Dehydrated Blueberries by the Continuous Explosion-Puffing Process

J. F. SULLIVAN, J. C. CRAIG Jr., E. D. DEKAZOS, S. M. LEIBY, and R. P. KONSTANCE

ABSTRACT

A blueberry dehydration process which includes the unique continuous explosion-puffing system (CEPS) is described. A drying study including alternate drying pretreatments failed to increase the dehydration rate. It was found that care during processing was necessary to prevent rupture of the berries as rupture caused bleeding during drying which reduced the drying rate. Optimum operating conditions for CEPS were established for blueberries. Measurements of dried blueberry properties such as bulk density, color, rehydration, and disintegration were used to determine optimum operating conditions for pressure (103 kPa), temperature (190°C), and feed moisture (18.5%) for CEPS.

INTRODUCTION

THE FIRST HIGHBUSH cultivar was released in 1920 (Draper, 1979); since then blueberries have become a major fruit crop in the United States. Blueberries are high in iron and manganese (Hope, 1965) and their vitamin content equals or exceeds that of most fruits (USDA Handbook #8, 1963). Qualities such as disease resistance, plant vigor, high production, and suitability to machine harvest have encouraged growers to process blueberries.

The technology of blueberry processing is limited. Most of the crop is freeze-packed. Excepting a minuscule portion which is dried. In an early drying study, berries took 13 hr to dry (Friar and Mrak, 1943). Eidt apparently reduced the drying time to 4 hr by using a hot lye dip (Eidt et al., 1944). Batch explosion-puffing of high bush blueberries created rapid drying and quick rehydrating blueberries (Eisenhardt et al., 1964; 1967). Because batch processing was costly and labor intense, the continuous explosion-puffing system (CEPS) was developed (Heiland et al., 1977). Potatoes, carrots, and apples have been successfully processed in CEPS (Sullivan et al., 1977, 1980, 1981).

The blueberry crop of 1980 was about 45,000 metric tons, of which 1/3 was frozen for later use in pies, tarts, or other baked goods and desserts. Frozen storage life is limited to 6 months or less because of a textural problem, that of woodiness or grittiness which has plagued growers and processors. One of the authors (Dr. Dekazos) testing explosion-puffed dried blueberries, found that this problem did not develop when these berries were put in storage (Dekazos, 1980). Other favorable characteristics of the explosion-puffed product are excellent flavor and color, fast rehydration, ambient temperature storage, minimal storage and transportation costs, and durability.

The purpose of our experiments was to adapt the explosion-puffing process to the "Rabbiteye" blueberry species, particularly the Tifblue variety, and to optimize the continuous explosion-puffing system (CEPS) for blueberry processing.

Authors Sullivan, Craig, and Konstance are with the USDA Eastern Regional Research Center, Agricultural Research Service, 600 E. Mermaid Lane, Philadelphia, PA 19118. Author Leiby is a Student Co-op from Drexel University, Philadelphia, PA. Author Dekazos is with the USDA-SEA-AR Richard B. Russell Research Center, Athens, GA 30604.

The Rabbiteye blueberry is a species native to the Southeast and is high in flavor and palatability. The crop has not been firmly established for freezing or canning. Breeding experts believe that the Rabbiteye offers the greatest potential for future expansion of the blueberry industry (Eck and Childers, 1967). Explosion-puffing was applied to Rabbiteye blueberries to enhance the economic value of the crop by adding another and better processing possibility. The Tifblue variety, which we studied, was introduced in 1955 and is a medium large berry with high dessert quality.

EXPERIMENTAL

TIFBLUE, Rabbiteye blueberries (a commercial variety) grown in Georgia (1978 crop, moisture 82.4% (wet basis)) were used in all experiments. The blueberries were washed and for more uniform drying were size separated with a pneumatic winnower. No other preprocessing was required. In addition, unlike most fruit processing, sulfiting was not needed, as nonenzymatic browning remained minimal during dehydration. The raw and processed berries were evaluated for moisture content, bulk density, color difference, and selected minerals.

