THE PHYSICOCHEMICAL PROPERTIES OF DIETARY FIBRE ARE DEPENDENT ON THE CHEMICAL COMPOSITION OF GLYCOPOLYMERS

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Abstract

Relationships were found between the water retention capacity and the concentration of alcohol insoluble pectins, particle size of dietary fibres. Parameters of π-electron cloud would have a significant role in the water adsorption capacity of fibres. Relationships were found between mixed biopolymer compositions and viscosity characteristics. These results show that the viscosity of 5% water suspension increased through the increase of the grade esterification of water soluble pectins and the galacturonic acid content of alcohol insoluble pectins in dietary fibres. The viscosity of 1% water dispersions of these fibres increased during increasing the molecular weight of water soluble pectin. The obtained fibres can serve to enhance water and oil retention, improve emulsion stability, production of the gel delivery system and foamed cream delivery system based on dietary fibres and bioactive components for use in the treatment, prevention, and diagnosis. The dietary fibres have shown the inhibition of cell proliferation (HT29).

Key words: mixed biopolymers, dietary fibres, physicochemical properties, viscosity, gelling strength

1. INTRODUCTION

The type of natural macromolecular compounds containing covalent bound fragments of polymers more than one class, called the mixed biopolymer, and more recently – glycoconjugate. Structures of mixed biopolymers are highly complex. Although this definition is applicable to different polymeric systems, we focus on fibre systems. The first, the plant cell wall is a complex macromolecular structure. The structure is formed by the glycopolymers, proteins, aromatic and aliphatic compounds of the cell wall of plants. The second, the ultra-structural model of wall structure, presented in recent reviews [Kerry Hosmer et al., 2009], argues for two independent networks within the primary cell wall; the pectin–pectin and xyloglucan–cellulose network. In that model, the glycopolymers of the pectin–network, proteins, and phenolic compounds are organized independently around the framework of the cellulose–xyloglucan network. Such a model utilizes the well-established model of the pectin–pectin network and the xyloglucan (XG)–cellulose network. Furthermore, there is increasing evidence that the pectin interacts, perhaps covalently with hemicelluloses. Hemicelluloses [Christina Schädel et al., 2010] are grouped into four classes according to their main types of sugar residues: xyloglucans, xylans, mannans and mixed-linkage β–glucans. Therefore, the realistic wall model should be integrated as the pectin network, the cellulose xyloglucan network and other wall structural components that were characterized. Pectin molecules are cross linked by phenolic compounds [Kerry Hosmer et al., 2009] that make up >2% of the wall [O’Neill M. A. et al., 2003]. The revised wall model would demonstrate the highly cross linked wall wherein pectin–pectin, pectin–xyloglucan, pectin–phenolic, pectin–protein, and xyloglucan–cellulose networks provide a cohesive wall network [Keegstra K. et al., 1973]. From these data it is clear that the chemical nature of fibres is the complex i.e. the mixed biopolymer. The fibre as a class of compounds includes a mixture of plant glycopolymers, both oligosaccharides and polysaccharides, e.g., cellulose, hemicellulose, pectin substances, gums, resistant starch, inulin, that may be associated with lignin, and other non-carbohydrate components (e.g., polyphenols, waxes, saponins, cutin, resistant proteins) [Mohamed Elleuch et al., 2011]. The first definition of dietary fibres (DF) [Mongeau R., 2003] was in 1972. The physiological actions of DF are likely based on their physicochemical properties such as water- and oil-holding capacities, water- and oil retention capacities, and absorption of organic molecules,
bacterial degradation, cation-exchange capacity, and antioxidant activity. In contrast to polysaccharides systematically describe and classify, the type structure of mixed biopolymers of dietary fibres is very difficult describe especially because of the limited number of reliable and fully decipher structures. The physicochemical and physiological properties of dietary fibres are dependent from their chemical composition and the structural characteristics. It was found that the particle size [Šereš Z. et al., 2005], chemical composition, and structure of dietary fibres influence to the water adsorption capacity (water holding capacity, water retention capacity and other) and rheology of these fibres. Functional properties of dietary fibres may be influenced byionic form, pH, temperature and ionic strength [Fleury N. et al., 1991]. Although there were no significant correlations between chemical composition and properties of DF, there were some relationships. For example, dietary fibre products with high pectin content had the high water holding capacity (WHC), and those with high cellulose content had the high GAC glucose absorption capacity (GAC). In this study WHC was measured as the water retention capacity. However, there were some exceptions, which had the high pectin content with the low WHC, and other, which had the high cellulose content with the low GAC [Xin Mei et al., 2010]. Earlier research found some relationships between properties and composition of DF. Marin et al. [Marin, F. R. et al., 2007] found a positive correlation between WHC and soluble DF from different citrus fibres. De Escalada Pla [de Escalada Pla M. F. et al., 2007] suggested that hydration properties (i.e., WHC, WRC — the water retention capacity, and SWC — the swelling capacity) of DF depended on the presence of rhamnogalacturonan and other hydrophilic pectin with side chains. In contrast, Figuerola et al. and Thebaudin et al. [Figuerola F. et al., 2005, Thebaudin J.Y. et al., 1997] suggested that SWC could be related to the amount of insoluble fibres. In addition, some research suggested that the components had the synergistic effect on DF properties, not the simple influence of one component. Chau and Huang [Chau C.F. et al., 2003] showed that hydration properties of DF products from citrus were higher than the alone cellulose, indicating that other components (e.g., pectin, lignin, and hemicellulose) affected the hydration properties of citrus DF products. However, the component with the predominant role in hydration properties of DF was not identified. Different ratios of cellulose, pectin, hemicellulose, and lignin lead to different cross-linked structural formations of glycopolymer molecules, which result in different physicochemical properties [de Escalada Pla M. F. et al., 2007].

