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Formulation and Structural Properties of Textured Vegetable Proteins Balls using Polydextrose

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The increasing global population accelerates environmental degradation, contributes to global warming, reduces agricultural land, and causes food shortages. Developing products that can reduce dependence on animal husbandry and ensure global carbon neutrality is necessary. This study aimed to create TVP (Textured Vegetable Proteins) meatballs with Polydextrose (PDX) supplementation. The fixed ingredient composition per 100 g was as follows: 70 g ISP (Soy Protein Isolate), 26 g soybean powder, 5 g HVP (Hydrolyzed Vegetable Protein), 4 g soybean oil, and 2 g salt. Added water content was 200 % (by weight). Additives and structural components used include PDX and wheat gluten. Structural properties such as texture, moisture, and water absorption capacity of the formulations have been performed. With 16 % gluten content and 0.9 % polydextrose, the TVP meatballs have a stable structure. This study provided knowledge on how to process alternative meat products that can reduce the burden on animal husbandry and protect the environment.

1. Introduction

Meat is a group of food that provides protein to humans and has been a part of the diet since ancient times. Meat has played a significant role in human culture and cuisine. The increasing global population pressured the industry to produce enough animal protein to meet the growing demand. The livestock sector was estimated to use around 30 % of the global land area, contributing to deforestation, biodiversity loss, and significant environmental impacts such as greenhouse gas emissions, fertilizer use, and water quality degradation. In this context, plant-based protein with Textured Vegetable Protein (TVP) structure is becoming an important component in meat alternatives (Lee et al., 2020). Plant-based protein with TVP structure can be defined as a source of protein with added fiber to create a fibrous texture similar to animal muscle. High protein content in TVP is typically made from legumes, oats, or wheat (Baune et al., 2022). Soybean is a high-protein plant with the ability to gelling properties and water-holding capacity (Kyriakopoulou et al., 2021). Additionally, it has a highly similar appearance to meat (Fang et al., 2014). Soybean is also a widely available protein source with low cost making soybean protein a key ingredient in plant-based products (Hong et al., 2022). The use of plant-based protein as a substitute for animal protein is still limited due to concerns that omitting meat may result in nutrient deficiencies and impact health. Vegetarian products need more diversity and meet consumer taste preferences. Melina et al. (2016) have commented that plant-based diets were considered environmentally sustainable compared to diets rich in animal products as they used fewer natural resources and caused less environmental damage to land, water, and air. Plant-based products contribute to lower total cholesterol levels and better blood glucose control. These factors reduced chronic diseases (Melina et al., 2016). Scientific and rational utilization of plant-based food can provide adequate nutrition for adults and children, enhance health, and reduce the risk of serious chronic diseases. A previous study has shown that vegetarians tend to have lower body mass index, lower total serum cholesterol with lower density lipoprotein, reduced mortality rates from ischemic heart disease, and lower rates of hypertension, stroke, type 2 diabetes, and certain cancers (Craig, 2010). Polydextrose (PDX) is a dietary fiber formed from glucose, sorbitol, and citric acid through a polymerization reaction (Cho, 1999). PDX was widely used in the food industry as a bulking agent with low caloric content (1 $kcal.g^{-1}$), aiding in water solubility and reducing product viscosity (Do Carmo et al., 2016).

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There have been numerous studies on TVP internationally. There are many different types of TVP, mainly based on various functional properties of plant proteins such as water and oil binding capacity, gel formation and gel strength, including categories such as chunk and minced products, structured meat analogs, fibrous protein products, and high-moisture meat analogs (Baune et al., 2022). In Vietnam, TVP is still a relatively novel product. In this context, plant-based protein with TVP structure, rich in high protein content and supplemented with PDX fiber, is a suitable solution to enhance fast food products such as instant noodles, contributing to a sustainable food supply. With the content mentioned above, this study aimed to develop TVP meatball products with the addition of PDX, focusing on specific research topics: 1) Determining TVP meatball formulation; 2) Investigating the structure of the formulated TVP.

