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Changes in Microwave-treated Wheat Grain Properties

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1. Introduction

The world faces the challenge of feeding, housing and clothing an everincreasing population. On 12 October 1999, the United Nations marked the birth of the six billionth human currently living on the planet (Morris et al., 2000). Throughout our history there has been an overall increase in food production through agricultural innovations including the efforts of plant breeders. Cereals play such an integral part in global agriculture and diet. More than 50% of our food comes from three cereals: wheat, maize and rice (Morris et al., 2000). An important step forward in the feeding of the world was the green revolution. Advances in plant breeding and the adoption of highly efficient production systems bring about of fourfold increase in grain yield during the second half of twentieth century. But a continued, sustainable increase will be hard to realize without introducing modern cereals biotechnology and strong determination towards limitation of cereals grain losses during shipment and storage.

Pests are one of the most severe threat for food products, but often ignored by many manufactures. According to Codex Alimentarius monitoring as well as fighting pests in production process is essential to maintain safe food products. Wheat is the world's most important crop species providing about one-third of the global production of cereals. Stored grain is vulnerable to damage caused by internal and external insects. About half of annual grain production requires storage (Grundas et al., 2008). Cereal grain losses caused by pests during storage can reach 50% of the total harvest in some developing countries, which leads to a world-wide loss equivalent to thousands of millions of euros per year (Fornal et al., 2007).

Generally postharvest food losses are estimated to range from 8 to 10% in industrialized countries (Ciepielewska & Kordan, 2001; Brader et al., 2002). Insects are a problem in stored grain throughout the world because they reduce the quantity and quality of grain (Sinha & Watters, 1985; Madrid et al., 1990; Warchalewski & Gralik, 2010). Many chemical insecticides and fumigates are used as protectants against insect infestation in stored grains. But their indiscriminate use and residual toxicity effect the non-target animals and human beings

(Modgil & Samuels, 1998). Furthermore, fumigation is being increasingly restricted for environmental reasons.

Many countries such as Australia, Canada and France, have zero tolerance for live insects in grain (Fields, 2006). On the other hand, increasing concern by consumers over insecticide residues in processed cereal products call for new approaches to control stored-product insect pests. The use of low temperature, the higher temperatures, gamma radiation, microwave treatment, atmospheric gases, natural protectants, hormones and natural cereals grain resistance mechanisms are an alternative to chemical pesticides for the control of stored grain pests (Warchalewski & Nawrot, 1993; Prądzyńska, 1995; Shayesteh & Barthakur, 1996; Modgil & Samuels, 1998; Aldryhim & Adam, 1999; Warchalewski et al., 2000; Ciepielewska & Kordan, 2001; Cox & Collins, 2002; Nawrot et al., 2006; Nawrot et al., 2010). Among physical methods, a known nonchemical alternative for controlling hidden infestations inside kernels is the application of extreme temperatures, preferably heat because its lethal effects are usually faster than cold (Field & Muir, 1996).

The main advantage of microwave is fast and selective heating ability compared with the conventional heating methods. Because relative values of dielectric properties of insects and grain are extremely different, selective heating of insects can be achieved (Shayesteh & Barthakur, 1996).

Microwaves are a nonionising form of energy that interact with polar molecules and charged particles of penetrated medium to generate heat. Use of microwave heating has the advantage of saving time and energy, improving both nutritional quality and acceptability of some foods by consumers (Nijhuis et al., 1998; Sumnu, 2001). On the other hand, a significant reduction of stored-grain damage by insect pests can be achieved with the use of microwaves (Nelson, 1996; Plarre et al., 1999; Nawrot et al., 2006).

Microwave heating shortens processing time because microwaves penetrate solid matter and therefore work faster than systems which transfer heat by conduction from surface to centre. This improves product quality by minimizing changes in product texture, nutritional value and lowering moisture content.

In addition microwave treatment is a technique significantly attractive to be applied widely in food production (Venkatesh & Raghavan 2004). Today the food industry is a major user of microwave energy, especially in the drying of pasta and postbaking of biscuits (Vadivambal & Jayas, 2007). Microwave drying of grain is also conducted in pilot plants in the USA, Canada (Nijhuis et al, 1998; Jayas & White, 2003), and India (Walde et al., 2002). Microwave treatment can generally reduce drying time of biological products without quality degradation (Nijhuis et al., 1998). Controling heating uniformity is important to ensure to microbial safety and high quality of microwave-dried foods (Sundaram & Huai-Wen, 2007).

The industrial and the domestic use of microwaves has increased dramatically over the past few decades. While the use of large scale microwave process is increasing, recent improvements in the design of high-powered microwave ovens, reduced equipment manufacturing cost and trends in electrical energy costs offer a significant potential for developing new and improved industrial microwave process (Vadivambal & Jayas, 2007). The term food quality includes three principal areas: nutritional value, acceptability and safety. Almost any method of processing raw food will have adverse effect on some of its nutrients. Acceptability includes large array of attributes like visual appeal, aroma, flavour and texture (Warchalewski et al., 1998). The overall quality of a product is judged by the number of parameters. Good quality is judged by freshness, expected appearance, flavour and texture. The quality changes that can happen in any product during drying are changes in optical properties (colour, appearance), sensory properties (odour, taste, flavour), structural properties (density, porosity, specific volume), textural properties, rehydration properties (rehydration rate and capacity) and nutritional characteristics e.g. vitamins, proteins (Krokida & Maroulis, 2001). Food safety is protecting the food from physical (drying out, infestation), microbial, insects and chemical (rancidity, browning) hazardous or contamination that may occur during all stages of food production, growing, harvesting, processing, transporting, distribution and storage.

Nijhuis et al. (1998) presented advantages and disadvantages of alternative technologies of dry conservation process like: freeze drying, microwave and radio frequency. Microwave drying has positive ratings for: drying rate, flexibility, colour, flavour, nutritional value, microbial stability, enzyme inactivation, rehydration capacity, crispiness and fresh-like appearance. These qualities pointed out that microwave irradiation is a good technology for dry conservation process of fruits, vegetables and cereals grain on condition that the time of heating is properly chosen.

There is a lack of general models for predicting the heating pattern, moisture and vapour distribution during the drying procedure based on dielectric properties, water distribution, density, changes in microstructure and composition of food (Nijhijus et al., 1998). Reliable date on microwave-treated food products are still missing. Also more knowledge is needed about the influence of geometry, size of object being dried and phenomena like shrinkage of kernels, resistance to insect infestation or puffing and stress-cracking.

Currently, microwave heating is often combined with other techniques for example gamma radiation to kill or reduce insects or mites that attack wheat grain (Gralik & Warchalewski, 2006).

When applying microwave energy to reduce grain damage by insects it should always be considered how this treatment will affect wheat grain properties (Grundas et al., 2008). Therefore research on direct effects of microwave-induced changes remains an important interesting challenge. Despite the importance of microwave/heat-induced changes that directly affected wheat seeds may also induce some changes in the next generation crops which should be considered. When wheat grain is treated by microwave energy particular attention should be drawn to preserve nutritional and technological properties. In the case of grain treatment as seeds, the germination potency should be preserved with acceptance of some unintentionally mutation in next generation of wheat crops. The treatment of infested grain by microwave appears a reliable alternative to conventional post-harvest insect control in the near future, either with stationary or mobile applicators on the farm or quarantine purposes during the loading process (pre- or post-shipment) before grain storage and seed sowing (Plarre et al., 1999; Dolińska et al., 2004).

2. Direct effect of microwave heating of wheat grain

Microwave energy directly applied to wheat grain significantly changed the colour of grain as was reported earlier (Warchalewski et al., 1998). The analysis of variance and calculation of the smallest significant value proved that from 90 to 180 sec (64 to 98^{o}C) of microwave treatment, the values of L^* (lightness) were significantly higher in comparison to control sample. Also visual inspection of grain samples confirmed these results. The total colour difference (ΔH) between microwave-heated samples and control grain was increasing gradually with the rise of heating time. The yellowness (b^*) and the redness (a^*) values were statistically significantly higher in the case of 120 and 180 sec (79 and 98°C) of heating time in relation to the control sample. However, the increase of these values was not significant enough due to equate the L* value, which was visually confirmed. The significant increase of L* value could be associated with some thermal decomposition and modification of grain components which was correlated with the increase of the grain temperature from 64 to 98°C. The temperature at which damage of wheat starch begins is suggested between 53-64°C (Cornell & Hoveling, 1998).

Burnt-like flavour is usually observed in overheated food (Garcia et al., 1975; Baldwin et al., 1991). Appearance and sensoric properties of the microwave treated plain starch and blended with some compounds pointed to the reactions occurring after treatment (Sikora et al., 1997). The development of the secondary food aromas was observed (Warchalewski et al., 1998). In the case of plain, microwave treated starch 'intensive, caramel, smoked plums' aroma appeared, similar to 'brown' observed by Warchalewski et al. (1998) when wheat grain was microwave-heated to 98°C (180 sec). On the other hand, starch blended with glutamic acid was characterized, after microwave treatment, as 'pleasant, ginger bread' (Sikora et al., 1997).

