Pol. J. Food Nutr. Sci., 2015, Vol. 65, No. 4, pp. 233–241
DOI: 10.2478/pjfns-2013-0020
http://journal.pan.olsztyn.pl

Original article
Section: Food Quality and Functionality

Effect of Quantity of Low–Methoxyl Pectin on Physical Properties of Freeze–Dried Strawberry Jellies

Agnieszka Ciurzyńska, Andrzej Lenart, Joanna Karwosińska*

Department of Food Engineering and Process Management, Faculty of Food Sciences, Warsaw University of Life Sciences, SGGW, 159c Nowoursynowska St., 02–776 Warszawa, Poland

Key words: low–methoxyl pectin, jelly, freeze–drying, porosity, mechanical properties, rehydration properties

The development of fruit–based products with a high proportion of fruit and good nutritional, sensory and functional properties may help to diversify market supply. These products ought to be attractive, especially to young people, easy to consume and have a reasonably long shelf life. Three recipes of freeze–dried strawberry jelly with low–methoxyl pectin (LMP) (2.0, 2.5, 3.5% LMP) with the use of strawberry pulp were obtained and physical properties were investigated to choose the sample with the best quality factors. The quantity of added low–methoxyl pectin influences the physical properties of freeze–dried strawberry jellies. The recipe with 2.5% addition of low–methoxyl pectin was chosen based on the results obtained. Despite the relatively high friability and low hardness, and higher shrinkage, it has a fast rate of rehydration. It is also characterised by high porosity and the parameters of the colour most similar to the raw material and low water content and activity.

INTRODUCTION

Strawberries are valued for their taste, flavour and nutritional value [Wang & Lin, 2000; Ciurzyńska & Lenart, 2009, 2010a], but fruit is still consumed at levels below those recommended for human health. This is particularly evident in countries where lifestyle has changed, people prefer a higher energy diet with a greater proportion of fat and added sugars in foods, greater saturated fat intake, reduced intakes of complex carbohydrates and dietary fibre and reduced fruit and vegetable intakes [Sheiham, 2001].

Strawberries are a rich source of fibre, minerals, vitamins and antioxidants [Ayala–Zavala *et al.,* 2004]. Most fruit is consumed when fresh, but market availability is generally limited by a short shelf life and seasonal production. Strawberries are delicate and highly perishable fruit, due to their intensive respiration, quick weight loss, and susceptibility to fungal contamination [Ciurzyńska & Lenart, 2010a; Ciurzyńska *et al.,* 2012; Martin–Esparza *et al.,* 2011].

Advancement in technology is aimed at improving the product so that its quality is repetitive, and the product is comfortable and functional. Introducing a wide range of products to bars, gas stations and small stores forces producers to use modern technology to allow preparation of products according to the demand [Dhansekharan *et al.,* 2004]. The development of fruit–based products with a high proportion of fruit and good nutritional, sensory (aroma, flavour, colour and texture) and functional properties may help to diversify market supply. These products need to be attractive, especially to young people, easy to consume and have a reasonably long shelf life [Martin–Esparza *et al.,* 2011]. In order to create new products and improve the existing ones, it is essential to know the changes in the rheological properties of semi–finished products and linking them to the results of sensory evaluation. One method of improving the textural properties of additives is stabilizing the structure of the products [Półtorak, 2007].

The development of fruit–gel products with the use of hydrocolloids has been studied in several works [Nussinovitch *et al.,* 2000; Haminiuk *et al.,* 2007; Wierzbicka, 2007]. However, almost all of them are concerned with fruit–based products made of gels that have been texturized with fruit flavour [Cheney *et al.,* 2007; Drouzas *et al.,* 1999] or by the addition of fruit juice or fruit pulps [Haminiuk *et al.,* 2007]. Few references can be found in literature about gelled products based on a high quantity of fresh or osmodehydrated fruit or fruit pieces [Martinez–Navarrete *et al.,* 2007]. Polish manufacturers of freeze–dried foods have found that a large amount of a by–product in the form of strawberry powder is formed during dried strawberry production, and especially dried product grinding, and this may also be used for the manufacture of valuable products. Both the market and consumer demand urge the creation of new recipes [Ciurzyńska *et al.,* 2013b]. Freeze–dried gels are a convenient model system in the study of cellular solids of biological origin, at least in principle. Selecting the gel composition and preparation conditions enables the creation of sponges with controlled microstructure and mechanical properties [Nussinovitch *et al.,* 1993].

* Corresponding Author: Tel. +4822 5937577;
E–mail: agnieszka_ciurzynska@sggw.pl (PhD Agnieszka Ciurzyńska)

TABLE 1. Recipes of freeze–dried strawberry jellies.

