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# Study of Trehalose Addition on Aroma Retention in Dehydrated Strawberry Puree

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**Summary**

In order to improve the quality of dehydrated fruit products, the influence of the addition of two sugars (sucrose and trehalose) on the retention of aroma components during dehydration of strawberry puree was investigated. Manual headspace solid-phase microextraction (SPME), containing polydimethylsiloxane coated fibre (100 µm) coupled with gas chromatography (GC-FID and GC-MS) was used for the analysis of the aroma of strawberry puree dehydrated by using freeze drying and foam-mat drying. The analytes identified included esters, carbonyl compounds, terpenoids, several alcohols and acids. The results obtained in this study give further insight into the mechanisms concerning the application of trehalose as flavouring additive, due to its ability to retain and preserve the fruit volatiles responsible for the characteristic flavour of fresh fruits during dehydration processes. The best retention of aroma components in dehydrated strawberry puree was obtained by trehalose addition when combined with freeze drying.

*Key words*: trehalose, flavour retention, dehydration process, strawberry puree, solid-phase microextraction

## Introduction

For many food products, especially fruits, the presence of volatile aroma compounds is a prime quality feature. During dehydration, as one of the major preservation techniques, these components may be partly lost or their ratio may be changed. Also, during this process, secondary compounds may be formed by various reactions in which the native components of food are degraded (*1*) leading to bland products or reconstituted products with a markedly different flavour compared to the fresh product (*2*).

Therefore, during the last two decades much research has been undertaken to improve the quality of dried products, especially fruits. Two different approaches have been taken, one to improve heat transfer, lower the process temperatures and expand the porous structure of the product, and the other to use non-thermal methods or additives (*3*). Among different processes freeze drying is generally considered to be the superior process of dehydration for many common fruits, including strawberries.

In addition to the previous research (*4,5*) concerning the influence of carbohydrates addition (sugar, pectin) on retention of aroma components during freeze drying in fruit products and model systems and as a result of the increasing body of literature, both in order to prevent degradative changes, the idea to apply trehalose addition in such and suchlike dehydrated products appeared (*6–8*).

Trehalose, as well as sucrose, is a nonreducing disaccharide with the same chemical formula ($C_{12}O_{11}H_{22}$)

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but slightly different structure. The sucrose molecule is composed of one fructose and one glucose ring, while trehalose is composed of two glucose rings and it is one of the most stable known sugars, whose glycosidic bond has a low free energy of activation ($K_o$ of 119 sec$^{-1}$ as opposed to $K_o$ of $4.44 \cdot 10^4$ sec$^{-1}$ for sucrose), making the trehalose structure very stable regarding hydrolysis. Both disaccharides have been studied extensively and one of the most promising saccharide cryoprotectants, trehalose, has only recently received more attention (*6–12*). A number of mechanisms have been suggested for explanation of trehalose and sucrose effectiveness. These include their ability to form glass, to mimic the hydrogen bonding character of water, to increase the surface tension of the bulk solvent, to prevent thermotropic phase separations in lipid bilayers and to prevent the fusion of membranes (*13*). Both pure sugars form glass at temperatures above ambient temperature, but the glass transition temperature for trehalose is the highest amongst sugars (115 °C as opposed to 77 °C for sucrose) (*14,15*).

Certain organisms, such as bacteria, yeast, fungi and several species of nematodes, contain 20 % of dry weight of trehalose, which is responsible for their remarkable ability to go through cycles of desiccation and rehydration without injury (*16*). In the dry state, these organisms appear biologically dead with no detectable metabolic activity and are resistant to extreme conditions of temperature, pressure and ionizing radiation. Dry cryptobionts have been successfully rehydrated after storage for 120 years in a museum. Moreover, these organisms can be repeatedly dried and rehydrated, without cumulative ill effects.

Trehalose occurs naturally in many widely consumed foods. Furthermore, being a major component of commonly eaten foods such as mushrooms, honey, some seeds or yeast products (bread, beer, wine and vinegar), humans and other omnivores have evolved specific intestinal enzymes which digest trehalose to two glucose molecules (*17*). The remarkable ability of trehalose to completely protect cryptobiotic plants and animals from desiccation damage can be applied in drying foods on an industrial scale. Trehalose itself is bland, non-toxic dietary sugar, which does not change significantly the flavour of foods to which it is added. An additional benefit of the use of trehalose in food processing is the inhibition of the Maillard reaction between the naturally occurring proteins and sugars in the foodstuffs that are dried. Since Maillard reaction results in both the production of potentially toxic by-products, as well as in the loss of reacting proteins and sugars, trehalose dried foods should contain less toxic by-products as well as higher nutritional content. Since the ability of trehalose to preserve biological molecules during drying extends to small molecules such as vitamins, trehalose-dried foods may have a higher nutritional value than foods dried without trehalose. Trehalose, already recognised as GRAS by the Food and Drug Administration, has also been introduced as a commercial ingredient in the U. S. by Cargill Health & Food Technologies (*18*).

