB | 0.210 | 0.270 | 0.261 | 0.291 | – |
| | Hexanal | 0.027 | 0.222 | 0.395 | 0.565 | |
| | Taste[b] | 4.00 | 3.69 | 3.44[c] | 2.92[c] | 2.47[c] |
| 38°C, $N_2$ | 2 + 3 MB | 0.210 | 0.646 | 0.670 | 0.794 | – |
| | Hexanal | 0.027 | 0.032 | 0.024 | 0.043 | – |
| | Taste[b] | 4.00 | 3.40[c] | 3.36[c] | 3.14[c] | – |

[a] Mean peak area ratio—area aldehyde peak/area internal standard peak
[b] Taste score as per Kramer and Twigg, 1962
[c] Indicates a confidence level of 95% or greater relative to control at same storage time

Table 4—Maine Russet Burbank high sugar

| Storage condition | Comp. | Time in storage (months) | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 3 | 12 |
| | | Mean peak area ratios[a] | | | |
| −18°C, $N_2$ | 2 + 3 MB | 0.513 | 0.542 | 0.516 | – |
| | Taste[b] | 4.09 | 4.36 | 4.06 | 4.07 |
| 23°C, $N_2$ | 2 + 3 MB | 0.513 | 0.558 | 0.599 | – |
| | Taste [b] | 4.09 | 4.21 | 3.88 | 3.87 |
| 23°C, Air | 2 + 3 MB | 0.513 | 0.486 | 0.578 | – |
| | Taste[b] | 4.09 | 4.14 | 3.25[c] | 2.67[c] |
| 38°C, $N_2$ | 2 + 3 MB | 0.513 | 1.005 | 1.248 | – |
| | Taste[b] | 4.09 | 3.50[c] | 3.43[c] | – |

[a] Mean peak area ratio—area aldehyde peak/area internal standard peak
[b] Taste scores as per Kramer and Twigg, 1962
[c] Indicates confidence level of 95% or greater relative to control at same storage time

Table 5—Maine Kennebec low sugar

| Storage condition | Comp. | Time in storage (months) 1 | 4 | 6 | 12 |
|---|---|---|---|---|---|
| | | Mean peak area ratios[a] | | | |
| | 2 + 3 MB | 0.107 | 0.122 | 0.114 | – |
| −18°C, $N_2$ | Hexanal | 0.064 | 0.092 | 0.105 | – |
| | Taste[b] | 4.00 | 4.05 | 4.12 | 3.92 |
| | 2 + 3 MB | 0.130 | 0.132 | 0.158 | – |
| 23°C, $N_2$ | Hexanal | 0.083 | 0.102 | 0.112 | – |
| | Taste[b] | 4.13 | 3.94 | – | 3.62 |
| | 2 + 3 MB | 0.129 | 0.134 | 0.131 | – |
| 23°C, Air | Hexanal | 0.461 | 1.276 | 1.170 | – |
| | Taste[b] | 3.19[c] | 2.72[c] | 3.00[c] | 2.62[c] |
| | 2 + 3 MB | 0.178 | 0.273 | 0.316 | – |
| 38°C, $N_2$ | Hexanal | 0.048 | 0.047 | 0.051 | – |
| | Taste[b] | 3.80 | 4.06 | 4.00 | – |

[a] Mean peak area ratio—area aldehyde peak/area internal standard peak
[b] Taste scores as per Kramer and Twigg, 1962
[c] Indicates confidence level of 95% or greater relative to control at same storage time

Table 6—Maine Russet Burbank low sugar

| Storage condition | Comp. | Time in storage (months) 1 | 3 | 6 |
|---|---|---|---|---|
| | | Mean peak area ratios[a] | | |
| −18°C, $N_2$ | 2 + 3 MB | 0.230 | 0.256 | 0.279 |
| | Taste[b] | 4.00 | 4.13 | 3.82 |
| 23°C, $N_2$ | 2 + 3 MB | 0.244 | 0.285 | 0.340 |
| | Taste[b] | 4.00 | 4.07 | 3.80 |
| 23°C, Air | 2 + 3 MB | 0.261 | 0.291 | 0.294 |
| | Taste[b] | 3.79 | 3.07[c] | 3.07[c] |
| 38°C, $N_2$ | 2 + 3 MB | 0.403 | 0.592 | 0.801 |
| | Taste[b] | 3.67 | 4.13 | 4.06 |

[a] Mean peak area ratio—area aldehyde peak/area internal standard peak
[b] Taste scores as per Kramer and Twigg, 1962
[c] Indicates a confidence level of 95% or greater relative to control at same storage time

temperature or atmosphere (see Tables 5 and 6).

### Organoleptic evaluations

All air-packed samples, regardless of variety or sugar content, showed rapid development of a rancid flavor (hexanal). This off-flavor was detectable after 1–3 months storage at a 95% or higher confidence level. After the third month the flavor scores remained relatively constant (Tables 3–6).