Microwave treatment longer than 90 sec (64°C) caused marked changes in wheat grain endosperm structure (Błaszczak et al., 2002). There was a statistically significant increase of intragrain cracks within the wheat kernel treated with microwave energy. Increasing percentage of damages with prolonged time of treatment was observed. The highest level was found in 180 sec heated of grain samples to 98°C. The roentgenograms confirmed observations by light microscopy (LM) and scanning electron microscopy (SEM) techniques, showing the tendency of individual grains to form highly bursting regions within the grain, in some cases resulting in overall increase of grain volume (Fornal et al., 2001; Błaszczak et al., 2002). Those techniques showed denatured proteins creating filaments connecting starch granules at 120 sec (79°C) of microwave treatment and as a next stage dense protein matrix covering high gelatinized and deformed granules at 180 sec (98°C). Denaturation changes in proteins creating visible fibrils, as well as high swelling and deformation of starch granules (radial and tangential swelling), which were related to falling number (FN) increase, decrease of Zeleny test results, and lowering gluten content and extensogram values (Błaszczak et al., 2002). Lower quality of bread with increasing time of microwave heat-treatment of grain was also observed. Generally, marked changes in kernel microstructure and technological properties were started when the temperature of grain exceeded 64°C (90 sec). These marked changes in endosperm microstructure of starch granule and proteins well explain why the larval development time of confused flour beetle (*Tribolium confusum* Duv.) and Mediterranean flour moth (*Ephestia kuehniella* Zell.) reared on microwave treated wheat grain, which was secondary infested by these pests became statistically significantly short, when compared to non-heated grain (Warchalewski et al., 2000).

Changes in the physical characteristics of grain that may be induced directly by microwave rays are important in relation to milling properties, insect resistance, and protein content which affect the properties of flour and its suitability for various purposes. The test for milling involves physical qualities such as bulk density (BD), thousand kernel weight (TKW), kernel size, shape, hardness, vitreousness, colour, and kernel damage (Satumbaga et al., 1995) more than chemical qualities. In addition, hard, virteous wheat grain is usually associated with high protein content (Cornel & Hoveling, 1998).The vitreous or mealy character of grain is genetically controlled but it is also affected by environment. On the other hand, hardness is not materially affected by the environment but is determined almost entirely by genetics (Hoseney, 1987). The Single Kernel Characterization System (SKCS) developed for wheat classification has potential for determining wheat quality parameters (Martin et al., 1993; Satumbaga et al., 1995; Gaines et al., 1996; Osborne et al., 1997; Ohm et al., 1998).

Bulk density and thousand kernel weight are two of the physical criteria of wheat grain quality. Bulk density is one of the most common parameters of evaluating wheat quality. Kernel size has very little influence on bulk density, but shape and uniformity are significant factors, as is the moisture content. Average range of bulk density value of wheat grain was ≈77-84 kg/L; the range of thousand kernel weight was 20-40 g (Cornel & Hoveling, 1998). Grundas et al. (2008) reported that thousand kernel weight was well above range, which was significantly changed only in grain directly exposed to the microwave rays at 60, 120 and 180 sec where the grain temperature was 64, 79 and 98^oC respectively.

Grain samples exposed directly to microwave heating showed decreased hardness index (HI), single kernel weight (SKW) and single kernel diameter (SKD) of all samples, with the exception of hardness index of M-120 (79^oC) sample and single kernel diameter of M-180 (98^oC) sample, where an increase of measured features was noted (Grundas et al., 2008).

Virtually biologically active wheat proteins were found in soluble proteins. The soluble proteins are therefore composed of what are known as albumins and globulins, together with glycoproteins, nucleoproteins, and many of the lipid-protein complexes in wheat flour (Kasarda et al., 1971). Microwave heating within the range of applied times of exposure caused a decrease in extractable protein content. However, a statistically significant drop in extractable protein contents were found only at 120 and 180 sec of microwave heating time, where grain reached 79 and 98^oC, respectively (Warchalewski & Gralik, 2010). These temperatures were high enough to cause a decrease of >42% of extractable proteins.

Statistically significant changes in reducing sugars content was noted in all microwave-heated grain samples. However, the application of the lowest heating times of 15 sec (28^oC), 45 sec (43^oC), and 60 sec (48^oC) caused significant increase in reducing sugars content. At the higher heating times of 90 sec (64^oC), 120 sec (79^oC), and 180 sec (98^oC) a gradual decrease in reducing sugars content was observed. Grain temperatures ≤48^oC probably enhance amylases activity within the grain during the heating process. Moreover, some changes in starch properties are possible due to differences reported by Dolińska et al. (2004) in falling number values, peak temperatures (T_p), and gelatinization enthalpy (ΔH). This could explain the increase in extractability of reducing sugars ≤60 sec of heating time, when grain temperature was not exceeded 48^oC. Changes in reducing sugars content was well correlated with endogenous amylolytic activity determined in samples of grain at ≥64^oC during microwave heating. Grain at 64, 79, and 98^oC showed a statistically significant decrease in reducing sugars content and amylolytic activity (Warchalewski & Gralik, 2010). The gradual decrease in reducing sugars and amylolytic activity can be attributed to the secondary reactions induced by increasing grain temperature from 64 to 98^oC. A distinct decrease of grain amylolytic activity to 10% of this activity in the control sample was noted when wheat grain reached 98^oC. This suggests significant reduction of grain endogenous amylase by denaturation of enzyme protein. Also all endogenous biological activities were distinctly diminished in grain samples heated to 79^oC. The decrease in wheat grain samples was 79% of amylolytic activity and inhibition activities against α-amylases from insects *Sitophilus granarius* L., *Tribolium confusum* Duv., *Ephestia kuehniella* Zell., also from human saliva and hog pancreas, as well as antitryptic activity by 50, 83, 31, 63, 39, and 20%, respectively. At the highest grain temperature of 98^oC, the loss of all biological activities were even more pronounced due to denaturation of ≈45% of extractable proteins. Differences in the decrease of biological activities among wheat grain samples microwave-heated to 79 and 98°C suggest that these activities are located in a number of soluble proteins with different thermal stabilities to the highest temperature. Substantial decrease in inhibitory activity against α-amylases and trypsin from mammalian sources should be considered beneficial from a nutritional point of view. The influence of microwave field on inactivation of antitryptic activity in soy (Boyes at al., 1997; Mitrus, 2000) and bean seeds (Bieżanowska et al., 2000) was also confirmed earlier.

Technological tests performed on microwave-heated grain proved changes in starch and proteins fractions which could be seen in deterioration of baking value (Błaszczak et al., 2002). Lowering of participation of vitreous grains especially in the case of two the longest heating times: 120 sec (79°C) and 180 sec (98°C) was correlated with deterioration in farinograph and extensograph tests. It can indicate some destruction of protein conformation within the grain. Also analysis of grain microstructure by scanning electron microscopy (SEM) proved some changes in protein structure (Błaszczak et al., 2002). In addition Sodium Dodecyl Sulphate (SDS) and Zeleny sedimentation tests confirmed this results. In the case of the two longest times of microwave exposure (120 and 180 sec) was observed decreasing volumes of precipitated proteins in sedimentation tests which indirectly indicate deterioration in gluten proteins hydration and in consequence in gluten quality. A distinct decrease of hand-washed wet gluten yield was noted when grain reached 79°C after 120 seconds while at 98°C (180 sec) wet gluten was not possible to wash at all (Gralik, 2003; Błaszczak et al., 2002).

Rheological properties of wheat gluten are very sensible to any physical or chemical modification of the gluten molecular and supramolecular structure (Shewry et al., 2002; Lefebvre et al., 2003; Belton, 2005). It could be therefore expected that even very fine changes in arrangement and physicochemical properties of the grain storage proteins induced due to microwave energy input to wheat grain would affect the gluten structure and its viscoelastic behaviour. Therefore wet gluten was isolated from the control and microwave-treated wheat grain. The grain microwave processing time ranged from 15 to 120 sec what corresponded to the final grain temperature of 28 to 79°C. From the grain sample microwave-heated to 98°C by 180 sec it was not possible to wash out wet gluten as was reported earlier (Błaszczak et al., 2002; Gralik, 2003). All hand washed out wet gluten samples were freeze dried and stored prior to analysis. Samples of freeze-dried gluten were rehydrated using a two-step procedure and next submitted to rheological measurement as previously described (Lefebvre et al., 2003; Pruska-Kedzior, 2006; Pruska-Kedzior et al., 2008). Mechanical spectra of studied gluten samples were plotted as functions of the storage and loss moduli (G', G'') (Fig. 1), or of the storage and loss compliances (J', J'') (Fig. 2), versus the angular frequency ω. The J', $J'' = f(\omega)$ mechanical spectra were fitted with phenomenological Cole-Cole functions yielding the viscoelastic plateau compliance J_N^0, viscoelastic plateau modulus $G_N^0 = 1/J_N^0$, loss peak characteristic frequency ω_0, and spread parameter n related to the peak broadness (Tschoegl, 1989). These parameters describe viscoelastic properties and provide information on the networking state of a polymer structure in the upper frequency limit of the viscoelastic plateau.

