Soaking Turkey Meat in Salt-Glucose Syrup Solutions—An Experimental Study Of Mass Transfers

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ABSTRACT Turkey meat can be salted and dried in one step by soaking in a concentrated salt-glucose syrup solution at low temperature. Sugar impregnation is minimal; only low molecular weight sugars generally penetrate the product. Glucose uptake is very quick, suggesting the possible involvement of passive glucose transporters. The operational scope of this process, depending on the targeted end-product features, was determined for turkey meat on the basis of clearly characterized mass transport phenomena between the product and the soaking solution. With 2 cm thick meat fillets processed at 10 C it is thus possible to obtain salted-dried end-products containing 2 to 10% salt and 35 to 70% water, ranges that are compatible with a broad range of commercial cured products.

(*Key words*: turkey meat, processing, salting, drying, mass transfer)

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INTRODUCTION

The poultry meat industry has been especially dynamic since the 1950s. All poultry meat, and especially turkey (Morris, 1989), has an excellent reputation with Western consumers (Bruhn, 1994). Moreover, the Western-vegetarian trend of meat avoidance does not concern poultry meat as much as red meats (Santos and Booth, 1996). Poultry is also a highly interesting source of animal proteins for developing countries (Gascoyne, 1989). The development of new processed products has diversified this industry. The development of poultry delicatessen meats has already been pinpointed as a potentially profitable option to fulfill consumer expectations (Cuisset, 1993). Northern consumer demand is currently geared toward low-processed products (Ohlsson, 1994) with low additive contents, especially salted meat- or fish-based products (Barbut and Findlay, 1989; Bruhn, 1994). This demand requires efficient control of processing operations.

The dehydrating and impregnation soaking (DIS) process involves soaking a food product in a complex concentrated solution (Raoult-Wack, 1994). It is a one-step, controlled process that can be used to salt and dry meats (Collignan and Raoult-Wack, 1992; Deumier et al., 1996) or fish (Collignan and Raoult-Wack, 1994) by soaking in a ternary water-NaCl-sugar solution (Collignan et al., 2001). The present study was aimed at quantifying mass transfers during DIS processing of turkey meat. We specifically focused on sugar transfers because few previous studies have investigated this aspect. The potential operational scope of DIS can be determined by assessing its processing performance.

MATERIALS AND METHODS

Turkey Meat and Concentrated Solutions

Refrigerated turkey (*Meleagris gallopavo*) meat was purchased from a local butcher. This meat was all from a single batch, with birds of the same age that were slaughtered at the same time. The muscle (pectoralis major) fillets ranged from 1 to 1.3 kg for all tests. Immediately after purchase, the fillets were frozen separately in an air-blast quick freezer[2] for 2 h at –50 C and then kept in a freezer at –18 C until use.

Before treatment, whole turkey fillets were thawed for 24 h at 4 C and then were chilled slightly. They were then sliced lengthwise to 2-cm thickness with an Italiana Macchi 370[3] meat slicer. A Plexiglas cutting jig was used to cut the slices into parallelepiped fillets (7 cm × 5 cm × 2 cm).

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Abbreviation Key: a_w = water activity; C_{su} = glucose syrup concentration; $\sqrt{C_{su}}$ = square root of glucose syrup concentration; C_{st} = NaCl concentration; DIS = dehydration-impregnation soaking; i.m. = index referring to the initial meat sample before processing; t = treatment time.

The DIS solutions used for processing the turkey meat were formulated with water, NaCl,[4] and glucose syrup[5] (dextrose equivalent DE 21) containing 2% (wt/wt) dextrose, 7% (wt/wt) maltose, 12% (wt/wt) maltotriose, and 79% (wt/wt) oligosaccharides with more than 2 U of glucose. The ingredients were solubilized and the solutions were stored until use at the selected processing temperature in a Cryo-Rivoire[6] thermostat-controlled unit.

Experimental Apparatus

The experimental design enabled vertical soaking of turkey fillets with vertical agitation. The pilot immersion apparatus included a 20-dm^3 tank with a Lauda RSK 20[7] cryothermostat-controlled inner shell, a wire basket with five trays, and a hydraulic pressure cylinder to lift the basket in the tank according to the following sequence: pressure cylinder rising time, 6 s; pressure cylinder plunging time, 4 s; and displacement amplitude, 0.1 m. This basket agitation cycle in the soaking solution was chosen because it efficiently renews the concentrated solution around emerged meat slices (Bohuon et al., 1998).

Experimental Methods

All tests were carried out at 10 C with batches of three turkey fillets soaked in excess solution (20 dm^3) to avoid dilution problems. Before treatment, fresh meat samples were quickly washed and dried with paper towels. They were then weighed, set on trays, and processed by immersion. After treatment, the fillets were washed with cold water for 10 s, dried with paper towels, weighed, and packaged with a Multivac A300[8] vacuum packing machine in heat-sealed bags. They were kept in a cold room at 4 C for 2 d to allow them to stabilize prior to blending (Moulinex blender[9]) and analyses. All tests were carried out in triplicate.

