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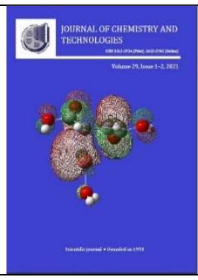

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EFFECT OF DIFFERENT PARTICLE SIZES OF AGARICUS BISPORUS AND SOYBEAN OIL ON RHEOLOGICAL PROPERTIES, MOISTURE DISTRIBUTION AND MICROSTRUCTURE OF CHICKEN BATTERS

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Abstract

This article is devoted the evaluation of the effects of different particle sizes of *Agaricus bisporus* and soybean oil as fat substitutes on the rheological properties, moisture distribution and microstructure of chicken batters. Four different treatments were processed: control (20 % Fat), D_1 (178 μm), D_2 (100 μm) and D_3 (34 μm) (60 % replacement of fat with different particle sizes of *Agaricus bisporus* and soybean oil, the weight ratio of *Agaricus bisporus* to soybean oil was 1 : 2). Rheological properties (storage modulus G' and loss modulus G''), microstructure (SEM), T_2 relaxation time (T_{2b}, T_{21}, T_{22}) and relaxation area (PT_{2b}, PT_{21}, PT_{22}) were evaluated. The storage modulus (G') and loss modulus (G″) of chicken batters increased with the decrease of *Agaricus bisporus* particle size, which were higher than that of the control, indicating that the combination of *Agaricus bisporus* with different particle sizes and soybean oil could improve the viscoelasticity of chicken batters. D_2 (100 μm) and D_3 (34 μm) had similar effects on viscoelasticity. The T_{2b}, T_{21}, T_{22} and PT_{22} of chicken gels added with *Agaricus bisporus* and soybean oil were significantly lower than those of the control group ($P < 0.05$) with the decrease of particle size, suggesting that the addition of *Agaricus bisporus* and soybean oil accelerated the transformation of free water into fixed water in the chicken gel matrix. D_1 had the smallest T_{2b} and the largest PT_{2b}, showing that D_1 had the largest water holding capacity. The gel network microstructure of chicken batters with different particle sizes of *Agaricus bisporus* powder and soybean oil was more uniform compared with the control group. D_2 and D_3 had similar and uniform gel network structure, indicating that small particle of Agaricus bisporus and oil compound could improve texture properties of chicken batters. Conclusions. The particle size of Agaricus bisporus will affect the rheological properties, T_2 relaxation time and microstructure of chicken surimi. Small particle sizes of Agaricus bisporus have a more positive effect on the viscoelasticity and microstructure of chicken gel, while large particle sizes of Agaricus bisporus have a stronger water holding capacity of chicken batters. The effect of particle size of Agaricus bisporus on product quality should be considered in production.

Keywords: Agaricus bisporus; soybean oil; particle size; rheological properties; moisture distribution; microstructure.

ВПЛИВ СТУПЕНЮ ПОДРІБНЕННЯ AGARICUS BISPORUS І СОЄВОЇ ОЛІЇ НА РЕОЛОГІЧНІ ВЛАСТИВОСТІ, РОЗПОДІЛ ВОЛОГИ І МІКРОСТРУКТУРУ СІЧЕНИХ ВИРОБІВ ІЗ ПТИЦІ

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Анотація

Ця стаття присвячена оцінці впливу розмірних характеристик порошку з печериці двоспорової (*Agaricus bisporus)* та соєвої олії як замінника жиру на реологічні властивості, розподіл вологи та мікроструктуру січених виробів із птиці. Було виготовлено чотири види різних зразків: контроль (20 % жиру), D_1 (178 μm), D_2 (100 μm) та D_3 (34 μm) (60 % заміни жиру на порошок із печериці двоспорової різного ступеню подрібнення та соєву олію, відношення грибного порошку до соєвої олії становило 1 : 2). Було досліджено реологічні властивості (модуль пружності G' та пластичний модуль G''), мікроструктуру (SEM), T_2 час релаксації (T_{2b}, T_{21}, T_{22}) та поверхню релаксації (PT_{2b}, PT_{21}, PT_{22}). Модуль пружності (G') та пластичний модуль (G″) січених виробів із птиці зростав зі зниженням розмірних характеристик частинок грибного порошку, що були вищими, ніж у контрольних зразків. Це вказує на те, що поєднання грибного порошку із різними розмірними характеристиками та соєвої олії може покращити в'язко-пружні властивості січених виробів із птиці. Зразки з розмірами частинок D_2 (100 μm) та D_3 (34 μm) мали подібний ефект за в'язко-пружними властивостями.