Sample designations	Low–methoxyl pectin (LMP)		
	2.0% LMP	2.5% LMP	3.5% LMP
Pulp amount (g)	60	60	60
Hydrocolloid amount (g)	2.0	2.5	3.5
Water amount (g)	36.95	36.45	35.45
Additives (g)	1.0 ascorbic acid 0.05 calcium lactate	1.0 ascorbic acid 0.05 calcium lactate	1.0 ascorbic acid 0.05 calcium lactate

Pectin plays an important role in the rheological behaviour of fruit pulp owing to its gelling properties. This natural polysaccharide, frequently used as a food additive, belongs to the group of polyuronates. It is a natural ionic polysaccharide undergoing chain–chain association and forming hydrogels upon addition of divalent cations (*e.g.* Ca^{2+}) [Cardoso *et al.,* 2003; Marudova *et al*., 2004; Fang *et al.,* 2008]. Very important factors during gelation process are *e.g.* pH or Ca^{2+}, which have different and partly opposite effects on the gelling process of different pectin types [Löfgren & Hermansson, 2007; Kastner *et al.,* 2012].

Many foods have a solid cellular structure. Hydrocolloid–based cellular solids can be produced by drying gels immediately after their production [Nussinovitch *et al.,* 1993] or after their immersion in different carbohydrate solutions to modify their physical and chemical properties. Fruit gels are used most often as fruit fillings for the manufacture of various kinds of products. In baked goods, they are fillings of confectionery products both thermally processed and unprocessed. In confectionery, fruit fillings are used for pastry and chocolate products. In the dairy industry they are widely used for milk products, such as yoghurts, milk drinks and desserts. Freeze–dried hydrocolloid gels could be useful as carriers for many food snacks, non–food matrices and biotechnological operations [Nussinovitch & Zvitov–Marabi, 2008].

It is very important to develop a product which is new, attractive and with beneficial properties that meet the needs of increasingly demanding consumers.

MATERIALS AND METHODS

Materials

The raw material included hydrocolloid – low–methoxyl pectin gels (LMP) (Hortimex Company).

The raw material for the study was freeze–dried strawberry powder obtained from freeze–dried strawberry, stored in a dark place at room temperature, manufactured by the Department of Food Engineering and Process Management in WULS–SGGW in Warsaw. Strawberry freeze–drying was conducted at heating shelves temperature of 30°C, under the pressure of 63 Pa for 24 h in a Christ Company ALPHA 1 – 4 LDC – 1m freeze–drier with contact heating of the raw material.

Preparation of freeze–dried strawberry jellies

On the basis of investigations conducted for freeze–dried strawberry jelly with the use of sodium alginate (manufactured by Hortimex), 60 g of strawberry pulp from rehydrated strawberry powder was used to obtain jelly with low–methoxyl pectin (LMP) [Ciurzyńska *et al.,* 2013b]. Physical properties of the obtained freeze–dried strawberry jelly were investigated to find the optimal recipe for jelly with low–methoxyl pectin (LMP) (Table 1).

Measured amounts of ingredients were added to water heated to 85–90°C and mixed. After solidifying, the jellies were cut manually into cubes of 1 cm side. The strawberry jellies were frozen in a National Lab GmbH freezer (ProfiMaster Personal Freezers PMU series) at a temperature of –18°C for 24 h. The frozen cubes were next moved to a Christ Company ALPHA 1 – 4 LDC – 1m freeze–drier with contact heating of the raw material. The process was conducted with constant parameters: pressure 63 Pa, safety pressure 137 Pa, temperature of freeze–drier heating shelves 30°C, time 24 h.

After the freeze–drying process, the jelly cubes were moved to glass vessels which were tightly closed and stored in a dark place at room temperature until the time of analyses (Figure 1).

Dry matter content determination

Dry matter content for freeze–dried strawberry jellies was determined before and after freeze–drying process [Ciurzyńska *et al.,* 2013b]. Gel cubes were crumbled in a mortar. The crushed samples were weighed on analytical scales with an accuracy up to 0.001 g, about 3 g of homogenate per glass weighing bottle. The drying process was conducted for about 24 h in a convection dryer at a temperature of 65°C until solid mass was obtained. The process was repeated three times.

Dry matter content was calculated from the formula:

$$ss = \frac{m_2 - m_0}{m_1 - m_0} * 100\% \qquad (1)$$

where: ss – dry matter content (%), m_o – the mass of empty glass weighing bottles (g), m_1 – the mass of glass weighing bottles with material before drying (g), and m_2 – the mass of glass weighing bottles with material after drying (g).