Chemical Analyses

Water content was calculated by the difference between the fresh matter weight and the dry matter weight determined after oven heating the product at 104 C to constant weight (AFNOR, 1968). Salt content was determined by measuring the chloride ion concentration with a Corning 926 chloride analyzer[10] after 0.3 *N* nitric acid extraction (Bohuon et al., 1998). Sugar content was measured by ion-exchange chromatography after two successive extractions with 10-g samples for 1 h by reflux boiling in 100 mL of 80% ethanol (vol/vol). A Dionex[11] DX300 chromatograph, fitted with a Dionex AGP pump,[12] a Dionex-PAD pulsed amperometric detector,[12] and a Shimadzu CR5A integrator,[12] was used under the following analytical conditions: a Carbopac PA1 column, elution with a sodium hydroxide/sodium acetate/water mixture at a constant elution rate of 1 mL/min (Peschet and Giacalone, 1991).

G_i represents the content of each sugar determined in the sample, where i values of 1, 2, 3, 4, 5, and 6 correspond, respectively, to glucose, maltose, maltotriose, and oligosaccharides with 4, 5, and 6 glucose units. Total sugar contents (Su) were determined by the addition of G_i levels with i ranging from 1 to 6 (Equation 1).

$$Su = \sum_{i=1}^{6} G_i \quad [1]$$

Water Loss and Salt Gain Calculations

Water loss (WL), salt gain (StG), total sugar gain (SuG), and i-glucose units oligosaccharide gain (G_iG, e.g., G_2G indicated maltose gain) were given as percentages (wt/wt) of the initial meat mass (% i.m.) and were calculated with Equations 2 to 5, respectively.

$$WL = W_0 - \frac{M_t}{M_0} \cdot W_t \quad [2]$$

$$StG = \frac{M_t}{M_0} \cdot St_t - St_0 \quad [3]$$

$$SuG = \frac{M_t}{M_0} \cdot Su_t - Su_0 \quad [4]$$

$$G_iG = \frac{M_t}{M_0} \cdot G_{it} - G_{i0} \quad [5]$$

Subscripts 0 and t refer to the initial product and the DIS-processed product, respectively.

Experimental Design

A Doehlert uniform shell design (Doehlert, 1970) was used to determine the effects of the main DIS command variables on mass transfers. Correlations were established with a second-order polynomial model (Equation 6) because previous studies highlighted the nonlinearity of mass transfers with respect to several factors such as solute concentration and processing time (Collignan and Raoult-Wack, 1992, 1994; Deumier et al., 1996; Bohuon et al., 1998). The Statgraphics[13] software package was used to determine and calculate the regression coefficients based on the least squares method (Draper and Smith, 1981).

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[5]Glucidex IT21, Roquette, France.
[6]Cryo-Rivoire SARL, Saint Gély du Fesc, France.
[7]Lauda, Lauda-Königshofen, Germany.
[8]Multivac, Lagny-sur-Marne, France.
[9]Groupe Moulinex, Paris la Défense, France.
[10]Ciba Corning Diagnostics, Medfield, MA.
[11]Dionex Corporation, Sunnyvale, CA.
[12]Shimadzu Head Office, Kyoto, Japan.
[13]Manugistics Inc., Rockville, MD.

TABLE 1. The experimental area

Domain	NaCl (g/kg water)	Glucose syrum (g/kg water)	Treament time (h)
Minimum	0	0	1
Maximum	350	1,900	24

$$Y = a_0 + \sum_i a_{ii} X_i^2 a_{ii} X^2{}_i + \sum_i a_i X_i + \sum_{i,j} a_{ij} X_i X_j \qquad [6]$$

where Y is a response (WL, StG, SuG, G_iG), X_i is factor i [NaCl concentration (C_{st}), square root of the glucose syrup concentration ($\sqrt{C_{su}}$) or $\log_{10}(t)$], a_0 is the constant of the model, a_i is the linear effect of X_i, a_{ii} is the quadratic effect of X_i, and a_{ij} is the effect of the interaction between X_i and X_j.

The factors studied are shown in Table 1. We used the square root of the syrup concentration and the decimal log of the processing time to accurately describe responses at low syrup concentrations and short processing times.

RESULTS

Mass Transfer Kinetics

Figure 1 shows variations in water loss, salt gain, and sugar gain for turkey fillets soaked in a ternary solution for center point concentration conditions (175 g salt and 475 g glucose syrup/kg water). Water loss was greater than salt gain, both of which, in turn, were greater than total sugar gain. Under mean concentration conditions, relatively high water losses (18% i.m.) can be obtained by the DIS process. Fifty percent of the mass transfers occurred within the first 3 h of processing. Moreover, 75% of salt gain and sugar gain transfers took place during the first 7 h of processing. In contrast, 75% of water loss transfers occurred during the first 15 h of processing.