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T_{2b}, T_{21}, T_{22} та PT_{22} курячого фаршу з додаванням грибного порошку та соєвої олії були значно нижчими ніж у групи зразків ($P < 0.05$) зі зменшенням розміру частинок. Це свідчить про те, що додавання грибного порошку та соєвої олії прискорює перетворення вільної вологи у зв'язану в матриці присутніх гідроколоїдів. Зразки D_1 мали найнижчий час релаксації T_{2b} та найбільшу поверхню релаксації PT_{2b}. При цьому зразки D_1 мали найвищу вологоутримуючу здатність. Мікроструктура січених виробів із курки з внесенням грибних порошків з різним ступенем дисперсності та соєвої олії була більш рівномірною, порівняно з контрольними зразками. Зразки D_2 та D_3 мали схожу та рівномірну структуру, що вказує на те, що невеликі розмірні характеристики грибного порошку та соєвої олії можуть покращити текстурні властивості січених виробів із курки. Було визначено, що невеликі розмірні характеристики грибного порошку покращують в'язко-еластичні характеристики фаршів, в той час, як фарші з порошками з більшою дисперсністю, мають кращу вологоутримувальну здатність Описані у статті дані стануть корисними під час розробки нових та вдосконаленні існуючих технологій виробництва харчової продукції оздоровчого призначення.
Ключові слова: порошок грибів Agaricus bisporus; соєва олія; розмірні характеристики; реологічні властивості; розподіл вологи; мікроструктура.

ВЛИЯНИЕ СТЕПЕНИ ИЗМЕЛЬЧЕНИЯ AGARICUS BISPORUS И СОЕВОГО МАСЛА НА РЕОЛОГИЧЕСКИЕ СВОЙСТВА, РАСПРЕДЕЛЕНИЕ ВЛАГИ И МИКРОСТРУКТУРУ РУБЛЕНЫХ ИЗДЕЛИЙ ИЗ ПТИЦЫ

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Аннотация
Статья посвящена оценке влияния степени дисперстности порошка из шампиньона двуспорового (*Agaricus bisporus)* и соевого масла как заменителя жира на реологические свойства, распределение влаги и микроструктуру рубленых изделий из птицы. Было приготовлено четыре вида различных образцов: контроль (20 % жиру), D_1 (178 μm), D_2 (100 μm) и D_3 (34 μm) (60 % замены жира на порошок из шампиньона двуспорового различной степени дисперсности и соевое масло, соотношение грибного порошка к соевому маслу составило 1 : 2). Были иссдедованы реологические свойства (модуль упругости G' и пластичный модуль G''), микроструктура (SEM), T_2 время релаксации (T_{2b}, T_{21}, T_{22}) и поверхность релаксации (PT_{2b}, PT_{21}, PT_{22}). Модуль упругости (G') и пластичный модуль (G″) рубленых изделий из птицы возрастал со снижением размерных характеристик грибного порошка, что было выше, чем у контрольных образцов. Это указывает на то, что сочетание грибного порошка рзличной степени дисперсности и соевого масла может улучшить вязкостно-упругие свойства рубленых изделий из птицы. Образцы со степенью дисперсности D_2 (100 μm) и D_3 (34 μm) имели подобный эффект по вязкостно-упругим свойствам. T_{2b}, T_{21}, T_{22} и PT_{22} куриного фарша с добавлением грибного порошка и соевого масла были значительно ниже чем у группы образцов зразків ($P < 0.05$) со снижением размера частиц. Это свидетельствует о том, что добавление грибного порошка и соєвого масла ускоряет превращение свободной влаги в связанную в матрице присутствующих гидроколлоидов. Образцы D_1 имели наинизшее время релаксації T_{2b} и наибольшую поверхность релаксации PT_{2b}. При этом образцы D_1 имели наивысшую влагоудерживающую способность. Микроструктура рубленых изделий из курицы с внесением грибных порошков различной степни дисперсности и соевого масла была более равномерной, сравнительно с контрольными образцами. Образцы D_2 и D_3 имели сходную и равномерную структуру, что указывает на то, что небольшие размерные характеристики грибного порошка и соевого масла могут улучшить текстурные свойства рубленых изделий из курицы. Было определено, что небольшие размерные характеристики грибного порошка улучшают вязкостно-эластичные свойства фаршей, в то время, как фарши из порошками с большей дисперсностью, имеют лучшую влагоудерживающую способность. Описанные в статье данные будут полезны при разработке новых и усовершенствовании существующих технологий пищевой продукции оздоровительного назначения.
Ключевые слова: порошок грибов Agaricus bisporus; соевое масло; размерные характеристики; реологические свойства; распределение влаги; микроструктура.

