Rheological Properties of Dough and Sensory Quality of Crackers with Dietary Fibers

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Abstract—The possibility of application the dietary fibers in production of crackers was observed in this work, as well as their influence on rheological and textural properties on the dough for crackers and influence on sensory properties of obtained crackers. Three different dietary fibers, oat, potato and pea fibers, replaced 10% of wheat flour. Long fermentation process and baking test method were used for crackers production. The changes of dough for crackers were observed by rheological methods of determination the viscoelastic dough properties and by textural measurements. Sensory quality of obtained crackers was described using quantity descriptive method (QDA) by trained members of descriptive panel. Additional analysis of crackers surface was performed by videometer. Based on rheological determination, viscoelastic properties of dough for crackers were reduced by application of dietary fibers. Manipulation of dough with 10% of potato fiber was disabled, thus the recipe modification included increase in water content at 35%. Dough compliance to constant stress for samples with dietary fibers decreased, due to more rigid and stiffer dough consistency compared to control sample. Also, hardness of dough for these samples increased and dough extensibility decreased. Sensory properties of final products, crackers, were reduced compared to control sample. Application of dietary fibers affected mostly hardness, structure and crispness of the crackers. Observed crackers were low marked for flavor and taste, due to influence of fibers specific aroma. The sample with 10% of potato fibers and increased water content was the most adaptable to applied stresses and to production process. Also this sample was close to control sample without dietary fibers by evaluation of sensory properties and by results of videometer method.

Keywords—Crackers, dietary fibers, rheology, sensory properties.

I. INTRODUCTION

DIETARY fibers relate to a heterogeneous group of components with different functional properties. The fibers in the gastrointestinal tract form matrix with fibrous and amorphous characteristics. Physicochemical properties of these matrices determine homeostatic and therapeutic functions of fibers in human nutrition. The fibers swell in aqueous media of intestinal juices, absorb water and small molecules. Between the fibers and the molecules that surround them different types of bonds form, such as ionic, hydrogen, week hydrophobic bond and dispersion forces, which may affect the absorption of minerals and steroids [1], [2].

Numerous studies show that the consumption of fibers

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protect against heart disease, cancer, normalize the lipid content in the blood, affect the glucose level and insulin secretion, prevent the constipation and digestive tract diseases [3], [4]. The enrichment of food with dietary fibers aims to increase the application of dietary fibers in the diet. Mainly, the enrichments observe bakery products, cookies, crackers and other products that may contain cereals. The possibility to increase the fiber content today is extended to different types of snack products, soft drinks, spices, sauces, frozen products, canned meat and other similar products. However, as a source of fibers, different by–products of milling of wheat, maize, sorghum and other cereals can be used, as well as the products obtained by wet milling of corn and wheat. There are many other products, such as fruits, vegetables and infrequently used grains, which are potential source of fibers [5], [6]. Soluble dietary fibers, including pectin and hydrocolloids are found in fruits, nuts fruits, vegetables, legumes. Insoluble fibers, including cellulose and hemicelluloses, may be found in whole grain cereals. Dietary fibers from cereals include 50% of all sources, 30–40% is obtained from vegetables, about 16% are of the fruit, and the remaining 3% is from other sources of dietary fibers [7].

The important technological characteristics of dietary fiber that determine the possibilities for their application are water holding capacity, capacity of fat binding, viscosity, gel forming ability, chelating capacity and the influence on food texture. The water holding capacity is associated with the length and density of the fibers. Also, the pH of the environment affects the water retention capacity. Capacity of fat binding is more dependent on the porosity of the fibers, than the molecular affinity. Fibers such as pectin, gums, β–glucan form solutions with large viscosity and are commonly used as thickeners. Viscosity of insoluble and some soluble fibers, such as inulin, are minimal. The ability to form a gel is the most important feature in using fibers as fat replacer. This ability is provided by cross–linking of polymeric units and by retention of water or other solvents in the gel structure. This characteristic depend on a number of factors, such as concentration, temperature, the presence of certain ions and the pH of the environment. Some fibers have a synergistic property and during the gel formation are used in conjunction with starch, the xanthan gum or carrageenan [2]. Other technological properties of fibers are to control the sugar crystallization and to modify the flavor. An important feature is that they prevent deformation and shrinkage of restructured products during cooking. Some fibers possess antioxidant properties, effectively affect during cooling and freezing of products that quickly rancid.