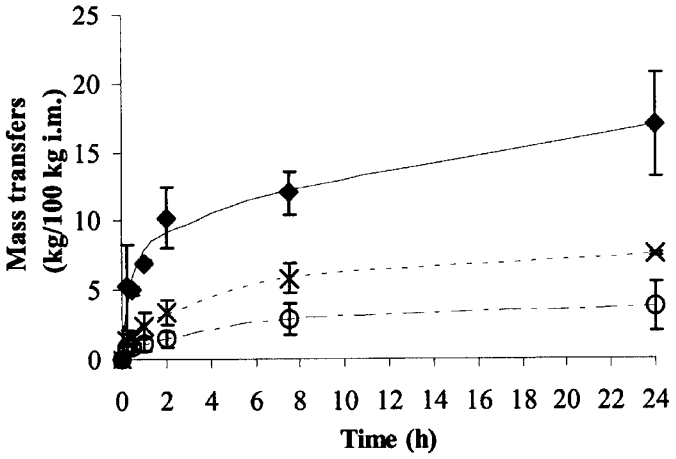

FIGURE 1. Mass trasfer – water loss (◆), salt gain (×) and sugar gain (○) – kinetics of turkey meat fillets (7 cm × 5 cm × 2 cm) soaked in a ternary solution (175 g NaCl/kg of solution and 475 g glucose syrup/kg of solution) at 10 C. i.m. = index referring to the initial meat sample before processing.

Figure 2 shows a time-course graph of sugar content variations. Glucose content increased very little after 15 min of processing. However, levels of sugars with a higher molecular weight than glucose increased with processing time. For processing times of less than 1 h, glucose was the main sugar that had impregnated the meat product (30 to 50% of total sugars). Sugars with higher molecular weights had slower transfer rates. The sugar mass composition in the product was becoming balanced after 1 h of processing.

Experimental Design Study

Table 2 shows coefficients obtained by multiple regression (Equation 6) and significance levels for each response variable studied. The second-order polynomial model used explained more than 94% of the variability in the experimental water loss, salt gain, and sugar gain data (all determination coefficients were higher than 0.94) and more than 90% of the variability in the experimental gain data of glucose, maltose, maltotriose, 4-glucose oligosaccharide, 5-glucose oligosaccharide, and 6-glucose oligosaccharide (all determination coefficients were greater than 0.90). For all responses, probabilities associated with the lack-of-fit were never significant, thus confirming that the model simulations were in close agreement with the distributions of experimental data.

Effect on Water Loss. All linear effects were positive and significant. The effect of $\sqrt{C_{su}}$ was 1.5-fold higher than that of $\log_{10}(t)$ and 2.7-fold higher than that of C_{st}. The linear effect of $\sqrt{C_{su}}$ was increased by a significant negative quadratic effect. The linear effects of C_{st} and of $\log_{10}(t)$ were both enhanced by significant positive quadratic effects. Other significant interactions included a negative correlation between C_{st} and $\sqrt{C_{su}}$ and a positive correlation between C_{st} and $\log_{10}(t)$ and between $\sqrt{C_{su}}$ and

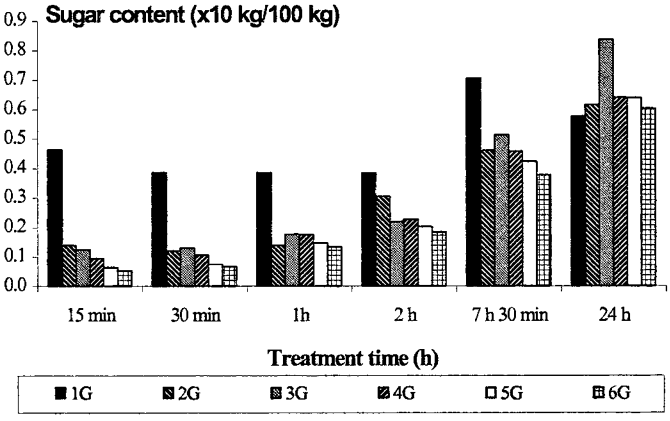

FIGURE 2. Sugar content of turkey meat fillets (7 cm × 5 cm × 2 cm) processed by dehydration-impregnation soaking (ternary solution: 175 g NaCl/kg of solution and 475 g glucose syrup/kg of solution) for different processing times and at 10 C. 1G = glucose content (G_1 in kg/100 kg final product) 2G = maltose content (G_2 in kg/100 kg final product); 3G = maltotriose content (G_3 in kg/100 kg final product); 4G = 4-glucose oligosaccharide content (G_4 in kg/100 kg final product); 5G = 5-glucose oligosaccharide content (G_5 in kg/100 kg final product); 6G = 6-glucose oligosaccharide content (G_6 in kg/100 kg final product).