Introduction

Meat products based on minced meat are popular all over the world: meatballs, dumplings, rolls, terrines, muffins, kyufta, dolma, lula, sausages, cutlets, stuffed vegetables and more. Such products have a high degree of assimilation, can be enriched with biologically active substances and their complexes in the form of vegetable purees, milk, eggs, mixtures of herbs, peppers, extracts of medicinal plants, mineral and vitamin complexes. In the United States, for example, about 50 % of beef is consumed annually as jellied meat products [1]. However, minced meat products have a low water-holding capacity, which reduces the organoleptic assessment of finished dishes (juiciness is lost and the consistency becomes dense) and reduces the shelf life of chilled and frozen semi-finished products due to the loss of presentation. To increase the adhesive properties, animal fat is often used, which negatively affects human health: blood pressure rises, there is a risk of cardiovascular diseases, hyperlipidemia and cancer [2]. However, animal fat contributes to the stability of emulsions, increases the yield of finished products by increasing the water-holding capacity, and changes the texture and taste of products for the better [2, 3]. Direct reduction of the fat content of minced meat will negatively affect the quality of meat products, therefore the use of fat substitutes is the best method. Until now, these fat substitutes mainly include proteins of soy, wheat, peas, peanuts, whey protein, collagen, etc.), carbohydrates (cellulose, starch, etc.) [3–5].

Mushrooms are rich in protein, carbohydrates and dietary fiber, and have low fat [6]. There are reports that straw mushrooms can improve the physicochemical, nutritional and sensory characteristics of Cantonese sausages [7]. The addition of mushrooms makes it possible to reduce the use of table salt in finished culinary products and phosphates in semi-finished meat products [8, 9], since mushrooms have a high content of minerals [10]. Due to the presence of antioxidants as well as minerals, the addition of mushrooms to minced meat allows for a longer shelf life [11]. Also, the presence of fungi makes it possible to enrich minced meat with polysaccharides [12], which have a high water-holding capacity, which also allows to reduce the content of fat and calories, for example, in pork sausages [13]. The paper [14] describes a decrease in the amount of fat in beef burgers due to the introduction of 2.5 % and 5.0 % Agaricus bisporus mushrooms. The addition of a mixture of Agaricus bisporus and Pleurotus ostreatus mushrooms instead of pork fat significantly improved the elasticity and adhesion of beef cutlets, reduced cooking losses, and reduced the amount of salt [15]. The authors of [16] proved the improvement of rheological characteristics and structural and mechanical properties of meat emulsions after inclusion in the composition of powder from mushrooms of the species Agaricus bisporus.

As can be seen from the presented analysis of the literature, the rheological properties of meat products play an important role in product development and quality control [17-19]. Minced meat is a type of food emulsion with intermediate viscous and elastic rheological properties. Influence of protein structure meat on the rheology of emulsions and gels has not been described fully enough today. An even larger gap exists in the study of the formation of emulsions and gels when adding mushroom minced meat and powders.

Basic rheological testing can provide key information about the molecular mechanism of the viscoelasticity of minced meat and the change in it protein structure during gelation or emulsion formation [20].

The relaxation time of nuclear magnetic resonance in a low field (LF-NMR) can be used to estimate the content of externally bound moisture in minced meat [21]. The relaxation time can indicate water mobility, and the area under the curve can represent the water content of the system when analyzed by LF-NMR [22], which provides good information about changes in the interaction of water and protein during the formation of a complex technological system - minced meat [23].

Particle size will affect product properties such as rheology, water holding capacity, microstructure [24–27]. Chicken meat has for its several health, benefits due to its high nutritional value and high protein content, and low cholesterol, calorie, and fat contents [28]. The largest percentage of poultry meat consumption is associated with its low price compared to lamb, beef and pork. [29]. Agaricus bisporus powder is widely used in the production of minced meat not only to increase the biological value, but also as a source of fiber and bioactive compounds, as well as a component that improves technological properties. Authors [30] noted good rheological and structural characteristics of meat emulsion with powder from Agaricus bisporus. A high protein content and antibacterial effect are noted by authors [31] in chiken minced meat.