Within our project we aim at maximizing the quality of dietary fibres and their effective use. The goal of this study was to prepare samples of dietary fibres with different structural features and to study impact of the chemical composition and the structural characteristics of dietary fibres on their physicochemical properties.

2. EXPERIMENTAL

2.1. Materials.

Dietary fibres were obtained as soluble and insoluble non-starch polysaccharides. The dry fibre samples with different structural features were crushed to a powder and were made the particle classification using the system to separate fractions of particulate to the size 0.100 mm and 0.250 mm. A mixture of dietary fibres was produced as follows: the fraction of 0.100 mm particle sizes was added under stirring into the fraction of 0.250 mm particle sizes the same fibres (20:80%, w/w). The commercial dietary fibre (Spain) was assayed.

2.2. Fibre analysis.

The alcohol insoluble pectin was submitted followed by acid hydrolysis [Ravin Gnanasambandam et al., 1999]. Ground fibres were extracted with 0.1 N HNO₃, (1:20), at 90°C for 40 min in a rotary evaporator, cooled to room temperature in a water bath, and centrifuged (2700 g, 15 min). The supernatant was collected, and the sediment was extracted twice more in 0.1 N HNO₃. All the three supernatants were combined and dispersed in equal volumes of 2–propanol to precipitate the pectin, and allowed to settle for about 4 h. The precipitate was collected, centrifuged, dispersed in 2–propanol, stirred for 30 min and centrifuged. This was repeated one more time with 2–propanol and, finally, with 70% 2–propanol. The sediment was dispersed in a small amount of water and freeze dried. The pectin
obtained by sequential extraction and the total pectin extracts were each subjected to the following analyses.

This method was developed for identifying (WSP) pectin. Two hundred mg of fibre were dispersed in 100 ml of 0.01 N Phosphoric acids and stirred for 1 h at room temperature. The supernatant was collected, and the sediment was extracted twice more in 0.01 N Phosphoric acid. All the three supernatants were combined, centrifuged. Combined supernatants, after centrifugation were concentrated in a rotary evaporator and then the supernatants were each subjected to the following analyses.

2.3. High-performance liquid chromatography method.

In addition to the gravimetric analysis the water soluble pectin, insoluble pectin was analyzed by the high-performance liquid chromatography method (HPLC). The HPLC [Ravin Gnanasambandam et al., 1999] was modified for identifying pectins [Ignaryeva G.N. et al., 2015].

2.4. The composition.

The composition was determined as total uronic acids (the galacturonic acid content) (Selvendran et al.) [Selvendran R.R. et al., 1979, Femenia A. et al., 1999] and the degree of methyl-esterification (DME) of pectin glycopolymers by the method described by Femenia et al. [Femenia A. et al., 1999, Nelina V.V. et al., 1992] was expressed as percent methoxy groups.