2. Materials and Methods

2.1 Raw materials

Soybean flour, soy protein isolate (ISP), gluten, and meat flavor enhancer (HVP) were obtained from the International Food Industry Corporation. Address: B2-52, Street No. 1, Tan Dong Hiep B Industrial Park, Tan Dong Hiep Ward, Di An City, Binh Duong Province, Vietnam. Ingredients in soybean flour as protein: 50.5%, moisture: 4.5%, fiber: 3.3%, fat: 0.9%, ash: 6%. ISP with the following parameters on the package label protein: 90%, moisture 6%, ash: 6%, fat: 1%. The control sample (CS) Vistessence Tex Crumble 1805, Ingredion Singapore Pte Ltd. It contains a minimum of 75% protein content (dry basis) with 100% pea-base texturised protein. Simply soybean oil: PET bottle with a capacity of 1000 mL, produced by CALOFIC Co., Ltd. Iodized iodine-enriched salt is a product of the Southern Salt Corporation (SOSAL GROUP).

2.2 Preparation of TVP meatball

Step 1: The ingredients were weighed according to the mixing formula (MF) in Table 1.

Table 1: Mixing ingredients of surveyed TVP formulas

Ingredients	Mixing Formula (MF)				
Soy flour			26		
ISP			70		
Soybean oil			4		
Gluten	0 % (MF1)	4 % (MF2)	8 % (MF3)	12 % (MF4)	16 % (MF5)
PDX	0 % (MF6)	0.3 % (MF7)	0.6 % (MF8)	0.9 % (MF9)	1.2 % (MF10)
Salt			2 %		
HVP			5 %		
Water			200 %		

Note: The main ingredient mixture was fixed according to the ratio of soybean flour: ISP: soybean oil = 26: 70: 4 (% by weight), while the remaining ingredients and water were calculated as a percentage of the total weight of the main ingredient mixture. The compositions of gluten (G) and Polydextrose (PDX) in the MFs were as follows: MF1: 0% G, 1% PDX; MF2: 4% G, 1% PDX; MF3: 8% G, 1% PDX; MF4: 12% G, 1% PDX; MF5: 16% G, 1% PDX; MF6: 16% G, 0% PDX; MF7: 16% G, 0.3% PDX; MF8: 16% G, 0.6% PDX; MF9: 16% G, 0.9% PDX and MF10: 16% G, 1.2% PDX.

Step 2: The water mixture for blending was prepared. The water mixture for blending the product includes water, salt, meat flavour enhancer, and pre-measured PDX. Using a graduated cylinder, measured the water and poured it into a beaker. Added salt, meat flavour enhancer (HVP-599), and PDX into the beaker. Stirred the mixture thoroughly with a glass rod until everything was dissolved.

Step 3: Mixing. All ingredients (except for the ones already included in the water mixture and oil) were added to a dough mixer (Model SP-800, Spar - Taiwan). Start mixing the dough at speed level 1 for 45 s to evenly blend the dry ingredients. Then, add the water mixture to the mixer and mix at speed level 2 for 1 min. Next, add the soybean oil to the mixture and adjust the mixer to speed level 2 for 1 min and 30 s to form a dough mass.

Step 4: Shaping. The dough mass was put into a meat grinder machine (Model KD-N18, Gali - China) to form strands of dough with a diameter of 5 mm. Then, these dough strands were cut into pieces with a length of 10 mm.

Step 5: Oil-Free Frying and Drying. The TVP pieces were placed into an oil-free frying pot (Model GA-M4A, GAABOR - China) and fried at 45 min. Then, transferred to a drying cabinet (Model UNB400 S/N: C412-1523, MEMMERT - Germany) and dried at a temperature of 80 °C for 45 min.

Step 6: Packaging. The TVP pieces were put to cool at room temperature for 30 min. Then, proceeded to pack them into three-sided sealed aluminum foil bags using a vacuum sealer machine (Model V300-10D, FUJI IMPULISE - Japan) to preserve the product.

2.3 Determination of the sample drying time and moisture determination

This work aimed to determine the appropriate drying time for the product after forming. After being shaped, the TVP meatballs were fried (Model UNB400 S/N: C412-1523, MEMMERT - Germany) at 80 °C for 30, 45, 60 and 75 min. The time selected corresponded to the drying sample reaching a moisture content equivalent to the desired moisture content of the CS. The moisture content was determined according to ISO 712:2009; and the drying time of 45 min at 80 °C was selected.