While most studies have focused on the effect of Agaricus bisporus on the quality of meat products, no research has focused on the effect of Agaricus bisporus particle size on the rheological properties, moisture distribution and microstructure of meat products. Thus, the purpose of this study is to assess the effect of the degree of dispersion of minced meat from Agaricus bisporus in a mixture with soybean oil, as a promising alternative to hard-to-digest fats, on the rheological characteristics of model systems, moisture distribution and microstructure of minced meat based on poultry meat.

Materials and Methods

Fresh Agaricus bisporus (Ab), soybean oil, chilled chicken breast oand pork backfat were purchased from Hualian Supermarket of Xinxiang City. Salt, white peper, sodium tripolyphosphate, sugar and ice water were all food grade.

Preparation of Ab powder. Fresh Ab mushrooms were washed using tap and drained the water on the surface, then cut into slices (5 mm thick), dried (45 °C, 8 hours) until the moisture content was 7 %. After natural cooling, the dried AB mushrooms were ground with a high-speed crusher, and then sieved with 80 mesh, 120 mesh, and 160 mesh sieves in sequence. Three kinds of under sieves, D_1, D_2 and D_3, were obtained. The particle sizes of Ab powder was measured by a laser particle size analyzer (BT-9300H, Sichuan Ke Yicheng Technology Co., Ltd, Chengdu, China). The mean diameters of particles of D_1, D_2 and D_3 were 178 μm, 100 μm and 34 μm, respectively. Then, Ab mushrooms powder was stored in polyethylene bags in a refrigerator (4°C).

Preparation of chicken mincemeat. The chilled chicken breasts meat were minced with a meat grinder (6mm perforated plate) after removing excess connective tissue and fat. Ground chicken was mixed with salt and tripolyphosphate by a laboratory food processor (HR7625, Philips Corp, Hong Kong, China) at 1500 rpm for 60 seconds. 1/3 ice water was added and homogenized at 1500 rpm for 60 seconds. Then, pork backfat, three particle sizes of Ab (pre-mixing with soybean oil.), 1/3 ice water and ingredients were added according to the Table 1. Then homogenized at 1500 rpm for 120 s.

Table 1

The formulations of Chicken mincemeat (units: g/100 g)

*T*Raw material/ ingredients	Samples			
	CK	D_1	D_2	D_3
Meat batter (100g)				
Chicken meat	60	60	60	60
Backfat	20	8	8	8
AB powder (178 μm)	-	4	-	-
AB powder (100 μm)	-	-	4	-
AB powder (34 μm)	-	-	-	4
Soybean oil				
Ice water	-	8	8	8
	20	20	20	20
Total	100	100	100	100
Others (% of meat batter)				
Refined salt	1.4	1.4	1.4	1.4
Sodium tripolyphosphate	0.3	0.3	0.3	0.3
Sugar	0.65	0.65	0.65	0.65
Ground white peper	0.15	0.15	0.15	0.15

Finally, the remaining 1/3 ice water were added and homogenized (3000 rpm, 60 seconds). The temperature of the chicken mincemeat was lower than 10°C during mixing. Raw meat emulsion was used for the analysis of dynamic rheological properties, and cooked meat emulsion was used for the analysis of T_2 relaxation time and microstructure.

Dynamic rheological properties measurement. According to the method of Zhou et al. [19] with some modifications. The measurements were carried out on a MCR301 dynamic rheometer (Anton Paar Co. Ltd., Austria). The initial temperature (20 °C) rose to 80 °C at 2 °C min^{-1} after holding for 10 min. the samples were continuously sheared at a fixed frequency of 0.1 Hz, and the changes of storage modulus (G ') and loss modulus (G'') with temperature were measured.

LF-NMR spin–spin relaxation (T_2) measurements. According to the method of Luo et al. [32] with some modifications. LF-NMR spin–spin relaxation (T_2) measurements were carried out on a Niumag Benchtop Pulsed NMR Analyzer PQ001 (Niumag Electric Corp., Shanghai, China). Approximately 2 g of cooked chicken mincemeat were placed into the NMR tube with a diameter of 15 mm for testing. The test conditions were as follows: the measurement temperature was 32 °C, and the proton resonance frequency was 22.6 MHz. The parameters were as follows: The τ-value (the time between 90°and 180° pulse) was 200 μs. The repetition interval is 6.5 s, and 12000 echoes were obtained as 32 scan repetitions, and each test was carried out at least 3 times.