Drying studies

An effort was made to increase the drying rate of blueberries. Experiments were made in which the blueberries received the following predrying treatments: (1) two separate 0.2% lye dips at 93.3°C were made, one at 4 and one at 8 sec, respectively; (2) a mild detergent wash at 24°C; (3) a steam blanch; and (4) no treatment. After the pretreatments, each test lot was dried in the continuous belt dryer (Anon., 1963). The drying conditions for these experiments were: air velocity 2.4 m/s; direction of air flow—downward through the bed; dry bulb temperature 82°C; wet bulb temperature 33°C; belt speed 1.44 m/hr; bed depth entering dryer 5 cm; and a feed rate of 33 kg/hr to a 0.6 m-wide dryer belt.

In the study, the rate of steam required to dry blueberries from about 85% to 19% moisture in a continuous dryer was determined and these dried berries were later used for the optimization study. For the drying study, the steam condensate from the air heating coils was passed through a chilled exchanger and weighed. The drying conditions were the same with one exception; air velocity was increased from 2.4 to 3.0 m/sec. Five hundred twenty-five kg of blueberries were dried in three batches of about 175 kg each.

Optimization of the continuous explosion-puffing system (CEPS)

Optimization of CEPS was achieved by determining the effect of feed moisture, internal pressure, and temperature on the puffing of partially dried berries, reflected in the final product. These blueberries were partially dried to four experimental moistures, approximately 120 pounds at each moisture (Table 1). An experimental design of 36 conditions, including four moisture levels (12.5–24.0%), three pressure levels (103–172 kPa), and three temperature levels

Table 1—Experimental conditions for optimization tests

Moisture (%)	Pressure (kPa)	Temp (°C)
12.4	103	149.0
17.5	138	165.5
21.2	172	188.0
23.7		

(145–192°C), were used (Table 1). The design was duplicated. The equipment used was described by Heiland et al., (1977).

The partially dried blueberries were fed to CEPS at the rate of 125 kg/hr for each test. After being explosion-puffed, the berries were returned to a hot air tray dryer and dried to 4-5% moisture. Because of the limited amounts of blueberries, the drying study was not continued through final drying. The physical attributes evaluated were: bulk density, rehydration, disintegration, and color. These properties were chosen because they reflect the quality of the explosion-puffed blueberry. Fast rehydration or water pickup is a desired characteristic. The greater the puff, the more porous the product, and the more readily the water is picked up as measured by rehydration. Bulk density is decreased because of explosion-puffing. An inadequate puff is indicated by a bulk density near that of the partially dried berries. To the other extreme, overpuffing is undesirable because it results in excessive disintegration. Minimal disintegration is desired. Color values relate to eye appeal and flavor. Hunter scales (Hunter, 1942) were used for color determinations.

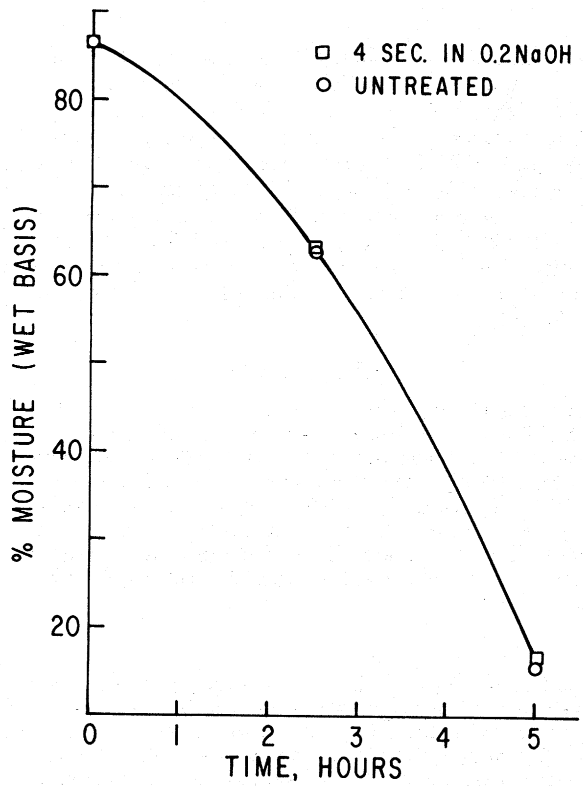

Fig. 1—Drying curves of treated vs untreated blueberries.