The storage protein system of wheat grain appeared very sensible to the grain microwaving as it reveal mechanical spectra of the gluten obtained from this material (Fig. 1). The absolute values of G' and G'' moduli increased slightly over entire frequency range following increasing microwave energy input to the grain for microwaving time 15 sec (28°C) to 90 sec (64°C). Very significant effect of the grain microwave heating on the gluten viscoelastic properties was observed at 120 sec (79°C) microwave treatment. The mechanical spectrum of the gluten obtained from the grain microwave-heated for 120 sec (79°C) is shifted up more than one logarithmic decade of G′ and G″ values proving that the gluten structure has became much more networked.

In the studied frequency range (Fig. 1), the mechanical spectrum of gluten encompasses only a part of the viscoelastic plateau. In this part of the plateau, gluten shows a transient viscoelastic network structure (Hamer & Van Vliet, 2000; Dobraszczyk & Morgenstern, 2003; Lefebvre et al., 2003; Belton, 2005; Pruska- Kędzior, 2006). Viscoelastic properties of the material manifested in the upper frequency region of the plateau can be quantified using Cole–Cole functions. The Cole-Cole parameters fitted to the mechanical spectra of the studied gluten samples are shown in Table 1. Noticeable increase of modulus of viscoelastic plateau G_N^0 was observed for the material obtained from the grain submitted to at least 60 sec of microwave heating what corresponded to the final grain temperature of 48°C. Tremendous increase of G_N^0, above 4.2 times, appeared for gluten obtained from the grain microwave-heated for 120 sec (79°C). In Fig. 2 positioning of the compliance of viscoelastic plateau J_N^0 on the J′ curve and the characteristic frequency ω_0 on the J″ curve of the mechanical spectra is shown for each studied gluten sample. The J_N^0 value of wheat gluten decreased as the grain microwaving time has been increased. The effect of the grain microwaving time on ω_0 values was more complex. Noticeable decrease of ω_0 comparing to the control gluten occurred for the grain microwaving time 15 sec to 90 sec and substantial increase of ω_0, more than one logarithmic decade, has been revealed when the microwaving time reached 120 sec (Table 1 and Fig. 2).

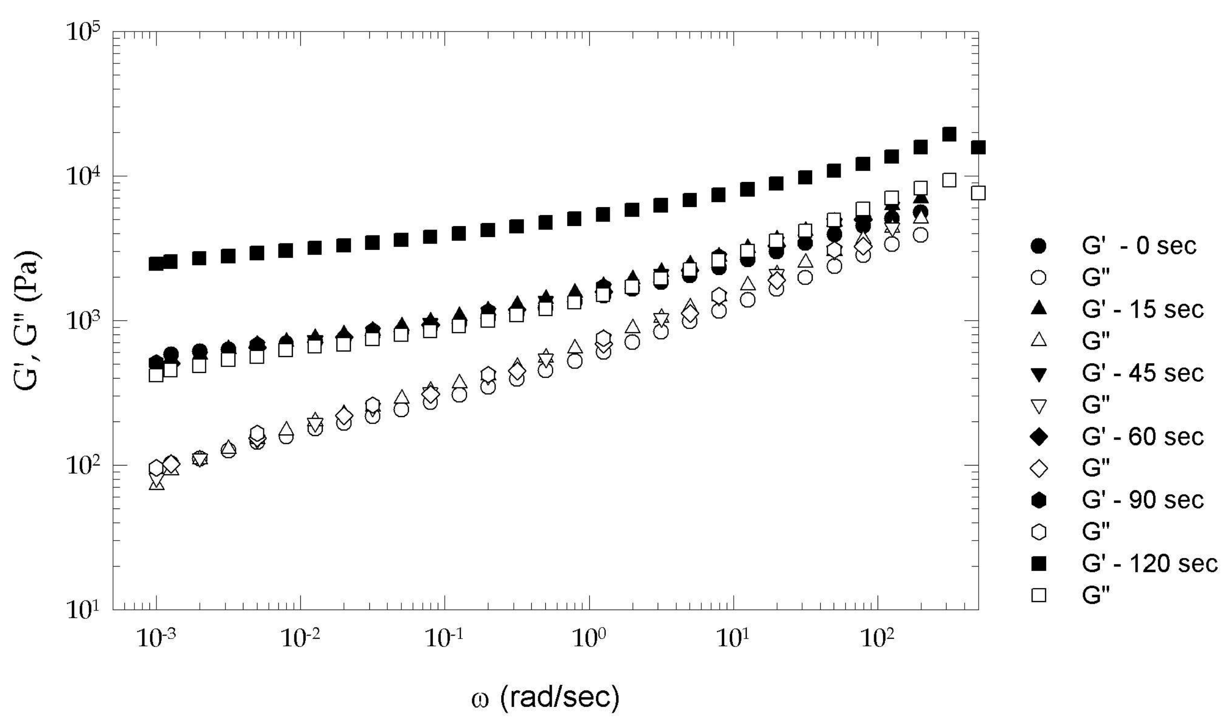

Fig. 1. The effect of microwave treatment of wheat grain on viscoelastic properties of wheat gluten. Mechanical spectra $G'(\omega)$, $G''(\omega)$

Exposure time [sec]	Grain temperature [°C]	$G_N{}^0$ [Pa]	$J_N{}^0$ [Pa^{-1}]	ω_0 [rad/s]	n	R^2
0	20	733	0.00136	0.19	0.409	0.996
15	28	751	0.00133	0.10	0.417	0.996
45	43	767	0.00130	0.12	0.418	0.996
60	48	838	0.00119	0.11	0.416	0.996
90	64	970	0.00103	0.17	0.437	0.997
120	79	3 795	0.00026	3.45	0.396	0.986

Table 1. The effect of microwave treatment of wheat grain on the Cole-Cole parameters calculated from the mechanical spectra of wheat gluten

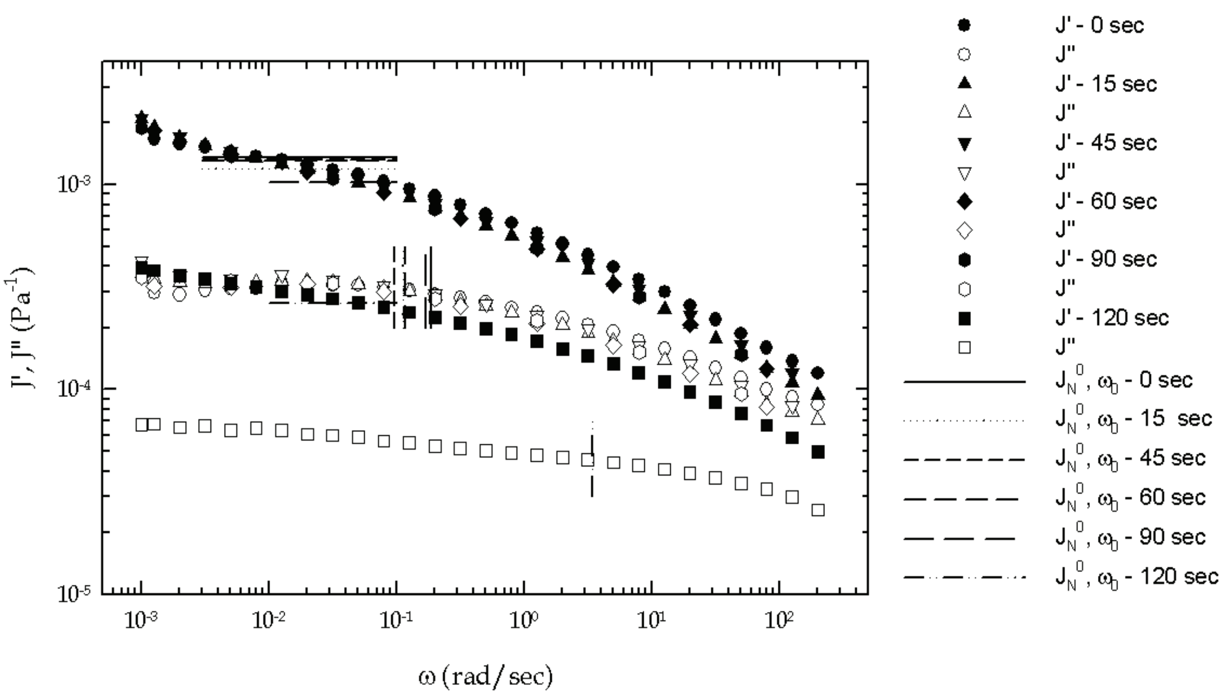

Fig. 2. The effect of microwave treatment of wheat grain on viscoelastic properties of wheat gluten. Positions of the Cole-Cole parameters $J_N{}^0$ (horizontal line crossing $J'(\omega)$ curve), and ω_0 (vertical line crossing $J''(\omega)$ curve) are marked

The effect of 120 sec microwave-treatment of wheat grain on the viscoelastic properties of gluten described in terms of $J_N{}^0$ and ω_0 values (Table 1) was intermediate to that observed for the control gluten submitted to the 5-hour contact preheating at 50°C and/or 70°C respectively, performed in the rheometer (Peltier effect). In this experiment $J_N{}^0$ value reached 0.00047 and 0.00024 Pa^{-1}, while ω_0 value varied from 3.4 for heating at 50°C to 12.6 rad/sec for heating at 70°C respectively (Pruska-Kedzior, 2006).
Studying viscoelastic properties of gluten appeared relevant to estimate degree of physicochemical denaturation of gluten protein system of wheat grain induced due to the controlled microwave treatment.