Scanning electron microscopy (SEM). According to the method of Wattanachant et al. [33] with some modifications was held. The microstructure was measured by SEM (Quanta 200, FEI CO., US). The cooked chicken matters was cut into cube sample (3 × 3 × 3 mm^3) and fixed with 2.5 % glutaraldehyde at 4°C for 24 hours, then the samples were washed (thrice) for 15 min with 0.1M phosphate buffer (pH 6.8) and dehydrated with 50 %, 60 %, 70 %, 80 %, and 90 % ethanol solution for 15 minutes respectively. Next the samples were dehydrated with absolute ethanol for 10 minutes (thrice), degreased with chloroform for 1h and replaced with the mixture of absolute ethanol and tert-butyl alcohol (1 : 1) and tert-butyl alcohol for 15 min respectively. Finally, the vacuum-dried sample were sputter-coated with gold after mounting on a bronze column for observing and photographing in SEM.

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Results and discussion

The dynamic rheological properties are closely related to the protein molecules, intramolecular and intermolecular bonds, and the dispersion state of the structure and organization [34]. The storage modulus (G') and loss modulus (G'') reflect important information during the of gelation process of muscle protein. The storage modulus (G') reflects the changes in the elastic properties of the gelling network structure and the strength of gel matrix, and the loss modulus (G'') reflects the changes in the viscous elements [18].

The thermal gel process of myosin includes two processes: protein denaturation and protein aggregation. When the protein is denatured, the conformation of myosin changes, and in the subsequent aggregation process, the denatured myosin cross-links to form a network structure [35]. Fig.1 shows that the G' values of all samples decreased at the beginning, which might be due to the fat melting in chicken mincemeat, while the G' values of the three treatment groups were relatively flat compared with the control group, which might be due to the partial replacement of fat in the group of experimental samples. Subsequently, the G' values of all samples first increased, then decreased to the lowest values, and then increase rapidly again. The G' values of the control group and the treatment group began to rise at about 43 °C and 35 °C, respectively. At this point, the aggregation of myosin head made the protein denatured, and the network structure began to form slowly [36], which made the G' increase. G' reached its peak when the temperature was between 46°C and 54 °C, then G' began to decrease, reaching its peak valley at 62 °C. This might be because the uncoiling of the myosin tail led to an increase in the fluidity of the protein, and destroyed the structure of the gel to a certain extent, thereby reducing G' values [37].

Subsequently, new chemical bonds were formed, and the cross-linking in system "protein - protein" increased, making G' increase, which was consistent with the change trend of the predecessors on the storage modulus (G') of meat emulsion [34]. Subsequently, as the temperature increased, the G' values of the samples containing Ab were higher than those of the control group, the reason for this might be that the Ab absorbed a large amount of water under the action of high temperature and formed a compact network structure during the heating process, thus making G' increase. The D_2 group of experimeltal samples had the highest G' value, but there was no significant ($P < 0.05$) difference from D_3.

However, the study by Wang et al. found that the storage modulus (G') and loss modulus (G″) of pork mince decreased with the decrease of soybean residue particle size, which was inconsistent with the results of this study. This might be due to the granules of Ab in the meat emulsion production process, it was first mixed with soybean oil. The smaller particles of Ab can fully disperse the oil, which reduced the accumulation of oil droplets to a certain extent. The protein content used for emulsification was reduced, and more protein was used for coagulation and the formation of the gel, so that the chicken mincemeat had a better network structure.

Experimental part

The increase in the viscosity of chicken mincemeat was related to the water/fat binding capacity and the stability of the emulsion [19]. The final G'' values of all treatment groups were higher than that of the control, indicating that the combination of Ab and soybean oil with different granularities improved the emulsion's stability. The change trend of loss modulus G" was similar to that of storage modulus G'. The value of G " first increased between 33 °C and 36 °C, reached the peak between 50 °C and 54°C, then dropped to the bottom at 63 °C, and then increased rapidly and reached the maximum at 80 °C (Fig. 2). Among them, the value of G" in the gel of D_2 treatment group was the highest, but there was no significant ($P < 0.05$) difference from that of D_3. The G" values of chicken mincemeat were lower than G' value during the entire heating process of gel formation, indicating that elasticity was more dominant than viscosity in chicken mincemeat system.