The objective of this study was to characterize the rheological and textural properties of dough and sensory properties of crackers with addition of different dietary fibers. The wheat flour for crackers was substituted with 10 % of oat fibers, potato fibers and pea fibers.

II. MATERIAL AND METHODS

A. Material

Materials used for experimental work were wheat flour for flour based confectionary products (Type 500), oat dietary fibers HF 200, potato dietary fibers KF 200 and pea dietary fibers EF 150 produced by J. Rettenmaier & Sonho GMBH + CO Rosenberg, Germany. Vegetable fat, yeast, sodium hydrogen carbonate ($NaHCO_3$), sodium chloride (NaCl) and water were also used. The composition of the wheat flour is presented in Table I.

TABLE I
COMPOSITION OF THE WHEAT FLOUR

Components of the flours	Wheat flour (%)
Moisture	6.82
Starch	71.70
Proteins	9.88
Reducing sugars	1.83
Fats	0.84
Ash	0.47

B. Preparation of the Crackers

The soda crackers were prepared by baking test method. The dough for soda crackers was prepared according to the long fermentation process. The process includes two phases: mixing of the sponge and mixing of dough in the vertical spindle mixer. The dough for cracker is soft consistency dough with 30% of moisture. The sponge contains wheat flour (70% of total amount of flour), yeast (0.4%) and water (30%). The mixing of sponge is 10 min at 27°C and the fermentation process is 18 h at relative humidity of 80–90%. The dough contains wheat flour (30% of total amount of flour), vegetable fat (11%), NaCl (1.5%) and $NaHCO_3$ (1.0%). The ingredients for the dough are added to sponge and mixed 5 min. Second fermentation process is 5 h at 27–29°C and relative humidity of 80–90%.

The control sample contained wheat flour. The wheat flour was substituted with 10% of different dietary fibers (oat, potato and pea fibers) in the samples with dietary fibers during mixing of dough.

Dough was pressed manually in a shape of a compact low cylinder. After 2min of the relaxation time dough stripe was developed by thinning dough twice in either direction between two rollers of the laminator (Laminoir Marchand LA4–500) at rollers gap 10, 7 and 5 mm. Dough relaxed for 0.5min after each lamination cycles. To avoid an adhesion, cloth stripe was floured by a small quantity of starch. After the relaxation time (2min) dough was shaped in crackers by round mould (50mm in diameter). Twelve pieces of shaped dough were replaced to perforate sheet–metal for baking. Crackers baking time was 15 min at 250±2°C. During baking the oven was closed and

without the vapor connection. Crackers were cooled for 30min on the baking sheet under ambient conditions.

C. Rheology Determination

Rheological properties of obtained dough for crackers were determined by rotational viscometer HAAKE RheoStress RS600 (Thermo Electron Corporation, Karlsruhe, Germany) with plate–plate sensor PP60 Ti (plate diameter was 60 mm and gap 1 mm). The measurements were done at 27±0.1°C.

Viscoelastic properties of the dough defined by storage modulus (G') and loss modulus (G'') were determined by dynamic oscillatory measurements in the range of linear viscoelastic regime (LVE). The moduli were observed during increased frequency from 1 to 10 Hz and at constant shear stress of 10 Pa. The results were expressed as value tan δ = G''/G' [8].

