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Texture characteristics, colour and satiety index of soy protein isolate and glucomannan based meat analogue for obesity intervention

[1]Hiasinta Anatasia Purnawijayanti, [1]Veronica Ima Pujiastuti, [2]M.I Ekatrina Wijayanti

[1]*Undergraduate Nutrition Study Program, Sekolah Tinggi Ilmu Kesehatan (STIKes) Panti Rapih Yogyakarta, Indonesia*

[2]*Nursing and Ners Undergraduate Study Program, Sekolah Tinggi Ilmu Kesehatan (STIKes) Panti Rapih Yogyakarta, Indonesia*

Abstract

A meat analogue was developed using the main ingredients soy protein isolate and glucomannan, and its texture, colour, and satiety index was observed. The experimental research was carried out in a completely randomized design (CRD) with four treatment proportion ratios (%) of soybean protein isolate-glucomannan in the meat analogue formula (30:0, 29:1, 27:3 and 25:5) and three replications. The procedure for making meat analogues includes preparation, mixing, cooking, kneading, and extrusion in a pasta machine, molding, and steaming. Texture testing using a Texture Profile Analyzer, colour testing using a colorimeter, and the satiety index were tested by 30 overweight/obese respondents who were students and employees of the Panti Rapih Yogyakarta College of Health Sciences. The results showed that the proportion of soy protein isolate and glucomannan affected all texture parameters, with hardness, cohesiveness, resilience, springiness, gumminess, and chewiness values being smaller than the R (reference) sample. The proportion of soy protein isolate and glucomannan also influences colour parameters in the form of L*, a*, b*, and ΔE values (the difference between the browning index of meat analogue and R) but does not affect the browning index of meat analogue. The satiety index of meat analogue was 112.6%, so could be used in obesity interventions.

Keywords:Meat analogue, satiety index, obesity, Soy protein isolate, glucomannan

Introduction

Obesity has become a world health problem. WHO states that in 2022 two and half billion adults will be overweight, and 890 million of them will be obese. A person is declared overweight if their body mass index is higher than 25 and obese if it is higher than or equal to 30. Obesity is a serious health problem because it can increase the risk of developing Type 2 Diabetes Mellitus and heart disease, affect bone and reproductive health, and increase the risk of cancer of certain types. The overweight prevalence in Asian and African countries is 31% while in countries on the American continent around 67%. Obesity also has economic impacts. If there are no serious efforts to control it, it was estimated that global costs related to handling it will reach 3 trillion US dollars in 2030 and 18 trillion dollars in 2060. Multisectoral cooperation is needed to prevent an increase in obesity rates, including in the food engineering industry (WHO, 2024).

Treating obesity through food engineering is carried out to produce food with a nutritional composition which suitable for weight loss, namely low calories and low fat, but still filling (E Kelezsade et al., 2020). Plant-based meat analogue can be an alternative food for obesity intervention because their composition can be engineered so that it meets specified criteria. Several types of vegetable ingredients have been explored as base ingredients for meat analogue, such as soybeans (Izalin Zahari et al., 2020), oats and peas (A. Kaleda et al., 2021), rapeseed (W. Jia et al., 2021), soy-corn flour (Bambang R et al., 2022), pea protein and gluten (S.T. Dinani et al., 2023), tempeh flour (Valentinus PB et al., 2023).

Plant-based meat analogue is generally still different from meat in terms of mouthfeel, texture, taste, and aroma (Gihyun W et al., 2020). Consumer acceptance of meat analogue depends on how similar their fiber structure is to meat muscle. Apart from that, meat analogue should have similar texture, sensory and nutritional properties (Malsya Dinali et al., 2024). However, to imitate meat in other characteristics, such as colour, aroma, and mouthfeel, non-protein additives must be used (Kyriakopoupou et al., 2021). Several researchers explored the use of non-vegetable protein

commodities to improve the characteristics of meat analogues, such as konjac gel (Jimenez-Colmenero et a, 2013); mushrooms (Arun K Das et al ., 2021; Valentinus PB et al., 2023), seaweed (B Rianto et al., 2022), iota carrageenan (Taghian Dinani et al., 2023a), various types of hydrocolloids (Taghian Dinani et al., 2023b) and vegetable oils (Youngjae et al., 2023).