The purpose of this work was to determine the retention of aroma components in strawberry puree with the addition of sugars during freeze drying and foam-mat drying, all in order to investigate the possible application of trehalose addition in dehydrated products aimed to prevent specific degradative changes.

Strawberry is a very delicious fruit grown in nearly all the countries in the world**.** Because of its typical, very attractive aroma, strawberry has always been a favoured object in aroma analysis. Volatile components of strawberries have been extensively studied (*19–21*) and more than 360 volatiles are assumed to be involved in strawberry flavour. A complex mixture of esters, aldehydes, alcohols and sulphur compounds mainly determines strawberry aroma, but esters are quantitatively and qualitatively the most important class of volatiles. Methyl butanoate, ethyl butanoate, methyl hexanoate and ethyl hexanoate, as the »fruity« smelling esters, and the »caramel-like« smelling odorants, 2,5-dimethyl-4-hydroxy-3(2H)-furanone (furaneol), and its methyl ether, 2,5-dimethyl-4-methoxy-3(2H)-furanone (mesifurane), which can be present at low levels relative to the other volatile materials, play an important role in the aroma of strawberry (*22,23*) as well as (Z)-3-hexenal (green), 2-methylbutyric acid (sweety) and γ-decalactone (peach--like), which have also been proposed as the key odorants in fresh strawberries (*24*).

Headspace solid-phase microextraction (SPME), as a recently developed technique of sampling (*25*), in combination with gas chromatography, GC-FID and GC-MS, has been applied to analyse fruit volatiles in dehydrated strawberry products. Headspace solid-phase microextraction is a solventless sample preparation technique that is well adapted to GC analysis of volatile compounds. SPME involves absorbing the analytes on a fibre coating immersed into the sample (usually the gas phase above the sample) (*25*). After equilibration the fibre is removed from the sample and the analytes are thermally desorbed in the injector of a gas chromatograph.

## Material and Methods

### Sample preparation

In order to compare the influence of the addition of different sugars on flavour retention during both freeze drying and foam-mat drying, strawberry puree (7.67 % solids) produced in a juice processing plant (Fructal, Ajdovščina) was used. Strawberry puree with and without trehalose or sucrose addition was prepared. Dehydration was performed alternatively by freeze drying and foam-mat drying. The addition of both sugars (trehalose and sucrose) in freeze dried products was 8 % (wet basis). Sugar addition in foam-mat dried products was lower (4 %) because of the difficulties in the foaming step, where 0.02 % Hamulsion CNF (Hahn, Lübeck) and 2 % carboxymethylcellulose sodium salt as thickening agents were also used. Foam-mat drying was performed in a cabinet drier (adapted for foam-mat drying) and samples were dried to approximately 7.3 % moisture content. The temperature was programmed as follows: 100 °C held for 4 min, 80 °C held 3.5 min and decreased to 65 °C where it was held for 45 min. Freeze drying was performed in CHRIST Freeze Dryer (GAMMA 2–20). The freeze drier consisted of a circular chamber with nine steel trays to hold the samples. Samples were dried

until they reached 2 % moisture content. It required a drying time of the order of 27 h. The following conditions were used: freezing temperature was –40 °C, the temperature of sublimation was from –20 to 20 °C under the vacuum of 1.030 mbar and the temperature of isothermal desorption was from 20 to 30 °C under the vacuum of 0.001 mbar.

### Solid-Phase Microextraction (SPME) analysis

A commercially available manual SPME fiber holder containing a 100 μm polydimethylsiloxane coated fiber (Supelco, Bellefonte, PA) was used. Before the analysis dried purees in powder form were rehydrated up to the mass proportion of total solids in the original puree. The rehydration of samples (20 mL) was followed by the addition of internal standard, 2,6-dimethyl-5-hepten-2-ol (0.5 ppm) and 4 g NaCl, which were also added in the original, not dried puree. Following this, samples were capped in 50-mL glass vials, warmed to 50 °C in water bath and gently mixed. Samples were equilibrated for 10 min prior to insertion of fiber and were maintained at 50 °C throughout the 30-min assay. The fibre was then removed from the headspace and inserted into the GC. Blank runs were performed regularly prior to the sample analysis to ensure the removal of impurities. Each new fiber was conditioned before use by a procedure recommended by the manufacturer in order to desorb any material on the fiber in a GC injector port at 250 °C for about an hour.