Viscoelastic effects are highly involved in such technological properties of wheat dough like dynamics of its structural development during kneading, dough stability, tolerance to mixing and extensibility, for instance. Wet vital gluten extensibility and spreadability are correlated with its overall viscoelasticity and the density of the structure forming networking bonds. General swelling capability of wheat flour which largely depends on water binding and swelling properties of the gluten proteins and therefore remains in some extent an indication of the potential structure-forming properties of the gluten proteins. Therefore, one could expect the existence of some correlation between the Cole-Cole parameters quantifying the wheat gluten viscoelastic properties and these technological qualitative parameters which depend significantly on the properties of gluten proteins. It was found that the viscoelastic plateau compliance J_N^0 is highly correlated with the technological baking quality parameters governed by the physicochemical properties of the gluten proteins. Correlation coefficient r varying from 0.87 for the dependency of J_N^0 versus farinographic valorimetric value to 0.99 for the dependencies of J_N^0 versus farinographic mixing tolerance index (MTI) and J_N^0 versus extensographic dough energy (Table 2). The technological parameters of this statistical analysis have been extracted from the study of Błaszczak et al. (2002).

Technological parameter	Terms of correlation equation		
	a	b	r
SDS SEDIMENTATION VALUE	75.85	9 774	0.916
Zeleny sedimentation value	40.36	12 613	0.911
Wet gluten	22.05	7 834	0.944
Gluten spreadability	-1.27	6 568	0.939
Dough stability	1.14	5 883	0.876
MTI	91.38	-45 990	0.992
Dough softening	86.89	-37 210	0.936
Valorimetric value	49.99	6 797	0.871
Dough energy	21.71	65 189	0.992
Dough extensibility	55.77	87 010	0.983
Ratio Number	5.58	-2 692	0.964

Table 2. Correlations between J_N^0 of wheat gluten and some technological parameters of wheat flour and dough obtained from the microwaved wheat grain

Particularly relevant correlation between J_N^0 and extensographic dough energy was also observed as presented in Figure 3.

Also farinograph and extensograph tests as well as baking test proved some changes in viscoelastic properties due to denaturation changes in gluten proteins (Błaszczak et al., 2002; Gralik, 2003). Bred volume was distinctly reduced in the case of all applied microwave heating times. All microwave doses also caused decreasing in bred score and shown some deterioration in bred freshness expressed by score points. On the basis of results obtained from technological tests it can be stated that longer time above 90 sec (64^{o}C) of microwave heating when the wheat grain moisture content was estimated on 11.7% disadvantage effect

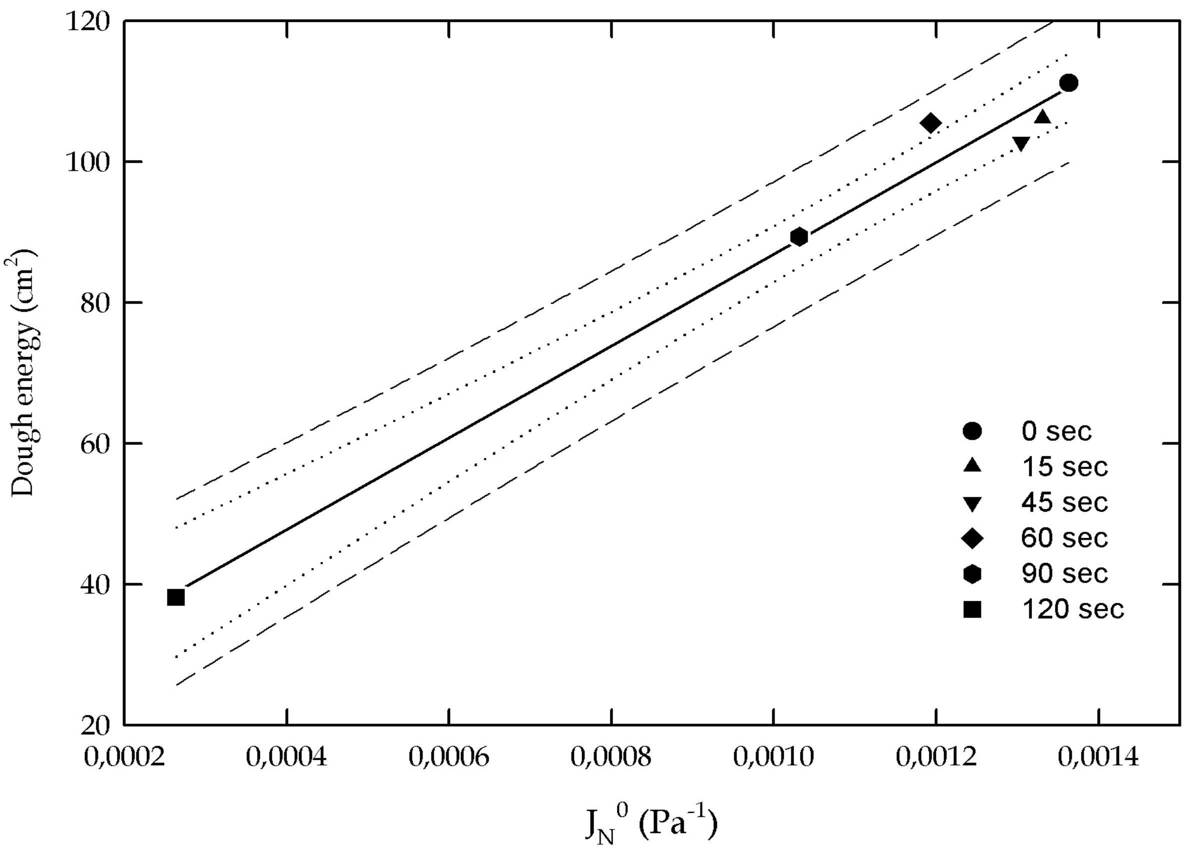

Fig. 3. Correlation between the viscoelastic plateau compliance J_N^0 of wheat gluten and dough energy. Legend: regression line – solid, dotted line – the 95% confidence interval, dashed line – the 95% prediction interval

on grain baking properties was observed (Błaszczak et al., 2002; Gralik, 2003). Similar results was reported earlier by MacArthur & D'Appolonia (1981) who analyzed of flour and bred and found that important qualities was adversely affected after 240 sec (61^{o}C) of microwave exposure where the moisture content of flour was estimated on 14%. When exposed the flour to high levels of microwave radiation at 360 sec (75^{o}C) and 480 sec (100^{o}C) they found abnormal farinograph curve exhibiting two peaks whereas low levels up to 240 sec (61^{o}C) produced bred with low volumes and overall bred characteristics equal to or better than those of the control flour. In general, storage improved all samples. The influence of microwave energy on certain chemical components was also investigated by MacArthur & D'Appolonia (1981). When starch pasting characteristics were examined, radiation appeared to have had no adverse effect on paste stability; however the rate of retrogradation decreased as microwave treatment increased. Decreasing starch intrinsic viscosity and total sugar values were observed with increased radiation levels after storage of flour for six months. A progressive decrease intrinsic viscosity was observed as irradiation increased except for 480 sec (100^{o}C) sample. The decrease in intrinsinc viscosity suggests a possible alternation in starch structure as a result of the microwave treatment, even though peak viscosity as measured by amylograph did not differ. The reason while the starch sample microwave-heated for 480 sec (100^{o}C) showed an increase in intrinsic viscosity is not clear; however, the increase might be related to thermal effects (MacArthur & D'Appolonia, 1981). As microwave treatment of flour increased, total sugar content at 0 and 30 days of storage showed a little change as the lengh of storage time was extended to 150 days, the sugar content for the control flour showed slight increase, which could be a result of flour maturation. However, with microwave-treated samples stored for 150 days, a trend toward reduction in sugar content with increased microwave energy was seen. The exact reason for such a result is unknown (MacArthur & D'Appolonia, 1981). Although the effects showed in MacArthur & D'Appolonia (1981) study can be explained in part as thermal and/or maturation-related, some alteration of the starch structure could be possibly occur during the microwave radiation of wheat flour.