2.5. The molecular weight.

The molecular weight was determined as the intrinsic viscosity by the method described by Nelina et al. [Nelina V.V. et al., 1992].

2.6. Viscosity measurement.

The procedure for the testing absolute viscosity by the traditional Brookfield rotary method was performed at room temperature. The absolute viscosity is reported in mPa×s.

2.7. The water-retention capacity.

The water-retention capacity of the DF was determined according to the method described elsewhere [Chau C.F. et al., 2003, Robertson J. A. et al., 2000] with slight modifications. According to the method, the water-retention capacity was determined by mixing the dietary fibre with distilled water (1:20, w/w) for 24 h. After centrifugation at 15000 rpm, 10 min, excess supernatant decanted and the WRC was expressed as the “g water/g dry DF”.

2.8. The fat adsorption capacity.

The fat adsorption capacity (FAC) was measured as the oil retention capacity [Caprez A., et al., 1986 but with few modifications. The Sample (5 g) was mixed with the sunflower oil (30 mL, 50°C), left overnight at room temperature, centrifuged (15000 rpm, 15 min), excess supernatant decanted and FAC expressed as the “g oil/g dry DF”.

2.9. Analysis of emulsion.

The fat emulsion, an intermediate product, contained fat (45.8%), water (45.8%), caseinate (6.5%) and salt (1.9%). Formulations of fibre-enriched materials replaced 2% of the fat, prepared by blending fat, salt and water in a Robo-coupe mixer for 2.5 min, with fibres then incorporated. The mixture was transferred to six glass pots and cooked in the CAPIC oven at 80°C for 20 min.

2.10. The colour determination.

The colour determination was carried out on dietary fibres using a Minolta Colorimeter (Minolta Co., Osaka, Japan) and results were expressed in accordance to the CIELAB system.

2.11. Statistical analysis.

All measurements were performed in triplicates (n = 3) and the values were averaged and reported along with the standard deviation (± S.D).
3. RESULTS AND DISCUSSION

Dietary fibres vary in their chemical composition and physicochemical properties, which subsequently affects their uses as ingredients in food applications [Espert A., 2003]. The physiological effects of fibres depend on the chemical and physical properties and thus vary between different types of fibres [Chau C.F. et al., 2003]. The viscosity-forming capacity such as water-soluble fibres has been suggested to be crucial in its effect on satiated-related attributes. [Marika Lyly et al., 2009].

Dietary fibres including soluble and insoluble dietary fibres (SDF and IDF) were isolated from the dried and fresh peel of Lemon Fino. Determination of individual pectin contents in fresh or dried biological materials and their dietary fibre products is an important analysis for evaluating structure, quality and variety of mixed biopolymers and food nutrition’s. A schematic diagram of the sequential steps of the part SDF, water soluble pectin (WSP), and alcohol insoluble pectin (AIP) extraction is presented a little earlier [Kerry Hosmer et al., 2009].

Dietary fibres hold water by adsorption and absorption (this process is called the limited swelling). The sorption isotherm of the water molecules of dietary fibres is complex, as well as the sorption isotherm of regular synthetic polymers [Dickel G., & Hartmann J., 1960]. There are different mechanisms that conduct the moisture penetration into fibres namely: (1) diffusion of water molecules into the micro gaps between polymer chains, which is the main mechanism, (2) capillary transport into the gaps and flaws at the interfaces between fibre molecules, due to incomplete wettability and impregnation, and (3) transport by micro cracks in the matrix, formed during the compounding process [Ubando-Rivera J. et al., 2005, Espert A., 2003]. For the given dietary fibres, the water adsorption capacity (WAC) depend on these mechanisms and also depend on both the mixed biopolymers orientation, area of the exposed surface, and permeability of fibres, void content and hydrophilicity of individual components and from the relationship fragments of glycospolymers with protein fragments. The ability to adsorb and to hold water is undoubtedly due in part to the general unfolding and expansion of insoluble pectin molecules. The water holding characteristic of fibres depends on both, the soluble pectin molecule and insoluble pectin molecule. The water retention capacity of fibres depends more on the insoluble pectin molecules. In this study WAC was measured as water retention capacity.

