Development of complex investigation of extrudats using acoustic echolocation method

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Abstract

The swelling parameters (swelling dynamics – Vd and degree of swelling – V) of rye in a composition with buckwheat were investigated by an acoustic echolocation method. The new provisions production experiment was performed with single and twin screw extruders. The obtained experimental results are presented.

The determined swelling parameters (Vd and V) of extrudates have a good correlation with parameters, analyzed by the instrumental method (expansion index, specific density, mechanical strength of the product and a mean diameter of pores). The experiment performed with both extruders proved that varied buckwheat percentage in rye composition (0 till 40 %) allows us to obtain products with various quality of texture – from snacks to breakfast cereals.

Analysis of solubility and water absorption of non – pores structures of extrudates was done using traditional methods additionally. It proved results obtained by acoustic echolocation method, that during extrusion rye starch granules tend be more degraded and depolymerized in comparison with buckwheat. Rye extrudates like snacks differed by intensive swelling dynamic and their structure in time of 60 seconds was collapsed, taking volume of water about 2,9 ml. Extrudates with buckwheat flour differently from pure rye have swelling property and make more equal structure. Analyzed extrudates with the highest amount of buckwheat flour like breakfast cereals were observed as having a long unbroken not interrupted swelling process, keeping structure during measurement time. This sort of products had a highest degree of swelling (V – 5,4 ml_{h2o}) and the structure looked most uniform.

This means that acoustic echolocation method gives a complex information both about the texture of end products and the processes during extrusion. This method can be implemented in practice to classify extrudates to different quality grades products.

Keywords: acoustic echolocation method, swelling parameters of extrudates, physical-mechanical properties of extrudates, structure of extrudates, cereals products, complex information about texture of extrudates.

Introduction

In investigations of high quality provisions [1, 2], e.g. rye and buckwheat extrudats having porous structure, they use at this time instrumental methods [3] shown in Table 1. These methods allow us to obtain information about porosity and other physical-mechanical properties of products. During extrusion in comparison with a usual baking of bread specific technological processes take place. Majority of components containing starch during heating and mechanical processing at a high temperature under effect of pressure and steam added to the mass change consistencies and become similar to the dough that swells out during extrusion [1, 2]. It gives specific properties of texture which are appreciated on swelling index, specific density and resistance against force of pressure.

In analysis of separate kinds of extrudats (light snacks or dry breackfast) enriched information about texture of product is a problem. For light snacks the main property of texture is cracky surface and volume and it is associated with resistance in mastication, while for the second kind of extrudats – the dry breackfast, which is used with milk it is essentially important to evaluate the moisten and swelling properties of the products surface. Swelling properties of extrudats usually are evaluated by contact methods after the solubility of mass and after water absorbtion of porousless extrudats up to time. Index of solubility gives information about degradation of starch granulas when the water absorbtion index is associated with the property of starch granulas to swell [4]. For increased amount of information about the texture of porous provision, e.g. crackers and ring-shaped rolls we used echolocation method [3, 5].

Table 1. **The methods for high quality provisions investigation and properties of these methods**

Properties of the methodes / The method	Destructive	Non-destructive	Slow analysis	Rapide analysis	Dangerous for personal health	Negative influence of other properties of the sample
Optical	+	-	+	-	-	-
Photographical	+	-	+	-	-	-
Electrical	-	+	-	+	-	+
Mechanical	+	-	+	-	-	+
Radioisotope	-	+	-	+	+	-
X-ray	-	+	-	+	+	-
Infrared	-	+	-	+	-	-
Acoustic	-	+	-	+	-	-

The main point of this method is employment of a short distance echolocator for non-contact measurement of samples swelling properties. Usage of the acoustic echolocation method enables to carry out measurements of water absorbtion without taking out the sample from a reservuar. The sample does not to disintegrate during measurement process and obtained results are precise enough. This feature emphasizes usefully the acoustic echolocation method in comparison with other mechanical methods. Other non-contact precise water level meters can be used instead of ultrasonic water level meter. It is proven that the swelling process dynamics depends on the peculiarities of raw materials used for cereals [6-13]. During the swelling the extrudats can be characterized as a highly hidrofillic colloidal systems [7, 9] formed from the massive molecules of polymers from a cereals raw materials.

