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THE INFLUENCE OF THE CONCENTRATION OF GELLING AGENTS ON THE STRUCTURAL-MECHANICAL PROPERTIES OF COMPOSITE FRUIT JELLIES FROM PEARS

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Abstract: *This study aims to evaluate the influence of the different types of gelling agents at various concentrations on the structural-mechanical properties of composite fruit jellies. Sodium alginate, iota-carrageenan and low-esterified amidated pectin were used as gelling agents at four different concentration levels for the preparation of composite jellies. All the structural-mechanical properties of obtained jellies were determined by a penetration test with a texture analyzer. The rupture force is reduced in the highest extent when the concentration of low-esterified amidated pectin (LEAP) increases, while the lowest change was observed when the content of sodium alginate increases. The highest values of rupture force of the composite jellies to the control were obtained at the maximum concentration (1.6%) of added iota-carrageenan. Increasing the concentration of iota-carrageenan made the composite jellies harder and more elastic. The addition of sodium alginate and LEAP made them softer compared to the control sample. Regardless of the type and the concentration of the added gelling agents in the composite jellies, their adhesiveness was significantly higher compared to the control sample.*

Key words: *gelling agents, structural-mechanical properties, composite jelly.*

1. Introduction

Gelling agents such as pectin, alginate, and carrageenan are widely used in the food and pharmaceutical industries and typically used for the preparation of composite jellies [34]. Gelling agents (hydrocolloids) form so-called "physical gels" by physically connecting their polymer chains, through hydrogen bonds, hydrophobic bonding or cationic cross-linking [37]. Alginate, pectin, and carrageenan are gelling hydrocolloids that are mainly used in jams, jellies, low-sugar

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gelatins, and ice creams [24].

Alginates are natural polysaccharides that isolated from brown seaweed and some types of bacteria [36]. They are straight, unbranched polysaccharides consisting of a mixture of monomeric uronic acids such as β-D-mannuronic acid and α-L-guluronic acid linked by 1→4 glycosidic bonds, with a higher content of guluronic acid forming stronger, transparent and brittle alginate gels, while at higher mannuronic acid content in them the alginate gels formed flexible jellies [5]. Alginates are used in edible films preparation and equally as food additives because of their stabilizing, thickening and gelling properties [26]. Alginate forms stable gels over a wide temperature range and low pH [4]. Their gels are thermo-irreversible [11], which are produced by ionotropic gelation in the presence of divalent calcium cations [7].

Carrageenans are natural polysaccharides obtained from the cell wall and intercellular matrix of red kelp. They are consisted of repeating disaccharide units of D-galactose and 3,6-anhydro-galactose linked to 3-β-D-galactose and 4-α-D-galactose containing 20-40% sulfate ester groups [16]. Carrageenans are divided into three main types - iota; kappa and lambda carrageenan depending on the number and position of the sulfate ester groups. They are used in the food industry because of their gelling, water-binding, stabilizing and texturizing abilities [27]. The aqueous solution of iota-carrageenan forms soft and elastic gels that are more resistant to syneresis compared to kappa-carrageenan gels [15]. In the presence of calcium ions they form thermoreversible gels [23].

Pectin is a complex acidic heteropolysaccharide and a structural component of plant cell walls. The pectin macromolecule is composed of three main polymers i.e. homogalacturonan (contains 70% D-galacturonic acid linked with α-1-4 glycosidic bonds), rhamnogalacturonan I and rhamnogalacturonan II [17]. During the interaction of ammonia with the carboxylic groups of the pectin molecule, amidated pectin is obtained. It forms gels more easily, the thermal stability and strength of which are higher compared to ordinary pectin [39]. Amidated pectin is used in food technology due to its reduced sensitivity to calcium ions and pH; in the formation of thermoreversible gels, in the production of jellies and jams and for the delivery of drugs to the colon and insulin for oral use [29].

The aim of this study is to investigate the influence of the concentration of different gelling agents on the structural-mechanical properties of composite fruit jellies through a penetration test using a Stable Microsystems Texture Analyzer.

2. Materials and Methods

2.1. Preparation of Composite Fruit Jellies from Pears

The pear fruits from the Conference variety were delivered from the local market (Plovdiv, Bulgaria). Sodium alginate - VIVAPUR Alginate FD 120 and low methoxylated amidated citrus pectin (Aglupectin LA-S10) were suppled from P.I.C.Co, Bulgaria and they were used for the pear jam preparation. All the other reagents and chemicals were supplied from Fillab Ltd. (Plovdiv, Bulgaria).