TABLE 2. Regression and analysis of variance of the second-order polynomial equation

$$y = a_0 + \sum_i a_{ii} X_i^2 + \sum_i a_i X_i + \sum_{i,j} a_{ij} X_i X_j$$

Coefficient[1]	Water loss	Salt gain	Sugar gain	G_1G	G_2G	G_3G	G_4G	G_5G	G_6G
a_0	12.844	4.958	1.690	0.543	0.272	0.398	0.215	0.164	0.119
Linear									
a_1	4.452**	4.072**	–0.358	–0.098*	–0.044	–0.062	–0.081†	–0.039	–0.028
a_2	12.225**	–3.159** 1.597**	0.319**	0.304**	0.405*	0.248*	0.183*	0.146*	
a_3	7.784**	1.641**	0.693*	–0.024	0.142*	0.206*	0.151*	0.121*	0.102*
Quadratic									
a_{11}	5.581*	–2.352*	0.1257	0.002	–0.026	–0.060	0.091	0.050	0.047
a_{22}	–9.105*	2.146*	–0.310	–0.160*	0.016	–0.020	–0.067	–0.046	–0.030
a_{33}	4.294*	–0.183	0.148	–0.004	0.037	0.065	0.017	0.017	0.018
Interaction									
a_{12}	–1.529†	–2.550**	–0.209	–0.096*	–0.019	–0.033	–0.046	–0.011	–0.003
a_{13}	2.865*	1.200*	–0.105	–0.019	–0.022	–0.017	–0.032	–0.007	–0.001
a_{23}	4.294**	–0.460	0.663†	–0.038	0.143*	0.194†	0.146*	0.118*	0.103*
R^2	0.94	0.95	0.94	0.94	0.91	0.93	0.93	0.92	0.90

[1]a_o = constant parameter; a_i = linear effect of of the i-factor; a_{iii} = quadratic effect of the i-factor and a_{ij} if the interaction effect between factors i and j; G_iG = i-glucose units oligosaccharide gain (e.g., G_2G indicates maltose gain).

[2]Indexes 1, 2, and 3 refer to NaCl concentration, square root of glucose syrup concentration, and $\log_{10}(t)$, respectively.

**, *, †Coefficient was significant at $P < 0.01$, $P < 0.05$, and $P < 0.10$, respectively.

$\log_{10}(t)$. Figure 3 shows the effects of C_{st} and glucose syrup concentration (C_{su}) on water loss at t = 4 h 54 min. When there was no glucose syrup in the solution, water loss was negative until C_{st} reached 350 g/kg of water. When C_{su} increased to 500 g/kg of water, water loss increased dramatically (from 3 to 23% i.m.). However, water loss stabilized at C_{su} levels above 500 g/kg, leveling off at 25% i.m.

Effect on Salt Gain. The linear effects of C_{st} and $\log_{10}(t)$ were positive and significant. The effect of C_{st} was 2.5-fold greater effect than the effect of $\log_{10}(t)$. The linear effect of C_{st} was enhanced by a significant negative quadratic effect. Moreover $\sqrt{C_{su}}$ had a marked significant negative linear effect that was increased by a significant positive quadratic effect. A highly significant negative relation between C_{st} and $\sqrt{C_{su}}$ and a highly significant positive relation between C_{st} and $\log_{10}(t)$ were noted. Figure 4 shows the effects of C_{st} and C_{su} on salt gain after 4 h 54 min of DIS processing. For low C_{su} values, salt gain increased sharply with C_{st}. When there was no glucose

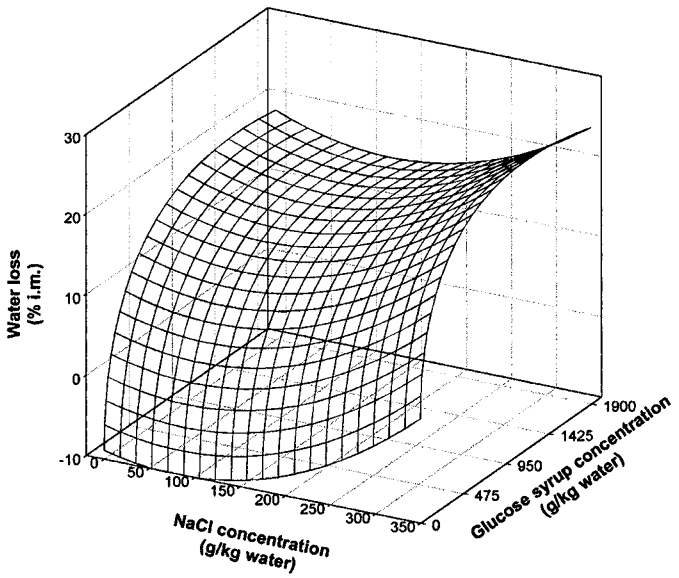

FIGURE 3. Response surface for water loss of turkey meat fillets (7 cm × 5 cm × 2 cm) as a function of salt and glucose syrup concentrations of the ternary solution after soaking for 4 h 54 min. i.m. = index referring to the initial meat sample before processing.