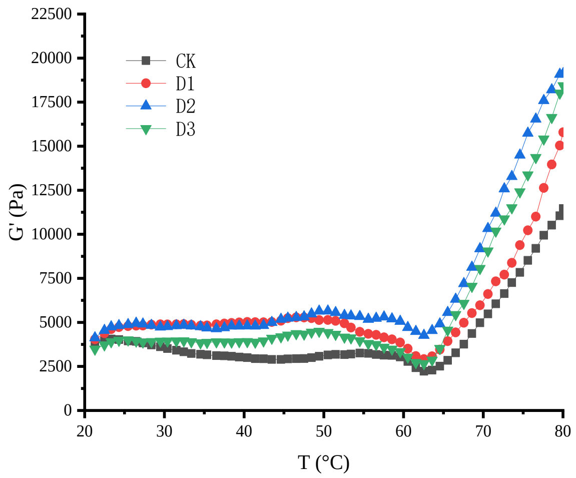

Fig. 1. Effect of temperature on the storage modulus (G') of chicken mincemeat with different particle size of powdered *Agaricus bisporus*

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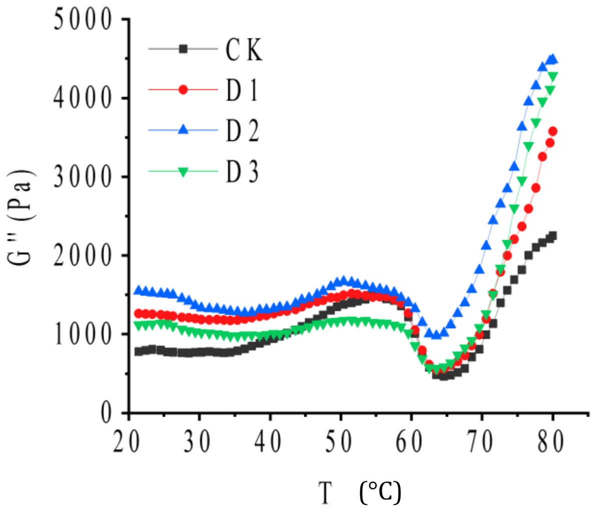

Fig. 2. Effect of temperature on the loss modulus (G'') of chicken mincemeat with different particle size of powdered *Agaricus bisporus*

LF-NMR spin–spin relaxation (T_2). LF-NMR technology can illustrate the state of water in the gel system. The continuous distribution of T2 values are presented in Fig. 3, 4, 5. T_2 relaxation time and corresponding peak areas percentages of water from chicken gel are showned in Tab.2.

Water can be classified into three types according to the activity of water in the muscle fiber structure.

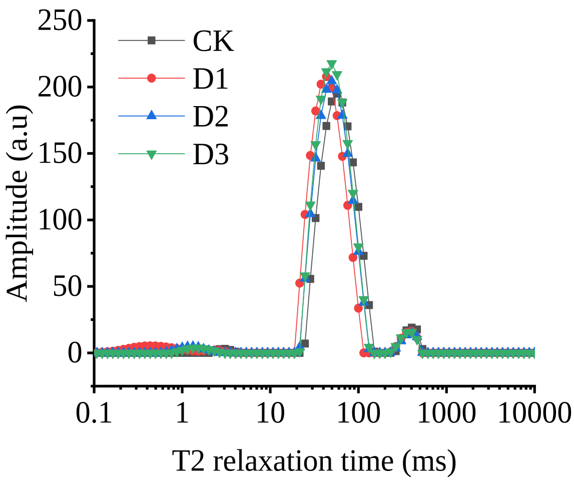

Fig. 3. T_2 relaxation time of chicken mincemeat

The first type of water, T_{2b}, tightly bounding to myofibrillar protein, has a relaxation time of between 0 and 10ms. The immobilized water, T_{21}, locating in the myofibrillar protein matrix , has a relaxation time of between 10 and100 ms. The free water, T_{22}, locating outside the myofibrils, is the most fluid water component in the meat and has a relaxation time of 100 and 400 ms [38; 39].The lower the proton mobility in the gel, the faster the T_2 relaxation time, and the more the T_{21} peak is to the left [32].