For the production of the composite fruit jellies, 5 variants (together with the control) were developed by direct mixing of all components. To establish the effect of the gelling agents on the structural-mechanical properties of the composite jellies, sodium alginate, iota-carrageenan and low-esterified amidated pectin were used at four different concentrations and fixed amounts of the other added components. All chemical substances (Tables 1 to 3) were mixed into beakers to obtain homogeneous mechanical dry mixtures to prepare the jellies. After that, the freshly prepared pear juice was added to make the content up to 100%. All the ingredients of the jellies were heated together with occasional stirring. The samples were boiled to a dry refractometric substance of 18% regardless of the type and concentration of the added gelling agents. Water losses in the jellies with the different concentrations of added gelling agents were with values from 9.4% to 13.3% (sodium alginate), between 10.3% and 18.1% for iota-carrageenan and between 9.4 to 15.2% for the low-esterified amidated pectin. After boiling, the resulting mixture was poured hot into glass petri dishes with a diameter of 50 mm and a height of 15 mm, which were placed in a refrigerator for 1 hour to cool down. Finally, the obtained jellies were left for 20 hours at room temperature to gel in the open petri dishes.

Table 1

Component composition of composite jellies at different concentrations of the gelling agent -sodium alginate

Composition	Sample no.				
	P00 control	P01	P02	P03	P04
Sodium alginate [%]	-	0.2	0.4	0.6	0.8
Iota-carrageenan [%]	1.2	1.2	1.2	1.2	1.2
Low-esterified amidated pectin [%]	0.6	0.6	0.6	0.6	0.6
Calcium lactate pentahydrate [%]	0.6	0.6	0.6	0.6	0.6
Sodium citrate [%]	1.0	1.0	1.0	1.0	1.0
Cellulose fibers [%]	1.0	1.0	1.0	1.0	1.0
Guar gum [%]	0.4	0.4	0.4	0.4	0.4
Pear juice [%]	95.2	95.0	94.8	94.6	94.4

Table 2

Component composition of composite jellies at different concentrations of iota-carrageenan

Composition	Sample no.				
	P00 control	P01	P02	P03	P04
Sodium alginate [%]	0.2	0.2	0.2	0.2	0.2
Iota-carrageenan [%]	-	1.0	1.2	1.4	1.6
Low-esterified amidated pectin [%]	0.6	0.6	0.6	0.6	0.6
Calcium lactate pentahydrate [%]	0.6	0.6	0.6	0.6	0.6
Sodium citrate [%]	1.0	1.0	1.0	1.0	1.0
Cellulose fibers [%]	1.0	1.0	1.0	1.0	1.0
Guar gum [%]	0.4	0.4	0.4	0.4	0.4
Pear juice [%]	96.2	95.2	95.0	94.8	94.6

Table 3

Component composition of composite jellies at different concentrations of low-esterified amidated pectin

Composition	Sample no.				
	P00 control	P01	P02	P03	P04
Sodium alginate [%]	0.2	0.2	0.2	0.2	0.2
Iota-carrageenan [%]	1.2	1.2	1.2	1.2	1.2
Low-esterified amidated pectin [%]	-	0.6	0.8	1.0	1.2
Calcium lactate pentahydrate [%]	0.6	0.6	0.6	0.6	0.6
Sodium citrate [%]	1.0	1.0	1.0	1.0	1.0
Cellulose fibers [%]	1.0	1.0	1.0	1.0	1.0
Guar gum [%]	0.4	0.4	0.4	0.4	0.4
Pear juice [%]	95.6	95.0	94.8	94.6	94.4

2.2. Determination of Structural-Mechanical Properties

All structural-mechanical properties were determined by penetration testing with a Stable Microsystems Texture Analyzer. The texture analyzer was operated in Y-axis uniaxial deformation mode with a test speed of 2 mm/s and a post-test speed of 2 mm/s using a 5 mm diameter (P/5) aluminum cylindrical probe with an area of 19,634 mm^2.

Each individual sample (variant) was measured 7 times. The rupture force and the rupture deformation were determined as the maximum value of the first inflection point of the penetration curves obtained using the texture analyzer. The compressive stress is calculated by dividing the rupture force by the cross-sectional area of the piston at the rupture point [13]. Firmness is defined as the slope of the force-deformation curve, reported in N/mm and reflects the apparent elastic modulus [18]. The rupture energy is calculated from the area under the force-deformation curve to the point of rupture [8]. Adhesiveness is determined from the force-time curve respectively as the area of the negative peak [25].