For production of extrudats usually maize, wheat and rice are used, starch of which contains greater amount of amylose [8, 11, 13]. Amylose having a line structure differently from amilopektyne is easier to orientate during extrusion under technological influence. This enables formation of a porous structure. Other grain, e.g. rye, barley, oat, buckwheat have a smaller amout of amylose. Extrudats of denser structure are produced from them. Under point of view of a food quality they are very valuable raw materials. It is reccomended to use them as widely as possible for new provisions production [8, 9, 11].

The purpose of this investigation is to evaluate influence of nontraditional grain raw material – rye in combination with buckwheat - on extrudats swelling properties using the acoustic echolocation method.

Methodics of investigations

Extrudats were produced using a single screw extruder (Schaaf Technologie GmbH) at the joint stock company "Naujasis Nevezis" (Lithuania) and the twin screw conoidal CM45-F type extruder (Cincinnati Milacron, Wien, Austria) at Wien nature stock and applied sciences university production base (Austria).

During production of samples by the single extruder the velocity of screw was changed (350, 410, 470 min^{-1}) when dose of friable products and temperature in separate zones of extruder (45/65/135 ^{o}C) was stable in investigations.

During production of samples by the twin screw extruder the screws of seweral steps were tested: the bigger step (DŽ) was SK 1552-300 B and the smaller step (MŽ) was SK1552-300. Additionally the velocities of screws were changed to 60 and 80 min^{-1}. Other parameters of the extruder: dozes of friable products and temperatures in separate zones of extruder (80/110/140/160 ^{o}C) were stable.

In both cases (by using the single and the twin screw extruders) the same prescription was used (Table 2).

The possibilities of ultrasonic echolocation method [3, 5] usage were investigated for evaluation of extrudats texture after swelling properties. The measurements of extrudats porosity by the ultrasonic echolocation method are based on the materials property to absorb liquid. The

Table 2. **Prescription of extrudats composition, %**

Rye flour, %	Buckwheat flour, %
100	-
80	20
60	40

pores filling process takes a time. The liquid level in the measurement vessel changes after the sample is immersed into liquid (Fig. 1). These changes depend on a materials porosity. The results of application of this method to investigation of porous food materials were described by us in [3, 5, 14-22].

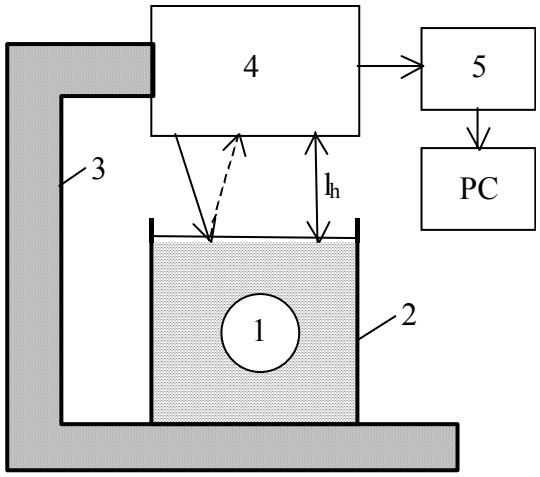


Fig. 1. **The diagram of measurement equipment using ultrasonic echolocation meter: 1 is sample, 2 is technological vessel with water, 3 is support, 4 is ultrasonic echolocation distance meter, 5 is interface, PC is personal computer**

The volume ΔV_S of the absorbed liquid may be evaluated by equation:

$$\Delta V_S = S \bullet \Delta l. \quad (1)$$

Here S is the area of the liquid surface, Δl is change of the liquid level.

The significant traits of the liquid absorption phenomenon are speed of absorption and its change till all holes will be filled. As we can see from Eq.1 the dependence between changes of volume and liquid level is rectilinear if we use vertical cylindrical vessels and area of the liquid surface does not change. We can obtain data about changes of speed of absorption from measurements of level changes. After investigation of functions

$$dl/dt = f_1(t) \text{ and } d^2l/dt^2 = f_2(t), \quad (2)$$

we can decide about usability of the porous material for a chosen purpose.