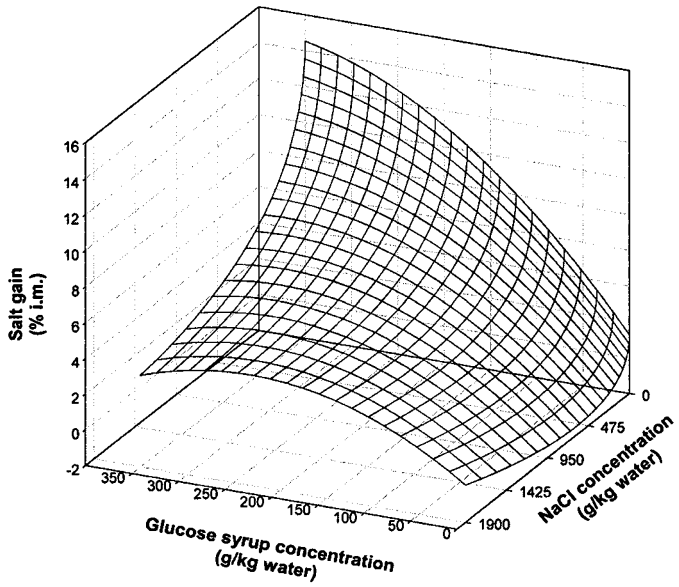

FIGURE 4. Response surface for salt gain of turkey meat fillets (7 cm × 5 cm × 2 cm) as a function of salt and glucose syrup concentrations of the ternary solution after soaking for 4 h 54 min. i.m. = index referring to the initial meat sample before processing.

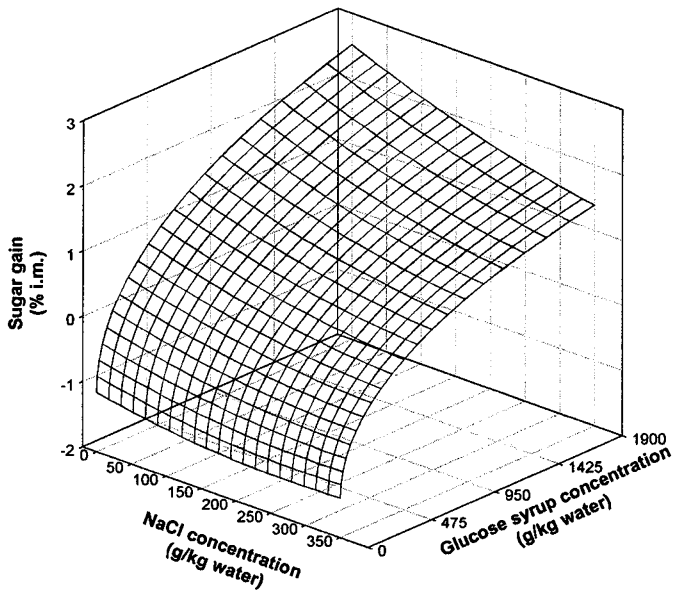

FIGURE 5. Response surface for total sugar gain of turkey meat fillets (7 cm × 5 cm × 2 cm) as a function of salt and glucose syrup concentrations of the ternary solution after soaking for 4 h 54 min. i.m. = index referring to the initial meat sample before processing.

syrup in the solution, salt gain ranged from 0 (C_{st} = 0 g/kg) to 14.5% i.m. (C_{st} = 350 g/kg). Salt gain decreased as C_{su} increased with all other factors remaining constant. When C_{su} was 1,900 g/kg, salt gain ranged from 0 (C_{st} = 0 g/kg) to 3.12% i.m. (C_{st} = 350 g/kg) and peaked at 4.19% i.m. $\sqrt{C_{st}}$ = 228 g/kg). Salt gain decreased by 78.5% when comparing a solution without syrup and one with 1,900 g/kg of syrup. Salt gain decrease occurred within 0 to 500 g syrup/kg water. Salt gain was no longer dependent on C_{su} when solutions had a glucose syrup concentration greater than 500 g/kg.

Effect on Total Sugar Gain. The linear effects of $\sqrt{C_{su}}$ and $\log_{10}(t)$ were significant and positive. Moreover C_{su} and $\log_{10}(t)$ showed a significant positive interaction, highlighting the synergy between these two factors. The linear effect of $\sqrt{C_{su}}$ was 2.3-fold higher than that of $\log_{10}(t)$. Figure 5 shows the effects of C_{st} and C_{su} on sugar gain at t = 4 h 54 min. The highest sugar gain value (3.75% i.m.) was achieved when turkey fillets were soaked in the solution with the highest syrup concentration and no salt.

