REHYDRATION KINETICS OF DRIED LATVIAN CRANBERRIES AFFECTED BY DRYING CONDITIONS

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Abstract
The aim of the current research was to study the effect of drying conditions on the rehydration kinetics of Latvia wild grown and on cultivated cranberries. The research was accomplished on fresh wild cranberries and cultivated cranberry cultivars 'Ben Lear' and 'Pilgrim' harvested in Kurzeme region of Latvia in the first part of October 2010 and immediately used in the drying experiment. Three methods were used for pre-treatment of berries: perforation, halving and steam-blanching. Before drying in a convective drier the berries were pre-treated using all three methods and berries were dried in a microwave vacuum drier using two pre-treatment methods – steam-blanching and halving. Parts of berries were dried in the microwave vacuum drier without pre-treatment (whole berries). For drying experiments, convective and microwave vacuum drier were used. Cranberry samples were rehydrated in water at +20±1 °C and +40±1 °C. The moisture content of the cranberry samples after rehydration was estimated as oven-dry method. The rehydration properties of cranberries increased with the increase in temperature, up to +40±1 °C, the increase being more significant at the initial stages of the process. Microwave drying possibly produces a sample with increased porosity, which in turn leads to improved rehydration characteristics and a softer product and may reduce processing time. Pre-treatment of berries did not significantly influence the increasing intensity of moisture content during rehydration, but the drying methods within rehydration at the temperature of +40±1 °C significantly influenced the increasing intensity of moisture content.
Key words: rehydration, cranberries, convective drying, microwave vacuum drying.

Introduction

Dehydrated products can be used in many processed or ready-to-eat foods in place of fresh foods and have several advantages such as convenience in transportation, storage, preparation and use (Lewicki et al., 1998). Dehydrated products need to be rehydrated before consumption or further processing (Oliveira and Ilincanu, 1999). During rehydration, absorption of water into the tissue results in an increase in the mass (Krokida and Marinos-Kouris, 2003). Rehydration is influenced by several factors, grouped as intrinsic factors (product chemical composition, pre-drying treatment, product formulation, drying techniques and conditions, etc.) and extrinsic factors such as composition of immersion media, temperature, and hydrodynamic conditions (Oliveira and Ilincanu, 1999). Some of these factors induce changes in the structure and composition of the plant tissue, which results in the impairment of the reconstitution properties (Taiwo et al., 2002).

Rehydration of dried plant tissues is composed of three simultaneous processes: the imbibition of water into dried material, the swelling and the leaching of soluble (McMinn and Magee, 1997).

Rehydration is a complex process aimed at the restoration of raw material properties when dried material is in contact with a liquid phase. Pre-drying treatments, subsequent drying and re-hydration induce many changes in structure and composition of plant tissue (Lewicki et al., 1997), which result in impaired reconstruction properties. Hence, rehydration can be considered as a measure of the injuries to the material caused by drying and treatments drying dehydration (Lewicki, 1998).

The term *quality* implies the degree of excellence of a product; it is a human perception encompassing many properties or characteristics (Abbot, 1999).

Cranberries belong to a group of evergreen dwarf shrubs or trailing vines in the genus *Vaccinium* subgenus *Oxycoccus*. Traditionally they grow in acidic bogs throughout the cooler parts of the world; when cultivated are grown on low trailing vines in great sandy bogs. Berries are rich in a vitamin C, organic acids, mineral substances, aroma, and phenol compounds. Many cultivars and native species of berries exist with substantially higher antioxidant levels than others (Moyer et al., 2002; Popleva, 2000).

Cranberries and their products have been historically associated with many positive benefits for human health. For many decades, cranberry juice has been widely used as a folk remedy to treat urinary tract infections. Cranberry juice extracts have also been suggested to exhibit anticancer effects and to inhibit the oxidation of low-density lipoprotein *in vitro*, potentially preventing the development of heart diseases (Vattem et al., 2005).

Drying is one of the oldest methods of food preservation and it is a difficult food processing operation mainly because of undesirable changes in quality and the removed water from a food product using conventional air drying may cause serious damage to the dried product (Wang and Xi, 2005). It is the most common and most energy-consuming food preservation process. With literally hundreds of variants actually used in drying of particulate solids, pastes, continuous sheets, slurries or solutions, it provides the most diversity among food engineering unit operations. Air-drying, in particular, is an ancient process used to preserve foods in which the solid to be dried is exposed to a continuously flowing hot stream of air where moisture evaporates. The phenomena underlying this process is a complex problem involving simultaneous mass and energy transport in a hygroscopic, shrinking system. Air-drying offers dehydrated products that can have an extended shelf life of a year but, unfortunately, the quality of a conventionally dried product is usually drastically reduced from that of the original foodstuff (Ratti, 2001; Feng and Tang, 1998).