Two swelling parameters were investigated by the non-contact ultrasonic level meter: dynamics of swelling Vd and swelling degree V. In addition the relation between the swelling parameter (Vd and V) and texture parameters measured by instrumental methods such as resistance force to the pressure, volume increase index, specific density and average diameter of pores was evaluated. The resistance against the acting pressure force (F) was evaluated using the Stevens-LFRA texture anlyzer (USA), by using 10mm diameter plunger [11, 12]. Structure of extrudats (geometrical parameters of pores) was investigated using

the SZ40-Sterio-Zoom type image analyzer. Additionally swelling properties of finished extrudats were evaluated by porousless mass solubility and water absorbtion by the Anderson method [12].

Data of investigations were processed using mathematical statistics method „Sistema Statgraphics 5.0" [23]. The values of parameters point values, standard evaluation errors and confidence intervals at the importance level of 0.05 were calculated.

Results and discussion

The influence of kind of raw materials on the swelling parameters Vd (swelling dynsmics) and V (swelling degree) was evaluated from the point of view of technological factors. The measurements were carried out according to the diagram in Fig.1.

Influence of grain raw material on swelling properties (e.g. Vd) is shown ion Fig.2.

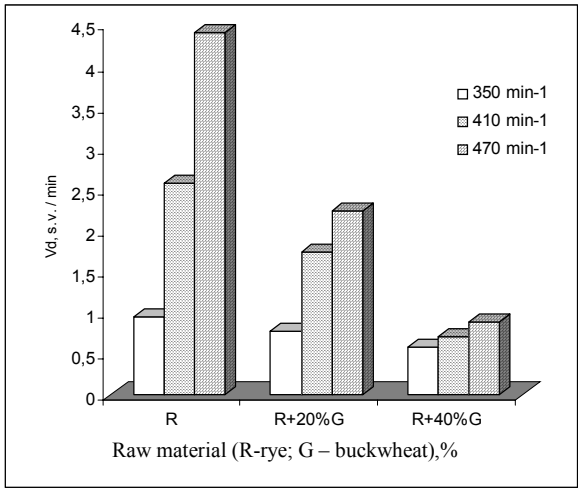


Fig. 2. **Grain raw material influence on the swelling parameters: water absorbtion dynamics (Vd)**

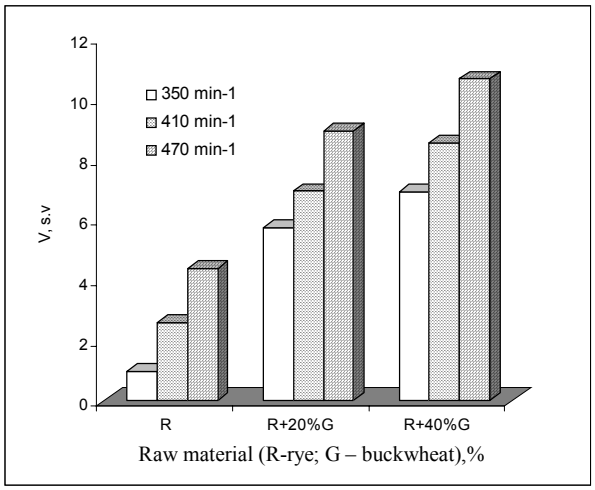
Investigation showed that by changing mass composition, i.e. by increasing the buckwheat flour persentage in the prescription the swelling dynamics (Vd) decreases.

The influence of the velocity of screw was analyzed by produsing extrudats using both the single screw and the twin screw extruders. Changing of screw velocities in the single screw case from 350 min^{-1} till 470 min^{-1} increases the dynamics of water absorbtion and amount of the absorbed water in products (Fig. 3). This tendency was observed in all production cases however in different degree.

The biggest influence of this parameter was rewealed in the single screw extruder case in production of rye extrudats: by increasing velocity of the single screw extruder from 350 min till 470 min the measured values of Vd and V increased 4.6. Meanwhile in the case of compositions with various buckwheat flour persentage no clear dependance on the screw velocity was established.