In this study, a meat analogue based on soy protein isolate and glucomannan was developed and its texture, colour, and satiety index were evaluated for obesity intervention.

Materials and methods

Research Design

Experimental research was carried out in a completely randomized design (CRD) with four treatments in the form of proportion ratios (%) of soy protein isolate-glucomannan in the meat analogue formula (30:0, 29:1, 27:3, and 25:5) and three replications.

Materials

The main research materials are soy protein isolate (SPI) (Para Agro) and Konjac glucomannan (KGM) (d3lynfood). Additional ingredients consisting of water, fresh oyster mushrooms, wheat gluten (Ric and Bris Fine Food Products), and stock powder (Maggi Block) were used in equal amounts in all treatments.

Research Equipment

Food processor, electric pasta machine (Wiratech Noodle Maker NOD-888) with knead and extrude mode, blender, cooking equipment, satiety index testing equipment, texture testing equipment TA1 Texture Analyzer (Lloyd-Instruments-AMETEX), color testing equipment (Chroma Meters CR-400, KONICA MINOLTA, INC., Japan) and anthropometric and body composition measurement equipment (In-Body).

Meat analogue formulation

The formulation of meat analogue based on soy protein isolate and glucomannan to obtain meat analogue with a water content of 60-65% refers to research by S.T. Dinani et al. (2023b) with modifications, as follows: Soy Protein Isolate (25-30%), glucomannan (0-5%), wheat gluten 10%, fresh oyster mushrooms 24%, distilled water 37.5% and stock powder 1%. The meat analogue formulations are listed in Table 1

Table 1. Meat analogue formulation with different soy protein isolate-konjac glucomannan proportions

Ingredients	Treatments			
	MA_0	MA_1	MA_2	MA_3
Soy Protein Isolate, gr	120	116	108	100
Glucomannan, gr	0	4	12	20
Wheat Gluten, gr	40	40	40	40
Fresh Oyster Mushroom, gr	100	100	100	100
Water, gr	150	150	150	150
Stock Powder, gr	4	4	4	4

Meat analogue preparation

1. Cut the oyster mushrooms into pieces and grind them with a wet blender add some distilled water.
2. Mix wheat gluten and stock powder well.
3. Dissolve the glucomannan in distilled water, then heat with the oyster mushrooms until thick, reduce heat, add the soy protein isolate, stir until evenly mixed, and remove from the heat.
4. Add the wheat gluten + stock powder, after checking the temperature of the mixture to no more than 80oC. Stir until evenly mixed
5. Put the dough into the pasta machine, install a barrier between the kneading chamber and the extrusion chamber, set the mixing time for 5 minutes, then press the knead button

6. Lift the barrier, set the lasagna mold mode, then press the extrude button, and the extrusion process continues until all the dough is extruded
7. Mould the extruded dough into a cylinder with a diameter of 3 cm, wrap it in aluminum foil, then steam it over medium heat for 30 minutes.
8. Cool the resulting meat analogue, then pack it in a plastic bag.
9. The product is then used for texture, color, and satiety index testing

The reference sample (R) is prepared from chicken lean meat plus wheat gluten in the same amount as the treatment.

Texture Profile Analysis

Texture profile analysis (TPA) was carried out using a TA1 Texture Analyzer (Lloyd-Instruments-AMETEX). The meat analogue samples are cut from the middle portion (10 × 10 × 10 mm). A cylinder probe was used, and the setting conditions were pre-calibrated. Three replicate tests were conducted for each sample, and the hardness, chewiness, springiness, gumminess, and cohesiveness values were obtained automatically.

Colour Measurements

Chromameter Konica Minolta CR-400 was used to measure the colour of meat analogue. The measurement method refers to the CIE system. The L* value is Lightness, between 0 and 100 is white, a* is a red color between 0 and 60 and a green color between 0 and -60, b* is yellow between 0 and 60 and blue between 0 and -60. Browning index (BI) was calculated using L*, a*, and b* data by Eq. (S.T. Dinani et al., 2023a):

$$BI = \frac{100}{0.17} \times \left(\frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} - 0.31 \right)$$