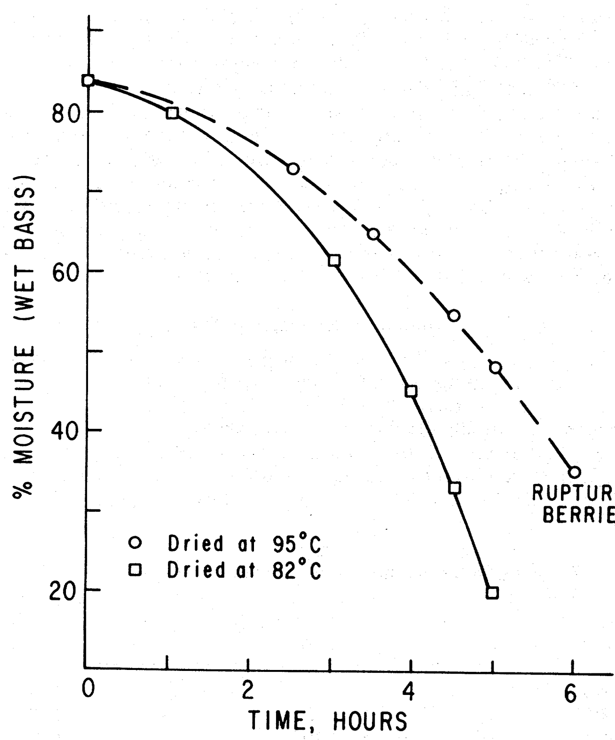

Fig. 2—Drying curves of ruptured and unruptured blueberries.

Analytical procedures

Color was determined on reconstituted blueberries at room temperature. Moisture content, bulk density, rehydration, and disintegration, were determined on the dehydrated blueberries.

Moisture

Moisture content was determined by the standard vacuum oven method. All samples were dried at 70°C under vacuum for 16 hr. Results are expressed on a wet basis.

Color measurement

A Gardner Automatic Color Difference Meter was used for all color measurements (Hunter, 1942). However, the color of the intact reconstituted berries (fresh and processed) was not measured directly because they were too dark. To insure consistency of results for comparative purposes, a calculated volume of water was added to a weighed amount of dehydrated berries so that the final moisture content of the rehydrated berries was always 87.5% (wet basis). Reconstitution was carried out by boiling the berries for 4 min, after which the liquid was filtered through cheesecloth and the colored water was collected for color measurement. To improve reflectance of the colored solution, three layers of Wahtman #1 filter paper were placed in the bottom of the cells before the colored solution was added. Once added, the solution and filter discs were allowed to soak for 10 min before measurements were made of the color of the filter discs and color solution together. Small beakers (50 ml) were used as weights to prevent the filter discs from floating. Color values for each sample were obtained in this manner and are reported as Hunter ΔE, a, b, and R_d units. The instrument was standardized each time with a standard color tile #CDR 001B (R_d = 5.9; a = +21.7; b = +6.0).

Disintegration

Disintegration was determined by manually separating disintegrated pieces in 100g sample and weighing this portion.

Rehydration

A 25g sample was boiled in water 3 min, then drained and weighed. The amount of water picked up per gram of dry solids was determined by subtracting the original sample weight (25g) from the weight of the rehydrated sample and dividing this weight by the solids in the 25g sample.

Bulk density

Bulk density was determined by filling a tared crystallizing dish of known volume with dried blueberries then weighing the blueberries and calculating the weight per volume.

RESULTS & DISCUSSION

Drying study

The initial drying of blueberries was from 85% to about 20% moisture (wet basis). Fig. 1 shows one drying curve—for fresh untreated blueberries and berries dipped in a 0.2% NaOH solution at 93°C for 4 sec. The curves are coincidental and the drying rates are the same. The other experiments, which included the mild detergent wash (to remove natural occurring wax) and the steam blanched, dried at the same rate as the untreated berries.

Temperature had a profound effect because the heat and elevated internal pressure within the berries led to easy rupture as they dried. Ruptured berries tended to bleed, which slowed drying (Fig. 2). Seasonal and area variations yielded some heat sensitive berries that had to be dried at a lower processing temperature to avoid rupture. During the first drying run, temperature had to be reduced gradually from 93°C (a normal drying temperature) to 82°C where the incidence of rupture was reduced and the drying rate increased. Five hundred twenty-five kg of berries were dried at 82°C to a moisture of about 30% (wet basis). At a bed loading of 36.5 kg/m^2 and increased air velocity (3 m/sec), 175 kg of berries required slightly over 3 hr to dry to 30%. Eight hundred pounds of steam per hr were used in drying 175 kg of berries from 82.4% to 30% moisture. After equilibration, the berries were sampled for moisture. Later they were further dried from 30% to selected moistures (Table 1) for the optimization of CEPS.