The effects of concentration and composition of AIP (an average molecular weight and a degree of methyl-esterification) on the water retention capacity of dietary fibres were investigated. The higher concentration of AIP leads to more water retention capacity of dietary fibres (Figure 1).

![Figure 1](image_url)
Water retention capacity was 10.81 g/g and 13.29 g/g for 10.7% and 23.1% alcohol insoluble pectin contents in dietary fibres respectively. This is probably due to the increase in the number of potential water binding sites, while the higher molecular weight of AIP did not increase the water retention capacity. The molecular weight of AIP and the galacturonic acid content in the insoluble pectin of DF had respective ranges of 19 – 70 KDa, and 23.50 – 74.75% (Figure 1; 2; 3). The capacity of dietary fibres to hold water also as WRC decreased from 13.29 g/g to 10.78 – 11.13 g/g with the increase of molecular weight of AIP ranging from 20 to 70 KDa (Figure 2) and with the increase of galacturonic acid contents on the AIP ranging from 30 to 75% (Figure 3). This is probably due to the increase of any appreciable extent of interlinking of insoluble pectin in a matrix of amorphous structure with some enmeshed cellulose micro fibrils and due to the change of structure and size of the micro gaps between polymer chains.

![Figure 2. The effects of molecular weight of the alcohol insoluble pectin on the water retention capacity of dietary fibres: the particle size is 0.100mm.](image1)

![Figure 3. The effects of concentration of the galacturonic acid content in the alcohol insoluble pectin on the water retention capacity of dietary fibres: the particle size is 0.100mm.](image2)
The author [Gregor H.P. et al., 1954] found that number of bound water molecules decreases when the degree of cross-linking polymer increases. However, it was observed in the present study that the increase in water retention capacity of dietary fibres is influenced by the extent of insoluble pectin charge resulting from low molecular weight of polymer of AIP. Ubando-Rivera et al. and Thibault et al. found the high WHC (or WRC) opens the possibility of using DF lime (such as other DF) concentrate as a functional ingredient for reducing calories, avoiding syneresis and modifying the viscosity of formulated foods [Thibault J.-F., 1979, Ubando-Rivera J. et al., 2005].

The analysis of fractions of presented fibres showed that the AIP contained methoxylated carboxyl groups ranging from 27 to 39%. Presence of methyl esters didn’t give any significant differences in the mean values of WRC for this range.

The relationship of the particle size of dietary fibre and the WRC was determined. The water retention capacity of fibres of 0.100 mm mean particle size (MPS), 0.250 mm and of 0.100/0.250 mm mixtures produced from the dried and fresh lemon peels is given in the table 1. The water retention capacity of fibres from the dried and fresh lemon peel is positively correlated with its MPS. As observed for WHC and for other parameters [Mario Villarroel et al., 2003, Muriel Colin-Henrion et al., 2009], the increase of particle size up to 0.420 mm led to an increase of WAC fibres. It is considered [Mongeau. R., 1972] that the large portion of held water by fibres appears to be free water.

<table>
<thead>
<tr>
<th>No.**</th>
<th>Proportion of the particles size 0.100/0.250 mm MPS of dietary fibres, %</th>
<th>WRC*, g/g</th>
<th>ORC*, g/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100/0</td>
<td>13.29</td>
<td>4.44</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>15.16</td>
<td>2.85</td>
</tr>
<tr>
<td>2</td>
<td>100/0</td>
<td>12.31</td>
<td>4.20</td>
</tr>
<tr>
<td></td>
<td>0/100</td>
<td>21.44</td>
<td>3.53</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>19.77</td>
<td>3.17</td>
</tr>
<tr>
<td>3</td>
<td>100/0</td>
<td>13.48</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>0/100</td>
<td>22.14</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>17.41</td>
<td>2.24</td>
</tr>
<tr>
<td>4</td>
<td>100/0</td>
<td>17.80</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td>0/100</td>
<td>20.93</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>17.66</td>
<td>2.44</td>
</tr>
<tr>
<td>5</td>
<td>100/0</td>
<td>16.20</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>0/100</td>
<td>20.10</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>18.92</td>
<td>1.61</td>
</tr>
<tr>
<td>6</td>
<td>100/0</td>
<td>11.32</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>0/100</td>
<td>20.00</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>20/80</td>
<td>21.36</td>
<td>1.95</td>
</tr>
</tbody>
</table>