2.4 Water absorption capacity (WAC) determination

WAC was determined using the method described by Oni Yuliarti et al. (2021) with modifications. The weight of the samples was measured and then moistened in 100 mL of distilled water at 50 °C for 12 h. Afterward, the excess water was drained from the samples using a strainer for 15 min. The results were calculated as the average of three measurements (Yuliarti et al., 2021). The formula for calculating WAC as shown in Eq(1):

$$WAC = \frac{\text{Weight of sample after moistening} - \text{Weight of sample before moistening}}{\text{Weight of sample before moistening}} \times 100\ (\%) \quad (1)$$

2.5 Determination of the TVP Texture

The texture of the TVP was determined following the method described by Lee et al. (2022) with slight modifications. The samples were cut into lengths of 10 mm and diameters of 5 mm and soaked in water for 45 min. Then, the excess water was drained using a strainer for 15 min. The TVP samples were placed on the closed end of a water-filled tube with a diameter of 21 mm and a height of 20 mm. Subsequently, the samples were compressed using a Texture Profile Analysis (TPA) machine equipped with a cylindrical probe with a diameter of 25.4 mm and a length of 35 mm. The testing conditions were as follows: pre-test speed = 2 $mm.s^{-1}$, test speed = 2 $mm.s^{-1}$, post-test speed = 2 $mm.s^{-1}$, deformation = 50 %, trigger force = 0.002 N, interval time between two compressions: 3 s.

2.6 Determination of the TVP density

The density of the sample was determined using millet. Use the measuring cylinder, fill the tube with the millet, and record the weight of the millet. The sample was filled in the cylinder with the millet; note the weight of the millet and the sample. The density of the sample is determined by the formula as Eq(2):

$$D = \frac{\text{Mass of millet} - \text{Mass of millet and sample}}{\text{Volume of the pycnometer}} \quad (2)$$

2.7 Data analysis

The experiments were repeated three times. The results were presented as mean ± SD. Statgraphics Centuration XV.I (Version 15.1.2, Corporate Enterprise, USA) was used to analyze experimental data and evaluate the LSD with α = 5 %.

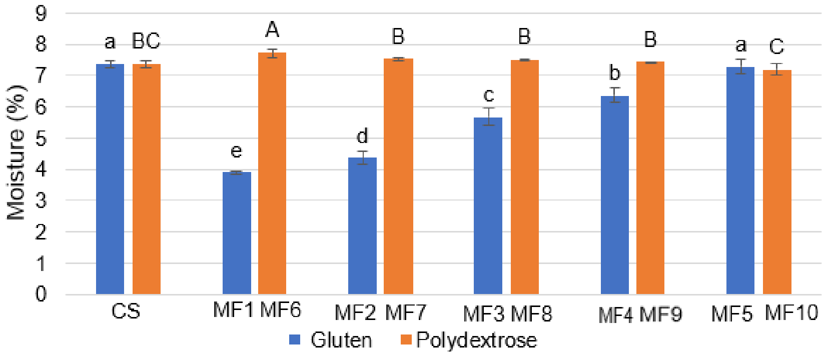
3. Results and Discussion

3.1 Effect of gluten and PDX on the moisture content of the TVP

The moisture content of the samples after assessing the gluten content, as shown in Figure 1, indicated a significant increase in moisture content ($P < 0.05$).

The moisture content of the gluten samples ranged from 3.89 % to 7.29 %, with MF1 having the lowest moisture content (3.89 %) as this formulation did not contain gluten. During the kneading process, when gluten came into contact with water, it activated the interaction between gliadin and glutenin, forming a network structure among the starch molecules, increasing viscosity, and contributing to the moisture content of the product (Schopf and Scherf, 2021). From MF1 to MF5, with increasing gluten supplementation from 0 (MF1) to 16% (MF5), the moisture content also increased.

The moisture content of the PDX samples ranged from 7.19 % to 7.53 % (as shown in Figure 1). MF6 was the sample without PDX and had the highest moisture content, while MF10, which contained the highest PDX content (1.2 %), had the lowest moisture content. The use of PDX often results in a firmer product structure, thereby reducing the moisture content of the product (Yang et al., 2019). The moisture content of the samples showed a small difference due to the relatively low increment in PDX content (0.3 % increment). Moriano et al. (2018) also found that there may be slight changes in moisture content when adding PDX.

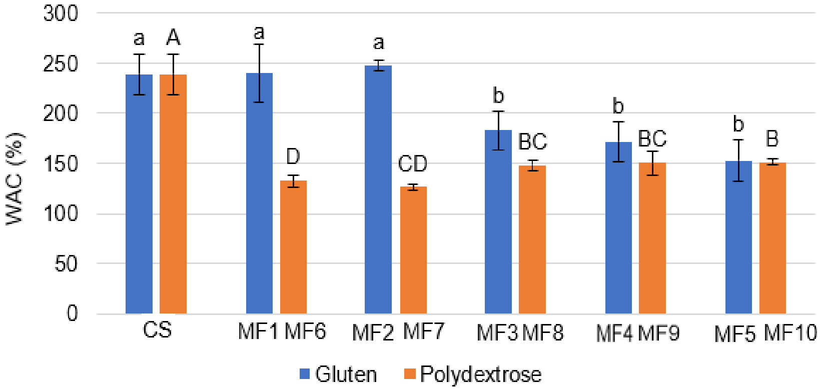


(Different letters represent the difference in the same color column, statistically significant at the P < 0.05 level.)