Optimization study

The results (responses) of these experiments were related to the three controlled variables by simple quadratic equations. The controlled or independent variables were pressure, temperature, and moisture. The responses chosen as dependent variables were bulk density, rehydration, percent disintegration and color measurements.

A second-order regression equation in terms of the independent variables was fitted to the data of each response. These empirical equations were used as models of the explosion-puffing process. Fig. 3 shows a typical response surface.

A computer program solving constrained nonlinear optimization problems was applied to these models. Table 2 lists the models and limits imposed on the optimal solution. The limits are maximum and minimum acceptable levels for a given response. These quality limits are chosen by the experimenter, external to the optimization. A line of optima was generated as a function of the model's radius ($\sqrt{P^2 + M^2 + T^2}$). Fig. 4 displays an optimal ridge for percent disintegration. It is evident that slight improvements in percent disintegration can be realized without other harm by extrapolating to higher feed moisture. An important consideration is that explosion-puffing at higher moistures allows the more difficult drying, that is drying in the falling rate period, to be done in the faster porous state (Eisenhardt et al., 1967; Sullivan et al., 1977, 1980). Table 3 lists the optimal (recommended) operating conditions at the highest moisture that could be selected with confidence.

Final drying

The bluberries were dried from about 15–26% moisture (there is about 3% moisture pickup during explosion-puffing) to 10% moisture (dry basis). Earlier studies (Eisenhardt et al., 1967) showed that blueberries need only be dried to 10% although explosion-puffed berries can readily be dehydrated to 4% moisture or lower. They were dried in a tray drier at 77°C. Moisture absorption isotherm developed from the dried blueberry product showed $a_w = 0.45$ at 10%.

Comparison of raw and processed blueberries

Nutrient losses and color changes occurred during processing. Differences from the fresh berries indicated the effects of dehydration. Some of the mineral values (Dekazos, 1978) are shown (Table 4) for raw highbush berries from North Carolina and Rabbiteye (Tifblue) from Georgia, both from the 1975 season. Also listed are values for processed Tifblue variety from the 1978 season (rehydrated to fresh basis). Although a comparison with the fresh berries cannot be made directly because of the different crop years, mineral losses appear to be between 10 and 20%. There is no other apparent reason why the Na value is high in the processed berries.

Color changes were slight (on a relative basis) when the R_d, a and b values for processed samples were compared with those of fresh berries. Table 5 shows variability between the fresh and processed berries at optimum conditions. Processing changes, with pressure decreasing in CEPS and the feed moisture increasing, cause the processed berry to become lighter in color, that is, going from a dark blue to a purplish hue. The optimum value (Table 3) includes color

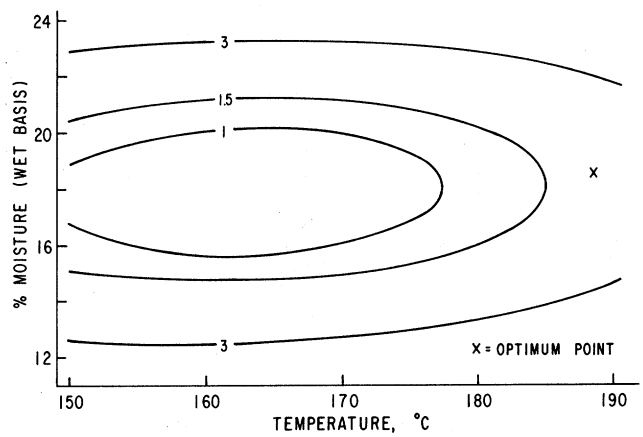

Fig. 3—Response surface of % disintegration at 103.4 kPa, % moisture vs temperature.