*WRC, the water retention capacity, gram of water per gram of fibre, using the centrifugation method. ORC, the oil retention capacity, gram of oil per gram of fibre, using the centrifugation method: mean ± 0.5 (standard deviations — SD) of three measurements. MPS, geometric mean particle size. **The sample No.1 was produced from the dried lemon peels and No. 2; 3; 4; 5; 6 were produced from the fresh lemon peels.
This is because the water retention capacity has been found to be higher for fibre mixture with proportion 20/80 of the particles size 0.100/0.250 mm (15.16; 19.77; 17.14; 18.92; 21.36 g/g) than for that with proportion 100/0 of the 0.100/0.250 mm MPS (13.29; 12.31; 13.48; 16.20; 11.32 g/g), respectively. This is likely caused by the great number of hydroxyl groups existing in the polymer structure of fibres, which allow more water interactions through hydrogen bonding, as was previously found by Rosell et al. [Rosell C. M. et al., 2001], working with different hydrocolloids. According to data (Table 1) we suggest that hydroxyl groups existing in the polymer structure of some particles with the MPS 0.100 mm being associated into system with other particles of fibres. Therefore, the decrease particle size led to a reduction of free hydroxyl group’s number that promoted to decrease of WRC.

Another possible explanation is a change in the ratio of water fixation on the sample of fibres. The isotherm of water sorption can be described in three parts [Alix S. et al., 2008]. Each part corresponds to a mode of water fixation on the sample of fibres. The first part of this process indicates Langmuir-type adsorption behavior: a first monolayer of water molecules appeared on the surface of the mixed biopolymer. This behavior results from a combination of two processes: adsorption at the surface of micro-cavities (free volume, micro pores, etc.) and adsorption due to the presence of hydrophilic groups. Such specific sites existing in the periphery of fibre consisted of the negative charge of the monomer of the pectin or pectin-like molecules. The following part of the process involves random absorption (dissolution) and diffusion of the water molecule inside the mixed biopolymer. This part corresponds to the adsorption of water molecules in the amorphous region of the fibres. This adsorption occurs mainly in the matrix of the secondary wall of mixed biopolymers where pectin polyanions are also present. This process corresponds to the adsorption of water molecules with the formation of aggregates. The water concentration in the fibre became sufficient at the high activity to cause a swelling of the fibre and an accumulation of aggregates of water molecules. This accumulation took place not only in the heart of elementary fibres, named the lumen, but also in the water free space corresponding to the macro pores of the cell wall.

The water absorption characteristic depends on the π–ε orientation and π–ε cloud surface density of mixed biopolymers. The grinding of fibres containing polyanions (pectin soluble) leads to an increase in the surface density of the π–ε cloud and the negative charge for samples with smaller than 0.400 mm of MPS. The increase of negative charge causes the increase of association between pectin soluble particles and dipole of water, which also can be associated into system structuring, similar network. As expected, this interaction increases the degree of soluble pectin’s transition into the solution, which reduces the WRC of fibres. Besides, the presence of the external orientation of the π–electron cloud around particles increases the density of the surface of the negative π–electron cloud particles in the surface layer of fibre polymers preventing the second stage of water sorption by the repulsion of the same charges. So, it reduces the number of incoming water molecules inside the polymer structure. As can be seen (Table 1), samples of dietary fibres containing the higher density of π–electron cloud with the particle size of 0.100 mm exhibit a lower WRC (11.32 – 17.80 g/g) than samples of dietary fibres with the particle size of 0.250 mm containing the lower density of the π–electron cloud (20.00 – 22.14 g/g). Moreover, samples of fibre mixture with proportion 20/80 of the MPS of 0.100/0.250 mm exhibit more water retention capacity (17.41 – 21.36 g/g) than samples of dietary fibres with the particle size of 0.100 mm (Table 1). The one of commercial fibres was analyzed. This commercial fiber contained 24.5% of the AIP. This commercial fiber contained the AIP with 16 KDa molecular weight, 25.6% galacturonic acid and methoxylated carboxyl groups which ranged from 30.1%. Particle sizes of this commercial fiber were 0.100 mm, 0.250 mm and more of 0.250 mm. But the value of WRC was 10.8 g/g that less than we proposed (12.2 g/g). This is likely caused by the presence of particle sizes more 0.250 mm in the fibre.