Figure 1: Effect of gluten and PDX on the moisture content of the TVP samples.

3.2 Effect of gluten and PDX on the water absorption capacity of the TVP

Water absorption capacity (WAC) was defined as the ability to retain water by the components present in the product. The water absorption capacity of the formulas ranged from 152.34 % to 239.58 % (see Figure 2).



(Different letters represent the difference in the same color column, statistically significant at the P < 0.05 level.)

Figure 2: Effect of gluten and PDX on the WAC of the TVP samples.

MF2 had the highest WAC, while MF5 had the lowest WAC. Each formula's gluten content variation led to different water absorption capacities. According to a recent study, wheat gluten had poor solubility in water and only absorbs twice its weight in water (Chiang et al., 2021). Based on the blending ratios of the formulas, the WAC decreased gradually. The control sample (CS) was a researched and commercially available product, which may have undergone technological processes such as extrusion, leading to the highest water absorption capacity. During the extrusion process, proteins were hydrated and plasticized in the extruder barrel through the application of pressure, heat, and mechanical shear. The plasticized mass was then forced through die - holes, where a portion of the moisture evaporates, and protein molecules rapidly aligned to form a fibrous structure. The natural structure of proteins was altered to accommodate the energy input during extrusion, resulting in denaturation and changes in physical, chemical, and functional properties. Thus, different extrusion conditions (moisture, temperature, pressure, and shear) yield TVP with different structures and textures (Hong et al., 2022). The decreasing water absorption capacity from MF1 to MF5 was due to the gluten being denatured during the oil-free frying and drying processes, resulting in a dense powdered mass with fewer air pockets, and lower WAC. MF1, which did not contain gluten, relies on soy protein for water retention. MF2, with the lowest gluten content (4 %), had a WAC similar to MF1 and the CS. The WAC of the PDX-supplemented samples was represented in Figure 2., and the CS also had the highest WAC (238.97 %). The WAC gradually increased from MF6 to MF10. The reason behind this result may be attributed to the addition of PDX. Moriano et al. (2018) concluded that PDX enhances the water-holding capacity of products. The previous research revealed that the enhancement of WAC depends on the concentration of PDX, indicating its potential as a stabilizing and bulking agent due to its inherent water-binding capacity (Huang et al., 2020).

3.3 Structural properties of the TVP

The structural properties (see Table 2) were crucial in determining the quality of plant-based proteins, as the main goal of meat substitutes was to mimic the desired texture of real meat. The structural properties significantly differ among the formulas ($P < 0.05$).

Table 2: Structural properties of the TVP samples

Samples	Hardness (N)	Cohesiveness	Springiness (mm)	Chewiness (mJ)
CS	$6.60 \pm 0.31^{a, B}$	$0.73 \pm 0.06^{a, A}$	$4.49 \pm 0.81^{ab, BC}$	$20.31 \pm 3.81^{a, A}$
Investigate suitable gluten content with a 4 % increment step and a fixed PDX content of 0.3 %				
MF1	1.50 ± 0.37^{d}	0.76 ± 0.22^{a}	4.20 ± 0.83^{c}	4.92 ± 0.44^{b}
MF2	1.46 ± 0.38^{d}	0.74 ± 0.12^{a}	4.53 ± 0.30^{bc}	5.19 ± 0.70^{b}
MF3	2.43 ± 0.21^{c}	0.56 ± 0.05^{ab}	5.43 ± 0.09^{ab}	7.33 ± 0.70^{b}
MF4	4.44 ± 0.05^{b}	0.43 ± 0.09^{b}	5.53 ± 0.40^{ab}	17.82 ± 3.83^{a}
MF5	6.52 ± 0.33^{a}	0.40 ± 0.05^{b}	5.75 ± 0.78^{a}	18.24 ± 5.30^{a}
Investigate suitable PDX content with a 0.3 % increment step and a fixed gluten content of 16 %				
MF6	2.33 ± 0.11^{D}	0.49 ± 0.02^{B}	3.47 ± 1.04^{C}	5.15 ± 0.92^{C}
MF7	2.37 ± 0.10^{D}	0.50 ± 0.05^{B}	4.11 ± 0.73^{C}	6.35 ± 1.12^{C}
MF8	4.61 ± 0.08^{C}	0.49 ± 0.06^{B}	5.36 ± 0.30^{AB}	12.17 ± 0.96^{B}
MF9	6.49 ± 0.25^{B}	0.48 ± 0.06^{B}	5.93 ± 0.12^{A}	16.98 ± 1.21^{A}
MF10	6.96 ± 0.18^{A}	0.45 ± 0.05^{B}	6.34 ± 0.13^{A}	18.29 ± 1.78^{A}

