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PII: S0963-9969(97)00059-8

Food Research International, Vol. 30, No. 5, pp. 359–364, 1997

Published by Elsevier Science Ltd
Printed in Great Britain
0963-9969/98 $19.00+0.00

Freeze-dried strawberries rehydrated in sugar solutions: mass transfers and characteristics of final products

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Sugar solutions with different sugar composition and concentration were used to reconstitute freeze-dried strawberries. The mass transfer between fruit pieces and solution during the rehydration process and the physicochemical characteristics of the reconstituted products were evaluated. The results indicated that by varying the concentration of the sugar solution and reconstitution time it was possible to obtain from the same freeze-dried product, rehydrated fruit pieces with different and peculiar characteristics such as water activity, freezing point, amount of freezable water and firmness. In addition, these characteristics were linearly correlated with soluble solids content in the rehydrated products. Using the above method, the reconstituted freeze-dried strawberries are able to be used as an ingredient in formulated foods at different levels of water activity and also in frozen dessert or ice cream. © 1998 Canadian Institute of Food Science and Technology. Published by Elsevier Science Ltd

Keywords: strawberries, rehydration, sugar solutions, water activity, freezing point, freezable water.

INTRODUCTION

Fruit pieces with medium or low levels of water activity could be obtained by single or combined drying techniques (Torreggiani *et al.*, 1991; Mastrocola and Pittia, 1992; Mastrocola *et al.*, 1996). In order to obtain a soluble solids uptake and further reduce water activity a direct osmosis pretreatment to air drying of fruit could be adopted (Hawkes and Flink, 1978; Lerici *et al.*, 1983, 1985; Monzini and Maltini, 1986; Mastrocola *et al.*, 1988; Le Maguer, 1988; Torreggiani, 1993). The osmotic dehydration process is also referred to as dewatering and impregnation soaking process (DIS) and some researchers have studied the counter-current water and solute transfer in order to better understand and model the mechanisms involved in the process itself (Raoult-Wack *et al.*, 1991*a*, 1994). In the case of strawberries it is very difficult to obtain, by partial drying, fruit pieces with low levels of water activity. Some authors have recently investigated the use of air-drying and osmotic dehydration to strawberries (Garrote and Bertone, 1989; Dalla Rosa *et al.*, 1989; Garrote *et al.*, 1992; Alvarez *et al.*, 1995; Shi *et al.*, 1995). Generally, results showed disruption of cell membranes of heat-treated fruit and cell wall alteration during the osmotic treatments. Water sorption properties of dried and osmodehydrated strawberries were investigated by Vidales *et al.* (1995).

On the other hand, freeze-dried strawberries have the quality of being readily reconstituted and are of excellent colour and flavour; however, this technology is very costly when considering the commercial dehydration of fruit. Outside of formulated foods, it is not very easy to find semi-manufactured (partially processed products able to be used by food industry) fruit pieces able to satisfy specific needs. In this latter situation it would be valuable to have high quality products such as freeze-dried fruit. In fact this kind of product can be diversified

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with regard to water activity, freezing point and firmness for desired end-uses. The modulation of dried fruit pieces characteristics can be obtained by a proper choice of reconstitution medium (Mastrocola *et al.*, 1995).

In this research work sugar solutions with different sugar composition and concentration were used to reconstitute freeze-dried strawberry slices. The mass transfer between fruit pieces and solution during the rehydration process and the physicochemical properties of the reconstituted products such as: water activity, freezing point, amount of freezable water and firmness at frozen state were evaluated.

MATERIALS AND METHODS

Raw material

Trials were performed on strawberries (*Fragaria vesca*, cv. Selva) supplied by farm 'S. Orsola' located in Trento—Italy.

Sample preparation

One day after harvesting, the strawberries were gently washed in tap water and sliced to give four slices for every fruit, then immediately frozen in a forced-air cabinet (Alaska, mod. EF 600, Bologna, Italy) operating at −40°C. After freezing fruit pieces were freeze-dried in a pilot plant (Edwards Alto Vuoto, Mini fast 1700, Milan, Italy), shelf temperature was 35°C. Dehydrated product was packed in polyethylene laminate pouches and held at room temperature until reconstitution.