Extrudats were divided in to three groups – from light snacks till dry breakfast, accordingly depending on the raw material used in production (Fig.4).

The products made from pure rye flour were attached to the first group of extrudats. Intensive swelling dynamics



Fig, 3. **Single screw velocity influence on swellng parameters; amount of absorbed water (V)**

is characteristic for them. Mathematically it is described by a rectilinear dependency. Structure of these products was fully destroyd during 1 minby absorbing 2,9 ml of water. The smallest amount of small pores <20μm and the biggest change of diameters of pores, i.e. from 20 till 401μm and more what is showing nonuniform structure of them, is characteristic for the structure of rye extrudats.

These products were characterized by the highest cracking, lowest hardness and were easy for mastication during investigation of products on quality by senses.

The groups of extrudats with different swelling properties were obtained by changing composition of mass, i.e. by increasing amount of buckwheat flour in the prescription from 20 till 40%.

The swelling process of the second group of extrudats made with the biggest amount of buckwheat flour in the composition (about 40% of the amount of the rye flour) was uniform, long time, whithout brakes. The dynamics of swelling is described by a complex function of dependancy. The extrudats of this group kept their structure the longest time (11 min) during the swelling process. The velocity of water absorbtion was the lowest – 0.5ml/min. The most uniform structure is characteristic for this group with the greatest number of the smalest pores (221…240 μm). According to quality demands the good cracking, optimal hardness, however a bigger resistance in mastication were characteristic for these extrudats

Addition of buckwheat flour gave the pleasant intensive smell and taste.

The products with the intermediate properties of light snacks and dry breakfast were ascribed to the third group. The swelling dynamics is described by a composed dependency. Two stages of swelling process can be marked out: during the first stage (till 1.7min) water was absorbed by the rectilinear dependency, and during the second stage (till 5.7 min) – by the composite dependency. The dynamics of swelling of this group was 3.7 times as higher as dynamics of the second group, however degree of swelling was 1.5 times higher. They were made with a smaller amount of buckwheat flour in comparison with dry breakfast (20% of the rye flour mass). The bigger number of smaller pores (321…340 μm) (1.6 times) and smaller

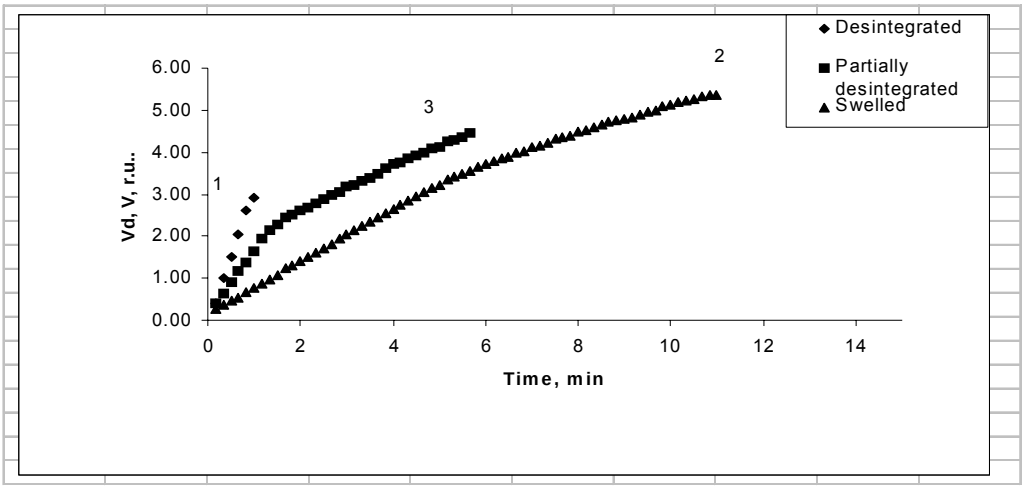


Fig. 4. **The extrudats swelling dynamics dependence on raw material composition; groups of extrudats made from different grain raw materials: 1 is from rye flour, 2 is from 80% of the rye flour and 20% of the buckwheat flour, 3 is from 60% of the rye flour end 40% of the buckwheat flour**