Microwave drying is rapid, more uniform and energy efficient compared to a conventional hot air drying. In this case, the removal of moisture is accelerated and, further-more, heat transfer to the solid is slowed down significantly due to the absence of convection. Also because of the concentrated energy of a microwave system, only 20–35% of the floor space is required, as compared to conventional heating and drying equipment. However, microwave drying is known to result in a poor quality product if not properly applied (Drouzas and Shubert, 1996; Yongsawatdigul and Gunasekaran, 1996).

Water accounts for the bulk of the dielectric component of most food systems especially for high moisture fruits and vegetables. Hence, these products are very responsive to microwave applications and will absorb the microwave energy quickly and efficiently as long as there is residual moisture. Microwave application for drying therefore offers a distinct advantage. Proteins, lipids and other components can also absorb microwave energy, but are relatively less responsive. A second advantage of microwave application for drying of vegetables is the internal heat generation (Wang and Xi, 2005).

The aim of the current research was to study the effect of drying conditions on the rehydration kinetics of wild and cultivated cranberries in Latvia.

Materials and Methods

The research was accomplished on fresh, wild (*Vaccinium oxycoccus* L.) and cultivated (*Vaccinium macrocarpon* Ait.) cranberries harvested in Kurzeme region in the first part of October 2010 and immediately used in the current drying experiment. Cranberry cultivars were: ‘Ben Lear’ and ‘Pilgrim’. Cranberries were used in the experiment immediately after drying.

Three methods were used for pre-treatment of berries: perforation, halving, and steam-blanching. Before drying in a convective drier, berries were pre-treated using all three methods, and berries were dried in a microwave vacuum drier using two pre-treatment methods – steam-blanching and halving. Part of berries were dried in the microwave vacuum drier without pre-treatment (whole berries).

Perforation of berries (3.000±0.001 kg) was realised manually with a needle (1 mm in diameter) - about 20 pricks on each berry surface; halving (3.000±0.001 kg) was realised manually with knife; steam-blanching (3.000±0.001 kg) was realised using “TEFAL VC4003 VITAMIN+” (Tefal, China) vessel at the temperature of +94±1 °C.

Drying conditions was elected accordingly to the results of previous experiments for maximal biological compounds preservation in cranberries during processing in elevated temperatures (Dorofejeva et al., 2010).

For air drying experiments, the convective drier “Memmert” Model 100-800 (Memmert GmbH Co. KG, Germany) was used; drying parameters were as follows: temperature - 50±1 °C, and air flow velocity - 1.2±0.1 m s^{-1}. Berries were placed on a perforated sieve (diameter − 0.185 m), with the diameter of the holes – 0.002 m.

For drying experiments the vacuum microwave drier „Musson-1” (OOO Ingredient, Russia) was used (at 2450 MHz frequency and 12.5 cm wavelength) (Vacuum microwave drier MUSSON-1, 2007). The power of each of the four magnetrons was 640 W. The necessary amount of microwave energy (magnetron minutes) was calculated. The following drying conditions for processing of cranberries in the microwave vacuum drier were selected: the first drying stage at 4 magnetrons – energy of 2100 kJ, the second stage at 3 magnetrons – energy of 2520 kJ, the third stage at 2 magnetrons – 1260 kJ, and the fourth stage at 1 magnetron – 756 kJ. Temperature in the microwave vacuum drier was 36±2 °C (moisture content - 9±1%).

Cranberry samples were rehydrated in water at +20±1 °C and +40±1 °C (temperature not higher than +40±1 °C was chosen mainly for maintenance of berries biological value). Samples were rehydrated by immersion: 3g of each sample in 100±1 ml of distilled water. The samples were weighed after 60 minutes of rehydration till unchanged weight. Sample weight changes were controlled throughout the hydration process. Before weighing, samples were gently blotted in order to remove the superficial water (Singh et al., 2008).

The moisture content of the cranberry samples after rehydration was estimated as oven-dry method at +105±1 °C (Temmingoff and Houba, 2004). All the experiments were performed in triplicate and average values were reported.

Data were expressed as mean ± standard deviation; for the mathematical data processing p-value at 0.05 was used to determine the significant differences.

Two-way ANOVA and three-way ANOVA analysis by IBM SPSS 20.0 were used to investigate the influence of factors and interactions among them.