The insect species that can attack stored grain and products are highly specialized and successfully exploit the storage environment. Internal insect infestation of wheat kernels not only degrades quality and technological value of wheat, but is one of the most difficult to detect and is generally considered to be the most damaging (Pederson, 1992, Fornal et al., 2007). Pest infestation causes grain loss by consumption, contaminates the grain with excrement and fragments, causes nutritional losses, and finally degrades end-use quality of flour (Nawrot et al., 2006). Additionally, during storage, grains can be contaminated by fungi and other microorganisms that will produce off odors and change the chemical composition of wheat and make it unsuitable for food products (Cornell & Hoveling, 1998). Many chemical insecticides are used as protectants against insect infestation in stored grains (Warchalewski et al., 2000). The high costs of developing new chemicals to replace those withdrawn from use because of pest resistance and the imposition of regulations to prevent environmental damage or human health risks have led to increased interest in nonchemical methods of pests control (Nelson, 1996; Watters, 1991). Many methods have been developed so far for the detection of pest-infested kernels, but none of them has been used in the monitoring of both storage and transport on a wide scale. Among the methods used in research laboratories it can be find: egg plug staining technique (Toews et al., 2006; Pearsons & Brabec, 2007), flotation and cracking (Brader et al., 2002; Haff & Slaughter,2004), acoustic method (Vick et al., 1988; Hagstrum et al., 1990; Nethirajan et al., 2007), immuno-assay method ELISA (Enzyme-Linked Immunosorbent Assay) (Piasecka-Kwiatkowska et al., 2005; Piasecka-Kwiatkowska et al., 2010), electrophoretic method (Piasecka-Kwiatkowska et al., 2006), near-infrared hyperspectral imaging (Mahesh et al.,2008; Singh et al., 2009), soft X-ray roentgenography (Schatzki & Fine, 1988; Grundas et al., 1999; Karunakaran et al., 2003, 2004; Fornal et al., 2007; Nawrocka et al., 2010,). Between physical methods, a known nonchemical alternative for controlling hidden infestations inside kernels is the application of extreme temperatures, preferably heat because its lethal effects are usually faster than cold (Fields & Muir, 1996). Higher temperatures increase locomotory activity in beetles generally (Cox & Collins, 2002). For example, *S. granarius* L. tend to move towards the top and sides of the bulk. Virtually all organisms, when they are exposed to temperatures 5-10^{o}C above the optimal growth temperature, undergo a robust heat shock response. Within the cell, an increase of this magnitude can have many deleterious effects, including increase in membrane fluidity and the partial unfolding of proteins that can finally lead to death (Ng, 2004). In a search for effective, safe and cheap methods of control of insects in stored grains, the attention was drawn to temperatures employed in a process of grain drying (Prądzyńska, 1995). Temperatures from 45^{o}C to 60^{o}C at a proper exposure time, sterilize or kill insects in a mass of goods without any disadvantageous influence on product quality. Grain weevil beetles exposed to conventional heat-treatment, without any product, died much faster than those in grain at 45^{o}C after 180 minutes while at 60^{o}C after 5 minutes. At a high grain humidity over 20%, pests can stand heating for longer time (Prądzyńska, 1995).

Beetles of the granary weevil that survived a conventional heat-treatment gave far less progeny in a new F_1 generation than in the control tests. Lethal temperatures very considerably and depend on factors such as species, stage of development, acclimation and relative humidity (Cox & Collins, 2002). Some storage species will die eventually at temperatures a little above 35°C, while at 55°C death will occur within a few minutes (Fields, 1992).
Use of microwave heating has the advantage of saving time and energy, improving both nutritional quality and acceptability of some foods by consumers as well as significant reduction of stored-grain damage by insect pests (Nelson, 1996; Nijhuis et al., 1998; Plarre et al., 1999; Sumnu, 2001; Dolińska & Warchalewski, 2003; Nawrot et al., 2006). The interaction of electromagnetic wave with free water in insects is of interest because of the disparity of free water in relatively dry cereal grain and in insects. Free water of insects occurs in significant amount because it is the major constituent of the hemolymph (Wyatt, 1961). The application of high-power microwaves for stored products pest control have shown, that selective heating of insects and their resulting mortality is a non-linear function of frequency and increases at frequences above 2.45 GHz in the vicinity of increasing relaxation processes associated with free water (Plarre et al., 1999). The target temperature range of 40 to 60°C were successfully delivered to the infested products by *Sitophilus zeamais* using microwaves of different power levels at 28 GHz. The treatment of an infested product with 28 GHz showed good efficiency for the control of adults and older larvae of the mize weevil at rather low products temperatures. Complete kill of adult weevil achieved with product temperatures as low as approximately 40°C and minimum specific load energies of 20 Jg^{-1} to 30 Jg^{-1}. Older larvae did not survived product temperatures approximately 50°C or specific load energies above 45 Jg^{-1}. A mortality level of over 90% in younger larvae was achieved at temperatures slightly above 50°C and specific load energies of above 60 Jg^{-1}. Exposure times for this procedure were less than 1 second (Plarre et al., 1999). The reaction kinetics of heat-induced changes are governed mainly by time, temperature, and moisture content. Microwave treatment of insect-infested grain in a dynamic procedure with high through-put rates appears to be a reliable alternative to conventional postharvest pest control (Plarre et al., 1999). Nowadays, microwave heating is often combined with other techniques for killing or reducing insects and mites that attack wheat grain (Dolińska & Warchalewski, 2003).
From the ecological point of view disinfestations and microbial decontamination of cereal grain with the application of different physical methods seems to be attractive. (Gralik et al., 1999). However, the effect of microwave treatment of wheat grain on microflora reduction was comparatively negligible. Some reduction of microflora , but only in the case of bacterial cells was observed when wheat grain was treated with microwaves at 180 sec (98°). At this maximum time 180 sec of grain exposure to microwave energy the efficiency of bacterial reduction can be comparable to certain extend to wheat grain gamma irradiated. After six months of grain storage microwave treated wheat showed some decrease in bacterial count however, it was not significant (Gralik et al., 1999). In all microwave treated samples the number of fungi was very low and constant which indicated that microwave energy did not have any effect on fungi within the range of time 15 to 180 sec and temperature 28 to 98°C. This was supported by the results obtained after six months of grain storage when the final count was on the same level. Additionally the increase of temperature and microwave treated grain has some influence on gradual decrease of moisture content in wheat grain from 12.22 to 9.87 % (Warchalewski et al., 2000).

The major problem in the use of microwave heat-treatment for the eradication of pests and pathogens in seeds has been its adverse effect on seed quality (Stephenson et al., 1996). However, the limitation of seed quality loss can be minimized by rigorous control over the microwave treatment factors, like absorbed microwave power (AMP) and the duty cycle or pulsing (PUL). These variables can interact both with themselves and with other variables such as initial seed moisture content (SMC), time microwave power (TMP) and seeds vigour. In the case of *Ustilago nuda* complete control of this pathogen was not achieved at any level of absorbed microwave power and pulsing combinations of these parameters. Although significantly was reduced the ability of *U. nuda* to colonize the kernels and produce smutted heads, while germination and vigor were maintained at acceptable levels (Stephenson et al., 1996).

Head blight of wheat caused by *Fusarium graminearum* Schwabe is one of the most important diseases. Infected seeds may show reduced germination rates and seedling vigour (Shotwell et al., 1985). *F. graminearum* produces mycotoxins in cereal grains which affect human and livestock health (Goliński & Perkowski, 1998). Seed treatment with fungicides can create hazardous non-target residual effects. Therefore is an increasing demand for alternative methods of disease control. As an innovative approach to eradicate seedborne pathogens was the use of microwave energy (Seaman & Wallen, 1967; Lozano et al., 1986; James & Gilligan, 1988; Bhaskara Reddy et al., 1998). Microwave energy can be used to significantly reduce seedborne *F. graminearum* in wheat (Bhaskara Reddy et al., 1998). The percentage of seed infection was reduced to below 7% (from 36% for the controls), without reducing the seed quality below the commercial threshold of 85% seed germination. Such results were occurred under various combinations of seed moisture content, absorbed microwave power and time microwave power. However, the data were not sufficiently consistent to lead to an operational model due to the variability resulting from infection, as well as from incubation procedures and the natural variability of the seeds.

3. Indirect effect of microwave heating of wheat grain.

Among 650 million tones of world's annual production of wheat grain, about 46 million tones is used for seeding purposes (Grundas et al., 2008; Anonimus, 2010). Stored cereal's seeds are vulnerable to insects attack however, significant reduction of stored-grain damage by insect pests can be achieved with the use of microwaves (Nelson, 1996; Plarre et al., 1999; Dolińska and Warchalewski, 2003; Nawrot et al., 2006). The degree of changes is largely proportional to the microwave treatment dose, which may vary considerably depending upon the treatment objective. In the case of grain treatment as seeds, the germination potency should be preserved with acceptance of some unintentionally mutation in the next generation wheat grain crops.

When applying microwaves to reduce grain damage by stored-grain pests, it should be consider also the question of how this heat-treatment will affect wheat grain properties not only directly, but also indirectly, on seeds secondary infested as well used for the production of next-generation grain crops. So far only a few papers on indirect influence of microwaves on wheat seeds have been published (Dolińska & Warchalewski, 2002; Dolińska et al., 2004; Warchalewski et al., 2007; Grundas et al., 2008).