Effect on Gains of Glucose, Maltose, Maltotriose, and Oligosaccharides with 4 to 6 Glucose Units. Glucose gain (G_1G) was independent of $\log_{10}(t)$. The variable $\sqrt{C_{su}}$ had a significant positive linear effect on glucose gain, enhanced by the significant negative quadratic effect on glucose gain. The negative linear effect of C_{st} was significant and had a 3.2-fold lower absolute value than $\sqrt{C_{su}}$.

For all sugars with a higher molecular weight than glucose, the linear effects and the interaction between $\log_{10}(t)$ and $\sqrt{C_{su}}$ were positive and significant. The linear effect of $\sqrt{C_{su}}$ was always higher than that of $\log_{10}(t)$, but the ratio between these two factors decreased as the molecular weight of the sugar increased. Hence for maltose gain (G_2G) and 6-glucose-unit oligosaccharide gain (G_6G), the linear effect of $\sqrt{C_{su}}$ was 2.1- and 1.4-fold higher than that of $\log_{10}(t)$. Sugar gains were generally independent of C_{st}, except for a slightly significant negative linear effect for 4-glucose-unit oligosaccharide gain (G_4G).

Effect of C_{su} on the Distribution of Sugars Transferred in the Product. Table 3 shows the experimental distribution of sugars transferred in the product after 4 h 54 min of processing and at C_{st} = 263 g/kg for C_{su} = 9 and 1,654 g/kg. Significant differences were noted between the proportions of the different sugars ($P < 0.05$), for C_{su} of 9 or 1,654 g/kg. The same analysis for C_{st} = 88 g/kg showed significant differences between proportions of the different sugars ($P < 0.001$), except for maltose, for C_{su} of 9 or 1,654 g/kg. Irrespective of the C_{st}, the uptake of high molecular weight sugars in the product decreased as the solution glucose syrup concentration decreased, with glucose representing about 90% (wt/wt) of the sugars transferred in the meat product under these experimental conditions. At higher C_{su}, all types of sugars impregnated the product approximately at the same level.

DISCUSSION

Water Loss

High water loss up to 40 kg/100 kg was obtained during DIS processing of 2 cm thick turkey fillets for approximately 24 h in a ternary water-salt-glucose syrup solution at low temperature (10 C). From 500 to 900 g/kg, the glucose syrup concentration effect leveled off, and there was no further significant water loss augmentation beyond 900 g/kg. These results are in line with those obtained in previous studies (Collignan and Raoult-Wack, 1994). Water loss could be hampered at high glucose syrup concentrations due to constraining internal mass transfers. Irrespective of the glucose syrup concentration, within 24 h of processing, 50, 75, and 90% of the water loss was achieved at 4, 14, and 18.5 h, respectively. Technologically, these results indicate that there is little advantage to extending the processing time beyond 14 h.

Finally, this study showed that water loss plateaued at high glucose syrup concentrations. Bohuon et al. (1998) demonstrated that in a ternary water-NaCl-sucrose solution, water loss plateaued at high sucrose concentrations only in natural convection conditions. This result suggests that in our study, external transfer conditions were limiting. Agitation was not sufficient at high sugar concentrations to renew the solution at the product interface, probably due to the high solution viscosity, which was greater than 165 mPa·s and could reach 24.6 Pa·s at syrup concentrations above 900 g/kg (Deumier, 2000).

Salt Gain

Interactions between salt and glucose syrup concentrations were significant with respect to salt gain. At high glucose syrup concentrations, salt gain was fourfold lower and actually no longer dependent on salt concentra-

TABLE 3. Experimental percentage of the different sugars transferred within turkey fillets after 4 h 54 min soaking in a ternary solution with 263 or 88 g NaCl and 9 or 1,654 g of glucose syrup/kg water

	Salt concentration (g/kg water)			
	263	88	88	88
	Glucose syrup concentration (g/kg water)			
Sugar	9	1,654	9	1,654
Total sugar content (kg sugar/100 kg product)	0.20	3.43	0.20	2.86
Proportion of the different sugars				
Glucose (kg/100 kg total sugar)	85.59	22.29	91.31	27.26
Maltose (kg/100 kg total sugar)	6.12	23.46	6.75	15.88
Maltotriose (kg/100 kg total sugar)	6.68	27.17	1.76	23.67
4-Gluose oligosaccharide (kg/100 kg total sugar)	0.89	11.63	0.18	14.53
5-Glucose oligosaccharide (kg/100 kg total sugar)	0.46	9.07	0.00	10.69
6-Glucose oligosaccharide (kg/100 kg total sugar)	0.27	6.39	0.00	7.97
Total (kg/100 kg total sugar)	100.00	100.00	100.00	100.00

tion. These results confirm those obtained with model gels and other meat products processed by DIS in ternary solutions (Collignan and Raoult-Wack, 1992, 1994; Deumier et al., 1996; Bohuon et al., 1998).