Fat adsorption capacity (FAC) was measured as oil retention capacity (ORC). The mechanism of oil adsorption is unknown [Thibault J.F. et al., 1992] but Fleury and Lahaye [Fleury N. et al., 1991] suggested that surface properties, overall charge density and the hydrophobic nature of particles could be important for oil adsorption and for the incorporation of fibres into foods. In agreement with the figure 4 the oil retention capacity of dietary fibres clearly shows a lower value (3.3 g/g) with high amounts of WSP (37.15%).

Page 519
The samples of fibre presented in the figure 4 were isolated from the dried lemon peel. The oil retention property of dietary fibres was influenced in the same manner as were those of the emulsion capacities. The greatest increases in ORC (range of 4.44 – 5.22 g/g) were noted for dietary fibre which has 18.3 – 19.3% water soluble pectin. The presence of ionic charge in soluble pectin and non-charge constituents may influence the emulsion of properties adversely. The higher concentration of water soluble pectin of dietary fibres would be more negatively charged due to the increased number of free carboxyl groups and fat globules being negatively charged. It was noted that in a sample with 25 – 37% of WSP of dietary fibres the reduction of emulsion capacity may be due to the repulsion of pectin from the oil phase. Marina F. de Escalada Pla [Marina F. et al., 2010] suggested that oil absorption seemed to essentially depend on the microstructural characteristics of fibre powders. In agreement with Table 1, the ORC of dietary fibres clearly shows the lower values 3.53; 1.89; 1.66 g/g for 0.250 mm size of fibre powders No. 2; 3; 4 respectively. Higher specific volume, which also was in part a function of structural differences, can be used as an index of the ability for oil uptake. The viscosities of water dispersions of dietary fibres are given in figures 5-9.

Figure 4. The effects of concentration of the water soluble pectin on the oil retention capacity of dietary fibres: the particle size is 0.100 mm

![Figure 4](image-url)

Figure 5. The effects of degree methoxylated of the water soluble pectin on the viscosity of 5% water dispersions of dietary fibres: the particle size is 0.100 mm.

![Figure 5](image-url)
We found significant differences between the viscosity-forming capacity of dietary fibres in 1% and 5% water suspensions, both for dietary fibres obtained from dried and fresh lemon peels. Viscosity of the 5% suspension depends on the surface area and MSP of fibres and the hydration properties of small pellets. Pectin-rich dietary fibres tend to exhibit higher values for swelling. The suspended solids in the 5% suspension had a tendency to increase volume due to swelling. Small pellets of fibres had the tendency to form a structured phase based on the aggregation of particles. The structured phase might be due to aggregation of the hair molecules of WSP. This aggregation caused a big resistance to flow and resulted in a behavior of increased shear rates and higher viscosity.

![Viscosity vs. Galacturonic acid content](image)

Figure 6. The effects of galacturonic acid content in the alcohol insoluble pectin on the viscosity of 5% water dispersions of dietary fibres: the particle size is 0.100 mm.

The model for estimating viscosity of 5% suspension was based on the volume fraction of swelling solids and rheological properties of the structured phase. We observed that the level of 23 – 26% DME of water soluble pectin and 57 – 75% galacturonic acid contents in the AIP resulted in increased viscosity of 5% water dispersions (5835 – 6835 mPas x s) (Figure 5; 6). But the capacity of dietary fibre to hold water (WRC) is decreased with the increase of galacturonic acid contents in the insoluble pectin ranging from 30 to 75% (Figure 4). We noted that the insoluble part of dietary fibres (such as the AIP) is characterised by their ability to increase faecal bulk and decrease intestinal transit and moreover it demonstrated greater capacity to change WRC, viscosity, and ability to strengthen the internal foamed network of emulsions.