### GC/FID and GC/MS analyses

Thermal desorption of the adsorbed volatiles was carried out by directly exposing the fiber in the injector port of the GC at 200 °C for 5 min. For thermal desorption the splitless injection mode was used and the split valve was opened after 3 min.

GC-FID

| | |
|---|---|
| Instrument: | Varian 3300 |
| Injector: | 200 °C |
| Split: | 28 mL |
| Column: | DB-624 (J&W) 30 m x 0.32 mm ID/1.8 μm |
| Carrier gas: | Nitrogen |
| Temperature programme: | 40 °C, 3 min →190 °C, 5 °C/min →10 min |
| FID Detector: | 250 °C |

GC-MS

| | |
|---|---|
| Instrument: | Hewlett-Packard 5890 gas chromatograph with a 5970 series mass selective detector, NBS library spectrum |
| Column: | DB-624 (J&W) 30 m x 0.32 mm ID/1.8 μm |
| Carrier gas: | Helium |
| Temperature programme: | 40 °C, 3 min →190 °C, 5 °C/min →10 min |

All the analyses were carried out in three replicates for each sample. The retention of fruit volatiles was calculated on the basis of peak areas of total aroma and individual components before and after sugar addition and dehydration.

### Chemical and physical analysis

An overall characterisation of strawberry puree before drying was carried out by measuring dry matter, pH-value, total acidity, percentage of cellulose, total pectins, and total and reducing sugars *(26,27)*. Dry matter, pH-value and total acidity were determined in accordance with AOAC methods *(28)*.

## Chemicals

All the chemicals were of p.a. purity. All standards, except γ-decalactone and 2,6-dimethyl-5-hepten-2-ol, were purchased from Merck. γ-decalactone and 2,6-dimethyl-5-hepten-2-ol were purchased from Roth, Karlsruhe.

## Results and Discussion

The analytical data for strawberry puree before drying are shown in Table 1. The results obtained in this investigation are shown as the peak area ratio and as percentage of the retention of total aroma and of individual compounds in relation to the data of strawberry puree before drying (Table 2). The peak area ratio was calculated by dividing the peak area of total aroma and individual compounds by the peak area of an internal standard (2,6-dimethyl-5-hepten-2-ol). Actual peak area of the internal standard was 53 383 on average with a coefficient of variation (CV) of 2.1 %. The peak area ratios ranged from 0.002 to 3.805 and CV values ranged from 0.2 to 11.8 % with a mean of 5 %. The identified compounds were divided into three groups: (*i*) esters, (*ii*) carbonyls and terpenes, and (*iii*) alcohols and acids. All the identified compounds in foam-mat dried and freeze dried strawberry puree are listed in Tables 3 and 4 as well as three not identified compounds, which were also determined. The retention of these compounds after drying is presented in Figs. 2–7. The retention of fruit volatiles in dehydrated strawberry puree varied in relation to the dehydration process and the kind of sugar added. As expected, the flavour compounds retention in freeze dried puree with sugar addition was the best, if compared either to foam-mat dried samples or the samples without sugar addition (*29,30*). The lowest loss of total aroma (10.34 %) as well as of individual fruit volatiles was noticed when freeze drying and trehalose addition were combined (Table 2).

This indicates that sugar addition to strawberry puree prior to dehydration prevented the loss of a part of

Table 1. Analytical data for strawberry puree before drying

| | |
|---|---|
| Dry matter/ % | 7.67 |
| pH | 3.66 |
| total acidity (as citric acid)/ % | 0.98 |
| cellulose/ % | 0.16 |
| total pectins/ % | 0.13 |
| total sugars/ % | 5.1 |
| reducing sugars/ % | 4.9 |