Table 3. **Characteristics of extrudats swelling**

Group of extrudats on the swelling	Dynamics of swelling, ml/min	Coefficients of regression equation			R^2	Regression equations	Degree of swelling, ml
		a	b	c			
1	2,93	-0,0275	3,0925	-	0,994	y = a+bx	2,93
2-1	0,79	0,1469	0,2511	-	0,999	y = a+bx	4,46
2-2		1,3626	0,6575	-0,0199	0,999	$y = a+bx-cx^2$	
3	0,49	0,0539	0,7471	-0,024	0,999	$y = a+bx-cx^2$	5,37

number of bigger pores (2 times) was found out in their structure in comparison with rye extrudats. According to quality demands extrudats with 20 % of buckwheat flour addition were sufficiently cracking however harder than products of the first group. They were easy for nastication however for full mastication process the longer time was necessary.

Influence of the extruder type was investigated during analysis of other parameter of porous structures: the amount of absorbed water using diagram of measurement in Fig.1. It was established that after change of mass composition in the single screw extruder this parameter increased and in the twin screws extruder this parameter decreased.

The velocity of screw influences forming of porous structures in rye matrices. The index of solubility increased by 69% and the water absorbtion index decreased in average by 14% (Fig. 5) in rye extrudats by increasing velocity of screw from 60 min^{-1} till 80 min^{-1} .

This can be explained by peculiarities of mechanical mass processing in the twin screws extruder. This mechanism has additional knead elements which process the mass longer and more intensive during extrusion [1, 2].

The influence of screw step on swelling parameters (in twin screw extruder) was established also. The higher dynamics of swelling and bigger amount of absorbed water was established for extrudats made using a small step (MŽ) screw than for extrudats made using a big step (DŽ) screw. This tendency was more evident in investigations of rye extrudats then in investigations of extrudats with addition of buckwheat flour as results show in Fig. 5. This was confirmed by results in Fig. 6. The rye extrudats made using the MŽ screw (velocity 80 $min^{-1)}$ in comparision with the DŽ screw distinguished themselves by the 43.2 % higher solubility index.

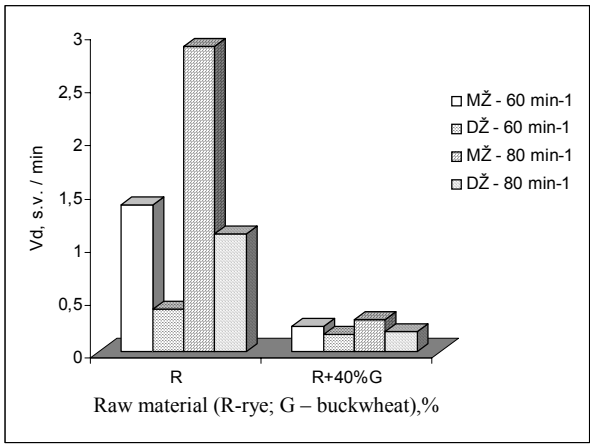


Fig. 5. **Influence of twin screws velocity on the swelling parameters: on dynamics of water absorbtion (Vd)**

Results of investigations show that increase of the solubility index is related to decrease of water absorbtion index. This coincides with data published by other authors [7].

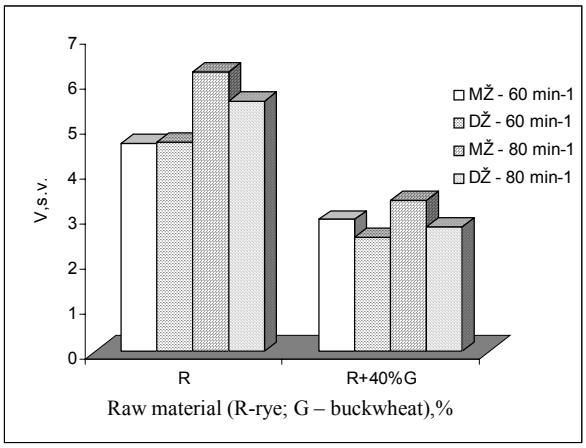


Fig. 6. **Influence of twin screws velocity on swelling parameters: on amount of the absorbed water (V)**

Conclusions

The results of investigations obtained by the acoustic echolocation method confirm strong correlation relation between swelling parameters – swelling dynamics (Vd) and swelling degree (V) values and parameters of extrudats quality established by instrumental methods (swelling index, specific density, resistance to acting pressure force, average diameter of pores).

