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THE STUDY OF PARTICLE SIZE DISTRIBUTION OF MICRONIZED OAT BRAN LAYER

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ABSTRACT

The aim of this work was to study the particle size distribution of micronized oat bran. An impact classified mill was used to pulverizing. Before the pulverizing raw material was sterilized using overheated steam at 150°C during 3.5 min. The moisture of bran after sterilization decreased from 7.2 to about 3.9%. Five speeds of the rotor disc were used: 2600, 2970, 3340, and 3710 rpm. For each speed of the rotor disc the following speeds of classifier wheel were applied: 480, 965, 1450, 1930, 2410 and 2890 rpm. The particle size distribution of oat bran layer was measured by laser light scattering. Moreover, the sense of touch of coarse particles of micronized oat bran on a tongue was assessed according to five point scale. The largest fragmentation of the oat bran was obtained at a disc speed of 3710 rpm and at a classifier rotation speed of 1930 rpm, whereas the most coarse particles were obtained when these parameters were 3340 rpm and 480 rpm, respectively. On the other hand, the highest uniformity in size of particles in size was observed when the lowest speed of disc and classifier were used. Moreover, for the most samples the pulverized particles of oat bran were almost not discernible on tongue.

Introduction

Oat (*Avena sativa*) has many potential health benefits. Oat is especially source of non-digestible fibre(β-glucan) with unique properties. β-glucan reduces the risk of type 2 diabetes and cardiovascular disease (Vizuete and Anta, 2016). Moreover, this compound reduces the blood cholesterol lever (Liatis et al., 2009) and helpcontrol level of glucose and insulin response (Vizuete and Anta, 2016). β-Glucan is able to attenuate glycemic response, increase satiety after meal, and stimulate healthy gut microflora (Dotsenko et al., 2019). However, a most of people do not consume the suggested daily fibre intake and especially β-glucan (Salmas et al., 2017). In oat β-glucan is mainly located in bran and aleurone layers

(Demirbas,2005). It is relatively inexpensive oat flour milling by-productand can be added to foods on the assumption that this willcontribute to health benefits (Bensalah et al, 2019,Xue et al., 2020).

Cereal flour particle size has a strong influence on flour properties and decides about properties of final products. Recently, the application of micronization in food products has gained a lot of attention (Frohlich et al., 2019,Protonotariou et al. 2020, Xue, et al., 2020).Micronization or superfine grinding is the process of reducing the particle size of material to nanosize (Chen et al., 2018).Ultrafine grinding technology changes properties of powdered rawmaterials and improves dispersion, chemical activity, biological activity and especially improves the nutritionalabsorption rate of food processed by the separatedraw materials (Zhu et al., 2014). In the case of rich fibre plant materials this process increases flour water absorption and solubility of dietary fibre (Hussain et al., 2018) but also releases flavor and improved mouth feel (Chen et al. 2018). Most importantly ultra-fine grinding enhances the antioxidant capacity of dietary fiber asa result of release many bioactive compounds bound to the food matrix (Bender et al., 2020, Liu et al., 2016, Zhu et al., 2014).

The aim of this work was to study the influence of working parameters of impact classified mill on the particle size distribution of micronized oat bran layer.

Materials and Methods

Material for the study was the oat bran layer received from ZMZM Kruszwica. The basic chemical composition of bran was determined (Romankiewicz et, al. 2017). Moreover the β-glucan content was assessed according to AOAC method (1995). Before the pulverizing material was sterilized using overheated steam at 150ºC during 3.5 min. The moisture content in raw material before and after sterilization was determined by drying the bran samples at 105ºC.Oat bran layer was pulverized using impact classified mill (capacity 500 $kg \cdot h^{-1}$). The mill cooperated with centrifugal fan with air flow 2 $m^3 \cdot s^{-1}$. Raw material was transported by air into the milling chamber through the stub end with 60 mm diameter (Fig. 1). The bran layer was pulverized on the rotor disc (725 mm diameter) equipped with 12 hammers (90x25x25 mm). The following speeds of the rotor disc were used: 2600, 2970, 3340, and 3710 rpm. Oat bran was pulverized by the hammers and was through on liner with corrugated surface. Pulverized material was transported through baffle assembly into classifier wheel, which allow or not to pass them outside the mill. Coarse particles were turn back into milling chamber. Classifier consistsof disc with 350 mm diameter and 36 vanes mounted at an angle 18° (Fig. 2). For each speed of the rotor disc the following speeds of classifier wheel were used: 480, 965, 1450, 1930, 2410 and 2890 rpm.