Table 2. Peak area ratio of total aroma of dehydrated strawberry purees in relation to strawberry puree before drying

| Strawberry puree before drying | Drying methods | Without sugar addition | Puree with sucrose addition | Puree with trehalose addition |
|---|---|---|---|---|
| 17.573 (100 %) | Freeze drying | 5.973 | 6.682 | 15.756 |
| | Foam-mat drying | 1.372 | 2.220 | 5.553 |

fruit volatiles and increased the retention of its characteristic aroma in dehydrated products, which is in agreement with previous results obtained by Lovrić and Pozderović (*5*). The results concerning flavour retention due to the addition of trehalose (independently of the dehydration process used, foam-mat drying or freeze drying), which have not been used in the previously mentioned investigations, will be pointed out in more detail. Peak areas of total aroma are shown in Table 2, while the retention expressed as percentage of total aroma depending on the dehydration process used and the kind of sugar added are shown in Fig. 1.
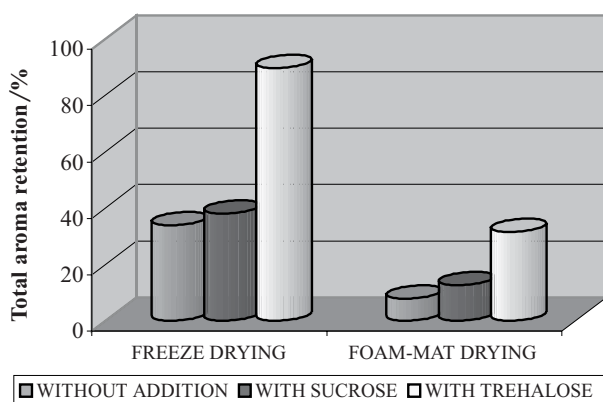


**Fig. 1. Retention of total aroma in dehydrated strawberry puree** (strawberry puree before drying = 100 %)

The retention of total aroma without sugar addition after foam-mat drying and freeze drying was only 7.81 and 33.99 %, respectively. In the case of sucrose addition (before drying) the retention of total aroma after foam-mat drying was 12.6 and after freeze drying it was 54.5 %. When trehalose was added in strawberry puree, total aroma retention was 31.6 % in foam-mat dried and 89.66 % in freeze dried puree. This means that with trehalose addition the retention of total aroma was increased up to 19 % in foam-mat dried and up to 35 % in freeze dried strawberry puree, when compared with sucrose addition.

**Esters**

Results of similar research works suggested that esters play an important role in strawberry aroma (*23,31*). As already mentioned, the major esters identified were fruity smelling esters as methyl butanoate, ethlyl butanoate, methyl hexanoate, hexyl acetate, ethyl hexanoate

and methyl anthranilate. Methyl anthranilate is responsible for the typical character of the wood strawberry aroma, characterised by an intensive spicy-aromatic and flowery note (*32*). All mentioned esters were determined in strawberry puree before drying and in all dehydrated samples of strawberry puree, except in foam-mat dried puree without the addition of sugars, where methyl butanoate was not determined, as listed in Table 3. In agreement with previous research, a decrease in total esters content was related to a decrease in product quality (*33*). It could be demonstrated that ethyl butanoate and ethyl hexanoate were found in higher amounts in the puree during this study compared to methyl butanoate and methyl hexanoate, which suggests that ethyl alcohol was esterified to a greater extent than methyl alcohol by alcohol acetyl transferase in fruits that were used in this present investigation. This is in agreement with recently reported results (*34*).

*Carbonyl compounds and terpenes*

Variation of carbonyl compounds and terpenoids content as well as of esters, alcohols and acids content, in freeze dried and foam-mat dried purees is listed in Tables 3 and 4. Hexenal is important for possible contribution to the green flavour note (*33*), mainly provided by hexenols. Besides linalool, as one of the general strawberry aroma compounds responsible for the floral character, and previously reported hexenal, from the class of carbonyl compounds and terpenoids, γ-decalactone, benzaldehyde and α-terpineol were determined in all samples in this study, while 2-heptanone was not detected in foam-mat dried strawberry puree without and with sucrose addition. γ-decalactone provides the fruity, peach-like smell (*24*).

*Alcohols and acids*

The unsaturated alcohol, *cis*-3-hexenol, is an important contributor to the green, leafy top note in strawberry flavour and in other fruit flavours (*33*). This alcohol was detected in strawberry puree before drying and in freeze dried samples, while it was not detected in foam-mat dried strawberry puree.

Hexanoic acid, which was also determined in almost all samples in the present study, contributes to an aroma impression which is perceived as unpleasant (*21*).

Although no characteristic impact compounds were found for strawberry aroma, some researchers consider DHF (furaneol) and mesifurane as two of the most important aroma contributors. Both furaneol and mesifurane have strong, sweet and pleasant odours (*35*). The failure to detect DHF in our study, which is widely used in industry as flavouring agent for food and beverages, may be due to either its low presence in the headspace and/or to its chemical instability (*36*).