These interaction phenomena are the result of the formation of a highly concentrated sugar area on the internal periphery of the product at the beginning of processing. This highly concentrated sugar zone could be maintained throughout the soaking process and was responsible for reducing the salt diffusion coefficient. Although ternary diffusion coefficients have not yet been determined for water-NaCl-sugar solutions, Reinfelds and Gosting (1964) and Henrion (1964) showed that adding sucrose to a KCl solution could decrease the KCl diffusion coefficient by 11-fold. This decrease in the diffusion coefficient after the addition of sucrose was probably the result of the high viscosities that occur in ternary water-NaCl-sugar solutions (Bohuon et al., 1997). The salt diffusion coefficient is inversely proportional to the relative viscosity of the solution when it is lower than 3×10^{-3} Pa·s (Robinson and Stockes, 1959). However, according to Eyning's theory (Glasstone et al., 1941), at higher viscosities the diffusion coefficients are proportional to negative two-thirds power of the relative viscosity (Hiss and Cussler, 1973; Easteal, 1989). For water-NaCl-sucrose solutions, Bohuon et al. (1998) showed that external NaCl transfers were nonlimiting, regardless of the sucrose concentration. This trend also applied to our experimental conditions with glucose syrup. Finally, the syrup concentration had a near complete barrier effect on salt gain once the syrup concentration reached 500 g/kg.

Sugar Gain

As the molecular weight of the glucose syrup sugar rises, impregnation dynamics slow down. At short treatment times, low molecular weight sugars mainly penetrated into the product, i.e., glucose, maltose, and maltotriose. The mass fraction of sugars transferred in DIS-treated products became balanced at longer treatment times. Concerning the molar fraction, low molecular weight sugar molecules—especially glucose—were the most abundant.

The results of many studies have revealed that sugar gain decreases in DIS as the mean molecular weight of the sugar or syrup used in the solution increases, especially when processing meat products (Collignan and Raoult-Wack, 1994). This result is in agreement with the fact that the mutual diffusion coefficient of water-sugar solution decreases as the molecular weight of the sugar increases (Sano and Yamamoto, 1993).

Glucose uptake in the turkey fillets was still very rapid (Figure 2) and not dependent on the processing time from 1 to 24 h (Table 2). This finding could be the result of simple diffusion phenomena and facilitated diffusion. Glucose is required for muscle contraction in living organisms. However, cell membranes are impervious to glucose, and extracellular to intracellular glucose transport systems supply muscles with this vital sugar (Barnard and Youngren, 1992). This facilitated glucose diffusion is especially rapid. Glut-1 non-insulin-dependent glucose transporters have been isolated from avian muscles, especially chicken (Wagstaff et al., 1995). Theoretically, these transporters could remain partially active in dead muscles even after freezing and thawing (Uechi et al., 1997; Lu et al., 1997; Lundqvist and Lundahl, 1997). Moreover, the half-life of Glut-1 could be greater than 50 h under glucose-deprivation conditions (McMahon and Frost, 1995). If these transporters are truly active in meat, the glucose impregnation rate could partially be explained by these facilitated diffusion mechanisms.

Sugar impregnation rates are not negligible in DIS, but the sugars transferred in the meat product have a relatively low sweetening power. The mean sweet taste thresholds are 0.75, 1.07, and 2.00% (wt/vol) for glucose, maltose, and glucose syrup with a dextrose equivalent of 21. The sweetening power of glucose is 100, that of maltose is 43, and that of DE21 glucose syrup is 22 (Dziedzic and Kearsley, 1984). This sugar impregnation could be beneficial. These compounds could indeed be considered as fillers that increase the mass yield of the process. Moreover, sugar uptake in meat products could be advanta-

TABLE 4. Optimization and validation of the experimental design

Targeted product[1,2]	Cold smoked filet	Turkey bacon
NaCl concentration of solution (g/kg water)	119	304.5
Glucose syrup concentration of solution (g/kg water)	766	1,026
Treatment time	2 h 2 min	1 h 22 min
Theoretical water loss (kg/100 kg i.m.)	11.47	15.18
Experimental water loss (kg/100 kg i.m.)	11.02	14.25
Theoretical salt gain (kg/100 kg i.m.)	2.27	2.82
Experimental salt gain (kg/100 kg i.m.)	1.90	3.30
Theoretical sugar gain (kg/100 kg i.m.)	1.79	1.46
Experimental sugar gain (kg/100 kg i.m.)	1.50	1.85

[1]Theoretical corresponds to duplication of commercial products, and experimental corresponds to the operating point leading to a minimum sugar gain value among all points required to achieve the targeted salt and water contents.