The particle size distribution of oat bran layer was measured by laser light scattering using a laser particle size analyser (Malvern Mastersizer 3000 instrument, Malvern Instruments Ltd., Worcestershire, UK). In the laser diffraction measurement, a laser beam passes through a dispersed flour sample, and the variation in intensity of the laser light is measured. The angular scattering intensity is analyzed, and the size of the particles is calculated. A 5 g amount of pulverized sample was put into the inlet chamber, and particle size was measured automatically by laser diffraction using dry dispersion method.

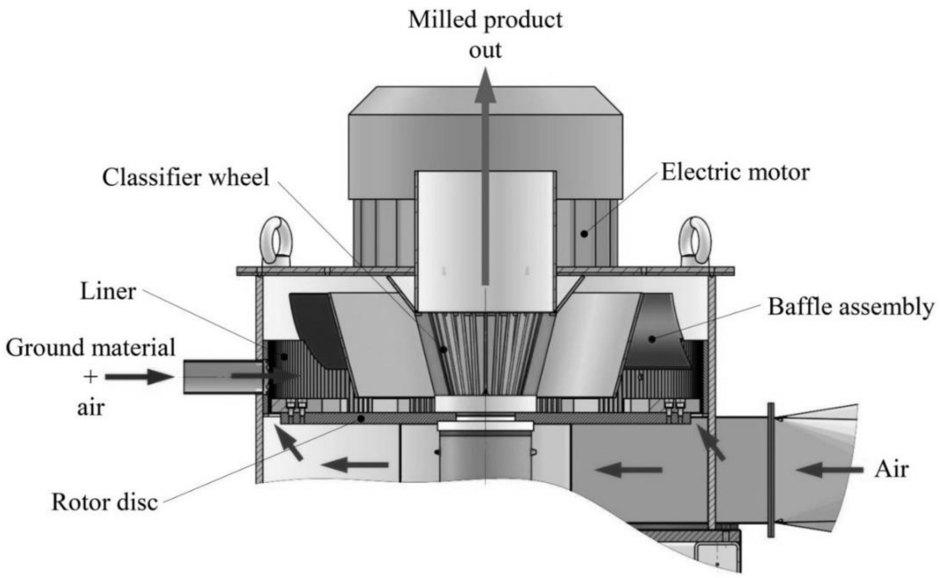

Figure 1. Process of micronization in impact classified mill

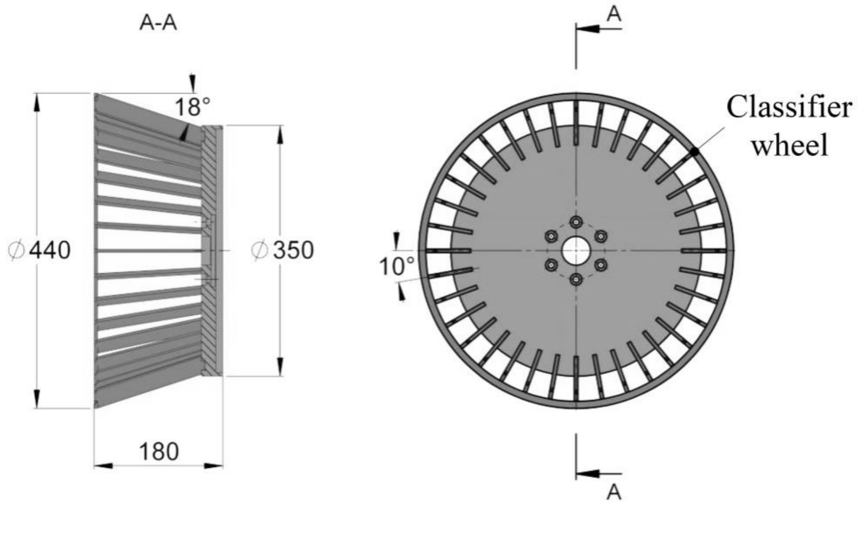

Figure 2. Diagram of classifier wheel

Measurements were carried out in eight replicates for each sample. From each particle size distribution d_{10}, $d_{50}$and d_{90} were evaluated. These parameters represented the particlediameters that cumulative volume of particles was 10%, 50% and 90%,respectively.The size dispersion index (*Span*) was also calculated accordingto the following equation (Liu et al., 2011):