2.3. Statistical Analysis

The results of the conducted research were processed with the MS Excel 2010 software. The data were processed statistically by applying a t-Test (t-Test: Paired Two Sample for Means) to test the hypotheses regarding the difference between the average values of two dependent samples (the control and the experimental sample) at the level of statistical significance $\alpha = 0.05$, ($p<0.05$).

3. Results

3.1. Structural-Mechanical Properties of Composite Jellies at Different Concentrations of Added Gelling Agents

In Tables 4 to 6 the values of the structural-mechanical properties of composite fruit jellies as a function of the concentration and type of gelling agents (sodium alginate, iota-carrageenan and LEAP) are presented.

It can be seen (Table 4) that with each

doubling of the concentration of the gelling agent (P01 and P02 or P02 and P04) the rupture deformation decreases, but remains always higher compared to the control sample. At the lowest concentration of the gelling agent (0.2%), the highest rupture deformation was observed compared to the control and vice versa (P01 and P04).

Table 4

Structural-mechanical properties of composite jellies at different concentrations of the gelling agent - sodium alginate

CSMP	Concentration of sodium alginate [%]				
	Control sample 0%	sodium alginate 0,2%	sodium alginate 0,4 %	sodium alginate 0,6 %	sodium alginate 0,8 %
	Sample no.				
	P00	P01	P02	P03	P04
RF [N]	0.29*±0.013^a	0.24*±0.026^b	0.23*±0.008^c	0.24*±0.006^d	0.25*±0.011^e
RD [mm]	2.25±0.050^a	3.47±0.299^b	2.98±0.033^c	3.09±0.232^d	2.79±0.205^e
CS [kPa]	14.88±0.001^a	12.00±0.001^b	11.56±0.0004^c	12.22±0.0003^d	13.00±0.001^e
FI [N/mm]	0.11±0.006^a	0.05±0.003^b	0.06±0.0004^c	0.06±0.003^d	0.07±0.005^e
RE [mJ]	0.40±0.025^a	0.51±0.080^b	0.42±0.012^a	0.47±0.045^c	0.44±0.070^a
TO [mJ/cm^3]	9.10±0.521^a	7.44±0.531^b	7.19±0.221^c	7.67±0.183^d	8.06±0.653^e
MY [kPa]	48.29±5.369^a	24.17±4.246^b	25.75±4.075^c	31.69±7.640^d	30.08±3.996^e
AD [N.s]	- 0.05±0.015^a	- 0.12±0.014^b	-0.12±0.025^c	-0.15±0.021^d	-0.19±0.010^e

Note: CSMP – structural-mechanical properties, RF – rupture force, RD – rupture deformation, CS – compressive stress, FI-firmness, RE - rupture energy, TO – toughness, MY– Young's modulus and AD – adhesiveness. * mean values of five measurements (n = 5) ± standard deviation. Values followed by the same letters in each row are not statistically significant ($p>0.05$) versus control according to t-test

Increasing the concentration of sodium alginate led to an increase in the firmness of the jellies to a minimal degree, but nevertheless their numerical values were lower compared to the control. The lower firmness values of the jellies compared to the control are due to the greater rupture deformation of the samples. The rupture energy changed little at certain concentrations (P02 and P04) compared to the control. As the concentration of the gelling agent (sodium alginate) increases, the rupture energy decreases to a small extent, approaching the value of the rupture energy of the control. To the greatest and most significant extent, the rupture energy increases at the lowest gelling agent concentration (P01) as compared to P00.

3.2. Composite Jellies at Different Concentrations of Iota-Carrageenan

The rupture force of fruit jellies increased significantly with increasing concentration of iota-carrageenan as compared to the control P00 (Table 5). Statistically the rupture deformation was not statistically significantly different from P00, but was nevertheless slightly increased with 1.2% added iota-carrageenan (P02). The compressive stress of all fruit jellies was always greater than the control as the concentration of iota-carrageenan increased. The firmness of the fruit jellies increased gradually with increasing iota-carrageenan concentration and was always significantly higher than the control.

The firmness of the sample P04 (Table 5) is 2.2 times higher than that of P01. This is due on the one hand to the higher concentration of iota-carrageenan and on the other hand to the significantly higher compressive stress of P04. As the concentration of the gelling agent (iota-carrageenan) increased, it was found that the rupture energy of the composite jellies significantly increased many times compared to P00. The minimum change in the concentration of iota-carrageenan caused significant increase in the rupture energy of the samples (Table 5).