Water content was calculated from the formula:

$$u = 100\% - ss \qquad (2)$$

where: u – water content (%) and ss – dry matter content (%).

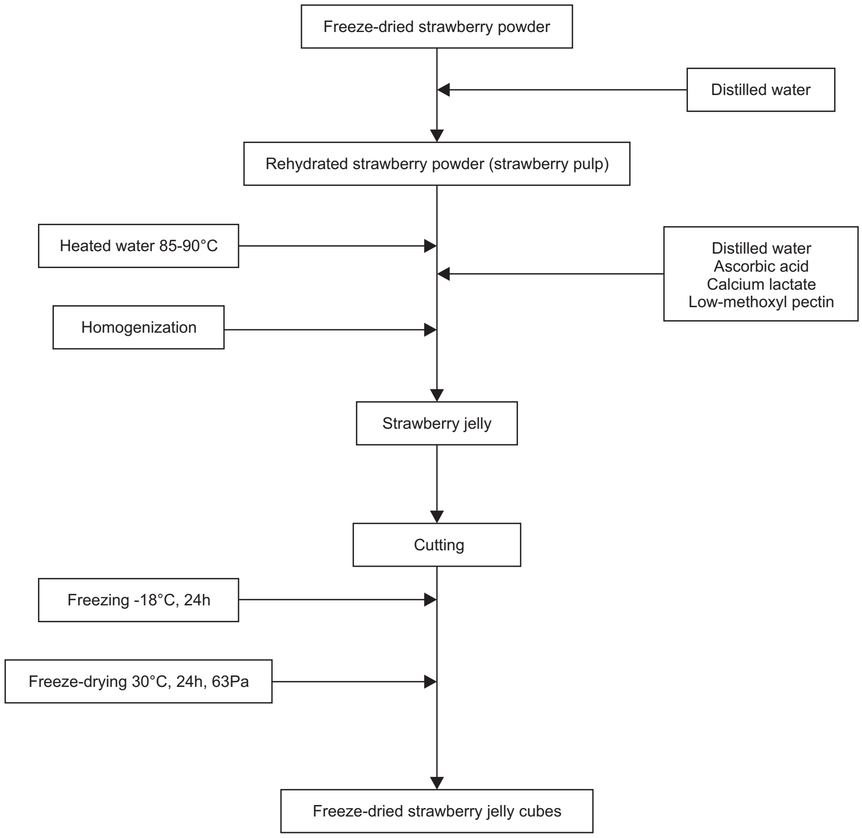

FIGURE 1. Diagram for the preparation of freeze–dried strawberry jelly.

Water activity determination

Water activity was determined in a Rotronic Hygroscop DT apparatus according to the manufacturer's manual at a temperature of 25°±1°C. Determination was conducted in three replications.

Colour determination

Colour was determined using a Minolta company (Austria) Chroma – Meter CR – 300 apparatus in a $L^*a^*b^*$ system. The examination was conducted with diffused lightning at an angle of 0°, the diameter of the measurement hole was 8 mm, standard light of c type. Measurements were conducted in five repetitions. Mean values were determined for the results obtained. Colour coefficients were also calculated [Ciurzyńska & Lenart, 2009]. Diagrams were produced for the values obtained and standard deviations were determined as well. Colour coefficients were determined from the following equations:

C^*_{ab} – chroma

$$C^*_{ab} = \sqrt{(a^*) + (b^*)^2} \tag{3}$$

ΔE – relative colour difference index

$$\Delta E = \sqrt{(L^{*0} - L^*) + (a^{*0} - a^*)^2 + (b^{*0} - b^*)^2} \tag{4}$$

where: L^* – lightness coefficient (dimensionless value), a^* – red colour coefficient (dimensionless value), b^* – yellow colour coefficient (dimensionless value), and L^{*0}, a^{*0}, b^{*0} – colour coefficients for raw jelly (relate to) (dimensionless value).

Rehydration properties determination

Determination of rehydration properties involved holding freeze–dried strawberry jellies in water for specified periods of time (5, 10 and 30 min). Measurements were done at temperatures of 20°C and 80°C for all kinds of strawberry jellies in three replications [Witrowa–Rajchert & Lewicki, 2006].

Mechanical properties determination

Determination of mechanical properties involved measurement of compressive force using a TA–XT2i texture analyzer device at a room temperature of 20°C±2°C in ten replications. The cubes were subjected to compression with a constant head speed of 20mm/min up to the moment when 50% deformation of the initial height of the sample was obtained. Diagrams of compression curves were produced, and the work performed during 50% cube deformation was determined [Ciurzyńska & Lenart, 2010b].