The increased retention of fruit volatiles during drying of fruit puree, due to the addition of some sugars (in this case sucrose and trehalose), is obviously a complex phenomenon that depends on several factors. These are probably physical and chemical properties of sugar added as well as of flavour compounds, *i.e.* molecular weight (mass) and structure, steric and other characteristics, related to different diffusion and sorption ability within

Table 3. Peak area ratio of identified aroma compounds in foam-mat dried strawberry puree with and without sucrose and trehalose addition

| Compound | Strawberry puree before drying | Puree without the addition of sugars | Puree with sucrose addition | Puree with trehalose addition |
|---|---|---|---|---|
| *Esters* | | | | |
| Methyl butanoate | 0.018 | – | 0.004 | 0.007 |
| Ethyl butanoate | 0.122 | 0.023 | 0.041 | 0.053 |
| Butyl acetate | 0.036 | 0.005 | 0.012 | 0.015 |
| Ethyl 2-methyl butanoate | 0.033 | – | 0.006 | 0.013 |
| Methyl hexanoate | 0.097 | 0.008 | 0.006 | 0.005 |
| Butyl butanoate | 0.083 | 0.017 | 0.040 | 0.037 |
| Ethyl hexanoate | 0.199 | 0.047 | 0.047 | 0.121 |
| Hexyl acetate | 0.189 | 0.037 | 0.033 | 0.041 |
| Ethyl octanoate | 0.121 | 0.009 | 0.007 | 0.005 |
| 2-phenylethyl acetate | 0.079 | 0.006 | 0.006 | 0.007 |
| Methyl anthranilate | 0.377 | 0.014 | 0.021 | 0.022 |
| Ethyl decanoate | 0.078 | 0.009 | – | 0.007 |
| *Carbonyls and terpenes* | | | | |
| Hexanal | 0.047 | 0.008 | 0.016 | 0.019 |
| 2-hexenal | 0.355 | 0.013 | 0.014 | 0.022 |
| 2-heptanone | 0.065 | – | – | 0.009 |
| Benzaldehyde | 0.067 | 0.006 | 0.005 | 0.006 |
| Linalool | 0.302 | 0.047 | 0.028 | 0.061 |
| $\alpha$-terpineol | 0.069 | 0.016 | 0.008 | 0.019 |
| $\gamma$-decalactone | 0.599 | 0.034 | 0.037 | 0.073 |
| *Alcohols and acids* | | | | |
| *cis*-3-hexen-1-ol | 0.056 | – | – | – |
| 1-hexanol | 0.148 | – | – | 0.006 |
| 1-octanol | 0.029 | 0.005 | 0.002 | 0 |
| 2-phenylethanol | 0.039 | 0.003 | 0.004 | 0.006 |
| Hexanoic acid | 0.062 | 0.003 | – | – |
| *Not identified compounds* | | | | |
| n.i.$_1$ | 0.859 | 0.007 | 0.011 | 0.014 |
| n.i.$_2$ | 3.805 | 0.010 | 0.011 | 0.017 |
| n.i.$_3$ | 0.544 | 0.054 | 0.043 | 0.044 |

the microstructure of the material. Earlier research *(5)* suggested the dependence of retention ability of some carbohydrates on their molecular weight. However, the difference in flavour retention ability registered between sucrose and trehalose cannot be attributed to this factor, but to other more complex mechanisms. According to earlier studies, the retention of some original compounds after drying may be due to their lower volatility. In addition, since the flavour compounds are generally larger than water molecules, they may not readily diffuse *(37)* or are trapped *(38)* within the fruit matrix during drying.

According to Saravacos *(39)*, carbohydrates are known to enclose volatile flavours. This shows that some original flavour components, which are responsible for the natural aroma of the product, could be retained within the dried solid.

Besides these theories and mechanisms of aroma retention during dehydration, aroma retention is certainly affected by the phenomenon of the reduction of molar ratio of the more volatile compounds in the vapor phase above the sample immediately after the addition of sucrose and trehalose before drying. This phenomenon, as well as the formation of microregions in the dried layer of the material, certainly has the greatest influence on the retention of the more volatile components during drying.

When sucrose and its solutions were compared with trehalose, the former demonstrated higher water diffusion coefficients, lower $T_g$, lower densities and higher intramolecular hydrogen bonding. Also, trehalose appears to exhibit a higher hydration capacity than sucrose. These characteristics play an important role in preservation processes. By binding water molecules more tightly, the glass formed by trehalose could hinder molecular motion more effectively, possibly leading to its superior cryo- and lyoprotection *(12,16)*.