$$Span = \frac{d_{90}-d_{10}}{d_{50}} \tag{1}$$

Moreover, the sense of touch of coarse particles on tongue in micronized oat bran was assessed according to five point scale: 1 – very discernible, 2 – discernible, 3 – slightly discernible, 4 – almost no discernible, 5 – no discernible. The evaluation was performed by five persons.Plain water was used to rinse mouth before and after each sample testing. The measurement was performed in triplicate for each sample.

The data were analyzed with Statistical program version 13.1. The mean values and standard deviations were calculated and the analysis of variance (two-way ANOVA), followed by the least significant difference test (Turkey test) were performed. The level of significance was $\alpha = 0.05$.

Results and Discussion

The moisture content in the oat bran samples was 7.2%±0.12 before sterilization and between 3.69% and 4.21% after this process. The others components of oat bran were as follow: ash content 2.74%±0.082; protein content 16.3%±0.814, and 5.52%±0.28 of fat. The β-glucan content in oat bran was 8.0% ± 0.31.

The analysis of variance showed that both speed of disc and speed of classifier had significant influence on the parameters described the particle size distribution of pulverized oat bran. Also the interaction of these parameters was significant (Table 1). Taking into account the parametersd_{10},d_{50} andd_{90}, the highest values of *F*-test were alwaysobtained for revolution of classifier wheel. It means that this parameter had the highest influence on the grinding patter of pulverized oat bran. On the other hand the revolution of disc had the highest influence on span. The spanrepresents the width of particles volume distribution.

An example of particle size distribution of powdered oat bran is presented in Fig. 3 and the parameters describingthe particle size distribution of micronized oat bran layer for all samples were included in Table 2. Both speed of disc and revolution of classifier wheel had little influence on the amount of fine particles. As a result of this the parameter d_{10} changed in the narrow range from 6.9 µm (sample B21) to 9.1 µm (sample B13). It means that for all micronized samples 10% of each sample has a size of 9.1 µm or smaller. The lowest values of d_{10} were found when the speed of disc was 3710 rpm and the revolution of classifier equal 1450 and 1930 rpm. Higher variability was observed in the case of d_{50} (median).This parameter ranged from 19.9 µm to 53.7 µm for samples B22 and B13, respectively. Although the lowest values of d_{50} were found in the most cases for the highest speed of disc we did not found the linear relation between speed of disc and the d_{50}.

Table 1.
The analysis of variance of parameters characterizing the particle size distribution of pulverized oat bran layer

Parameter	Source of variance	Sum of squares	Degrees of freedom	Mean square	F – test	p-value
d_{10}	V_w*	7.27	3	2.42	403	<0.0001
	V_k	36.21	5	7.24	1204	<0.0001
	$V_w \cdot V_k$	23.75	15	1.58	263	<0.0001
d_{50}	V_w	1277.4	3	425.8	1144.9	<0.0001
	V_k	6608.4	5	1321.7	3553.8	<0.0001
	$V_w \cdot V_k$	4822.4	15	321.5	864.5	<0.0001
d_{90}	V_w	32450	3	10817	834.2	<0.0001
	V_k	194349	5	38870	2997.8	<0.0001
	$V_w \cdot V_k$	127246	15	8483	654.3	<0.0001
Span	V_w	27.850	3	9.283	1027.5	<0.0001
	V_k	14.992	5	2.998	331.9	<0.0001
	$V_w \cdot V_k$	36.804	15	2.454	271.6	<0.0001

V_w - revolution of disc, V_k - revolution of classifier wheel

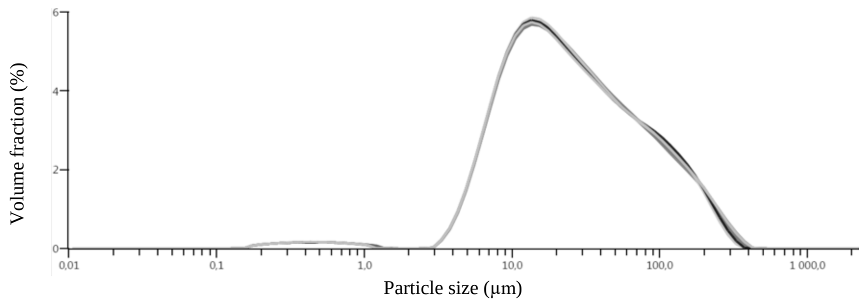

Figure 3. Example of particle size distribution curves (eight repetitions) of the micronized oat bran layer (sample M23) determined by laser diffraction