Shrinkage determination

The cubes of freeze–dried jelly used for shrinkage determination were previously coated with pectin. The solution of 2.0% low–methoxyl pectin was used. In addition, 2.0% calcium chloride solution was prepared. Using laboratory tweezers, jelly cubes, were plunged consecutively for one second, first in a beaker with 2.0% pectin solution, and then in 2.0% calcium chloride solution. The cubes were left for 24 h at a room temperature of 20–25°C for drying. The determination of shrinkage was performed on the next day.

Determination of contraction was performed using hydrostatic method. The shrinkage was determined on the basis of measurements of material volume, and the measurement of sample mass enabled additionally to determine density [Ciurzyńska & Lenart, 2010b]:

$$S = \left(1 - \frac{Vk}{V0}\right) * 100\% \tag{5}$$

where: S – shrinkage (%), V_k – average volume of a jelly cube after drying (cm^3) and V_0 – average volume of a jelly cube before drying (cm^3).

Porosity determination

Porosity of the freeze–dried material was measured with stereopycnometer helium pycnometer of Quantachrome Company according to the producer instruction. The research material of a known mass and unknown volume was introduced to a large measurement cell of a known volume. Next, it was placed in an apparatus. The inflowing helium filled all the interspaces and pores between the cubes, which enabled the measurement of the volume of the studied sample. Each sample was rinsed three times with gas. Helium pycnometer determined the value of pressure. After introduction of the obtained values to the Pycnometer software version 2.7, the apparent density of the analysed jelly materials was determined [Ciurzyńska *et al.,* 2013a].

Volume of the samples was calculated from the formula:

$$V_p = \frac{V_c + V_a}{1 - \frac{P_1}{P_2}} \tag{6}$$

where: V_p – volume of sample (cm^3), V_c – volume of cell (cm^3), V_a – references volume (cm^3), and P_1, P_2 – pressure, which was read from the pycnometr (Pa).

Apparent density was calculated from the formula:

$$P_s = \frac{m}{V_p} \tag{7}$$

where: ρ_s – apparent density of particles (g/cm^3), m – particle mass (g), and V_p – volume of particles (cm^3).

Porosity was calculated from the formula:

$$\varepsilon = \left(1 - \frac{pb}{ps}\right) * 100\% \tag{8}$$

where: ε – porosity (%) and ρ_b – density of particles (g/m^3).

Statistical methods

The mathematical and statistical analyses involved the use of StatGraphics Plus v. 5.1. (Manugistics Corp., Rockville, MD, USA) and MS Excel. Corresponding standard deviations (SD) were calculated for the averaged results obtained. The least significant difference between mean values was calculated for the analysed technological coefficients, considering pairs of the investigated samples, with respect to the used variables, using an F–test (multiple range test). For the purpose of analyses, a significance level was assumed at 0.05 [Galus *et al.,* 2013].

RESULTS AND DISCUSSION

Influence of low–methoxyl pectin (LMP) quantity on water content and activity of freeze–dried strawberry jellies

The average water content in all recipes of jellies with low–methoxyl pectin (LMP) was at a low level, not exceeding 6.0% (Table 2). Only for jelly with 2.5% low–methoxyl pectin addition the water content was statistically significant lower in comparison to other samples. It can be related to the different mode of binding water during gel formulation. All jellies had also low water activity, which was beneficial and typical of freeze–dried products (Table 2). Similar to water content results, water activity for jelly with 2.5% hydrocolloid addition was statistically significantly lower in comparison to other samples. Low water content and activity for freeze–dried jellies reduces the rate of biochemical reactions in the product, thus leading to an increase in its stability and extending shelf life. Similar results were obtained by Woźnica & Lenart [2006] for freeze–dried strawberries and by Ciurzyńska *et al.* [2013b] for freeze–dried strawberry jellies with sodium alginate.

Influence of low–methoxyl pectin (LMP) quantity on colour of freeze–dried strawberry jellies

The corresponding appearance, including the colour of the product, significantly affects its attractiveness and provides information about the quality. For the consumer the most attractive colour of this product is close to that of the raw material. In order to characterise and accurately compare the colour system, CIE L*a*b* was used. The results obtained confirm that the quantity of added hydrocolloid affected colour changes of freeze–dried strawberry jellies. For all freeze–dried jellies, the increase of lightness coefficient (L*) by about 10 units was shown in comparison to freeze–dried strawberry powder (Table 3). It was probably connected with re–drying of the powder component of straw-

TABLE 2. Water content and water activity of freeze–dried strawberry jellies in relation to amount of low–methoxyl pectin.