Reconstitution procedure

The following reconstitution media were used: W = distilled water; Gluc. 15 = solution of 15% (w/w) glucose; Gluc. 30 = solution of 30% (w/w) glucose; Glic. 15 = solution of 15% (w/w) corn syrup (Glicosa—Cerestar, Ferrara, Italy) ; Glic. 30 = solution of 30% (w/w) corn syrup (Glicosa—Cerestar, Ferrara, Italy). Fixed amounts of dehydrated fruit pieces (30 g) and reconstitution medium (600 ml) were placed in 1000 ml glass beakers and the product was submerged by a plastic screen. All trials were performed at room temperature and using the same stirring rate (100 RPM). The fruit pieces, after removal from the solutions (after 5, 10, 20, 40 or 60 min for each solution), were drained for 5 min on a plastic screen and blotted.

Analysis

Dry matter (DM) determinations were carried out in a vacuum oven for 12 h (AOAC Methods 22.013, 1980). Insoluble solids were determined in accordance with Barbier and Thibaults (1982) and Maltini *et al.* (1993). Water activity (a_w) was evaluated at 25°C with an electric hygrometer (Hygroskop DT Rotronic, Zurich) calibrated with saturated solutions of different salts. Prior to a_w determination the samples were cut into small pieces and equilibrated for 12 h.

The firmness of fruit pieces after reconstitution was measured with an Instron Universal Testing Machine (Instron International Ltd, High Wycombe, UK), model 4301, equipped with a temperature cabinet (model 3119-005), using a standard Kramer Shear press cell (model CS1) with a crosshead speed of 20 cm min^{-1} on 50 g of fruit. Extrusion force was taken as the maximum peak of recorded force on the charts expressed as Newtons (N) (Maltini *et al.*, 1993). The amount of frozen water at −15°C was determined by thermal differential analysis using a differential scanning calorimeter Mettler TA 4000 (Mettler, Greifensee, Switzerland) with a DSC-30 measuring cell, supplied with a processor Mettler TC-11 TA. The equipment was calibrated for temperature and heat flow with indium, lead and zinc. For the calorimetric analysis, about 15 mg of sample were put in 40 μl aluminium DSC pans. An empty aluminium pan (equal to the one used for the sample) was used as reference. Heating rate was 5°C min^{-1} in all experiments. A nitrogen gas flow of 20–30 ml min^{-1} was used to avoid water condensation in the measuring cell.

Water uptake (WG), solid loss (SL) or solid gain (SG) due to rehydration and amount of soluble solids in the water phase (SSw) was calculated in accordance with Mastrocola *et al.* (1995).

Data analysis

The values for water content, water activity, firmness and frozen water were the average of three repetitions. Analysis of water uptake (WG), solids loss (SL) or solids gain (SG) and soluble solids content (SSw) were analysed by least square fit of response surface (Response Surface Metodology, RSM) (Barbanti *et al.*, 1990; Dalla Rosa *et al.*, 1990). The quadratic polynomial model used had the general formula

$$Y = \beta_0 + \beta_1 t + \beta_2 C + \beta_{11} t^2 + \beta_{22} C^2 + \beta_{12} tC$$

where

Y = estimated WG, SL or SG and SSw values;
t = reconstitution time (min);
C = syrup concentration (°Bx);
β_0 = intercept;
β_1 = linear effect of time;
β_1 = linear effect of syrup concentration;
β_{11} = quadratic effect of time;
β_{22} = quadratic effect of concentration;
β_{12} = interaction effect of time and concentration.

In order to consider only the linear phase of the rehydration process the first value of each response surface was taken at 5 min.

The equations indicating the variation of water activity, frozen water at −15°C and firmness at −15°C of reconstituted strawberry pieces as a function of soluble solids content were obtained by linear regression. The statistical data for the quadratic polynomial model are reported in Table 1.