Recently three theories have been put forward to explain the mechanism of the action of trehalose: water

Table 4. Peak area ratio of identified aroma compounds in freeze dried strawberry puree with and without sucrose and trehalose addition

| Compound | Strawberry puree before drying | Puree without the addition of sugars | Puree with sucrose addition | Puree with trehalose addition |
|---|---|---|---|---|
| *Esters* | | | | |
| Methyl butanoate | 0.018 | 0.006 | 0.007 | 0.009 |
| Ethyl butanoate | 0.122 | 0.047 | 0.062 | 0.064 |
| Butyl acetate | 0.036 | 0.024 | 0.019 | 0.024 |
| Ethyl 2-methyl butanoate | 0.033 | 0.014 | 0.016 | 0.020 |
| Methyl hexanoate | 0.097 | 0.016 | 0.039 | 0.061 |
| Butyl butanoate | 0.083 | 0.042 | 0.062 | 0.071 |
| Ethyl hexanoate | 0.199 | 0.072 | 0.087 | 0.136 |
| Hexyl acetate | 0.189 | 0.089 | 0.066 | 0.146 |
| Ethyl octanoate | 0.121 | 0.029 | 0.062 | 0.107 |
| 2-phenylethyl acetate | 0.079 | 0.027 | 0.030 | 0.065 |
| Methyl anthranilate | 0.377 | 0.152 | 0.168 | 0,199 |
| Ethyl decanoate | 0.078 | 0.038 | 0.039 | 0.041 |
| *Carbonyls and terpenes* | | | | |
| Hexanal | 0.047 | 0.008 | 0.009 | 0.033 |
| 2-hexenal | 0.355 | 0.084 | 0.126 | 0.246 |
| 2-heptanone | 0.065 | 0.015 | 0.014 | 0.008 |
| Benzaldehyde | 0.067 | 0.033 | 0.032 | 0.035 |
| Linalool | 0.302 | 0.168 | 0.154 | 0.185 |
| $\alpha$-terpineol | 0.069 | 0.045 | 0.039 | 0.048 |
| $\gamma$-decalactone | 0.599 | 0.408 | 0.398 | 0.471 |
| *Alcohols and acids* | | | | |
| *cis*-3-hexen-1-ol | 0.056 | 0.020 | 0.026 | 0.021 |
| 1-hexanol | 0.148 | 0.021 | 0.024 | 0.029 |
| 1-octanol | 0.029 | 0.017 | 0.017 | 0.025 |
| 2-phenylethanol | 0.039 | 0.023 | 0.026 | 0.027 |
| Hexanoic acid | 0.062 | 0.017 | 0.021 | 0.027 |
| *Not identified compounds* | | | | |
| n.i.$_1$ | 0.859 | 0.163 | 0.342 | 0.632 |
| n.i.$_2$ | 3.805 | 1.767 | 1.925 | 3.568 |
| n.i.$_3$ | 0.544 | 0.353 | 0.378 | 0.499 |

replacement hypothesis, glass transformation hypothesis and chemical stability hypothesis (*40*).

The ability of sugar molecules to bind protectively onto the surface of molecular structures has been ascribed also to their ability to form hydrogen bonds, the so called »water replacement hypothesis«.

Unlike most other disaccharides, trehalose has no direct internal hydrogen bonds. All four internal bonds are indirectly connected via the two water molecules, which form part of the native dihydrate structure. This arrangement gives the molecule an unusual flexibility around the disaccharide bond, which may allow trehalose to fit more closely to the irregular surface of macromolecules than other, more rigid disaccharides, in which the rings are directly hydrogen bonded to each other.

The well-known ability of sugars to solidify as glass from solution rather than by crystallisation has also been suggested as an important element in the mechanism by which trehalose confers desiccation tolerance on cryptobionts. A further property of glass transition is

to prevent the loss of small hydrophobic volatile esters during drying and storage, thus ensuring their release only after rewetting and dissolution of the glassy matrix. Unlike many other sugars that also undergo glass transition, trehalose produces glasses that are not hygroscopic. Furthermore, when dried without trehalose, the products were more difficult to reconstitute and lost much of their fresh flavour in the dehydrated puree, which is in agreement with the results of Colaco and Roser (*40*).