The major problem in the use of microwave energy for the eradication of pests and pathogens in seeds has been its adverse effect on seed quality (Stephenson et al., 1996). The lost of seed germination and deterioration technological quality are the major limitation of microwave heat treatment for the control of grain insect, so the growth of temperature during process must be under rigorous control (Nelson, 1996; Shayesteh & Barthakur, 1996; Stephenson et al., 1996; Warchalewski et al., 2000). Wheat grain microwave-treated for 120 sec and 180 sec before sowing caused a distinct decrease in the yield of the first generation crop due to the higher temperature of grain noted after treatment at 79^{o}C and 98^{o}C, respectively (Grundas et al., 2008). However, the yield of the crop in the second generation appeared to be higher, and in the third generation, the yield was restored independently to the level at microwave treatment. Possible genetic modification of microwave-treated wheat grain was also earlier reported (Dolińska et al., 2004; Grundas et al., 2008). Resistance mechanisms of cereal grain to attack by insect species are complex and depend on several chemical factors such a sterols and α-amylase inhibitors levels or to physical properties including thickness of the brain layer and hardness of the endosperm (Warchalewski & Nawrot, 1993; Cox & Collins, 2002; Warchalewski et al., 2002; Nawrot et al., 2006; Nawrot et al., 2010). Genetically modified cereals can contain proteins or other compounds detrimental to critical insect life functions (Gatehouse & Gatehouse, 1998). The indirect effect of microwave heating of wheat grain within temperature range from 28^{o}C to 98^{o}C, on seeds microstructure in two consecutive years was examined. The two highest temperatures applied during microwave heating process of wheat seeds with initial moisture content 12.2 % before sowing weakened the germination power in seed samples treated for 120 sec (79^{o}C) and 180 sec (98^{o}C), and in consequence lowered grain yield by 9 % and 57 % respectively (Warchalewski et al., 2007). No visible changes in microstructure of pericarp, aleurone layer, subaleurone and starchy endosperm of wheat kernels collected in two generations crops grown from microwave treated seeds were found. However, some small changes in external epidermal cells were noted, but only in the first generation crops examined by scanning electron microscopy (Dolińska, 2004).

Changes in grain colour were associated with some thermal decomposition and modification of grain components which was correlated with the increase of the grain temperature from 64 to 98^{O}C (Warchalewski et al., 1998). The temperature at which damage of wheat starch begins is suggested at between 53 to 64^{O}C (Cornell & Hoveling, 1998). However, it depends on the initial moisture content of the grain. On the other hand, alpha-amylases like lipooxygenases of wheat grain are fairly heat-stabile since no inactivation occurred below 60^{o}C (Kruger & Reed, 1988). The colour of the flour, due to both its content of wheat and bran pigments, affects bred whiteness. But other factors influence the colour of bred crumb greatly as well. Foremost among these is the fineness of the grain. The brightness of grain and flour is probably only a minor factor in the formation in bred crust colour (Warchalewski et al., 1998). The statistically significant influence of microwave heating on changes of colour in the first and second generations grain was observed. The sample IM-90 (64^{o}C) was characterized by higher value of lightness (L^*) and more intensive red colour (b^*) which was correlated with decreased length and increased width and thickness of external epidermal cell walls of wheat kernels (Dolińska, 2004). This grain sample shown also the highest hardness index (HI) as was determined by Grundas et al., (2008). In the case of grain samples IM-15 (28^{o}C) and IM-45 (43^{o}C) was observed more intensive redness (b^*) while grain sample IM-180 (98^{o}C) was characterized by slighter yellowness (a^*) which was also correlated with the similar seeds diameter (Dolińska, 2004; Grundas et al., 2008). Grain samples collected in the second generation crop indicating some vanishing tendencies in differences of grain colour among grain samples. Flavour profile of the next generations crops of wheat grain obtained from microwave-treated seeds was similar to control grain samples (Dolińska, 2004).

All post-harvest grain insects infest new seed parts passively, rarely searching for food over long distances (Nawrot et al., 2010). Some wheat grain properties may constitute a source of resistance against pests, the amounts of proteins, enzyme inhibitors, starch, lipids and fiber, as well as selected physical and technological attributes, including water content, hardness, vitreosity, weight by volume and thousand kernel weight, are characteristic features of each variety that may be related to insects infestation levels (Warchalewski et al., 2002; Nawrot et al., 2006).

When microwave treated wheat seeds reached 98^{o}C after 180 sec the total protein content (TPC) in the first generation crop significantly increased while in the third generation crop decreased (Dolińska, 2004; Grundas et al., 2008). All wheat samples of the second generation crop were characterized by similar total protein content (TPC). It is interesting, that the highest soluble protein content was found in all three generation crops breeded from wheat seeds microwave heated to 98^{o}C by 180 sec. In the first and third generations, statistically significant tendencies in total protein content (TPC) were additionally described by quadratic and logistic equations (Grundas et al., 2008).

As a result of the indirect effect of microwave heat-treatment, thousand kernel weight (TKW) was statistically different in the three next-generation crops compared with the control samples (Grundas et al., 2008). Microwave heated wheat grain by 180 sec to 98^{o}C before sowing caused increase in the total protein content to the highest level and the lowest thousand kernel weight (TKW) in the first generation crop, but this is not upheld in the next two generations. According to Slaughter et al. (1992) and Satumbaga et al. (1995), wheat kernel mass has a negative relationship to protein content. It is well known that protein content of wheat grain is influenced less by heredity than by edaphic factors (soil and climatic conditions) prevailing at the place of growth and by the fertilizer treatment. Since growing conditions were exactly the same each year, so the observed differences in protein content as an indirect effect of microwave treatment of wheat grain versus control grain samples should be rather attributed to some genetic modification of wheat seeds. Wheat albumins extracted from grain collected as the first and second generations crops which were obtained from microwave heat-treated seeds had statistically significant lower true and apparent digestibility of protein in comparison to untreated grain (Dolińska & Warchalewski, 2002). Indirect effect of microwaves caused statistically significant fluctuation in addition to total protein content (TPC) also thousand kernel weight (TKW), single kernel moisture content (SKM), single kernel weight (SKW), hardness index (HI) and single kernel diameter (SKD) in all three wheat grain crops in relation to their control samples (Grundas et al., 2008). As an indirect consequence of microwave heating, there was a statistically significant increase of hardness index (HI) in samples IM- 15 (28^{o}C), IM-45 (43^{o}C), IM-60 (48^{o}C), IM-90 (64^{o}C), IM-120 (79^{o}C), IIM-60 (48^{o}C) and IIM-180 (98^{o}C) from the first and second generation crops, respectively. On the other hand, all samples from the third generation crop had lower kernel hardness in relation to the control sample. Also bulk density (BD) of the first generation crop showed a statistically significant tendency described by a quadratic equation but mainly due to seeds heated by 180 sec to the 98^{o}C before sowing. The lowest bulk density value (BD) in this grain sample was well correlated with the lowest yield of grain harvested as well as the lowest statistically significant single kernel diameter (Grundas et al., 2008). The reducing sugars content in next generations of wheat grains was also affected by pre-sowing application of microwave heating of seeds from 28 to 180 sec. In general, the increasing tendency of reducing sugar content was noted in the first and second generation crops, while in the third grain crop the lower in relation to the control wheat grain samples (Dolińska, 2004). Statistically significant changes in falling number values and some changes in the peak temperatures (T_p) and enthalpy of gelatinization (ΔH) caused by indirect effect of microwaves were reported in all three generations of wheat grain crops (Dolińska et al., 2004). This support some minor changes in protein and starch granules causing them more susceptible to grain endogenous amylases which was documented by increasing reducing sugars content in the next generations crops.

Favorable changes in the inhibition activity against exogenous alpha-amylases of human saliva, *Sitophilus granarius* and *Tribolium confusum* were noted in all grain samples of three grain generations crops collected from microwave-treated seeds before sowing to the grain temperature 28°C by 15 sec (Dolińska, 2004). From nutritional point of view substantial decrease of inhibition activity of human saliva alpha-amylase as well as an increase of inhibition activity against alpha-amylases of *Sitophilus granarius* and *Tribolium confusum* should be recognized as profitable. Cereal grains with the highest inhibition activities against alpha-amylases of insect pests was suggested to reduce to some extend insect populations in grain storage facilities (Warchalewski et al., 2002). This indicates that the studied physicochemical and biochemical properties of wheat grain were affected not only directly but also indirectly by microwave rays.

The technological properties of wheat grain collected in the three generations crops which were sown from microwave-heated seeds were presented in table 3, 4 and 5.

The highest temperature of microwave heating of wheat seeds before sowing weakened the germination power in most seeds treated by 180 sec (98°C) and 120 sec (79°C) as was reported by Grundas et al (2008). Statistically significant fluctuation in some parameters of farinograph (Table 3) and extensograph analysis (Table 4) as well as baking quality properties (Table 5) were noted in the next generation wheat grain collected in the consecutive year.