RESULTS AND DISCUSSION

In Figs 1 and 2 the amounts of water gained (WG) and solids lost (SL) or gained (SG) as function of reconstitution time and syrup concentration for freeze-dried strawberry slices are reported. The shapes of response surfaces (RSM) obtained by elaboration of experimental data, indicate that the majority of mass transfer phenomena among fruit and sugar solutions took place in the first period of the rehydration process. In fact, the reconstitution of freeze-dried fruit pieces involves, in the first phases of the process, mostly diffusive phenomena because the product becomes impregnated with liquid and, when the diluted solutions are used, high quantities of soluble solids are lost. When the cell walls become partially rehydrated they act like semipermeable membranes, as well as a 'pseudo' osmotic process (Lerici *et al.*, 1985; Le Maguer, 1988) absorbing water and carrying out a selective action towards soluble solids, depending on their molecular weight. During the so called 'osmotic dehydration' the transfer of solutes from the concentrated solution into the food occurs countercurrent to the water flux (dewatering), while during the reconstitution process, the impregnation fluxes of water and solutes flow in the same direction. Regardless of the process the influence of concentration of soaking solution on water/solute flux ratio should be considered. Raoult-Wack *et al.* (1991*a*) noted this consideration for dewatering–impregnation. Also in the case of reconstitution a compartmental model with 'outer' and 'inner' compartments could probably help to represent the complex transfer mechanisms (Raoult-Wack *et al.*, 1991*b*).

In our trials, when the concentration of rehydrating solution increased, freeze-dried strawberry pieces showed decreasing water uptake and soluble solids loss. On the other hand, in solutions containing more than 15% of sugar, a solid uptake was detected (Fig. 2). The use of water or low concentrated sugar solutions allowed for very high levels of water uptake in the first 15–20 min of reconstitution; if the process was prolonged, a remarkable loss of soluble solids form fruit was observed.

In the opinion of many authors (Levine and Slade, 1986; Maltini *et al.*, 1993), the 'compatibility' of the fruit with other components of a formulated food is highly dependent on the equilibrium between its water activity (a_w) value and that of the base-food in which it

Table 1. Statistical data on quadratic polynomial model adopted to evaluate water uptake (WG), solids loss (SL) or solids gain (SG) and soluble solids content (SSw) in reconstituted strawberry slices

Observed parameter	Adjusted R^2	*p*	*n*
WG	0.995	< 0.001	45
SL or SG	0.991	< 0.001	45
SSw	0.974	< 0.001	45

n: number of samples.

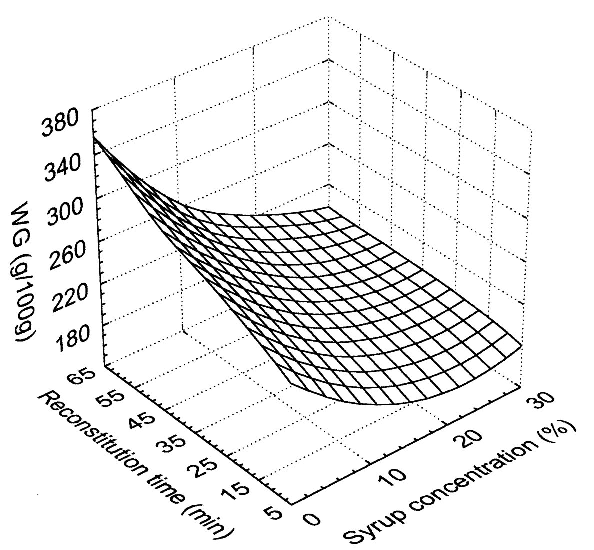

Fig. 1. Response surface plot of water uptake (WG) as function of reconstitution time and syrup concentration for freeze-dried strawberry slices.