Hardness was calculated from the maximum force during the first compression. The hardness of the gluten-examined samples increased from 1.50 N to 6.60 N. This difference was attributed to the variation in gluten content among the samples. Among them, MF5 had the highest hardness (6.52 N) and was the closest to CS (6.60 N) due to its highest gluten content. Gluten played a role in creating a protein network and was the primary binding agent in the mixture to improve the structure, hardness, and chewiness of the product. The cohesiveness force value decreased from 0.73 to 0.40. This difference may be due to the increased moisture content of the samples ranging from 3.89 % to 7.29 %. Wi et al. (2020) reported that cohesive force decreases as moisture content increases. Both springiness and chewiness tended to increase from MF1 to MF5, indicating that higher gluten content helps the product's structure to better recover its original shape after being subjected to force.
The hardness of the PDX-examined samples, MF6 (2.33 N) and MF7 (2.37 N), showed similarities. MF6 did not contain PDX, while MF7 had 0.3 % PDX supplementation. It can be observed that PDX at a low concentration (0.3 %) did not significantly affect the structure of the product. Serin and Sayar (2017) reported that using PDX increases the product's hardness. The increasing concentration of PDX led to differences among the samples. MF10, with the highest PDX content (1.2 %), had a higher hardness than the control sample. MF9, with a PDX content of 0.9 %, had a structural similarity to the control sample. This study proved that both gluten and PDX had a common effect of increasing hardness, springiness, and chewiness while reducing cohesiveness.
The developed TVP meatball (illustrated as Figure 3c) achieved moisture content 7.42 ± 0.02 %, specific weight 0.43 ± 0.03 ($kg.m^{-3}$), WAC: 150.68 ± 5.40 %, hardness: 6.51± 0.37 (N), cohesiveness: 0.47 ± 0.04, springiness: 5.73 ± 0.19 (mm), chewiness: 17.53 ± 1.16 (mJ). Some main nutritional components of TVP pellets were determined as follows (in % weight) protein: 77.25 ± 1.88, lipid: 4.75 ± 0.26, total ash: 5.25 ± 0.63, and fiber: 6.54 ± 1.97. As a designed formula, the final nutritional components of TVP pellets have a very high protein content, more than three times that of animal meat.

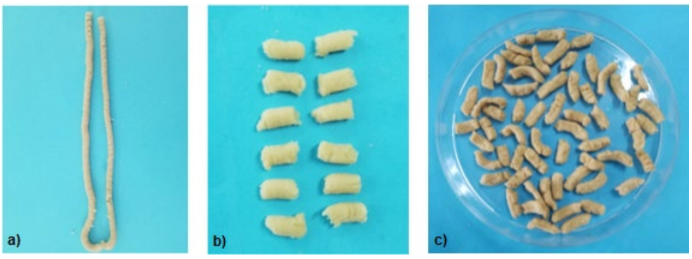


Figure 3: Pictures of a) formed TVP wire b) TVP pellets after shaping c) after drying collecting TVP product

4. Conclusions

The results of this study demonstrate that the water absorption capacity, moisture content, and structural properties of TVP meatballs depend on the gluten and PDX content in each formulation. A gluten content of 16

% and PDX content of 0.9 % contribute to a stable structure of TVP meatballs. These findings provide some blending formulas for TVP meatball production using soy protein, gluten and insights into the structural properties, water absorption capacity, and moisture content, which can aid in developing TVP meatball products in the future. However, sensory evaluation by consumers should be conducted before scaling up to industrial production. The study successfully developed TVP meatballs with an average moisture content of (7.42 ± 0.02) %, high protein content, and suitable characteristics for ready-to-eat products.

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