Results and Discussion

Dehydration operations are important steps in the chemical and food processing industries. The basic objective in drying food products is the removal of water in the solids up to a certain level, at which microbial spoilage is minimized. The wide variety of dehydrated foods, which today are available to the consumer (snacks, dry mixes and soups, dried fruits, etc.), and the interesting concern for meeting quality specifications and conserving energy emphasize the need for a thorough understanding of the operation and the problems related to the design and operation of dehydration and rehydration plants (Vagenas and Marinos-Kouris, 1991).

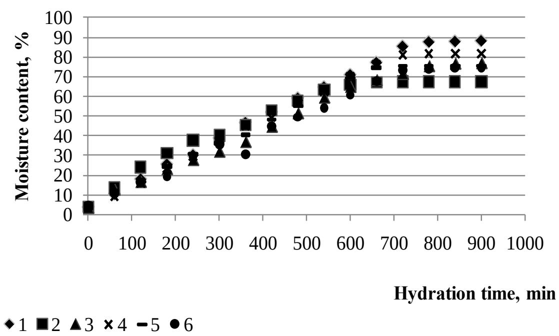
The effect of temperature on the water absorption of severally pre-treated and dried cranberry cultivars "Ben Lear", "Pilgrim" and wild berries are shown in Figures 1, 2 and 3.

In the present research it was detected that temperature had an influence on rehydration behaviour with initial rehydration rates increasing with temperature of up to +40±1 °C (Figs. 1, 2 and 3). In experiments it was found that the cultivar of berries, pre-treatment, drying conditions and hydration solution (water) temperature influence the rehydration capacity. As a result, hydration water quantity was different too.

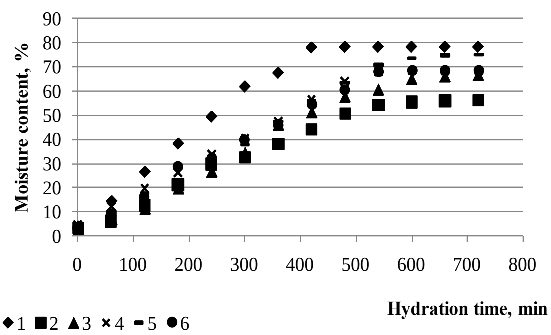
In other researches it has been detected that moisture content of fresh wild berries initially was 85.91±2.40%, of cranberry cultivar "Pilgrim" − 87.36±2.12%, and of cranberry cultivar "Ben Lear" − 87.36±2.91% (Dorofejeva et al., 2011).

For cranberry cultivar "Ben Lear", after (perforated and dried in convective drier) rehydrating the berries in water at the temperature by +20±1 °C the initial moisture content (i.e. 88.56±1.20 %) was reached after 14 h (Fig. 1). However, if severally ways pre-treated berries were dried in the microwave vacuum drier – maximal moisture content (75.00±1.14%), was reached after 13 h. For berries rehydrated in water at +40±1 °C, the moisture content was lower (70.00±1.36% in average) and rehydration time was shorter (9 h) (Fig. 1). The obtained results could be explained with drying methods particularity. Within berries processing in microwave vacuum drier, structure of berries was changed less, than if cranberries were dried in oven-dry drier. As a result the cells of berries absorb water faster and swell more rapidly.

Similar results were acquired in experiments with cranberry cultivar "Pilgrim". However, for cranberry cultivar "Pilgrim", the maximal moisture content (75.00±0.32%) during rehydration was reached at the temperature by +20±1 °C (Fig. 2), which was by ~12% less compared the moisture content by fresh berries. Rehydration time at the temperature by +20±1 °C was 13−14 h. For berries rehydrated at +40±1 °C, the maximally reached moisture content was 85.14±2.18% (Fig. 2), which was very similar to parameters of fresh berries. The rehydration time was 13 h.