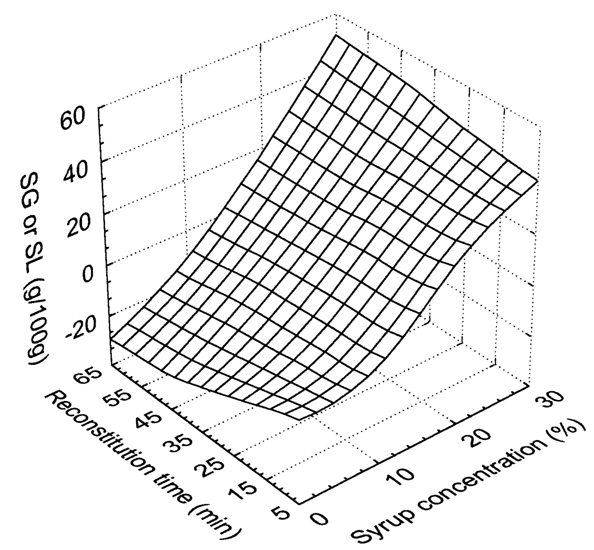

Fig. 2. Response surface plots of solid gain (SG) or solid loss (SL) as function of reconstitution time and syrup concentration for freeze-dried strawberry slices.

is included. The control of this parameter avoids or reduces the diffusion of moisture between ingredients at different levels of water content (Maltini *et al.*, 1993).

In our trials, the water activity values of rehydrated products were highly correlated to the soluble solids content, independent of time and reconstitution media (Fig. 3). From results reported in this paper, using a combination of process time and solution concentration, it was possible to obtain a soluble solid content of fruit pieces corresponding to a given a_w value suitable for the inclusion in a formulated food (Fig. 4). Data on the freezing point, calculated from a_w values (Fennema, 1981), could be helpful when rehydrated fruit pieces are mixed with frozen products such as ice-creams, sherbets and frozen desserts. In these cases, it is possible to choose fruit ingredients which do not form ice at a given temperature. For example, products with an a_w value lower or equal to the equilibrium a_w at that temperature, or fruit with water activities higher than the equilibrium one in which a definite amount of ice will separate according to the freezing behaviour (Maltini *et al.*, 1993). Moreover, in the case of inclusion of fruit pieces in ice-creams, generally consumed at an average temperature of −15°C, it is interesting to know the amount of frozen water in these pieces at this temperature (Fig. 5). In the case of reconstituted freeze-dried strawberries, even if their freezing temperature is higher than that at which the ice-cream is consumed, for soluble solids contents higher than $50\,g\,100\,g^{-1}$ of water, these products show a very low quantity of freezable water (less than 40%). When reconstituted fruits are kept at freezing temperatures, the texture is strongly influenced by frozen water and, only for low water quantities, by the compositive characteristics of solids and by their hydration level. For freeze-dried strawberries, hardness is quite constant (about 500 N) at soluble solids content over $50\,g\,100\,g\,H_2O^{-1}$ then it dramatically increases when soluble solids decrease (Fig. 6).

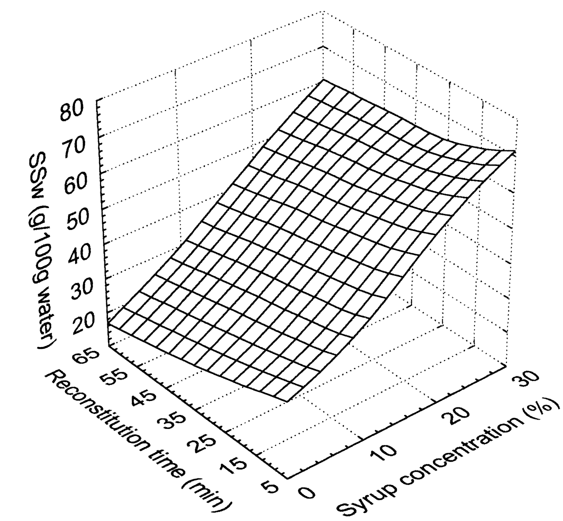

Fig. 4. Response surface plot of soluble solids content (SSw) as function of reconstitution time and syrup concentration for freeze-dried strawberry slices.