Generally indirect effect of microwave-heated seeds before sowing worsening technological properties of wheat grain collected in the next generations crop. In addition, as was earlier reported (Dolińska, 2004) in all next generations grain samples amount of hand washed wet gluten as well as wet gluten deliquescent were lower in relation to the wheat grain control samples. The most distinct changes are visible particularly in the case of Sodium Dodecyl Sulphate (SDS) sedimentation test in all three generations grain collected from wheat seeds microwave-heated by 60 sec (48°C) and above. The results of sedimentation tests and gluten content proofed the negative effect of microwave heating applied before sowing on wheat grain collected in the consecutive years (Dolińska, 2004).

Cereals grain harvesting, drying and handling prior to storage will all affect the quality of the grain and its suitability for each potential pest (Cox & Collins, 2002). Grain damaged during harvesting and augering is more susceptible to attack by most storage beetles than are whole grains. Since, microwave may induce changes in a number of wheat grain properties not only directly but also indirectly in grain harvested in the next generation crops, it can be expected also some changes in susceptibility to insect infestation in wheat seeds as well as grain collected in the consecutive years. However, directly microwave-treated of wheat grain had no effect on secondary infested grain by the granary weevil (*Sitophilus granarius* L.) as was reported by Warchalewski et al. (2000). On the other hand, it

Farinograph analysis	Sample						
First generation	**IM-0**	**IM-15**	**IM-45**	**IM-60**	**IM-90**	**IM-120**	**IM-180***
Water absorption of flour [%]	61,3 a	61,7 a	61,7 a	62,6 a	62,7 a	62,8 a	-
Dough development [min]	2,0 a	2,0 a	**1,5 b**	2,0 a	2,0 a	2,0 a	-
Stability of dough [min]	6,0 a	6,0 a	6,0 a	**4,5 b**	5,5 a	**7,0 c**	-
MTI [FU]	45 a	45 a	**40 b**	**50 c**	45 a	**40 b**	-
Degree of dough softening [FU]	70 a	70 a	80 a	80 a	**85 b**	75 a	-
Valorimetric value [-]	48 a	48 a	47 a	46 a	47 a	48 a	-
Second generation	**IIM-0**	**IIM-15**	**IIM-45**	**IIM-60**	**IIM-90**	**IIM-120**	**IIM-180**
Water absorption of flour [%]	60,6 a	**61,2 b**	60,5 a	**60,0 c**	60,9 a	60,7 a	61,0 a
Dough development [min]	2,5 a	2,0 a	2,0 a	2,5 a	2,5 a	2,0 a	2,0 a
Stability of dough [min]	10,0 a	8,0 a	10,0 a	10,0 a	9,5 a	9,5 a	9,0 a
MTI [FU]	25 a	25 a	25 a	25 a	25 a	25 a	25 a
Degree of dough softening [FU]	50 a	**40 b**	30 a	30 a	30 a	30 a	30 a
Valorimetric value [-]	53 a	51 a	53 a	**55 b**	54 a	53 a	53 a
Third generation	**IIIM-0**	**IIIM-15**	**IIIM-45**	**IIIM-60**	**IIIM-90**	**IIIM-120**	**IIIM-180**
Water absorption of flour [%]	58,2 a	57,8 a	57,7 a	**57,2 b**	57,6 a	58,0 a	58,0 a
Dough development [min]	2,5 a	2,5 a	2,5 a	2,5 a	**2,0 b**	2,5 a	2,5 a
Stability of dough [min]	**12,0 a**	**5,5 b**	9,5 b	7,0 b	**6,0 b**	7,5 b	**11,5 a**
MTI [FU]	**40 a**	50 b	50 b	55 b	**60 c**	**40 a**	**40 a**
Degree of dough softening [FU]	40 a	60 a	50 a	60 a	**70 b**	55 a	40 a
Valorimetric value [-]	55 a	51 a	53a	52 a	**50 b**	52 a	55 a

* Due to the lowest yield of the first generation crop the technological analysis were not performed.

Table 3. Farinograph analysis of flour obtained from the three generation wheat crops (IM, IIM and IIIM) microwave-heated seeds before sowing. Mean values followed by the same letter in the column are not significantly different (P ≤0.05).

Extensograph analysis	Sample						
First generation	**IM-0**	**IM-15**	**IM-45**	**IM-60**	**IM-90**	**IM-120**	**IM-180***
Dough energy [cm²]	80,5 a	77,5 a	80,1 a	**72,6 b**	79,5 a	**86,6 c**	-
Resistance R_{50} [EU]	288 a	280 a	280 a	**265 b**	298 a	298 a	-
Extensibility-E [mm]	160 a	164 a	163 a	160 a	160 a	**168 b**	-
Ratio R_{50}/E [-]	1,80 a	1,71 a	1,72 a	**1,66 b**	**1,86 c**	1,77 a	-
Second generation	**IIM-0**	**IIM-15**	**IIM-45**	**IIM-60**	**IIM-90**	**IIM-120**	**IIM-180**
Dough energy [cm²]	95,2 a	**99,1 b**	94,9 a	94,3 a	87,8 a	88,9 a	81,0 a
Resistance R_{50} [EU]	355 a	**270 b**	302 a	322 a	290 a	312 a	**265 b**
Extensibility-E [mm]	158 a	**192 b**	178 a	170 a	171 a	164 a	168 a
Ratio R_{50}/E [-]	2,25 a	**1,41 b**	1,70 a	1,89 a	1,70 a	1,90 a	1,58 a
Third generation	**IIIM-0**	**IIIM-15**	**IIIM-45**	**IIIM-60**	**IIIM-90**	**IIIM-120**	**IIIM-180**
Dough energy [cm²]	123,6 a	**107,7 b**	**125,8 c**	**104,8 b**	112,8 a	120,5 a	120,5 a
Resistance R_{50} [EU]	470 a	462 a	**470 b**	**408 c**	435 a	440 a	440 a
Extensibility-E [mm]	158 a	**144 b**	160 a	154 a	156 a	162 a	161 a
Ratio R_{50}/E [-]	2,97 a	**3,21 b**	2,94 a	**2,65 c**	2,97 a	2,72 a	2,73 a

* Due to the lowest yield of the first generation crop the technological analysis were not performed.

Table 4. Extensograph analysis of flour obtained from the three generation wheat crops (IM, IIM and IIIM) microwave-heated seeds before sowing. Mean values followed by the same letter in the column are not significantly different (P ≤0.05).

Baking quality				Sample			
First generation	**IM-0**	**IM-15**	**IM-45**	**IM-60**	**IM-90**	**IM-120**	**IM-180***
Falling number in flour [sec]**	393 a	403 a	366 a	365 a	439b	391 a	-
Yield of dough [%]	166,8 a	167,0 a	167,1 a	167,3 a	167,6 a	167,8 a	-
Yield of bread [%]	147,7 a	147,8 a	145,8 a	147,3 a	148,3 b	148,1 a	-
Loaf volume [cm³]	587 a	581 a	**577 b**	580 a	579 a	**624 c**	-
Baking test [score]	127 a	124 a	122 a	123 a	1237 a	**158 b**	-
Estimation of loaf freshness [score]	69 a	61 a	63 a	**72 b**	56 a	**53 c**	-
Second generation	**IIM-0**	**IIM-15**	**IIM-45**	**IIM-60**	**IIM-90**	**IIM-120**	**IIM-180**
Falling number in flour [sec]**	427 a	**380 b**	413 a	427 a	439 a	452 a	392 a
Yield of dough [%]	165,7 a	**166,8 b**	166,1 a	165,8 a	166,3 a	166,6 a	166,4 a
Yield of bread [%]	147,8 a	147,1 a	**146,1 b**	146,9 a	1473 a	148,9 a	146,7 a
Loaf volume [cm³]	573 a	**551 b**	583 a	580 a	584 a	605 a	**603 c**
Baking test [score]	118 a	**109 b**	125 a	123 a	**117 b**	**139 c**	**139 c**
Estimation of loaf freshness [score]	89 a	**68 b**	79 a	78 a	69 a	71 a	72 a
Third generation	**IIIM-0**	**IIIM-15**	**IIIM-45**	**IIIM-60**	**IIIM-90**	**IIIM-120**	**IIIM-180**
Falling number in flour [sec]**	547 a	**511 b**	542 a	533 a	540 a	542 a	533 a
Yield of dough [%]	163,5 a	**163,9 b**	163,5 a	**163,2 c**	163,4 a	**163,9 b**	1634 a
Yield of bread [%]	145,8 a	147,0 a	145,8 a	**145,7 b**	146,0 a	**149,4 c**	147,2 a
Loaf volume [cm³]	687 a	**587 b**	633 a	604 a	**600 b**	**596 b**	635 a
Baking test [score]	118 a	**109 b**	125 a	123 a	**117 b**	**139 c**	**139 c**
Estimation of loaf freshness [score]	84 a	**57 b**	72 a	72 a	**57 b**	75 a	77a

* Due to the lowest yield of the first generation crop the technological analysis were not performed.
** Falling number value measured before standardization to 220 sec for the purpose of baking test.