Satiety Index Measurements

The satiety index test involved 30 overweight/obese respondents. Before testing, the anthropometry and basic health parameters of respondents were measured including body weight, height, and blood pressure as well as body composition including total body water, fat mass, skeletal muscle mass, percent body mass, and obesity degree. Respondents carried out the test twice, namely consuming processed meat analogue in the first test and white bread in the second test. A serving of meat analogue and white bread contains the same number of calories, 240 calories. Respondents fast for at least 8 hours/night, and testing was carried out in the morning. Respondents give a satiety score using a satiety scale before eating the sample, immediately after eating the sample, and every 30 minutes thereafter until the 180th minute. The data obtained is then plotted on a graph to determine the satiety index by calculating the area under the curve (M Skotnicka, 2022). The satiety score scale is 1-10 using a scale developed by University Health Services, University of California, Berkeley, as follows:

1. Starving, feeling weak, lethargic
2. Feeling very hungry, lack of energy, very rumbling stomach
3. Feeling a bit hungry, and start growling
4. Start to feel hungry
5. Neutral, neither hungry nor full
6. A bit full
7. Feel full and satisfied
8. Feel fuller, stomach feels comfortable
9. Feel very full and uncomfortable in the stomach
10. Extremely stuffed, nauseous

Statistical Analysis

All experimental work was carried out freshly prepared samples in three replicates. Data were reported as means ± standard deviations. Analysis of variance and the Duncan Multiple Range Test were used for statistical analysis.

RESULTS AND DISCUSSIONS

Texture Profile of Meat Analogue

Table 2. Texture profile analysis of meat analogue at different formulation

Sample	Hardness Bite (N)	Cohessive ness	Resilience	Springiness	Guminess (N)	Chewiness (N)
MA_0	73,95 ± 4,59a	0,42 ± 0,058a	0,42 ± 0,11a	0,85 ± 0,01a	30,89 ± 5,28a	26,23 ± 4,50a
MA_1	67,34 ± 9,19ab	0,38 ± 0,058ab	0,43 ± 0,11a	0,81 ± 0,02a	25,85 ± 5,89ab	21,17 ± 5,48ab
MA_2	62,20 ± 13,31b	0,32 ± 0,056bc	0,26 ± 0,05b	0,76 ± 0,05b	20,31 ± 7,32b	15,75 ± 6,27b
MA_3	36,02 ± 5,91c	0,26 ± 0,048c	0,21 ± 0,04b	0,69 ±0,03c	9,27 ± 1,45c	6,40 ± 1,24c
P-value	0,00	0,00	0,00	0,00	0,00	0,00
R	197,47	0,64	0,7474	0,924	126,46	116,81

The proportion of soy protein isolate-glucomannan affects texture parameters covering hardness, cohesiveness, resilience, chewiness, springiness, and gumminess. The hardness corresponds to the maximum force required to compress meat analogue and is defined as the force needed to compress the sample using teeth. The hardness is determined as the maximum force of the first compression. The cohesiveness indicates the strength of the network formed and is determined by the number of samples that stand together during chewing (D. De Angelis et al., 2020). The cohesiveness results were expressed as the area of work during the second compression divided by the area of work during the first compression. Resilience is how strong and fast the recovery. It is calculated by dividing the upstroke energy of the first compression by the downstroke energy of the first compression. Springiness describes the recovery of the meat analogue after deformation and defines to what extent the sample recovers after a second compression to its initial height. The springiness was expressed as the ratio between the height of the meat analogue at the start of the second compression and the meat analogue's height at the initial of the first compression. The gumminess is a mechanical textural characteristic associated with the cohesiveness of a tender product. It corresponds to the effort needed to disintegrate sample in the mouth to a ready form for swallowing and is defined as the product of hardness times cohesiveness. Chewiness represents the energy required to chew the meat analogue and is defined as the force needed to masticate the sample before swallowing. The chewiness is calculated by multiplying the gumminess by the springiness (A Kaleda et al., 2020).

All meat analogue samples had hardness, cohesiveness, resilience, springiness, gumminess, and chewiness values that were smaller than sample R. The higher proportion of konjac glucomannan in the meat analogue formula tends to decrease the hardness cohesiveness, resilience, springiness, gumminess, and chewiness values. KGM molecules contain a large number of hydroxyl and carbonyl groups. The hydroxyl group in KGM can reduce the formation of disulfide, hydrogen, and hydrophobic bonds, thus reducing the aggregation of proteins and preventing their denaturation (Ning Zhou et al., 2022). Inhibition of protein denaturation in meat analogue causes the protein to lose its ability to form a gel (gelation), even though the gelling properties of proteins are very important as their thickening, stabilizing, and water absorption abilities influence the rheological, textural, microstructural, nutritional and organoleptic properties of food matrix (Smriti Shrestha et al., 2023). The texture characteristics of the resulting meat analogue are not similar yet to the texture of the reference sample.