By changing buckwheat percentage in rye mixes (from 0 % till 40 %) irrespective of the type of extruder it is possible to obtain products with various properties of a texture – from light snacks till dry breakfast.

Rye extrudats with properties of light snacks reveal themselves by intensive swelling dynamics. Their structure was destroyed in 1 min after absorbtion of the smallests amount of water (V=2.9 ml).

For extrudats with addition of buckwheat flour differently as in case from pure rye flour it is characteristic to swell and form more uniform structure of product.

The swelling process of extrudats with the biggest amount of buckwheat flour (corresponding to dry breackfast) was going on uniformly, was of long duration and without brakes, structure destroys. Products of this kind revealed themselves by the biggest swelling degree (V=5.4 ml) and uniform structure.

It can be concluded that the acoustic echolocation method is suitable for evaluation of depolimerization of rye starch granulas during extrusion, because the results obtained using the acoustic echolocation method were confirmed by results of extrudats mass solubility and water absorbtion obtained by traditional methods. Thus, the properties of extrudats swelling evaluated by the acoustic echolocation method give an additional information about processes that happened during extrusion and peculiarities of finished products. In production practice this method can be successfully applied for extrudats distribution in grades according to quality.

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Kompleksinis ekstrudatų tyrimas akustiniu aidolokaciniu metodu

Reziumė

Tirti rugių ir grikių mišinių ekstrudatų brinkumo parametrai (brinkumo dinamika Vd ir išbrinkimo laipsnis V). Jie įvertinti akustiniu aidolokaciniu metodu, naudojant mažų atstumų lygio matuoklį. Naujų produktų gamybiniai bandymai atlikti su vieno ir dviejų sraigtų ekstruderiais. Pateikti matavimų rezultatai.

Nustatyta, kad tirtieji ekstrudatų brinkumo parametrai (Vd ir V) gerai susiejami su rodikliais, vertintais instrumentiniais metodais (išsipūtimo indeksu, specifiniu tankiu, pasipriešinimu veikiančiai slėgio jėgai, vidutiniu porų skersmeniu). Eksperimentai, atlikti su dviem ekstruderių tipais įrodė, kad keičiant grikių kiekį rugių mišiniuose (0% ir 40%) galima gauti įvairių tekstūros savybių gaminius – nuo lengvųjų užkandžių iki sausųjų pusryčių.

Ekstrudatų masių tirpumo ir vandens įgėrimo tyrimai tradiciniais metodais patvirtina akustiniu aidolokaciniu metodu gautus tyrimo rezultatus, kad ekstruzijos metu labiau pakinta ir depolimerizuojasi rugių krakmolo granulės nei grikių. Ruginiai ekstrudatai su lengviesiems užkandžiams būdingomis savybėmis išsiskyrė intensyvia brinkumo dinamika ir jų struktūra per 60 s visiškai suiro, įgerdama mažiausią vandens kiekį (V – 2,9 ml). Ekstrudatams su grikinių miltų priedais, skirtingai nuo vien tik ruginių miltų gaminių, būdinga savybė brinkti ir formuoti tolygesnę produktų struktūrą. Ekstrudatai su didžiausiu grikinių miltų kiekiu (atitinkantys sausuosius pusryčius) brinko tolygiai ilgą laiką, be pertrūkių, matavimo metu jų struktūra nesuiro. Be to, šios rūšies produktai išsiskyrė didžiausiu išbrinkimo laipsniu (V – 5,4 ml) ir struktūros vienalytiškumu.

Tyrimais įrodyta, kad akustinis aidolokacinis metodas suteikia kompleksinę informaciją tiek apie ekstrudatų tekstūrą, tiek apie procesus, vykstančius ekstruzijos metu, ir gali būti rekomenduojamas taikyti praktikoje gaminant geresnės mitybinės vertės produktus ir suskirstant juos į rūšis pagal kokybę.

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