Table 5. The baking quality of flour obtained from the three generation wheat crops (IM, IIM and IIIM) microwave-heated seeds before sowing. Mean values followed by the same letter in the column are not significantly different (P ≤0.05).

was observed some differences in progeny number, number of eggs, development time and weight of dust but they were not statistically significant. It was interesting that microwave-treated wheat grains which were secondary infested by the Mediterranean flour moth (*Ephestia kuehniella* Zell.) and confused flour beetle (*Tribolium confusum* Duv.) had statistically significantly shorter larval development time than on control seeds (Warchalewski et al., 2000). Although the range of damage depends on dosage and time of treatment. Table 6 presents the results of the granary weevil (*Sitophilus granarius* L.) development parameters on the next generation wheat grain crops bred from seeds microwave heated.

Sample	Survival of beetles after 14 days [%]	Beetle developed [%]	Progeny number [-]	Development time [days]	Weight of dust [mg]
IM-0	92 ab	100 a	9.0 a	58.4 a	46.5 a
IM-15	96 ab	86 a	7.8 a	59.4 a	46.8 a
IM-45	96 ab	89 a	8.0 a	58.2 a	40.8 a
IM-60	96 ab	**192 b**	**17.2 b**	58.6 a	**84.7 b**
IM-90	100 b	106 a	9.5 a	59.4 a	55.5 a
IM-120	86 a	136 ab	12.3 ab	57.0 a	62.6 ab
IM-180	98 b	**168 b**	**15.1 b**	56.8 a	**78.8 b**
IIM-0	88 ab	100 c	15.3 c	59.6 b	64.6 a
IIM-15	74 a	**63 ab**	**9.6 ab**	**54.2 a**	51.3 a
IIM-45	90 ab	**54 a**	**8.2 a**	61.2 b	39.7 a
IIM-60	100 b	**63 ab**	**9.6 ab**	60.4 ab	62.5 a
IIM-90	100 b	84 abc	12.8 abc	59.2 ab	65.5 a
IIM-120	98 ab	88 bc	13.5 bc	58.2 ab	62.8 a
IIM-180	98 ab	87 bc	13.4 bc	58.0 ab	60.9 a
IIIM-0	98 ab	100 a	10.5 a	58.8 a	65.8 ab
IIIM-15	100 b	126 a	13.2 a	59.2 a	65.9 ab
IIIM-45	100 b	138 a	14.2 a	59.2 a	103.6 b
IIIM-60	96 ab	137 a	14.4 a	61.0 a	89.3 ab
IIIM-90	78 a	130 a	13.6 a	56.8 a	40.1 a
IIIM-120	98 ab	133 a	13.9 a	58.8 a	60.5 ab
IIIM-180	98 ab	122 a	10.8 a	57.6 a	64.2 ab

Table 6. The effect of wheat seeds microwave treatment in the range of temperature 28 to 98°C and time from 15 to 180 sec on *Sitophilus granarius* L. development parameters in three consecutive years. Mean values followed by the same letter in the column are not significantly different (P ≤0.05).

Statistically significant increase of developed beetle was found in the first generation crop in wheat grain samples coded IM-60 (48°C) and IM-180 (98°C) which resulted also in the higher progeny number and weight of dust. This was well correlated with the highest level of reducing sugars content (Dolińska, 2004). In the second generation crop were observed lower statistically significant beetle developed and progeny number in grain samples coded IIM-15 (28°C), IIM-45 (43°C) and IIM-60 (48°C) compared to the control grain. Although the development time of granary weevil was significantly shorter but only in grain coded IIM-15 (28°C). In the third generation crop no significant differences in development parameters of granary weevil was found which was well correlated with restoring tendencies of all physicochemical, biochemical and technological properties earlier described in relation to control grain samples. The development parameters of *Tribolium confusum* Duv. and *Ephesita kuehniella* Zell. fed on three generation wheat grain crops bred from seeds microwave heated shown some statistically significant differences as can be seen in Table 7. Extension statistically significant development time of *Tribolum confusum* Duv. in grain samples coded IIM-120 (79°C), IIM-180 (98°C) and IIIM-45 (43°C) by 7.2, 4.6 and 6.4 days respectively, as well as significantly less beetles developed in wheat grain IIIM-120 (79°C) and IIIM-180 (98°C) should be regarded as beneficial. Which means less population of *Tribolium confusum* Duv. will hatching during storage of wheat grain.

Changes in wheat grain physicochemical, biochemical, technological, nutritional and insect resistance properties may be ascribed not only to microwave heating but also to other

Sample	*Tribolium confusum* Duv.		*Ephestia kuehniella* Zell.	
	Beetles developed [%]	Development time [days]	Moths developed [%]	Development time [days]
IM-0	60 ab	23.6 a	47 ab	24.8 a
IM-15	80 b	22.6 a	66 ab	28.3 ab
IM-45	64 ab	24.0 a	40 ab	26.0 a
IM-60	72 ab	22.6 a	20 a	**33.0 b**
IM-90	72 ab	22.2a	40 ab	28.0 ab
IM-120	48 a	24.8 a	53 ab	27.0 ab
IM-180	60 ab	24.8 a	67 b	**33.0 b**
IIM-0	36 a	14.6 a	53 a	26.2 a
IIM-15	24 a	14.4 a	67 a	27.8 a
IIM-45	24 a	15.0 a	67 a	28.2 a
IIM-60	28 a	14.0 a	60 a	29.2 a
IIM-90	16 a	16.4 ab	67 a	25.4 a
IIM-120	24 a	**21.8 c**	73 a	27.8 a
IIM-180	28 a	**19.2 bc**	67 a	26.4 a
IIIM-0	84 c	20.0 bc	60 ab	25.4 a
IIIM-15	92 c	21.6 bcd	93 b	29.2 a
IIIM-45	72 bc	**26.4 d**	60 ab	26.2 a
IIIM-60	76 bc	24.8 cd	60 ab	24.4 a
IIIM-90	64 abc	23.2 bcd	80 ab	27.2 a
IIIM-120	**36 a**	**14.6 a**	53 a	26.8 a
IIIM-180	52 ab	18.2 ab	67 ab	30.4 a

Table 7. The effect of wheat seeds microwave treatment in the range of temperature 28 to 98°C and time from 15 to 180 sec on *Tribolium confusum* Duv. and *Ephestia kuehniella* Zell. development parameters in three consecutive years. Mean values followed by the same letter in the column are not significantly different ($P \leq 0.05$).

factors such as heritability and possible genetic modification of the wheat crop. However, each year, the climate, soil and fertilization treatment of wheat seeds were exactly the same, the influence of different climate conditions during the three cultivation periods should not be excluded (Dolińska, 2004; Dolińska et al., 2004; Grundas et al., 2008).

4. Recapitulation

Microwave drying is most effective at product moisture content below 20 % like in the case in cereals grain. In addition drying operational cost is lower since microwave energy is consumed only by cereal grains not by surrounding environment. Direct application of microwave heating for drying and partial elimination of insect pests is possible with the use microwave heating time up to 90 sec where the grain temperature not exceeded 64^{o}C. In addition, microwave heating of wheat grain to ≤ 64^{o}C should be safe from a technological and baking point of view, as well as a reliable alternative to postharvest pest control during grain shipment and storage.

In general, it should be noted that microwave heating of wheat seeds did not have a negative effect on reproductive materials (seeds) in the second and third generation crops. Although, it should be pointed out that observed changes as direct effect of microwave heated wheat seeds showing some restoring tendency in all discussed wheat grain properties in the third generation crop.

Moreover, in the nearest future microwave heating combined with the other techniques like gamma radiation can be even more effective and attractive techniques for killing of insects and mites that infested stored cereals grain. However, in order to successfully using this techniques more knowledge is needed about the influence of microwave-treated different cereal varieties and theirs influence on physicochemical, biochemical, technological, nutritional and insect resistance properties, also shape and size of kernels as well as on seeds germination power

5. References

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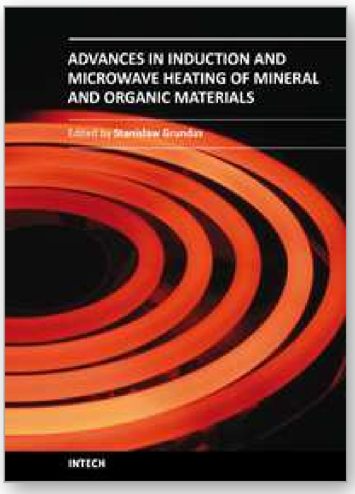

Advances in Induction and Microwave Heating of Mineral and Organic Materials
Edited by Prof. StanisÅ‚aw Grundas

ISBN 978-953-307-522-8
Hard cover, 752 pages
Publisher InTech
Published online 14, February, 2011
Published in print edition February, 2011

The book offers comprehensive coverage of the broad range of scientific knowledge in the fields of advances in induction and microwave heating of mineral and organic materials. Beginning with industry application in many areas of practical application to mineral materials and ending with raw materials of agriculture origin the authors, specialists in different scientific area, present their results in the two sections: Section 1-Induction and Microwave Heating of Mineral Materials, and Section 2-Microwave Heating of Organic Materials.

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