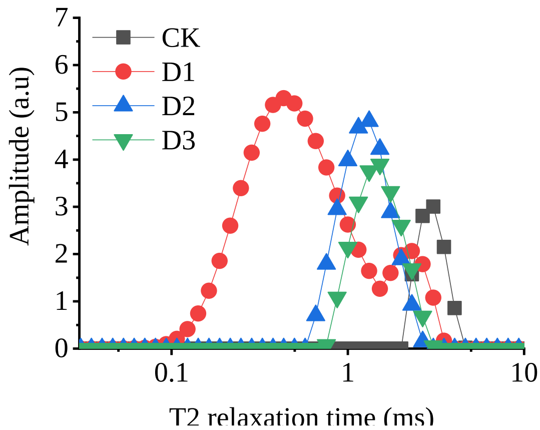

Fig. 4. T_{2b} relaxation time of chicken mincemeat

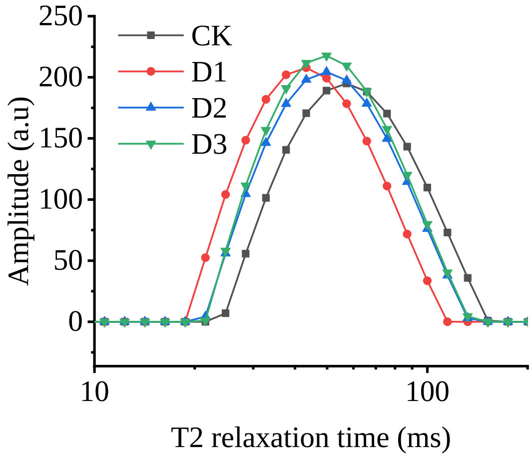

Fig. 5. T_{21} relaxation time of chicken mincemeat

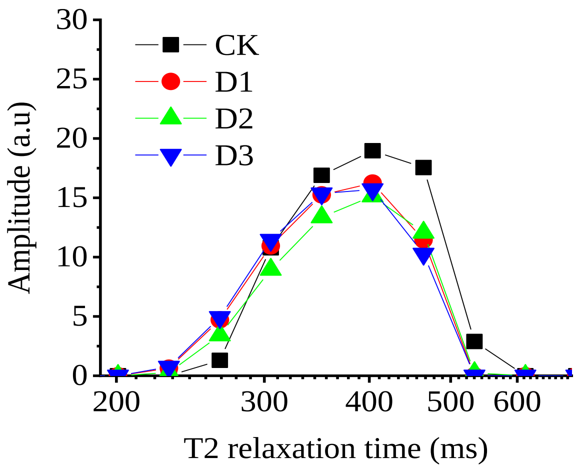

Fig. 6 T_{22} relaxation time of chicken mincemeat

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Table 2

Relaxation times (T_2) and corresponding peak areas percentages of water from chicken gel

Treatments	Traits					
	T2b	T21	T22	PT_{2b}(%)	PT_{21}(%)	PT_{22}(%)
CK	$2.01\pm0.04^{a*}$	21.54 ± 2.15^{a}	231.01 ± 13.62^{a}	0.63 ± 0.21^{d}	95.25 ± 1.34^{a}	4.12 ± 1.87^{a}
D_1	0.03 ± 0.01^{c}	18.74 ± 2.53^{b}	200.92 ± 13.42^{b}	3.83 ± 0.24^{a}	92.70 ± 1.42^{b}	3.46 ± 0.31^{b}
D_2	0.57 ± 0.08^{b}	18.74 ± 2.47^{b}	200.92 ± 12.38^{b}	1.67 ± 0.22^{b}	95.13 ± 1.67^{a}	3.20 ± 0.37^{b}
D_3	0.66 ± 0.10^{b}	18.74 ± 3.01^{b}	200.92 ± 12.98^{b}	1.21 ± 0.32^{c}	95.48 ± 1.51^{a}	3.30 ± 0.45^{b}

* $^{a\text{-}d}$ Different letters in the same column indicate significant differences ($P < 0.05$)

It can be seen from Tab.2 that the cooperation of mushroom powder from Agaricus bisporus and soybean oil caused the T_{21} shifted toward faster relaxation times compared with the control group, and D_1 had the fastest T_{21} ($P < 0.05$). This may be due to the fact that the active groups of dietary fiber in mushroom powder from Agaricus bisporus enhanced the interaction between proteins, and then promoted the self-binding of proteins, forming a firm network, thus limiting the mobility of water protons[40]. In addition, watered mushroom powder particles and the hydrophilic groups of it dietary fiber combined more hydrogen proton and the gel matrix hydrated more fastly [41]. Compared with the control, the addition of mushroom powder significantly increased the P_{2b} of l ($P < 0.05$) and accompanied by a remarkable decrease in PT_{22} ($P < 0.05$), which indicated that adding of mushroom powder and soybean oil promoted the tight bounding of water and protein, reducing the proportion of free water, and improved water retention.