Colour of Meat Analogue

Table 3. Colour characteristics (L*, a*, b*), browning index (BI-Browning Index) and color difference with standard (ΔE) of meat analogue

Sample	Colour Characteristics			BI	ΔE
	L*	a*	b*		

MA_0	65,81 ± 1,70ab	-2,71 ± 0,36a	23,12 ± 0,39a	38,85 ± 2,50a	13,38 ± 1,73ab
MA_1	67,88 ± 1,87b	-3,18 ± 0,13bc	23,42 ± 0,29a	37,44 ± 1,57a	11,50 ± 1,76a
MA_2	64,76 ± 2,15a	-2,88 ± 0,54ab	23,14 ± 0,25a	39,44 ± 1,86a	14,42 ± 2,04b
MA_3	66,68 ± 0,92ab	-3,38 ± 0,17c	23,23 ± 0,31a	37,59 ± 1,15a	12,59 ± 0,89ab
P-value	0,033	0,013	0,38	0,204	0,041
R	78,77	-2,69	19,82	25,63	

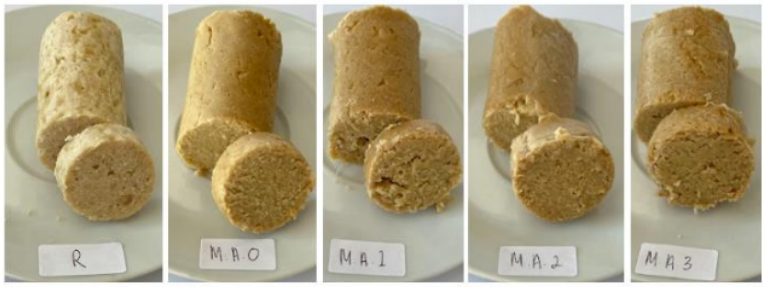

Figure 1. Images of meat analogues with different formulation: MA-0 (30% SPI, 0% KGM); MA-1 (29% SPI, 1% KGM); MA-2 27% (SPI, 3% KGM) and MA-3 (25% SPI and 5% KGM). R was reference sample, made from chicken lean meat and wheat gluten

The proportion of soy protein isolate and glucomannan in the formula affected the L*, a*, b*, and ΔE values of the meat analogue, but did not affect the browning index. All samples had a greater browning index than the reference sample made from chicken meat. The browning index is closely related to the occurrence of the Maillard reaction. This reaction generally occurs during processing using high temperatures. The free carbonyl group in the reducing sugar binds to the amino acid via a covalent bond and forms a brown compound (S.T. Dinani et al., 2023a). KGM molecules contain a large number of carbonyl groups (Ning Zhou et al., 2022), and thus the Maillard reaction occurs more intensively and produces the brown Amadori compound.

Satiety Index of Meat Analogue

Table 4 Characteristics of Satiety Index Test's Respondents (n = 30)

Characteristics	Values
Age (y)	26,00 ± 8,99
Weight (kg)	89,35 ± 20,9
Height (cm)	161,71 ± 9,08
Body Mass Index (kg/m2)	33,6 ± 5,47
Percent Body Fat (%)	45,78 ± 6,00
Fat Mass (kg)	40,88 ± 12,91
Skeletal Muscle Mass (kg)	26,55 ± 6,49
Total Body Water (kg)	35,15 ± 7,98
Obesity Degree (%)	158,13 ± 27,01
Systolic Blood Pressure (mm Hg)	125,23 ± 14,43
Diastolic Blood Pressure (mm Hg)	87,17 ± 8,70

Respondents were students and employees of the Panti Rapih Yogyakarta College of Health Sciences, with ages ranging from 20 to 55 years, with a mean of 26 years. Out of 30 respondents, four were overweight (BMI 25-29.9 kg/m2) and 26 were obese (BMI ≥ 30 kg/m2). The obesity degree of respondents varied from 121 to 261%, with a mean of 158%. The obesity degree normal range was 90-

110%. Three respondents had high blood pressure, while the rest had normal blood pressure (< 140/90 mm Hg).