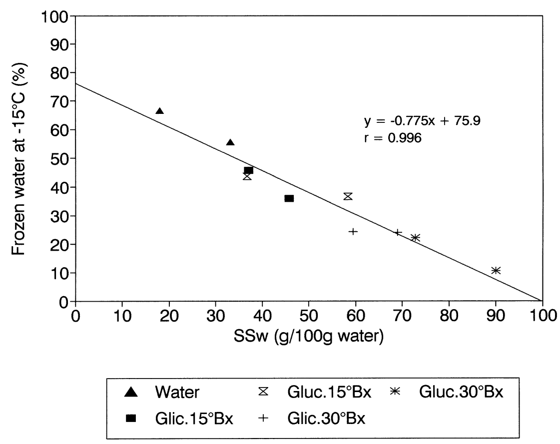

Fig. 5. Percentage of frozen water at −15°C as functions of soluble solids content in freeze-dried strawberry slices reconstituted in water or sugar solutions for 10 or 60 min.

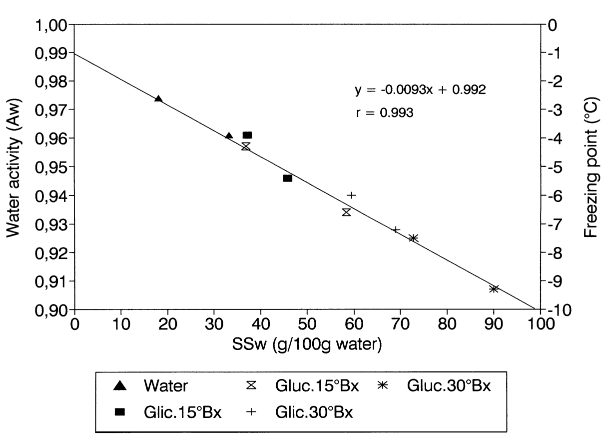

Fig. 3. Water activity (a_w) and freezing point as functions of soluble solids content in freeze-dried strawberry slices reconstituted in water or sugar solutions for 10 or 60 min.

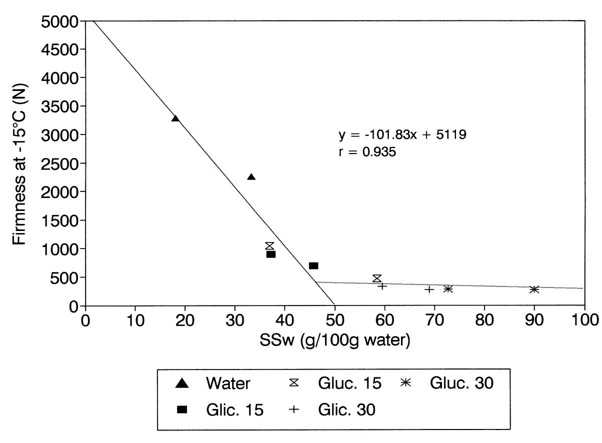

Fig. 6. Firmness at −15°C as functions of soluble solids content in freeze-dried strawberry slices reconstituted in water or sugar solutions for 10 or 60 min.

Freeze-dried strawberry slices reconstituted in water, exhibited hardness value similar to that of a fresh-frozen fruit (4730 ± 123 N), which at −15°C is not chewable.

Therefore, freeze-dried and reconstituted strawberry pieces will have a low amount of ice crystals which will not influence the firmness of the product if the soluble solid content is higher than 50 g 100 g $H_2O.^{-1}$

CONCLUSIONS

From the results obtained in this study, it was possible to modulate the water uptake and soluble solids balance of reconstituted freeze-dried strawberries pieces by controlling the time process, type and concentration of the reconstitution media. The latter leads to rehydrated products with different functional properties for specific uses in different food formulations. Thus, the dried fruits can be considered as semi-manufactured products which can be 'modified' depending on the final product, by manipulating the reconstitution treatment. In this context, the high quality level of the final product could balance the cost of the freeze-drying–reconstitution process, in particular when these products are used in formulated foods with high added value.

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(Received 23 April 1997; accepted 24 August 1997)