Among the samples, D_1 had the largest PT_{2b} and the smallest PT_{21}, while PT_{22} had no significant ($P < 0.05$) difference with D_2 and D_3, which might be attributed to the physical retention of water of porous surface of the mushroom powder. Meanwhile, it indicated that the water in D_1 to the bound, which significantly ($P < 0.05$) increased the stability of hydrogel and made D_1 sample had the largest water holding capacity, which was consistent with our previous research results. These results suggested that it was necessary to optimize the particle size of mushroom powder for the gel system.

Microstructure of cooked chicken mincemeat. Fig. 7 displays photo of samples, obtained SEM with and without added mushroom powder particle different sizes and soybean oil. It can be seen from Fig. 7 that the microstructure of gel network changed obviously with the decrease of the particle sizes.

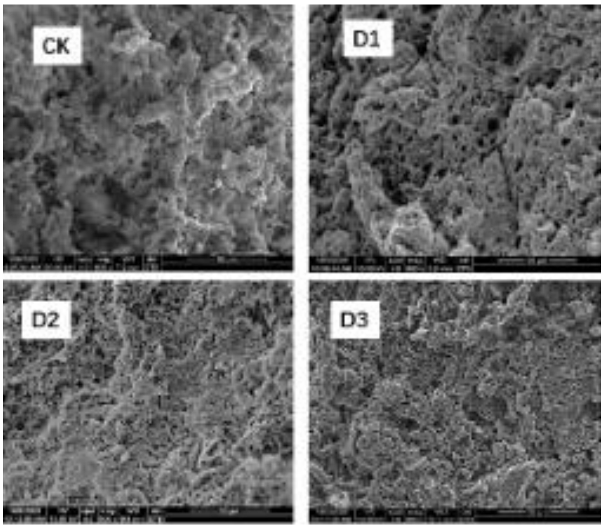

Fig.7. Typical scanning electron micrographs (SEM) samples at 2000 × magnification

The SEM image reflected the microstructure of the gel and can be used for explaining the water holding capacity. Smooth gels can effectively bind water, while coarse gels have fragile and had low water holding capacity [42].The control group had rough surface and large, irregular cavity structure, whereas the others objects showed uniform, compact, homogeneous and ordered network structure. The pores in the microstructure of gel was water channels [36], it was easy for water to escape from the protein network in through them, resulting in the increase of water loss. Therefore, it could be inferred that the cooking loss of all treatment groups should be less than that of the control, which was consistent with the result of water holding capacity in our experiment.

It can be seen from Fig. 7 that the microstructure of gel network changed obviously with the decrease of the particle sizes.

Among the SEM images of D_1, D_2 and D_3, D_1 showed a larger pore size, the possible reason was the mushroom powder with larger particles had greater water holding capacity and swelling characteristics. Most of the water in the gel was captured by particles mushroom powder by hydrogen bonding, then the mushroom powder swelled and filled the gel network gap of protein, creating big cavity. Nevertheless, mushroom powder with small particle size had less water holding, oil holding and swelling capacities. Mushroom powder with small particle size and soybean oil made the gel network structure more uniform. However, the SEM images of D_2 and D_3 did not show a distinct difference, the possible reason was the absorbable and expanding powder just filled the gaps in the protein three-dimensional network structure, showing a more uniform microstructure.

Conclusions

Thus we can conclude, the particle size of mushroom powder from Agaricus bisporus was affected the rheological properties, water distribution and microstructure of chicken mincemeat. Rheology researches, study of method LF-NMR relaxation time and using scanning electron microscopy can explain quite fully the specific interactions between different components of chicken mincemeat, which be in hydrogel form including next heat-induced processing. The article shows that Agaricus bisporus mushroom powder mixed with soybean oil acts as a full-fledged substitute for hard fats, which have the ability to rapidly oxidize. Such a replacement made it possible to increase the shelf life of minced meat and products based on them, which is quite an important decision for the food industry. The combination of large dispersion mushroom powder and soybean oil has been increased the water holding capacity of gel by converting the free water to the bound water in the chicken mincemeat system. The combination small dispersion mushroom powder and soybean oil improved the viscoelasticity of the chicken mincemeat, and made have microstructure a more compact and uniform.

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