Table 5

Structural-mechanical properties of composite jellies at different concentrations of iota-carrageenan

CSMP	Concentration of sodium alginate [%]				
	Control sample 0%	sodium alginate 0,2%	sodium alginate 0,4 %	sodium alginate 0,6 %	sodium alginate 0,8 %
	Sample no.				
	P00	P01	P02	P03	P04
RF [N]	0.031*±0.003^{a}	0.15*±0.007^{b}	0.24*±0.026^{c}	0.26*±0.010^{d}	0.31*±0.016^{e}
RD [mm]	2.93±0.731^{a}	2.31±0.113^{a}	3.47±0.299^{a}	2.79±0.096^{a}	2.90±0.062^{a}
CS [kPa]	1.60±0.0002^{a}	7.72±0.0004^{b}	12.00±0.001^{c}	13.12±0.001^{d}	15.64±0.001^{e}
FI [N/mm]	0.01±0.002^{a}	0.04±0.003^{b}	0.05±0.003^{c}	0.07±0.002^{d}	0.09±0.005^{e}
RE [mJ]	0.05±0.014^{a}	0.25±0.030^{b}	0.51±0.080^{c}	0.45±0.024^{d}	0.53±0.020^{e}
TO [mJ/cm^{3}]	0.79±0.170^{a}	5.57±0.447^{b}	7.44±0.531^{c}	8.22±0.571^{d}	9.31±0.394^{e}
MY [kPa]	3.55±0.787^{a}	14.12±0.615^{b}	24.17±4.246^{c}	25.36±0.926^{d}	29.10±0.984^{e}
AD [N.s]	- 0.002±0.001^{a}	- 0.10±0.010^{b}	-0.13±0.014^{c}	-0.15±0.006^{d}	-0.17±0.006^{e}

Note: CSMP – structural-mechanical properties, RF – rupture force, RD – rupture deformation, CS – compressive stress, FI-firmness, RE - rupture energy, TO – toughness, MY– Young's modulus and AD – adhesiveness. * mean values of five measurements (n = 5) ± standard deviation. Values followed by the same letters in each row are not statistically significant ($p>0.05$) versus control according to t-test

The rupture energy of the sample P02 and P04 is more than two times higher than that of P01. This is due to the higher values of compressive stressand elastic modulus (Young's modulus) of these samples. The toughness of all fruit jellies was significantly higher and increased gradually with increasing gelling agent concentration as compared to the control. This fact is due to the increase in elastic modulus (Young's modulus) and adhesiveness of the composite fruit jellies. As the concentration of iota-carrageenan increases, the elastic moduli of all samples are greater as compared to control P00.

The numerical values for the adhesiveness of all fruit jellies (P01; P02; P03 and P04) increased smoothly with increasing gelling agent concentration and were higher than the control. The increase in adhesiveness of all samples compared to the control with increasing gelling agent concentration and other gelling conditions being equal, depended to the greatest extent on compressive stress and Young's modulus (elastic modulus) (Table 5).

3.3. Composite Jellies at Different Concentrations of Low-Esterified Amidated Pectin

From Table 6 it was found that the concentration of LEAP increases, the rupture force of all samples is approximately two times lower than the control P00. The rupture force of (P02) increased up to 2.3 times that of P00 and then decreased, regardless of increasing pectin concentration.

To the smallest extent, the compressive stress of P01 is lowered compared to control P00. After that, the compressive stress of the samples (P02, P03, and P04) starts to increase smoothly with increasing LEAP concentration without exceeding the value of P00.

Table 6

Structural-mechanical properties of composite jellies at different concentrations of low-esterified amidated pectin (LEAP)