Viscoelastic response of the samples at constant stress, as well as their behavior after removing the stress, were determined by creep and recovery test. The test was performed in the LVE regime in which the deformation amplitude was proportional to applied stress amplitude. The creep time with constant stress (σ=10 Pa) was 150 s and the recovery period after removing the stress was 300 s. Creep data, collected under constant stress (σ) over time (t), can be described by a creep compliance (J) function, in terms of shear deformation (γ), using (1):

$$J(t) = \gamma(t)/\sigma \qquad (1)$$

The linear development of compliance as a function of time is imitated by mechanical model with several springs (elastic contribution) and dashpots (viscous contribution) [9]. Mathematically, the relationship between elastic and viscous properties can be simulated by Burger's model that is combination of Kelvin model (consisting of a spring and dashpot connected in parallel to each other) and Maxwell model (consisting of a spring and dashpot connected in series to each other) placed in series.

The creep data were analyzed by Burger's model presented by (2):

$$J(t) = J_0 + J_1 \cdot (1 - \exp(-t/\lambda)) + t/\eta_0 \qquad (2)$$

For the recovery phase the equation of the Burger's model is (3):

$$J(t) = J_{max} - J_0 - J_1 \cdot (1 - \exp(-t/\lambda)) \qquad (3)$$

The value J_0 is the instantaneous compliance, J_1 is retarded (viscoelastic) compliance, J_{max} is maximum compliance, λ is mean retardation time and η_0 is Newtonian viscosity [10]–[12]. Also, the relative elastic part J_e/J_{max} and relative viscous part J_v/J_{max} of maximum creep compliance were determined from creep and recovery curves [13].

D. Textural Properties

Textural properties of the dough for crackers were determined by Texture Analyzer TA.HD Plus (Stable Micro

Systems, Godalming, U.K.). The method specified by device producer, *Extensibility of dough and measure of gluten quality* was used. The load cell of 5 kg and adequate accessories, Kieffer Dough and Gluten Extensibility Rig were applied.

E. Sensory Properties

Sensory quality of crackers was described by quantity descriptive method (QDA). Members of trained panel participated in the evaluation. The sensory properties of crackers external appearance (surface, color), hardness, structure, crispness, flavor, salinity, taste were evaluated. The sensory attributes were rated on a scale in range of 1–7 where 1 was the lowest score and 7was the highest score of each property, as it was present in Table II.

TABLE II
MARKS FOR SENSORY PROPERTIES

Sensory property	Range of marks
Surface	1–Rough, with many cracks, deformed 7–Smooth, without cracks, a little wavy
Color	1–yellow 7–brown
Hardness	1–Weak, decompose, crumble 7–Strong, distinct hardness
Structure	1–Not uniform, compacted structure 7–Uniform, structure is very uniform, layered
Crispness	1–Weak, not crispy, but soft 7–Strong, very crispy
Flavor	1–No flavor 7–Distinct flavor, unpleasant smell, very distinct intensity, highlights some of the row materials
Salinity	1–Weak, no salty taste 7–Strong, distinct salt taste
Taste	1–No taste, very low intensity 7–Distinct off taste, unpleasant taste, very distinct taste, highlights some of the row materials

Obtained scores of 1–7 for each quality parameter were presented by polar coordinates in the aim to present the QDA diagram of the observed crackers samples [14].

F. Videometer

The surface and the color of the crackers were additionally determined by device of new generation named VideometerLab 3. This unit provides the scanning of sample surface with high resolution (from 2448x2048 pixels) and to 20 spectral groups with defined wavelength in the range from 360 nm to 1050 nm.

III. RESULTS AND DISCUSSION

A. Rheology Characteristics of the Dough

Unlike the other samples, the sample with 10% replacement of wheat flour with potato dietary fibers could not be obtained. The dough with potato fibers and 30% of moisture was undeveloped and further manipulation with the dough was not possible. Thus, the amount of water for this sample was increased and was 35% in the aim to achieve sufficient consistency of the dough.