Taking into account the revolution of classifier the lowest value of this parameter were usually found for middle speed of classifier (965, 1450 and 1930 rpm). Relatively high content of fat in oat bran can cause a grinding and separation problem problems (Sibakov et al. 2011, Stevenson et al., 2008), particles are more plastic and can combine into agglomerates. This could be a reason why an increase in the speed of disc had relatively low influence on particle size distribution of micronized oat bran. Liu et al. (2015) studied the oat bran fragmentation by using the planetary rubbing mill. After six hours of grinding they obtained ground material with average particle size from 141 to 169 µm. Wu and Doehlert (2020) used a pin mill and defatted oat bran for powder production from oat bran. They obtained powder with average particle size between 86 and 184 µm. In our study we obtained much better degree of fineness of oat bran without defeating but with decreasing of moisture content up to about 3.9%. Moisture of biological materials is a crucial parameter which decides about the grinding process. Materials with low moisture are more fragile and ground more easily in comparison to raw materials with higher moisture content (Dziki, 2008).

Table 2.
Parameters described the particle size distribution of micronized oat bran layer

Sample	Revolution of disc (rpm)	Revolution of classifier wheel (rpm)	Moisture content (%)	d_{10} (µm)	d_{50} (µm)	d_{90} (µm)	*Span*
B1	2600	480	4.19	7.5±0.11^{gh*}	26.4±0.49^{i}	107.4±3.74^{e}	3.8±0.07^{b}
B2	2600	965	4.21	7.2±0.07^{cd}	24.5±0.09^{gh}	95.1±0.77^{abc}	3.6±0.03^{a}
B3	2600	1450	4.07	7.4±0.10^{ef}	24.7±0.24^{h}	93.2±1.16^{ab}	3.5±0.02^{a}
B4	2600	1930	4.11	7.8±0.06^{i}	28.8±0.18^{i}	122.4±1.41^{g}	4.0±0.03^{cd}
B5	2600	2410	4.23	8.1±0.08^{kl}	31.5±0.48^{k}	138.6±2.26^{h}	4.1±0.03^{de}
B6	2600	2890	4.31	8.1±0.04l^{m}	33.6±0.60^{l}	160.4±2.77^{i}	4.5±0.04^{hi}
B7	2970	480	4.19	8.2±0.06^{m}	35.2±0.89^{m}	189.0±5.40^{k}	5.1±0.10^{m}
B8	2970	965	3.85	7.4±0.08^{ef}	23.6±0.36^{efg}	114.6±4.21^{f}	4.5±0.12^{hi}
B9	2970	1450	4.07	7.2±0.07^{cd}	22.5±0.18^{de}	106.5±2.98^{e}	4.4±0.10^{gh}
B10	2970	1930	4.05	7.1±0.06^{cd}	21.7±0.06^{cd}	97.9±1.95^{bc}	4.2±0.09^{ef}
B11	2970	2410	3.44	8.0±0.12^{jkl}	32.4±0.54^{k}	168.0±4.93^{i}	4.9±0.08^{l}
B12	2970	2890	3.77	8.7±0.03^{o}	45.4±0.89^{o}	189.6±2.13^{k}	4.0±0.04^{cd}
B13	3340	480	3.81	9.1±0.07^{p}	53.7±2.10^{p}	242.3±4.92^{m}	4.3±0.09^{fg}
B14	3340	965	3.85	7.9±0.09^{ijk}	26.9±0.84^{i}	163.4±6.78^{ij}	5.8±0.11^{n}
B15	3340	1450	4.01	7.1±0.07^{bc}	21.2±0.20^{bc}	105.4±4.67^{de}	4.6±0.19^{ijk}
B16	3340	1930	4.05	7.5±0.10^{fg}	24.4±0.38^{fgh}	106.4±3.54^{e}	4.1±0.09^{cde}
B17	3340	2410	3.94	7.9±0.08^{ij}	27.2±0.34^{i}	114.0±1.60^{f}	3.9±0.03^{bc}
B18	3340	2890	3.99	8.5±0.10^{n}	35.3±0.49^{m}	193.4±3.02^{k}	5.2±0.04^{m}
B19	3710	480	4.12	8.7±0.04^{o}	37.8±0.43^{n}	225.1±3.00^{l}	5.7±0.04^{n}
B20	3710	965	3.81	7.6±0.09^{h}	23.3±0.24^{ef}	143.1±6.51^{h}	5.8±0.23^{n}
B21	3710	1450	3.46	6.9±0.06^{a}	20.5±0.16^{ab}	99.8±3.88^{cd}	4.5+±0.16^{hi}
B22	3710	1930	3.08	7.0±0.06^{a}	19.9±0.05^{a}	91.1±1.96^{a}	4.2±0.09^{ef}
B23	3710	2410	3.68	7.2±0.03^{cd}	23.2±0.19^{e}	118.3±2.19^{f}	4.8±0.07^{kl}
B24	3710	2890	3.69	7.3±0.09^{de}	22.8±0.06^{de}	114.8±0.89^{f}	4.7±0.05^{jk}