Change in viscosity of 1% suspension which was observed in the present study is influenced by the soluble dietary fibre content in the medium. This could be attributed to the extraction of WSP into the medium. In the case of 1% suspension of fibres the WSP was extracted into the medium by the swelling process of fibres, which was based on the diffusion of water molecules into the micro gaps, on the association between the WSP of fibre particles and dipole of water and on the soluble pectin’s transition into the solution. The higher molecular weight of WSP leads to more viscosity of 1% water dispersions of these fibres (Figure 7).
The domains of WSP may self-associate depending on the degree of esterification and thus increase viscosity of 1% water dispersions. The three-dimensional conformation of side chains (WSP) with high molecular weight was found to be mostly stationary in solution, while the three-dimensional conformation of side chains of water soluble pectin with low molecular weight was dynamic. The stationary behavior and dynamic behavior of pectin side chains may provide an increasing viscosity of 1% water dispersions. Although the higher molecular weight of WSP leads to more viscosity of 1% water dispersions of these fibres, compared with other water soluble polysaccharides from plant cell walls, the 1% water dispersions have relatively low viscosities (7 – 14 mPas x s).

Additionally, results showed that the viscosity of 5% water dispersions of these fibres was much higher (ranging 980 – 20590 mPas x s, but not lower than 103 mPas x s) than 1% (ranging 10.00 – 20.33 m Pas x s) (Figure 8; 9). The increase of viscosity of 5% water dispersions was considerably above and does not correspond to the proportional number of dietary fibres in water suspensions. The differences in viscosity of 1% y 5% were due to many factors depending on the physicochemical properties of pectin. This effect can be explained by the following model [Gregor H.P. et al., 1954]. This model assumes that the water infiltrated into hydrated polymer chains pushes the granules of dietary fibres and increases the observed amount of dietary fibres and thereby increases the viscosity of 5% water dispersions.

The significant increase in viscosity was observed in 1% (13.20 mPas x s) and 5% suspension (6835 mPas x s) at pH 5.1 (Figure 8) and in 1% (20.33 mPas x s) and 5% suspension (20590 mPas x s) at 4.9 (Figure 9) for isolated fibres from the dried and fresh lemon peel respectively. Samples of 5% (3000 mPas x s) and 1% water dispersions (12.60 m Pas x s) have low levels of viscosity at range pH 3.37 – 4.01 (Figure 8) and the samples of 5% (980 mPas x s) and 1% water dispersions (10.00 – 10.70 mPas x s) have low levels of viscosity at range 4.46 – 4.60 (Figure 9) of dietary fibres which were isolated from the dried lemon peel and fresh lemon peel, respectively. Understanding the different aspect of viscosity-forming capacity of dietary fibres in 1% or 5% water dispersions and the factors that affect them can help to make better the fibre enriched final products.

Figure 7. The effects of molecular weight of the water soluble pectin on the viscosity of 1% water dispersions of dietary fibres: the particle size is 0.100 mm.
Most of the recent related researches are focused on color analysis of fibres [Šereš Z. et al., 2005]. We examined the color of fibres obtained from dried and fresh lemon peels. The objective of future work is the effect of the chemical composition and structural characteristics on the color of dietary fibres. It is based on the following consideration:

1. Dry dietary fibres were generally lighter (“L*” ranging 78.21 – 86.84).
2. Differences the “a*” parameter of color were greatest between samples which having the pH= 3.4 (“a*” ranging 0.1 – 0.3) or at pH 5.16 (a*= 0.25) and at pH 4. 9 (“a*” around (~0.66]) and at pH 4.5 (a*= 0.02) (from fresh lemon peels) and 0.5 (from dried lemon peels).
3. The parameter of color “a*” did not change at 32-37% galacturonic acid content of the WSP in dietary fibres obtained from dried lemon peel and “a*” was around 0.5.

Figure 8. The effects of pH of dietary fibres on the viscosity of 1% (1) and 5% (2) water dispersions of dietary fibres obtained from dried lemon peels. The particle size is 0.100 mm.

Figure 9. The effects of pH of dietary fibres on the viscosity of 1% (1) and 5% (2) water dispersions of dietary fibres obtained from fresh lemon peels. The particle size is 0.100 mm.
4. The change of “a*” parameter of color was observed with increasing content of galacturonic acid of the WSP in dietary fibres.

5. The change of “a*” parameter of color to 0.1 was determined at 46.56% galacturonic acid content of the WSP in dietary fibres obtained from dried lemon peels.