Sample	Water content u (%)	Water activity a_w
LMP 2.0%	$4.98^a \pm 0.17$	$0.25^a \pm 0.02$
LMP 2.5%	$4.24^b \pm 0.12$	$0.23^b \pm 0.01$
LMP 3.5%	$5.17^a \pm 0.23$	$0.25^a \pm 0.01$

Designations as in Table 1. Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p<0.05$).

TABLE 3. Colour coefficients (L*, a*, ΔE, SI) of freeze–dried strawberry jellies in relation to the amount of low–methoxyl pectin.

Sample	L*	a*	ΔE	SI
Strawberry powder	$39.51^{a}\pm0.66$	$20.13^{a}\pm0.65$	–	–
LMP 2.0%	$51.26^{b}\pm1.39$	$12.75^{b}\pm0.60$	$14.36^{a}\pm0.82$	$19.25^{a}\pm0.70$
LMP 2.5%	$49.94^{c}\pm1.53$	$13.26^{c}\pm0.53$	$12.94^{b}\pm1.08$	$19.85^{b}\pm0.68$
LMP 3.5%	$52.15^{b}\pm0.80$	$12.48^{b}\pm0.25$	$15.03^{a}\pm0.54$	$19.75^{b}\pm0.56$

Designations as in Table 1. Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p<0.05$).

berry jelly after it is formed. The increase of lightness coefficient for all recipes was similar, irrespective of the amount of hydrocolloid addition. Only for jelly with 2.5% addition of low–methoxyl pectin, the investigated index was significantly lower in comparison to other samples, and the most similar to that of strawberry powder. Similar values (lightness coefficient in the range of 54–57 units) were obtained by Pasławska & Pełka [2006] for freeze–dried strawberries as well as by Ciurzyńska *et al.* [2013b] for freeze–dried strawberries jellies with sodium alginate. Drouzas *et al.* [1999] also obtained an increased lightness coefficient for freeze–dried material in comparison to the other drying methods. For microwave–vacuum dried jellies with pectin the lightness coefficient was in the range of 49–52 units.

Anthocyanin content, which is subject to degradation by heat treatment has the greatest effect on the red colour coefficient (a*) of strawberries and strawberry products. A decrease of red colour coefficient was shown for all strawberry jellies with low–methoxyl pectin content, by about 5 units in comparison to freeze–dried strawberry powder (Table 3). A significant decrease of the investigated coefficient for all jellies was probably affected by the re–freeze–drying ingredient of jellies (freeze–dried strawberry powder). The lowest decrease was noted for jelly with 2.5% low–methoxyl pectin addition, which was significantly different in comparison to the other jelly samples. Slightly higher values (14.2–21.5 units) of red colour index in freeze–dried jelly with sodium alginate were obtained by Ciurzyńska *et al.* [2013b] and in freeze–dried strawberries (26 units) by Ciurzyńska & Lenart [2010b]. Differences in red colour index may be related to changes due to addition of hydrocolloid, or varieties of strawberries, including sugars, which contribute to the reduction of the enzymatic degradation of anthocyanins.

The absolute difference of colour (ΔE) is a coefficient which characterises the product in terms of differences in all colour parameters in comparison to the raw material, which was the freeze–dried strawberry powder. Pasławska & Pełka [2006] argue that the absolute difference in the colour of freeze–dried strawberry compared to the fresh material is about 9 units. For investigated jellies, the ΔE index was higher, by about 12 units (Table 3). With increase of hydrocolloid addition from 2.0% to 3.5%, the investigated index also increased. A similar effect was also observed by Galus & Lenart [2013] for edible films with pectin. Only the sample with 2.5% pectin addition had a statistically significantly lower absolute difference of colour index. Considering the difference noticeable by a human eye (2–3.5 by CIE International Commission on Illumination), for the average consumer, the jelly with 2.5% hydrocolloid addition, compared to other samples, is closer in colour to a strawberry powder [Anonymous, 1999]. However, on the basis of investigations of Pasławska & Pełka [2006], all jelly samples show a clear colour deviation in comparison to the raw material (strawberry powder).

According to Pasławska & Pełka [2006], the chroma index (C^*_{ab}) for fresh strawberries equals more than 26 units, whereas for freeze–dried strawberry powder it is about 21 units. Jellies made with freeze–dried strawberry powder reached values not exceeding 20 units (Table 3). Differences in chroma index for the investigated freeze–dried jellies and strawberry powder from Pasławska & Pełka [2006] studies can be connected with differences in maturity and variety of strawberries, as well as the fact that the component of jelly (freeze–dried strawberry powder) was again freeze–dried. The increase of low–methoxyl pectin addition from 2.0% to 2.5% in freeze–dried jellies influenced significantly the chroma index increase. A further increase in the content of pectin did not change significantly the C^*_{ab} index.