CSMP	Concentration of sodium alginate [%]				
	Control sample 0%	sodium alginate 0,2%	sodium alginate 0,4 %	sodium alginate 0,6 %	sodium alginate 0,8 %
	Sample no.				
	P00	P01	P02	P03	P04
RF [N]	0.41*±0.046^{a}	0.24*±0.026^{b}	0.18*±0.010^{c}	0.18*±0.013^{d}	0.19*±0.004^{e}
RD [mm]	2.30±0.060^{a}	3.47±0.299^{b}	5.43±0.083^{c}	5.22±1.227^{d}	2.84±0.062^{e}
CS [kPa]	20.82±0.002^{a}	12.00±0.001^{b}	9.16±0.001^{c}	9.30±0.001^{d}	9.92±0.0004^{e}
FI [N/mm]	0.15±0.020^{a}	0.05±0.003^{b}	0.02±0.002^{c}	0.03±0.009^{d}	0.03±0.013^{e}
RE [mJ]	0.55±0.054^{a}	0.51±0.080^{a}	0.74±0.029^{b}	0.71±0.176^{a}	0.35±0.012^{c}
TO [mJ/cm^{3}]	12.22±1.454^{a}	7.44±0.531^{b}	6.95±0.294^{c}	6.96±0.303^{d}	6.28±0.247^{e}
MY [kPa]	47.08±16.011^{a}	24.17±4.246^{b}	10.48±0.897^{c}	12.74±5.910^{d}	18.49±9.588^{e}
AD [N.s]	- 0.05±0.013^{a}	- 0.13±0.014^{b}	-0.18±0.005^{c}	-0.20±0.014^{d}	-0.21±0.024^{e}

Note: CSMP – structural-mechanical properties, RF – rupture force, RD – rupture deformation, CS – compressive stress, FI-firmness, RE - rupture energy, TO – toughness, MY– Young's modulus and AD – adhesiveness. * mean values of five measurements (n = 5) ± standard deviation. Values followed by the same letters in each row are not statistically significant (p>0.05) versus control according to t-test

From the conducted structural-mechanical measurements, it was found that as the concentration of the gelling agent increases, the firmness of the samples (P01, P02, P03, and P04) decreases significantly from 3.0 to 7.5 times compared to the control (Table 6). The rupture energy of P03 increases and that of P01 decreases compared to P00 with increasing LEAP concentration, but these changes are nevertheless statistically insignificant. The same changes in the energy were observed for P02 and P04 relative to P00, but statistically significant. The rupture energy of P02 is 2.1 times higher than that of P04, which is due to the almost two times higher rupture strain of this sample (P02) than that of P04. A larger value of deformation force and rupture energy means that a sample can absorb more energy per unit volume before it breaks. It was found that the toughness of the fruit jellies decreases significantly compared to P00 when the concentration of the added LEAP increases (Table 6).

The elastic moduli of all samples were numerically lower than P00. With a minimal increase in LEAP (from 0.6% to 0.8%), the elastic modulus of P02 decreases 2.3 and 4.4 times compared to P01 and P00. The addition of 0.8% LEAP makes the fruit jellies (P02) least elastic and hard, i.e. softer, which is confirmed by the highest rupture deformation (5.43 mm) of this sample among the others. The adhesiveness of all fruit jellies increased with the increasing concentration of added LEAP and was 2.6 to 4.2 times higher than the control sample P00.

4. Discussion

4.1. Structural-Mechanical Properties of Composite Jellies at Different Concentrations of Added Gelling Agents

When the concentration of sodium alginate increases (Table 4), the rupture force increases minimally and is always lower than the control. This phenomenon can be explained by the weaker cross-linking of gelling agent (iota-carrageenan or low-esterified amidated pectin) with calcium ions compared to alginate and calcium ions.

The determined rupture deformation of P04 composite jelly was numerically identical (2.79 mm) to that of calcium-alginate beads containing *Rosa damascena* hydrosol [22].

As the concentration of the gelling agent (sodium alginate) increases from 0.4 to 0.8%, the compressive strength of P02, P03 and P04 increases (Table 4). A similar effect of sodium alginate on compressive strength was observed in the restructured pimiento alginate-guar gels [19]. Regardless of the increase in sodium alginate concentration, the compressive stress was always lower compared to P00, which could be due to the higher concentration of iota-carrageenan compared to sodium alginate.

The measured rupture energy of P01 (0.51 mJ) is very close in numerical value to the energy (0.567 mJ) required to rupture energy of an acacia jelly with added borage seeds [32].

As the concentration of the added sodium alginate increases (Table 4), the toughness of the jellies increases to a minimal extent, but does not exceed the value of the control sample. The numerical values of toughness are directly related to the increase in compressive strength of fruit jellies. The obtained toughness values of P01, P02, P03 and P04 were higher compared to the *Aegle marmelos Correa* subjected to different temperature treatments [30].