[2]i.m. = index referring to the initial meat sample before processing.

geous if a subsequent fermentation process is planned. Lactic fermentation is often induced to extend the shelf life of traditionally processed products (Bartholomew and Blumer, 1980; Roca and Incze, 1990) and new relatively unprocessed products (Leroi et al., 1996).

DIS Process for One-Step Salting and Drying of Cold Salt-Cured Products

Two experiments were carried out to check the prediction power of the model; the data are presented in Table 4. The results validated the experimental design and highlighted the potential of the DIS process for duplicating traditional, cold salt-cured products. The traditional process discussed is based on salt and not on other traditional curing ingredients such as sodium or potassium nitrites or nitrate.

Very high drying rates and controlled salt gain can be achieved by low-temperature DIS processing in ternary solutions (water, salt, glucose syrup). This process is, therefore, an interesting alternative to obtain salted-dried products resembling traditionally cured products. Salt gain and water loss are not, however, independent. Figure 6 shows a range of products that can be obtained by the DIS process along with their final water and salt contents. This illustrates that the DIS process can be used to replicate most moderately to highly salted and slightly to moderately dried meat products, which encompasses a wide range of products from bacon to Brazilian *charque*.

However, it is hard or even impossible to match the low water and salt contents of some very dry products like *kilichi* (African dried meat). Long-term processing in solutions with very high syrup concentrations and very-low salt concentrations is required to obtain low-salt moderately moist products such as dried ham. Soaking highly perishable foodstuffs under these conditions can be microbiologically hazardous. The soaking solutions used had a relatively high water activity (a_w) because salt is a much more powerful moisture depressant than glucose syrup. For instance, a salt concentration of 107 g/kg in a water-salt solution and a syrup concentration of 1,900 g/kg in a water-syrup solution are required to obtain 0.90 a_w in a binary solution. A high-salt solution thus seems essential to hamper microorganism growth. For instance, for C_{st} = 350 g/kg, the solution a_w is less than 0.75. Finally, solutions with very high glucose syrup concentrations are quite viscous (Deumier, 2000), which could be a technological handicap (stirring, regeneration, etc.). Technologically ideal solutions would have a high salt concentration (to depress a_w) and a low glucose syrup concentration (to increase water loss while limiting the solution viscosity). Salted and moderately dried products could be produced with such solutions. An additional drying step would be required to obtain very dry products. DIS would thus be efficient for preprocessing such products.

In this study, we assessed mass transfers during DIS processing of turkey meat soaked in ternary water-salt-syrup solutions at low temperature. The results were in line with those obtained with other meat products under similar conditions. We also specifically focused on sugar transfers. Glucose showed remarkable transport in this meat product as compared to all other sugars investigated. We discussed the likelihood that this transport could—in addition to simple diffusion—have involved

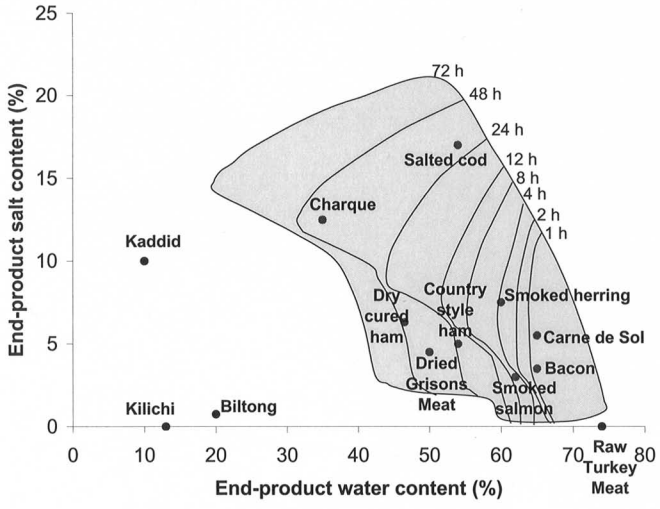

FIGURE 6. Simulation of final water and salt contents of turkey meat (2 cm thick slices) after dehydration-impregnation soaking (DIS) in a ternary water-NaCl-glucose syrup solution at 10 C. The DIS-processed products encompassed a broad range of reference products.

facilitated diffusion. Passive, non-insulin-dependent glucose transporters such as *Glut-1* might also enhance glucose transfer. Further biochemical studies should now be undertaken to confirm this hypothesis.

This study also highlighted the potential operational scope and limits of the DIS process for salting and drying turkey meat. The operational scope was limited to the production of slightly or moderately dried products (35 to 70% moisture), with 2 to 10% salt, depending on the extent of dryness. The DIS process could thus be used to extend the shelf life of many cured products in a single step. This process cannot, however, duplicate all existing products, e.g., an additional drying step is necessary to obtain dry low-salt products such as dried ham. The technological constraints involved in using concentrated solutions should now be taken into consideration to accurately characterize the potential operational scope of the DIS process.

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