The ability of the dough samples to resist to the constant stress and to proportionally recover after the removing of stress was observed by creep and recovery method. Obtained creep and recovery curves are presented at Fig. 1.
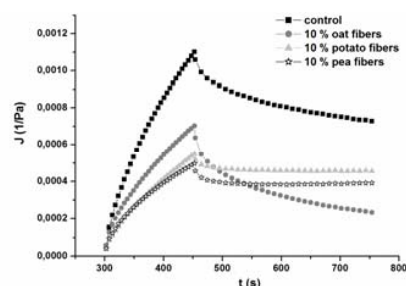

Fig. 1 Creep and recovery curves of the dough samples

Parameters obtained by fitting the creep and recovery curves to Burger's model are collected in Table III.

TABLE III
PARAMETERS OF BURGER'S MODEL

	$J_0 \cdot 10^5$ (Pa^{-1})	$J_1 \cdot 10^4$ (Pa^{-1})	$\eta_0 \cdot 10^{-5}$ (Pas)	λ_1 (s)	$J_{max} \cdot 10^4$ (Pa^{-1})	
Creep phase						
Control	5.23	3.63	4.11	196.7	11.01	
Oat	5.92	2.32	6.44	196.7	7.03	
Potato	4.07	1.81	8.24	196.7	5.49	
Pea	4.16	1.64	9.09	196.8	4.98	
Recovery phase	$J_0 \cdot 10^4$ (Pa^{-1})	$J_1 \cdot 10^4$ (Pa^{-1})	$\eta_0 \cdot 10^{-6}$ (Pas)	λ_1 (s)	J_e/J_{max} (%)	J_v/J_{max} (%)
Control	10.59	7.67	1.04	327.7	66.92	33.08
Oat	6.37	2.41	1.24	327.7	33.90	66.10
Potato	5.18	1.52	1.66	327.7	17.05	82.94
Pea	4.57	1.29	1.922	327.7	21.22	78.78

The parameters of creep and recovery curves for all samples with dietary fibers decreased compared to control sample of the dough. Thus, their creep compliance was lower than the control dough and pointed the stiffer and less elastic structure. The materials that exhibit high creep values over time have weak material structures whereas low values are representative of stiffer structure [11].

The values of maximum compliance J_{max} also decreased and the Newtonian viscosity η_0 that describe the viscosity of the systems increased. Observing the samples with dietary fibers it was noticed that the sample with 10 % of pea fibers was with lowest parameters of compliance and with highest viscosity.

After the relaxing time, the ability of the samples to recover was observed. The balance of elastic and viscous component in maximum creep compliance (J_v/J_{max} and J_e/J_{max}) for samples with dietary fibers was directed to higher amount of viscous component, compared to control sample. That indicated the brittle structure with low ability to recover.

Results of dynamic oscillatory measurements were in agreement with results of creep& recovery method. All dough samples were viscoelastic systems with dominant elastic (storage) modulus G' over viscous (loss) modulus G". The value of tan δ (G"/G') was the highest for control sample.

Application of dietary fibers in the dough reduced the values of tan δ and pointed to stiffer structure with higher domination of elastic modulus (Table IV).

TABLE IV
VALUES OF TAN Δ

Dough sample	tan δ
Control	0.407
Oat fibers	0.352
Potato fibers	0.278
Pea fibers	0.280

B. Textural Properties of the Dough Samples

Large deformation method was used to determine the textural properties of the observed dough for crackers. Hardness of the dough and the dough extensibility are presented at Fig. 2.
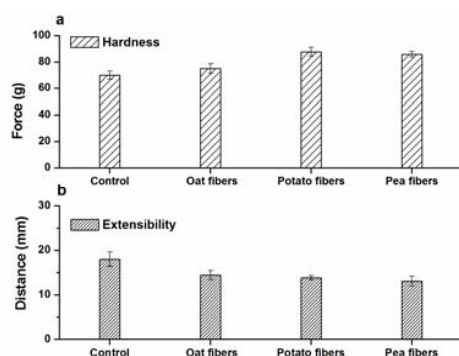
Fig. 2 Texture properties of the dough with fibers; (a) hardness (b) extensibility of dough