After rehydration of all dried strawberry purees, the most characteristic flavour of the fresh strawberry puree, without *off flavours*, was regained in the sample which was freeze dried with trehalose addition. These results can be related to the results of similar investigations, which suggest that the presence of trehalose during drying actually inhibits the Maillard reactions between the naturally occurring sugars and proteins in the dried foodstuffs. These reactions not only result in the production of high amounts of undesirable compounds
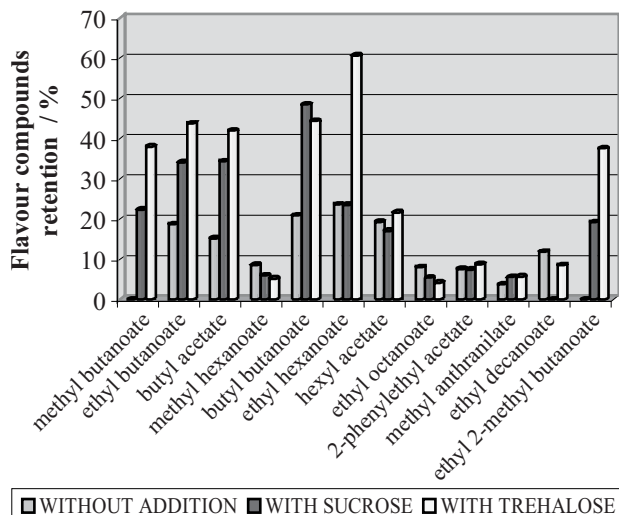
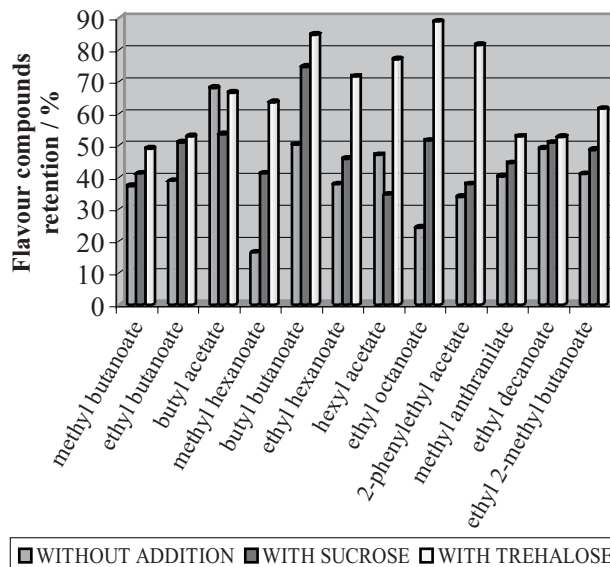Fig. 2. Retention of esters in foam-mat dried strawberry puree



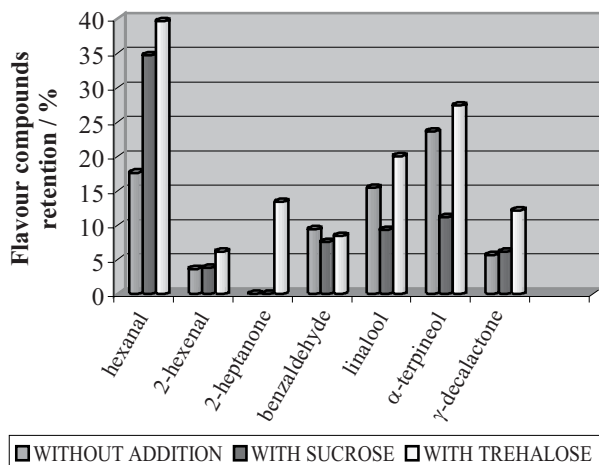Fig. 5. Retention of esters in freeze dried strawberry puree



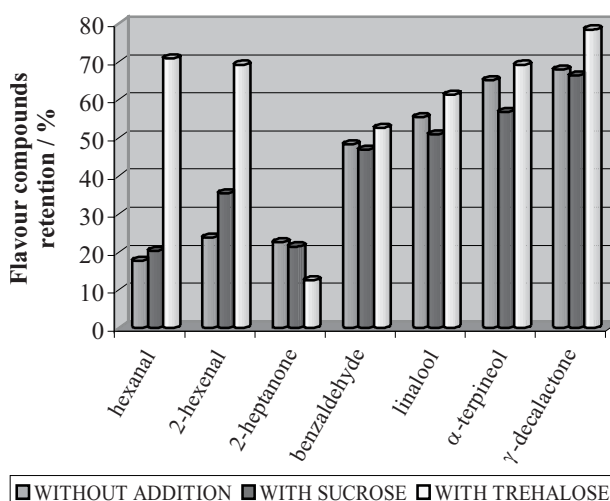Fig. 3. Retention of carbonyls and terpenes in foam-mat dried strawberry puree