Table 2—Multiple correlations and coefficients of blueberry model for optimum study

Model form: $Y = b_o + b_1 P + b_2 T + b_3 M + b_4 P^2 + b_5 T^2 + b_6 M^2 + b_7 PT + b_8 PM + b_9 TM$

Y	Bulk density	% Disintegration	Rehydration	ΔE
R^2	0.89	0.93	0.89	0.64
Upper limit	435 kg/m^3	5.0	2.0g H_2O/g d solid	14.0
Lower limit	365 kg/m^3	0.0	0.60 H_2O/g d solid	1.0
Intercept, b_o[a]	−711.759	115.613	7.8842	−124.210
b_1	−22.447	−4.243	0.01192	−6.07091
b_2	20.877	−0.469	−0.09770	2.7384
b_3	−27.650	−5.317	0.02123	−1.7062
b_4	0.2307	0.07473	0.000718	0.04386
b_5	−0.06658	0.001797	0.002881	−0.009358
b_6	0.44028	0.081638	−0.000165	0.01508
b_7	0.01996	−0.005510	0.0000273	0.01661
b_8	0.15474	0.18081	−0.000166	0.01883
b_9	0.02329	0.00193	0.0000661	0.002861

[a] Sufficient significant places are provided so that the reader can recalculate the response surface. No unexpected precision should be inferred.

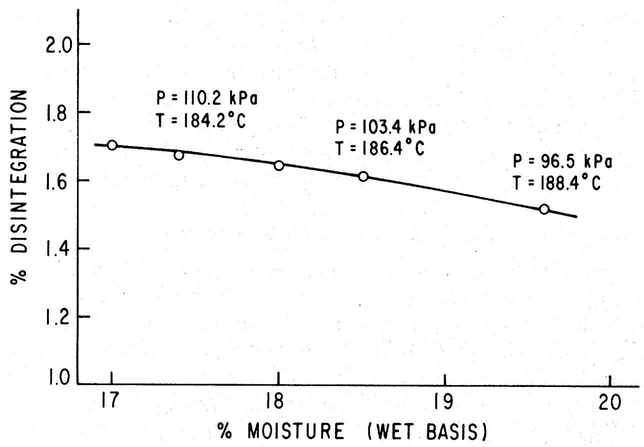

Fig. 4—Optimal ridge generated from model's radius, % disintegration vs % moisture.

Table 3—CEPS optimum point for Rabbiteye blueberries using dependent variables as constraints

Independent variables	Dependent variables	
Pressure 103 kPa	ρ (bulk density)	393 kg/m^3
Temp 190°C	% disintegration	1.80
Moisture 18.5%	Rehydration	0645g H_2O/g dry solids
	ΔE (color difference)	14

Table 4—Mineral levels in highbush and Rabbiteye blueberries (mg/100g fresh fruit)

Mineral	Raw[a] highbush (NC)	Raw[a] Rabbiteye (GA)	Dried explosion-puffed[b] Rabbiteye (GA)
Ca	5.20	5.60	5.15
P	10.70	7.95	6.81
K	84.00	84.60	67.78
Na	0.32	0.95	1.96
Fe	0.14	0.24	Trace

[a] Dekazos (1978); 1975 crops
[b] 1978 crop

Table 5—Color values of fresh and processed blueberries

Moisture	Raw 82.4% (wet basis)	Dried explosion-puffed moisture 5.75% (A_w 0.2)
ΔE	–	14
a	+28.50	+20.88
b	+ 0.09	– 7.86
R_d	3.30	10.96
b/a	+ 0.0032	– 0.376

ΔE — Color difference $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$
ΔL — is linearly related to R_d. By multiplying by a factor, R_d can be converted to L
a — Signifies redness if positive and greenness if negative.
b — Signifies yellowness if positive and blueness if negative.
R_d — Measure of the reflectance of the sample.

values (R_d, a and b) which have gone toward the purple, but these berries when reconstituted appear dark blue and when made into a pie or tart are indistinguishable in color from those in a fresh-berry pie.

CONCLUSIONS

VARIOUS PREDRYING treatments were tried but failed to affect the drying rate. Drying temperature had a pronounced effect on the drying. The drying temperature was reduced from 93° to 82°C which reduced bleeding and lessened the incidence of rupture. This indirectly increased the drying rate. CEPS was optimized for blueberries. The optimization indicated that blueberries should be dried to 18.5% moisture and processed with CEPS internal pressure and temperature at 103 kPa and 190°C. A final moisture of 10% is sufficient although lower moistures are readily obtainable.

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