The elastic modulus (Young's modulus) of P01, P02 and P03 increase gradually with the increasing concentration of the gelling agent, and for P04 the elastic modulus slightly decreases (Table 4). At the lowest concentration of added alginate (0.2%), the elastic modulus of fruit jellies (P01) decreased almost twice compared to P00. Regardless of the increasing sodium alginate concentration, the elastic moduli of all samples were statistically different and numerically smaller than P00. A similar effect associated with a decrease in elastic moduli compared to the control was observed with partially oxidized (4 and 8%) alginate in calcium-saturated hydrogels and agar gel with added chokeberry juice [10]. It was found that the elastic moduli of all experimental samples were many times higher compared to the elastic moduli of plum, apple, strawberry and peach fruit jams enriched with microalgae without added sugar [35].

Adhesiveness is stickiness that is related to the molecular structure of the product and represents the force between the surface of the food and other materials in contact with the food product [9]. A significant increase in the adhesiveness of the fruit jellies from 2.4 to 3.8 times compared to the control can be seen when the concentration of alginate increases (Table 4). A similar effect was observed with low-sugar strawberry jam [12].

4.2. Composite Jellies Prepared with Different Concentrations of Iota-Carrageenan

The concentration of the gelling agent (samples P01 and P04) increases from 1.0% to 1.6%, the rupture force increases twofold (Table 5). The results obtained for the rupture force of P02 and P03 are very close in numerical value, i.e. similar to that of kappa-carrageenan pearls from dragon fruit [6]. The rupture deformation of P02 is comparable (3.47 mm) to the mango and pineapple alginate jelly mixed in a 4:1 ratio [14]. When the concentration of iota-carrageenan is increased by 60%, the compressive stress of P04 increases twice as much as that of P01, which is due to the two-fold increase in the compressive stress of P04 compared to P01. The compressive stress results obtained in our study were similar to those of a reusable hydrogel based on 5% added gelatin [40]. In this study, the toughness of iota-carrageenan-supplemented fruit jellies was found to be 6.7 to 11.2 times higher than the toughness of the *Terminalia bellerica* fruits measured along the transverse axis [20].

The elastic modulus is a parameter used to determine the firmness of the material, so samples with higher elastic modulus are harder materials [28]. This means that increasing concentration of iota-carrageenan makes all composite jellies harder and more elastic. The Young's modulus of P04 has the highest value among the other samples and is twice as high as that of P01. This is due to the twice higher tearing strength of P04 compared to P01. The determined elastic moduli of composite jellies with added iota-carrageenan are from 1.4 to 2.9 times higher than pectin film with the addition of the halophytic plant *Salicornia ramosissima* [21].

A similar increase in adhesiveness compared to the control was found in carrageenan jelly with added 13 and 20% mulberry powder [33].

4.3. Composite Jellies Prepared with the Different Concentrations of Low-Esterified Amidated Pectin

The decrease in the rupture force of the composite jellies can be explained with the fact that as the pH increases to 4.5 or more, the ionic bonds in the pectin increase to a maximum. Therefore, an increase in the distance between the pectin molecules can be observed and leads to a decrease in hydrogen bonds and weakens the structural network [38], and the strength of the pectin gel decreases. The results obtained in our study on the deformation of the jellies are similar to those of a jellied pectin marmalade with added cranberry concentrate [3].

The compressive stress of all samples was lower compared to P00 with an increasing LEAP concentration. The decrease in firmness is due to the depolymerization of pectin at high temperature and the increase in pH [2], which, on the other hand, leads to the reduction of compressive stress and rupture force.

The change in the toughness of the samples depends mostly on the change in the firmness and the rupture force, respectively.

When the concentration of added LEAP in the composite gels increases, it can be seen that Young's modulus initially decreases (P01 and P02), and then begins to increase (P03 and P04), but does not exceed the elastic modulus of P00. A similar increase in elastic modulus (Young's modulus) with increasing concentration of low-esterified pectin was found in pectin hydrogels with added starch [31].

Increasing the percentage of LEAP has a positive and enhancing effect on the degree of adhesiveness. A similar effect of pectin on adhesiveness was found in pomegranate jams [1].

5. Conclusions

From the obtained results of the conducted study, it was found that the rupture force is reduced to the highest extent when the concentration of low-esterified amidated pectin increases. The reduction decreased when the content of sodium alginate increased. The rupture force of the composite jellies was the greatest relative to the control at the maximum concentration (1.6%) of added iota-carrageenan. Increasing the concentration of iota-carrageenan made the composite jellies harder and more elastic, and sodium alginate and low-esterified amidated pectin softer compared to the control. Regardless of the type and concentration of the added gelling agents in the composite jellies, their adhesiveness is always significantly higher as compared to the control sample.

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