* The values designated by the different small letters (a, b, c, d…) are significantly different ($\alpha = 0.05$).

Table 2 presents the span results. This parameter shows the width of the particle size distribution and gives an indication of how far the 10 percent and 90 percent points are apart, normalized with the midpoint. Interestingly the highest uniformity of particles in size was observed when the lowest speed of disc and classifier were used. This parameter changed from 3.5 (sample B3) to 5.8 (sample B14).

The result of sense of touch of coarse particles on tongue is presented on Fig. 4. Generally for the most ground samples of oat bran the coarse particles were almost not discernible. The lowest notes for the sense of touch were found when the speed of disc and classifier was 3340 rpm and 480 rpm (sample B13, Table 2, Fig. 4C), respectively and coarse particles were completely no discernible when the speed of disc was 3710 rpm (Fig. 4A) and the speeds of classifier were 1450 and 1930 rpm (B21 and B22 samples, Table 2). However, the significant differences were only found between the sample B13 and the samples B21 and B22. Beside this we found positive and significant correlation between d_{90} and the sense of touch of coarse particles (Fig. 5).

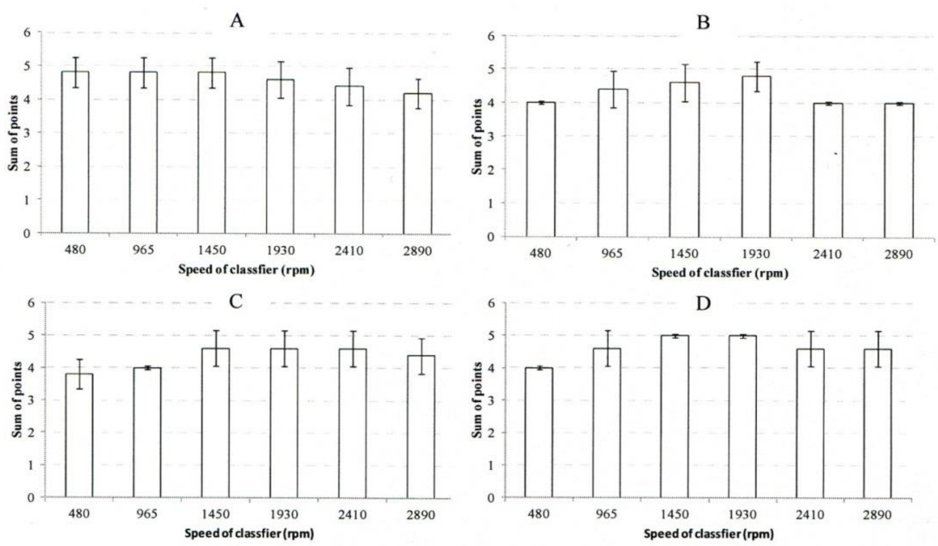

Figure 4. The result of sense of touch of coarse particles on tongue of micronized oat bran for different speeds of disc: A – 2600 rpm, B – 2070 rpm, C – 3340 rpm, D – 3710 rpm