Hardness of the dough samples increased with application of dietary fibers compared to control sample, as it was expected. Accordingly, the dough extensibility decreased for the samples with dietary fibers and it was the lowest for the dough with 10% of pea fibers. Obtained texture properties were in good accordance with previous discussed rheological characteristics of the dough samples.

C. Sensory Evaluation

Results of sensory evaluation of crackers described the sensory characteristics of obtained crackers and thus acceptability by consumers. Compared to control crackers all sensory properties for crackers with dietary fibers were mainly reduced. Surface was rougher and more deformed with application of dietary fibers. Color for the sample with 10% of oat dietary fibers in the range from yellow to brown was with the highest amount of yellow tone. Hardness of the crackers with dietary fibers increased and that was in accordance with rheological and textural measurements. Uniformity of structure decreased, which caused reducing crispness. The crispness of sample with 10% of oat fibers was the lowest, strived to weak, not crispy but soft. Also the marks for flavor and taste of the crackers with dietary fibers were lower than for control sample. The specific aroma of dietary fibers, especially of pea fibers contributed to reducing marks of these sensory properties. The marks for sensory characteristics for obtained crackers were presented by QDA diagram, Fig. 3.
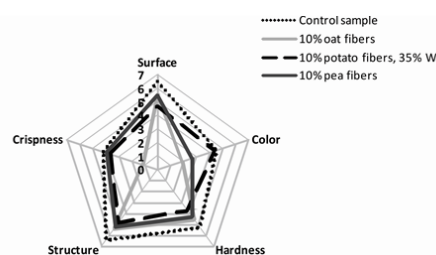

Fig. 3 QDA diagram for crackers samples

D. Videometer

Videometer provided scanning of sample surface and at defined wavelengths obtained values described the brightness of the surface color. The sample is lighter if the values on defined wavelengths are higher.

Graphically presented results from videometer are at Fig. 3. The control sample and sample with increased amount of water (35%) and 10% of potato fibers were very close by color brightness. The samples with pea fibers and oat fibers were with higher brightness and these results confirmed the sensory evaluation of crackers color.
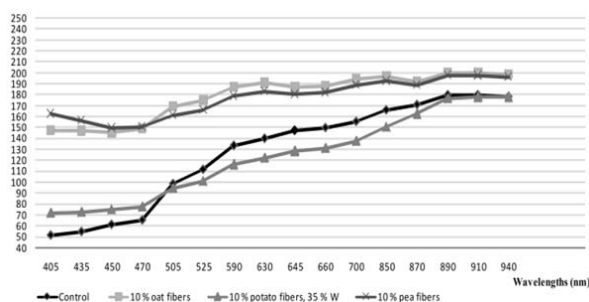

Fig. 3 Results of determination with Videometer

IV. CONCLUSION

Obtained results for dough for crackers and for final product-crackers showed that application of dietary fibers in amount of 10% in long fermentation production of crackers is possible. The application of dietary fibers influenced on rheological and textural properties of the dough for crackers and reduced the dough compliance and resistance to stress, due to increased hardness of the dough, especially for sample with 10% of potato fiber. It required the recipe modification and increase in water content at 35%. Significant water holding capacity of the dietary fibers certainly contributed to increase of dough firmness and rigidity.

Changes of dough for crackers caused changes of sensory characteristics of crackers with dietary fibers. They were mainly reduced, especially structure and crispness for sample with 10% of oat fibers, as well as flavor and taste for all other samples.

The highest flexibility during production and the smallest changes of observed properties of final product had crackers with 10% of potato fibers and increased water content.

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