Samples stored at 23°C under a nitrogen atmosphere, did not, in any case, exhibit a flavor change.

At 38°C high sugar Maine Kennebecs (Table 3) showed a rapid decrease in flavor scores within the first 2 months of storage. The developing flavor was described as "toasted" or "burnt," indicating browning. The low sugar Kennebecs (Table 5) showed no significant change in flavor throughout the experiment.

### Product acceptability

Potato dice, stored at 23°C were rehydrated, drained and added to a bland cream sauce and served warm to 45 untrained tasters, at the beginning and the end of the storage test to obtain judgments of acceptability as a prepared food. Results of this test indicate that the ratings given were not affected by air or $N_2$ pack, high or low sugar level, or age of the product. Scores averaged between 6.8 and 7.4 on a 9-point hedonic scale. These scores fall in the "like slightly" to "like moderately" range. It is realized that a panel so small cannot provide a positive judgement of quality; however, a trend can be indicated.

## CONCLUSIONS

THE ANALYTICAL and organolpetic data are parallel under all conditions and these data indicate that low sugar potatoes are most suitable for explosion-puffing. The relationship between sugar content and initial 2 + 3 MB levels is evident. Comparison of these factors shows that in all cases a higher sugar content yields greater quantities of the Strecker aldehyde.

The use of a steam/$N_2$ mixture in explosion puffing is an effective method of retarding initial development of 2 + 3 MB. With the exception of 38°C, high sugar samples, the 2 + 3 MB levels remain relatively stable throughout storage.

Although the $N_2$ packing atmosphere effectively retards the autoxidation of potato lipids, further research into a more practical means of controlling this autoxidation is presently under study.

## REFERENCES


Braverman, J.B.S. 1963. Nonenzymatic browning. In "Introduction to the Biochemistry of Foods," p. 302. Elsevier Publishing Co., New York.

Cording, J. Jr., Willard, M.J. Jr., Eskew, R.K., Edwards, P.W. and Sullivan, J.F. 1955. Potato flakes. A new form of dehydrated mashed potatoes. 2. Some factors influencing texture. U.S. Dept. of Agriculture, Agricultural Research Service, ARS 73-9.

Cording, J. Jr., Sullivan, J.F. and Eskew, R.K. 1959. Potato flakes. A new form of dehydrated mashed potatoes. 4. Effects of cooling after precooking. U.S. Dept. of Agriculture, Agricultural Research Service, ARS 73-25.

Cording, J. Jr. and Sullivan, J.F. 1973. Retarding the browning reaction in the explosion-puffing of potato pieces. Food Eng. Accepted for publication.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics 11: 1.

Eisenhardt, N.H., Cording, J. Jr., Eskew, R.K. and Sullivan, J.F. 1962. Quick-cooking dehydrated vegetable pieces. 1. Properties of potato and carrot products. Food Technol. 16(5): 143.

Kramer, A. and Twigg, B.A. 1962. Taste testing. In "Fundamentals of Quality Control for the Food Industry," p. 123. Avi Publishing Co., Westport, Conn.

Peryam, D.R. and Pilgrim, F.J. 1957. Hedonic scale method of measuring food preference. Food Technol. 11(4): Insert, p. 32.

Sapers, G.M. 1970. Flavor quality in explosion puffed dehydrated potato. 2. Flavor contribution of 2-methylpropanal, 2-methylbutanal and 3-methylbutanal. J. Food Sci. 35: 731.

Sapers, G.M., Sullivan, J.F. and Talley, F.B. 1970. Flavor quality in explosion puffed dehydrated potato. 1. A gas chromatographic method for the determination of aldehydes associated with flavor quality. J. Food Sci. 35: 728.

Sapers, G.M., Osman, S.F., Dooley, C.J. and Panasiuk, O. 1971. Flavor quality of explosion puffed dehydrated potato. 3. Contribution of pyrazines and other compounds to the toasted off-flavor. J. Food Sci. 36: 93.

Turkot, V.A., Sullivan, J.F., Cording, J. Jr., Eskew, R.K. and Heiland, W.K. 1967. Explosion puffed dehydrated potatoes. 3. Estimated cost of commercial production using shortened cycle. U.S. Department of Agriculture, Agricultural Research Service, ARS 73-55.



Ms received 6/23/73; revised 8/21/73; accepted 8/24/73.

Presented at the 33rd Annual Meeting of the Institute of Food Technologists in Miami Beach.

The authors acknowledge N.C. Aceto, Chief, Engineering & Development Lab.; E.S. DellaMonica, Research Leader, Product Analysis; G.M. Sapers, Research Leader, Fruit & Vegetable Technology; and C. Ross and B.S. Clark, Technicians, of this Laboratory for their invaluable assistance in this storage study.