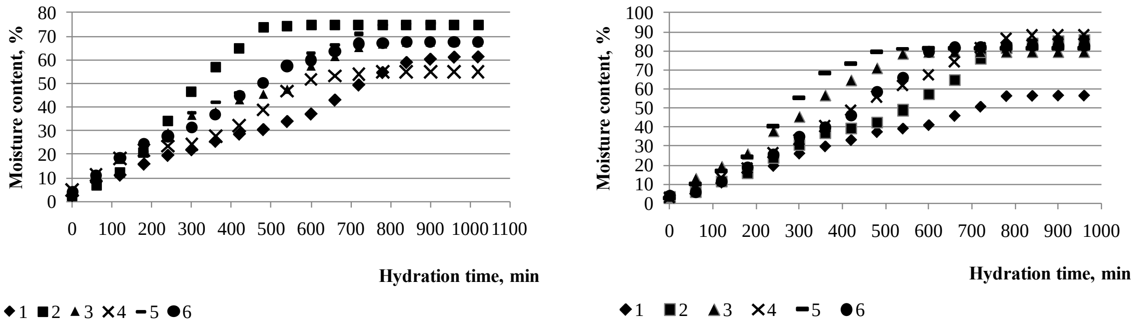


Rehydration temperature +20±1 °C



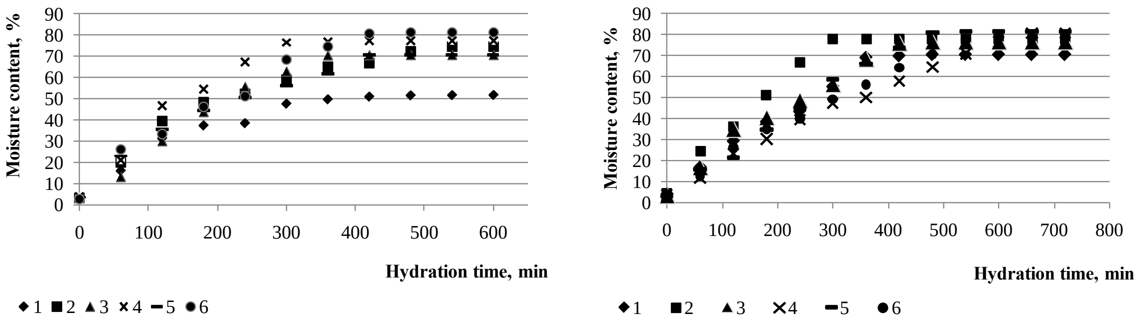
Rehydration temperature +40±1 °C

Figure 1. Rehydration water quantity of cranberry cultivar "Ben Lear".
***1** – perforated berries dried in convection drier; **2** – halved berries dried in convection drier; **3** − steam-blanched berries dried in convection drier; **4** – whole berries dried in microwave-vacuum drier; **5** − halved berries dried in microwave-vacuum drier;**6** − steam-blanched berries dried in microwave-vacuum drier.*



Hydration temperature +20±1 °C   Hydration temperature +40±1 °C

Figure 2. Rehydration water quantity of cranberry cultivar "Pilgrim".
1 *– perforated berries dried in convection drier;* ***2*** *– halved berries dried in convection drier;* ***3*** *− steam-blanched berries dried in convection drier;* ***4*** *– whole berries, dried in microwave-vacuum drier;* ***5*** *− halved berries dried in microwave-vacuum drier;* ***6*** *− steam-blanched berries dried in microwave-vacuum drier.*



Hydration temperature +20±1 °C   Hydration temperature +40±1 °C

Figure 3. Rehydration water quantity of wild cranberries.
1 *– perforated berries dried in convection drier;* ***2*** *– halved berries dried in convection drier;* ***3*** *− steam-blanched berries dried in convection drier;* ***4*** *– whole berries dried in microwave-vacuum drier;* ***5*** *− halved berries dried in microwave-vacuum drier;* ***6*** *− steam-blanched berries dried in microwave-vacuum drier.*

Opposite results were obtained in rehydration experiments with wild cranberries. Were moisture content in berries ranged from 52% to 81% (Fig. 3). However, the highest moisture content was found in berries rehydrated at +40±1 °C. Rehydration time at the temperature by +20±1 °C and +40±1 °C was similar – 8−9 h.

In our experiments the acquired results were very various. Therefore, for the detection of significance of differences mathematical data processing was used. As a result, Greenhouse-Geisser test was suited. It was established that, for severally processed berries rehydration in water at temperature +20±1 °C, that changes in moisture content within the tested time period were significant with p=0.0001; however, pre-treatment of berries and drying methods did not significantly influence the changes in moisture content (p=0.6830) (Table 1) during rehydration.