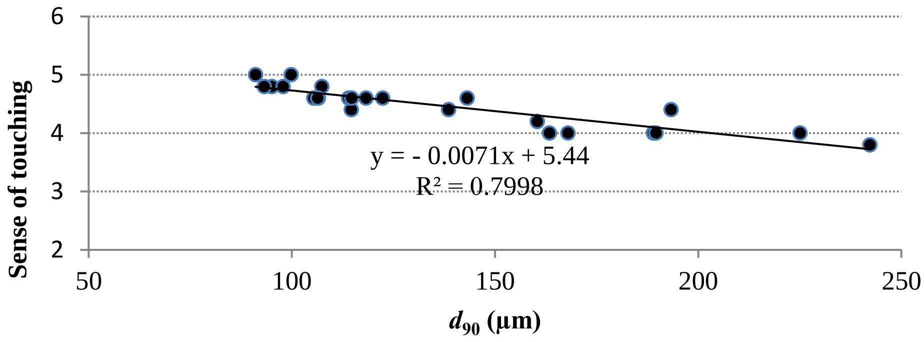

Figure 5. The relation between the d_{90} parameter and the sense of touch of coarse particles on tongue

Conclusions

1. Although both the speed of disc and classifier significantly influenced on particle size distribution of oat bran, there was no linear relation between these parameters and the size of particles.
2. The largest fragmentation of the oat bran was obtained at a disc speed of 3710 rpm and at a classifier rotation speed of 1930 rpm whereas the most coarse particles were obtained when these parameters were 3340 rpm and 480 rpm, respectively. On the other hand, the highest uniformity of particles in size was observed when the lowest speed of disc and classifier were used.
3. The evaluation sense of touch of coarse particles on tongue showed positive correlation with d_{50} and d_{90} parameters. Generally for the most samples the coarseparticles of pulverized oat bran were almost not discernible.
4. The result showed that proposed method of grinding is adequate to pulverize oat bran into particles with d_{50} equal about 20 micrometer. Although the largest fragmentation was obtained for the highest speed of disc, the satisfying grinding results were also obtained for lower speeds of disc and classifier.

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ANALIZA SKŁADU GRANULOMETRYCZNEGO ZMIKRONIZOWANEJ WARSTWY OWOCOWO-NASIENNEJ ZIARNA OWSA

Streszczenie. Celem pracy była analiza składu granulometrycznego zmikronizowanej warstwy owocowo-nasiennej ziarna owsa. Przed rozdrabnianiem surowiec był poddany procesowi sterylizacji parą przegrzaną o temperaturze 150ºC przez 3,5 min. Wilgotność surowca po sterylizacji zmniejszyła się z 7,2 do około 3,9%. Rozdrabnianie przeprowadzono wykorzystując młyn wirnikowy z klasyfikatorem cząstek. Zastosowano cztery prędkości obrotowe wirnika (2600, 2970, 3340, i 3710 obr·min^{-1}). Przy każdej prędkości wirnika stosowano pięć prędkości obrotowych klasyfikatora (480, 965, 1450, 1930, 2410 i 2890 obr·min^{-1}). Skład granulometryczny sproszkowanej okrywy ziarna owsa określono metodą dyfrakcji laserowej. Ponadto przeanalizowano skład chemiczny okrywy i przeprowadzone ocenę sensoryczną wyczuwalności większych jej fragmentów na języku, stosując skalę pięciopunktową. Największy stopień rozdrobnienia okrywy uzyskano przy prędkości wirnika wynoszącej 3710 obr·min^{-1} oraz przy prędkości klasyfikatora równej 1930 obr·min^{-1}. Natomiast w najgorszym stopniu okrywa ulegała mikronizacji przy prędkości wirnika i klasyfikatora równych odpowiednio 3340 obr·min^{-1} i 480 obr·min^{-1}. Z kolei największą jednorodność wymiarów uzyskiwano przy najniższych prędkościach wirnika i klasyfikatora. Ponadto dla większości zastosowanych warunków mikronizacji nie stwierdzono podczas oceny sensorycznej obecności grubszych cząstek okrywy na języku.

Słowa kluczowe: owies, okrywa owocowo-nasienna, mikronizacja, skład granulometryczny cząstek, analiza sensoryczna