Influence of low–methoxyl pectin (LMP) quantity on rehydration properties of freeze–dried strawberry jellies at water temperature of 20°C

Rehydration is one of the main factors which determine the consumer evaluation of freeze–dried jelly, which can be a component of products, such as breakfast cereals. The desired result of rehydration is to obtain a product with values as close as possible to the raw material. Rehydration effects largely depend on the drying and the pretreatment process conditions and the properties of the rehydrated material [Kaleta *et al.,* 2008]. The increase of water content during rehydration process is shown in Figure 2. At the beginning, all samples absorbed water very quickly. Its content in the first 5 min of rehydration rapidly increased to more than 90%. After this time, the small increase in water content was for jelly with 2.5% and 3.5% pectin content, whereas for sample with the 2.0% hydrocolloid addition, the equilibrate state was achieved. This may be related to the soft structure of jelly with 2.0% pectin content, for which lower levels of hydrocolloid resulted in a reduced ability to absorb water. Kaleta *et al.* [2008] suggest that rinsing out the soluble solid substances from the rehydrated material to the solution is possible, but considering the same process conditions for all the recipes and the fact that the material was not heated, in this case it seems insignificant.

Water content after 30 min of rehydration was the highest for the jelly with 2.5% hydrocolloid addition, whereas the low-

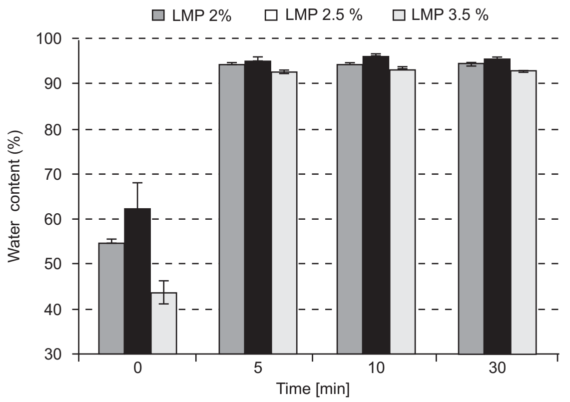

FIGURE 2. The rehydration properties of freeze–dried strawberry jellies in relation to the amount of low–methoxyl pectin during rehydration in water temperature of 20°C. Designations as in Table 1.

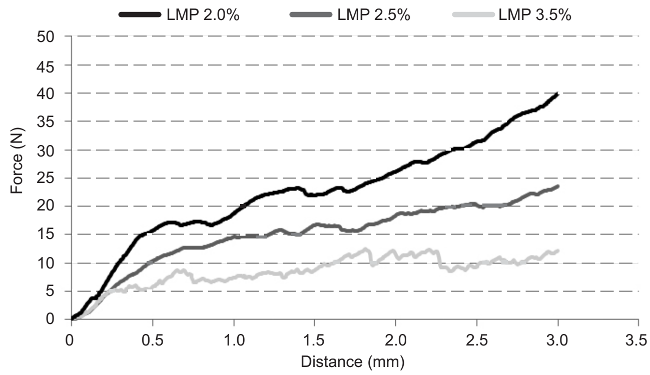

FIGURE 4. Mechanical properties (compression test) of freeze–dried strawberry jellies in relation to the amount of added low–methoxyl pectin. F – force necessary for 50% sample deformation. Designations as in Table 1.

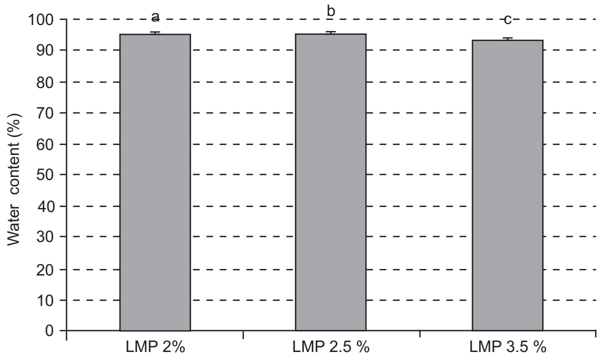

FIGURE 3. Water content during 30 minutes of rehydration of strawberry jellies in water in temperature of 20°C, in relation to the addition of low–methoxyl pectin. Designations in as Table 1. Values were given as mean ± standard deviation. Values with the same superscript letters within are not significantly different ($p<0.05$).