Very similar results were established in mathematical data processing of results acquired during berries rehydration at the +40±1 °C temperature (Table 2). Significant moisture content changes were found within rehydration time. It was proved that pre-treatment by berries does not significantly (p=0.311) influence the intensity of moisture content increases within hydration at the temperature by +40±1 °C (Table 2). However, drying methods significantly (p=0.001) influenced the intensity of moisture content increases within rehydration, mainly could

Table 1

Tests of within-subjects effects (hydration at temperature +20±1 °C)

Source	Type III sum of squares	Degree of freedom	Mean square	Variance ratio, F	Significance, p value
Rehydration time	465511.918	1.742	267186.531	525.119	0.000
Rehydration time and pre-treatment method	2021.390	3.485	580.101	1.140	0.341
Rehydration time and drying	301.478	1.742	173.037	0.340	0.683
Rehydration time, pre-treatment and drying method	1980.906	3.485	568.483	1.117	0.351
Error	42551.424	83.629	508.811	-	-

Table 2

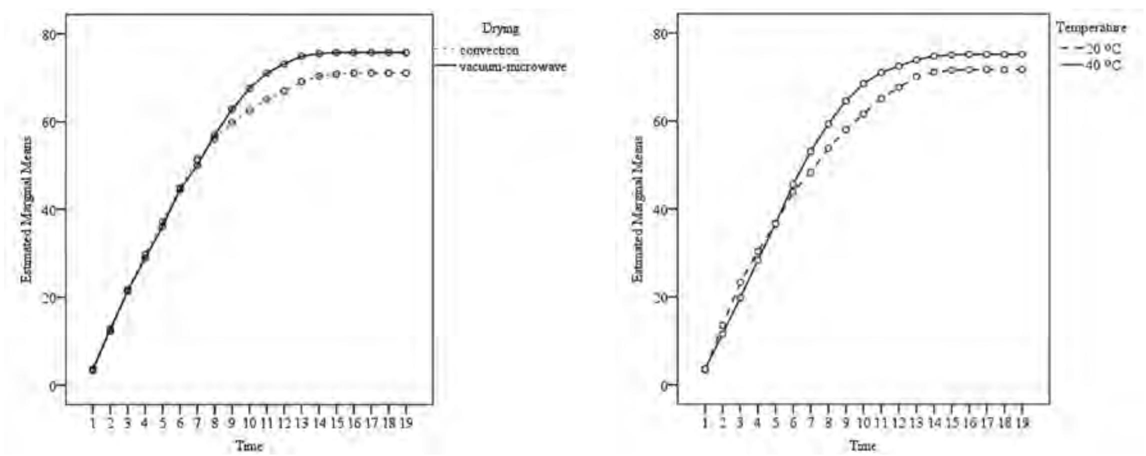
Tests of within-subjects effects (hydration at temperature +40±1 °C)

Source	Type III sum of squares	Degree of freedom	Mean square	Variance ratio, F	Significance, p value
Rehydration time	569335.708	1.731	328871.637	936.114	0.000
Rehydration time and pre-treatment method	1476.381	3.462	426.409	1.214	0.311
Rehydration time and drying	5299.336	1.731	3061.113	8.713	0.001
Rehydration time, pre-treatment and drying method	3862.506	3.462	1115.571	3.175	0.023
Error	29193.150	83.097	351.316	-	-

be explained with the influence of drying temperature and time on the structure of berries. Interconnection in berries pre-treatment and drying methods significantly (p=0.023) influenced the changes in moisture content during rehydration, with maximal probability P=97.70%.

Pre-treatment method, berry cultivar and rehydration temperature had no significant influence on rehydration capacity by berries if berries were dried in convection drier. However, if berries were dried in microwave-vacuum drier the rehydration temperature had the major influence on rehydration capacity.

If time factor is not taken into consideration in mathematical data analyse, interconnection (berry pre-treatment and drying methods, rehydration temperature) of analysed factors has not significant influence on rehydration capacity with probability P=95.00%.



(A) (B)

Figure 4. Influence by drying conditions (A) and rehydration temperature (B) on berry hydration capacity.

It was ascertained that pre-treatment methods by berries do not significantly (P=83.90%) influence the rehydration capacity. Whereas, drying methods (P=99.10%) and rehydration temperature (P=99.50%), on the contrary have significant influence on the rehydration process by berries (Fig. 4).

Conclusions

1. The rehydration properties of cranberries increased with the increase in temperature, up to +40±1 °C, the increase being more significant at the initial stages of the process.
2. Berries pre-treatment did not significantly influence the intensity of moisture content increase during rehydration. Whereas, drying methods significantly influenced the intensity of moisture content increase during rehydration at the temperature of +40±1 °C.
3. Pre-treatment method, berry cultivar and rehydration temperature had no substantial influence on cranberry rehydration capacity if berries were dried in convection drier. However, if berries were dried in microwave-vacuum drier, rehydration temperature had the main influence on the rehydration process.

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