Figure 2. Graph of respondents' satiety scores against time before and after consumption (minutes)

In the satiety index test, the MA_2 sample was used. Sample selection was due to previous research, where the MA-2 sample had better sensory characteristics than other samples (H.A. Purnawijayanti et al., 2024). The test results show that the area under the imitation meat curve is 48.4 and the white bread curve is 42.97. Thus, the satiety index for meat analogue with the MA_2 formula is 112.6%. A satiety index of more than 100% indicates that meat analogue provides a sensation of fullness for longer than control/white bread. Foods with a high satiety index can suppress hunger, making them suitable for treating obesity (M Skotnicka, 2022). Foods that generate intense satiety sensations have obvious benefits for weight management. Food's satiating power is dependent on the amount of protein, carbohydrate, fat, and fiber it contains (L Chambers, 2015).

Dietary fiber has been evidently to increase the satiety index (Paulo E.S. Munekata et al. 2021). In meat analogue formulations, the sources of fiber are oyster mushrooms and glucomannan. Oyster mushrooms are a type of mushroom, and mushrooms are foods rich in dietary fiber (M Wang and R Zhao, 2023). Glucomannan is a soluble fiber that forms a viscous, gel-like mass when hydrated in the stomach. This contributes to a reduction in the gastric emptying rate and can induce satiety leading to a decrease in subsequent energy intake (E Keleszade et al. 2020).

Compared to carbohydrates and fat, protein provides the highest satiating effect. Increasing the protein composition of the diet without changing net energy can lead to enhanced feelings of satiety (L Chambers, 2015). In the satiety index test, meat analogue and white bread were used at the same energy value, 240 Calories. The protein content of meat analogue is 21.24% while white bread is 8%. Meat analogue protein comes from soy protein isolate and wheat gluten. As related proteins, several studies reported their higher satiating potential than other macronutrients. Evidence suggests that the satiating effect of proteins is higher when compared to iso-energetic amounts of carbohydrates and fat (D Martini et al. 2018). The mechanism of how protein could increase the feeling of satiety results from elevated anorexigenic hormone levels lowered orexigenic hormone levels, increased diet-induced thermogenesis, elevated plasma amino acid levels, increased gluconeogenesis in the liver, and increased ketogenesis due to higher protein intake (M Skotnicka et al. 2022).

Conclusions

The proportion of soy protein isolate and glucomannan influences all texture parameters, including hardness, cohesiveness, resilience, springiness, gumminess, and chewiness. The scores of all imitation meat texture parameters are smaller than the R (reference) sample. The texture characteristics of the meat analogue are not similar yet to the reference sample. The proportion of soy protein isolate glucomannan also influences colour parameters in the form of L*, a*, b*, and ΔE values (the difference between the browning index and R) but does not affect the browning index of the meat analogue. The

browning index of the meat analogue is greater than the reference sample. The satiety index of meat analogues is 112.6%, so it is suitable for obesity interventions.

Acknowledgments

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Possessive Review the rules for possessive nouns.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

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Missing "," Review the rules for using punctuation marks.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Missing "?" Review the rules for using punctuation marks.

Missing "," Review the rules for using punctuation marks.

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Proofread This part of the sentence contains an error or misspelling that makes your meaning unclear.

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Missing "," Review the rules for using punctuation marks.

Article Error You may need to use an article before this word.

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Missing "," Review the rules for using punctuation marks.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Word Error Did you type **the** instead of **they**, or have you left out a word?

Article Error You may need to remove this article.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to remove this article.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Confused You have used either an imprecise word or an incorrect word.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Missing "," Review the rules for using punctuation marks.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

Article Error You may need to use an article before this word.

Missing "," Review the rules for using punctuation marks.

Run-on This sentence may be a run-on sentence.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Article Error You may need to remove this article.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Article Error You may need to use an article before this word.

Prep. You may be using the wrong preposition.

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Article Error You may need to use an article before this word.

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PAGE 5

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to remove this article.

Article Error You may need to use an article before this word. Consider using the article **the**.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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