Fig. 6. Retention of carbonyls and terpenes in freeze dried strawberry puree
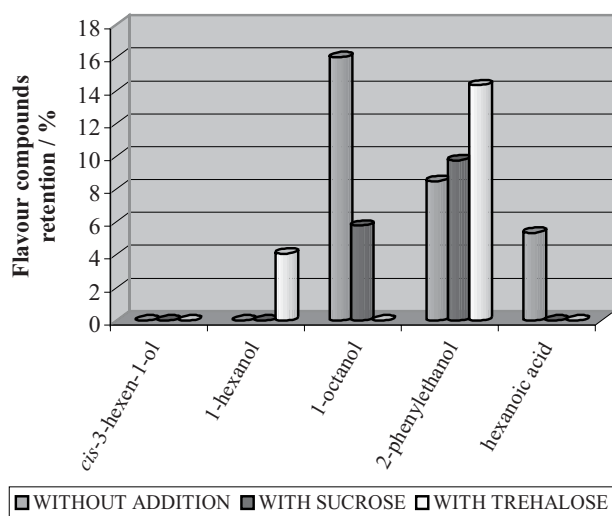


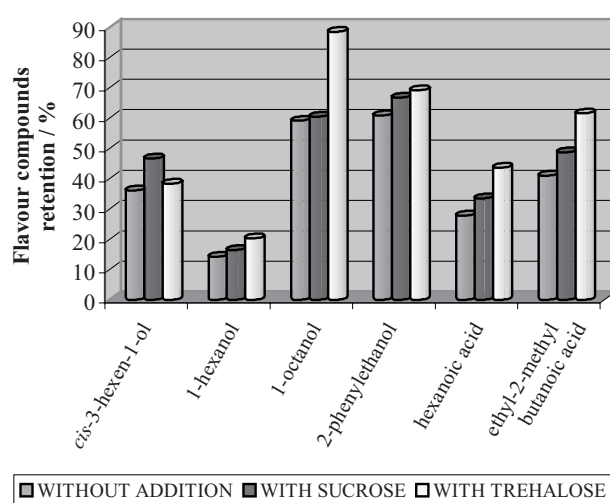Fig. 4. Retention of alcohols and acids in foam-mat dried strawberry puree



Fig. 7. Retention of alcohols and acids in freeze dried strawberry puree

such as furans, furfurans, imidazoles, *N*-nitroso derivatives and melanoids, but also in significant losses in nutritive value (*41,42*).

Apart from the explanation of mechanisms concerning aroma retention in dehydrated fruit products, which was given in previous papers, the obtained results related to the role of trehalose need an additional explanation of registered phenomenon in further research.

## Conclusion

The results obtained in this study give a further insight into the mechanisms concerning the application of trehalose as flavouring additive, due to its ability to retain and preserve the fruit volatiles responsible for the characteristic flavour of fresh fruits during dehydration processes.

When added to foods prior to drying, trehalose reduces the loss of fruit volatiles much more than sucrose.

Regarding the retention of aroma compounds in dried strawberry puree, the results obtained are generally in agreement with those reported in literature and show that freeze drying positively influences the retention of the aroma compounds more than foam-mat drying.

Finally, the ability of trehalose to retain and preserve the volatile aromatic molecules responsible for the characteristic flavours of fresh fruits during drying enables the development of new processes to maximise this effect and to produce superior dried products.

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# Utjecaj dodatka trehaloze na zadržavanje
# arome u dehidratiranoj kaši jagode

**Sažetak**

Da bi se poboljšala kakvoća dehidratiranih voćnih proizvoda, proučavan je utjecaj dodatka saharoze i trehaloze na zadržavanje aromatičnih sastojaka u kaši jagode tijekom dehidratacije. Pri analizi arome kaše jagode, dehidratirane liofilizacijom i sušenjem u pjeni, primijenjena je tehnika mikroekstrakcije na čvrstoj fazi (SPME), s vlaknom punjenim polidimetilsiloksanom (100 μm PDMS), u kombinaciji s plinskom kromatografijom (GC-FID i GC-MS). U kaši jagode identificirani su esteri, karbonilni spojevi, terpeni, te nekoliko alkohola i kiselina. Rezultati ovog istraživanja omogućavaju dublji uvid u mehanizme djelovanja trehaloze kao sredstva koje pospješuje bolje zadržavanje i očuvanje aromatičnih sastojaka odgovornih za karakterističnu aromu svježega voća tijekom postupaka dehidratacije. Najbolje zadržavanje aromatičnih sastojaka u dehidratiranoj kaši jagode postignuto je dodatkom trehaloze povezane s postupkom liofilizacije.