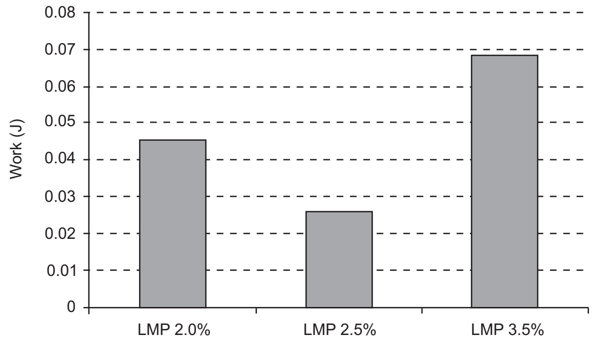

FIGURE 5. The effect of different amounts of added low–methoxyl pectin on compression work during 50% deformation of representative samples of freeze–dried strawberry jelly. Designations as in Table 1.

est was observed for the sample with 3.5% pectin addition (Figure 3), but for this sample the initial water content was also the lowest and the curve course suggests a high water uptake (Figure 2). Differences in water content for all samples were statistically significant (Figure 3).

An attempt was made to carry out the rehydration process for jellies at water temperature of 80°C, but it was impossible, due to thermal instability of the hydrocolloid jellies and their strong deformation, as well as enhanced diffusion of water–soluble components. This resulted primarily in a colour change of the solution and the physical destruction of jelly in the first period of rehydration. Pasławska & Pełka [2006] describe a similar situation during the rehydration of freeze–dried strawberries at 95°C.

Influence of low–methoxyl pectin (LMP) quantity on mechanical properties

The hardness and brittleness are some of the basic parameters affecting the quality of freeze–dried strawberry jelly. Products which are too fragile can be exposed to extensive damage during production, packaging, and transport. However, too hard structure can be evaluated by consumers as even worse. For compression tests performed in 10 replications for each recipe involving low–methoxyl pectin (LMP), three representative samples were selected (Figure 4). Compression curves depend largely on the composition and quantity of the added hydrocolloid, which causes a change in the structure of the material. The increase of low–methoxyl pectin (LMP) amount to 3.5% in freeze–dried strawberry jelly caused the increase of hardness and decrease of material fragility in comparison to the jelly with 2.0% and 2.5% low–methoxyl pectin content (Figure 4).

The most fragile was the jelly with 2.5% low–methoxyl pectin content, which can be seen in Figure 4. For jellies with 2.0% and 3.5% addition of low–methoxyl pectin, compression curves are characterised by similar "smoothness", which proves similar fragility and less structural rigidity of the dried material. Ciurzyńska *et al.* [2013b] who investigated mechanical properties of freeze–dried strawberry jelly with sodium alginate showed the increase of material hardness after increase of freeze–dried strawberry powder quantity in the recipe with the same amount of alginate.

The highest hardness of the jelly containing 3.5% low–methoxyl pectin (LMP) also confirms the determined compression force necessary for 50% deformation of the sample (Figure 4). It was shown that the force of about 40 N is needed to deform the jelly containing 3.5% low–methoxyl pectin. Feformation of the other jellies required lower force. The highest fragility was observed for the jelly with 2.5% low–methoxyl pectin. For 50% deformation of this jelly, 3 times less force

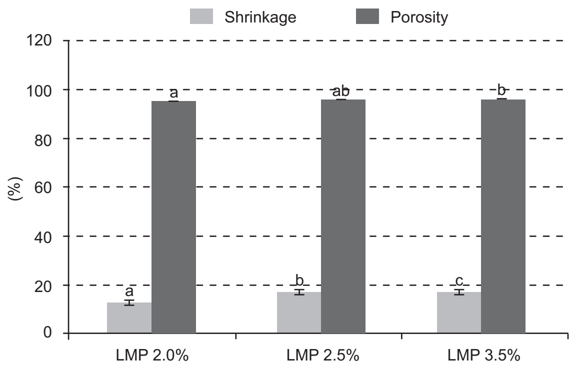

FIGURE 6. The effect of different amount of added low–methoxyl pectin on shrinkage and porosity of freeze–dried strawberry jelly. Designations as in Table 1. Values were given as mean ± standard deviation. Values with the same superscript letters are not significantly different ($p<0.05$).

(12 N) needs to be used, which is probably related to a different structure of this sample. Ciurzyńska & Lenart [2010b] obtained the maximum force in the range of 35 N for 25% sample deformation. In comparison to dried strawberries, the applied force was lower for all tested jellies, which is typical of fruit gels and indicates much more delicate structure of jellies. Półtorak & Wierzbicka [2005] in their studies of fruit jelly textures, obtained hardness results from 16 N to almost 40 N depending on the type of pectin and density (%Brix).

Similar relationships were obtained for compression work (Figure 5). Work which was done during 50% deformation of jelly with 3.5% low–methoxyl pectin was almost 3 times greater than compression work during deformation of jelly with 2.5% addition of low–methoxyl pectin and was almost 0.07 J. A similar value (0.085 J) was obtained by Ciurzyńska & Lenart [2010b] in their studies on mechanical properties of freeze–dried strawberries without osmotic pre–treatment.