6. The effect of change in indices “a*” shows change of structural characteristics.

The food industry can take advantage of the physicochemical properties described above to improve the viscosity, texture, sensory characteristics and shelf-life of their products. Dietary fibres may be incorporated into food products as inexpensive, non-caloric bulking agents for partial replacement of flour, fat or sugar, as enhancers of water and oil retention and to improve emulsion or oxidative stabilities. However, the literature contains reports that the percentage of fibres that may be added is finite, because it can cause undesirable changes to the colour and texture of foods [Mohamed Elleuch et al., 2011]. We studied effects of the dietary fibre addition on the gelling strength of the jam and firmness of the foamed cream. It was showed that jam, in which dietary fibres replaces industrial pectin, has pseudoplastic behaviour, and higher content of dietary fibres up to 17% (or more) the better the viscosity and more gelling strength of the jam, where the minimum percentage 2.3% of dietary fibres was sufficient to form the gel strength 100° SAG. Their evidence from sensory evaluations indicates that samples of the jam enriched with high content of dietary fibres were as acceptable as conventional jam, without change its color, odour and taste. The incorporation of fibres in the foamed cream increases firmness, but the extent of modification depends on the technology production of fibres. We noted also that the sensory quality of foamed cream enriched with powders of dietary fibres is improved, compared with standard. The emulsion cream product was with significantly higher volume and more elastic than the control. The dietary fibre improves handling properties primarily by hindering crystal growth, as temperature fluctuates during storage. Also we suggested that the potential use of dietary fibres is the crystallisation and recrystallization controllers in foamed cream products.

The study of the WHC (or WRC), high solubility (a water solubility index - WSI) and ORC opens the possibility to production the gel delivery system and foamed cream delivery system with dietary fibres includes the active component such as drug [Gagarin A. N., 2011] for use in the treatment, prevention, diagnosis, cure of mitigation of disease or illness, or substances which affect the structure or function of the body. The term "drug" includes medicaments, vitamins, mineral supplements and other chemical or biological substances [Gagarin A. N., 2011]. This article relates to a fibre-containing confectionery composition (without the use of pectin), which is soft in texture and smooth in mouthfeel. The product of our work has a consistency which can be described as having the textural characteristics commonly associated with chewy gels and strengthen of the i

Page 524
4. CONCLUSION

In summary, data are presented that chemical and physical properties of dietary fibres play a predominant role in their functional properties.

1. Relationships were found between the water retention capacity of dietary fibres and the concentration, molecular weight, galacturonic acid of alcohol insoluble pectin, and particle size of dietary fibres.

2. Dietary fibres with the higher concentration of alcohol insoluble pectins demonstrated the higher water retention capacity.

3. Samples with the particle size of 0.250 mm exhibited the higher water retention capacity than samples of dietary fibres with the particle size of 0.100 mm.

4. The number of potential water-binding sites into pores of dietary fibre pellets has been linked with the concentration of alcohol insoluble pectin. For this reason, the water retention capacity was higher when the concentration of alcohol insoluble pectin was higher. These data are in agreement with the fact that parameters of π-electron cloud directly or indirectly would have a significant role in the water sorption of dietary fibres.

5. In agreement with our studies the oil retention capacity of dietary fibres clearly showed lower for the size of 0.250 mm of the fibre powders.

6. However, in our study, the differences in the oil retention capacity of samples do not completely explain differences in their specific surface area of powders. One suggested mechanism through which the high concentration of water soluble pectin could affect ORC is via more intense ionic charge of fibre pellets causing the decreased oil retention capacity.

7. Numerous relationships were found between fibre chemical properties and viscometric characteristics. These results show that the viscosity of 5% water suspension increased through the increase of the grade esterification of water soluble pectins and the galacturonic acid content of alcohol insoluble pectins in dietary fibres.
8. The viscosity of 1% water dispersions of these fibres increased during increasing the molecular weight of water soluble pectin.

9. In the present study the high-performance liquid chromatography method has been successfully applied to the characterization and quantification of the water soluble pectin and the alcohol insoluble pectin in dietary fibres.

10. The 2.3% of dietary fibres was sufficiently to form the gel having 100 ± 0.5° SAG of the strength. The sensory evaluation indicated that samples of the jam, foamed cream enriched by high content (17% and more) of dietary fibres did not change their color, odor and taste.

11. The dietary fibres may be used for production the gel delivery system and foamed cream delivery system, with including the active component, for use in the treatment, prevention, diagnosis of illness.

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