Shrinkage and porosity of freeze–dried jellies with low––methoxyl pectin

Shrinkage is a natural phenomenon in all dried products. It affects the change of shape and volume of dried samples, and mainly causes the loss of water in freeze–dried material [Maskan, 2001]. The results of shrinkage investigations for freeze–dried samples with the low–methoxyl pectin were shown in Figure 6. All jelly samples were characterised by low shrinkage, which is typical of freeze–dried material. In comparison to hot–air drying, the shrinkage of gel during freeze––drying is much lower and such gel is called a cryogel [Tamon *et al.,* 2000]. Also Ciurzyńska *et al.* [2013b] and Nawirska *et al*. [2009] reported that freeze–dried products had lower shrinkage compared to product obtained with other drying methods. Although it is generally considered that the gas–liquid interface does not form and the shrinkage stress does not appear in freeze–drying, there is a possibility that gel shrinks for some reason during freeze–drying [Tamon *et al.,* 2000].

The low shrinkage of all jelly samples is probably associated with strong aeration ability of hydrocolloids added during jellies homogenization, which can be seen in significant porosity. The largest shrinkage was found in the jelly with 2.5% pectin content, and it can be assumed that it was characterised by low aeration. The smallest shrinkage value was shown for jelly with 2.0% pectin addition, while the jelly with 3.5% pectin content was characterised by an average shrinkage. Results for all samples were significantly different (Figure 6).

Jellies porosity is largely dependent on the degree of aeration during homogenization in the manufacture of the product, which influenced the development of a highly porous product. The physical form of the food may significantly alter the feeling of fullness and satiety. Addition of a bulking agent such as a hydrocolloid has been proposed to control body weight by increasing the feeling of fullness, thus reducing the energy intake [Pasman *et al.,* 1997]. In solid foods, the microstructure has a major influence on the feeling of satiety by slowing down the rate of breakdown in the gastrointestinal tract. The structured food slowly digested in the stomach increases the satiety by a yet unknown mechanism, thus providing a higher sense of fullness. Enhancing satiation may restrict the daily food intake and the desire for overeating, therefore, contributing to control of body weight [Hoad *et al.,* 2004]. Designed aerated gels with tailored texture, low caloric density and flavour properties, may help in developing new dietetic foods for the treatment of obesity [Zúñiga & Aguilera, 2008].

Gelation of jelly, and then freeze–drying, the advantage of which is the high quality of the product, resulted in the maintenance of many gas bubbles in a consistent product and in a high porosity of the material. Porosity of freeze––dried jellies with the addition of low–methoxyl pectin was shown in Figure 6. The highest porosity characterised the jelly with 2.5% low–methoxyl pectin and it was different in a statistically significant way from the jelly with pectin content of 2.0%. Increasing the amount of hydrocolloid from 2.0% to 2.5% caused a significant increase of porosity of the freeze––dried jelly. Further increasing the amount of pectin to 3.5% did not influence significantly the increase in porosity as compared to other formulations.

CONCLUSIONS

On the basis of analysis presented above, the optimal recipe of jelly with low–methoxyl pectin was selected, which could then be used in cereals. The selected jelly should have a high degree of rehydration, be moderately resistant to mechanical damage, have a long shelf life, which is associated with the low water content and activity, and be as close as possible to the raw material (freeze–dried strawberry) from which the jelly was made from physical properties point of view.

The recipe with 2.5% addition of low–methoxyl pectin was chosen on the basis of the results obtained. Despite the relatively high friability and low hardness, and higher shrinkage as compared to other jellies, it had a fast rate of rehydration, and the water content after this process was the highest. Additionally, it was characterised by a high porosity and the parameters of the colour most similar to the raw material, as well as the best content and water activity which affects the stability of the product. Probably this jelly is characterised by different mechanism of water binding during gelation, which affected values of other investigated indexes in comparison to jellies with 2.0 and 3.5% hydrocolloid addition.

Jellies with 2.0% and 3.5% hydrocolloid addition had similar results of water activity and content, as well as colour coefficients, rehydration properties, shrinkage and porosity. Only mechanical properties of jelly with 3.5% hydrocolloid addition showed the highest hardness of the obtained dried material.

ACKNOWLEDGEMENTS

The study was financed from the funds of the Department of Food Engineering and Process Management, Faculty of Food Sciences, Warsaw University of Life Sciences,

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Submitted: 17 April 2014. Revised: 18 August 2014. Accepted: 11 September 2014. Published on–line: 15 December 2014.