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Optimization of Processing Technology for Compound Vegetable Quick-Frozen Fish Balls

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Abstract
To improve the quality of traditional fish balls, grass carp surimi was used with purple cabbage juice, soy protein isolate (SPI), TG enzyme, and sweet potato starch. Single-factor and orthogonal tests evaluated sensory score, water retention, and thawing loss. Optimal addition levels: purple cabbage juice 12%, SPI 4%, TG enzyme 0.6%, sweet potato starch 6%. TG enzyme had the greatest impact on sensory quality. The optimized fish balls scored 9.15, showing good color, texture, elasticity, and low thawing loss. This provides a reference for functional frozen surimi products.

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Keywords: Grass Carp Surimi, Purple Cabbage Juice, Soy Protein Isolate (SPI), TG Enzyme, Quick-Frozen Fish Balls

1. Introduction

To address the limitations of traditional fish balls (single fish species, poor nutrition, texture deterioration, short shelf life), quick-frozen composite vegetable fish balls have emerged as a new solution. Purple cabbage vegetable juice, rich in anthocyanins, vitamin C, and dietary fiber, improves color stability, water retention, antioxidant capacity, and sensory quality, fitting the low-fat, high-fiber trend. Recent studies have enhanced surimi products by adding plant ingredients, exogenous proteins, TG enzyme, and starch, optimizing gel strength, water retention, freeze-thaw stability, and sensory quality. Research shows that plant-derived ingredients improve gel structure and color and increase dietary fiber content [1-5]; TG enzyme promotes protein crosslinking and enhances gel networks [6-7]; sweet potato starch and other fillers improve hardness and freeze-thaw stability [8-9]; quick-freezing and other processes extend shelf life [10]. However, limited research exists on the synergy between purple cabbage juice, SPI, TG enzyme, and sweet potato starch in quick-frozen fish balls. This study optimizes the full processing technology to promote functional, standardized, and industrial development of fish ball products.

2. Materials and methods
2.1. Materials and reagents

Table 1: Materials and Reagents

Materials and Reagents	Level	Manufacturer
Fresh grass carp	Food grade	Subanqiao Vegetable Market, Jingmen, China
Purple cabbage	Food grade	Subanqiao Vegetable Market, Jingmen, China
Soy protein isolate	Food grade	Shandong Yuxin Biotechnology Co., Ltd.
Transglutaminase (TG enzyme)	Food grade	Shandong Longkote Enzyme Preparations Co., Ltd.
Sweet potato starch	Food grade	Hubei Yucheng E-commerce Co., Ltd.
Table salt	Food grade	China Salt Tianjin Salt Industry Co., Ltd.
Five-spice powder	Food grade	Subanqiao Vegetable Market, Jingmen, China
Monosodium glutamate (MSG)	Food grade	Subanqiao Vegetable Market, Jingmen, China
Sichuan pepper	Food grade	Subanqiao Vegetable Market, Jingmen, China
Lard	Food grade	Subanqiao Vegetable Market, Jingmen, China
Cooking wine	Food grade	Subanqiao Vegetable Market, Jingmen, China

2.2. Instruments and equipment

Table 2: Main instruments and equipment

Instruments and Equipment	Manufacturer
FA224C Electronic Analytical Balance	Shanghai Lichen Bangxi Instrument Technology Co., Ltd.
RZ-348T Juicer	Hefei Royalstar Small Household Appliance Co., Ltd.
C21-WK2102 Induction Cooker	Midea Group Co., Ltd.
BH-80L Variable Frequency Bowl Cutter	Shandong Zhucheng Bohai Machinery Co., Ltd.
HH-4 Digital Constant-Temperature Water Bath	Shanghai Lichen Bangxi Instrument Technology Co., Ltd.
DW-86L388J Ultra-Low Temperature Freezer	Qingdao Haier Biomedical Co., Ltd.

2.3. Experimental method
2.3.1. Preparation process of vegetable quick-frozen fish balls
Fresh fish → pretreatment (meat picking, rinsing) → preparation of purple cabbage vegetable juice → chopping and mixing (air chopping → salt chopping → seasoning chopping and mixing) → molding → low temperature gelation → high temperature maturation → cooling → quick freezing → packaging → metal detection → refrigeration (-18℃)

2.3.2. Sensory evaluation method
Referring to the method of Ma Ani *et al.* [11], 10 evaluators who have undergone professional sensory evaluation training were selected to form a sensory evaluation team.The weighting method is used to calculate the total score. Among them, the weighting coefficients of taste, smell, color, tissue state, and elasticity are 0.20, 0.25, 0.10, 0.25, and 0.20, respectively. The formula for calculating the total score is: Total score=σxiyi (i=1,2⋯⋯ n) (where X represents the evaluation index and Y is the weighting coefficient).The sensory evaluation criteria for vegetable quick-frozen fish balls are shown in Table 2-3

Table 3: Sensory Evaluation Criteria for Fish Balls [11]

Evaluation Item	Sensory Quality	Scoring Criteria
Taste	Moderate saltiness with strong juiciness	8~10
	Slightly salty or bland with relatively strong juiciness	5~7
	Excessively salty or bland, lacking juiciness, with a rough texture	0~4
Odor	Characteristic mixed aroma of fish meat and purple cabbage	8~10
	Insufficient meat aroma with slight fishy odor	5~7
	No meat aroma and strong fishy odor	0~4
Color	Purple color with glossy appearance	8~10
	Light purple with a slight yellowish tint	5~7
	Dull color without gloss	0~4
Tissue Structure	Smooth surface with few air holes and a compact, uniform structure	8~10
	Relatively smooth surface with small air holes and a relatively compact, uniform structure	5~7
	Rough surface with cavities and a loose structure	0~4
Elasticity	Good elasticity, no gritty sensation during chewing, and no residue	8~10
	Moderate elasticity with slight gritty sensation during chewing and no residue	5~7
	Poor elasticity with obvious gritty sensation during chewing and residue remaining	0~4

2.3.3. Determination method of holding water pressure
Refer to the method of Zheng Jie *et al.* [12].

2.3.4. Determination method of thawing water loss rate
Refer to NY/T 3905-2021 "Determination of the Water loss Rate of Frozen Meat Thawing" [13].

2.3.5. Single-factor experiment
The basic formula of fish balls: salt 2.5% (the mass percentage of salt is salt/surimi×100%, other ingredients are

the same as above), five-spice powder 0.5%, monosodium glutamate 0.5%, lard 5%, pepper water 2.5%, cooking wine 1.5%.The amount of soy protein isolate added, the amount of purple cabbage vegetable juice added, the amount of TG enzyme added, and the amount of sweet potato starch added were selected for a single-factor test, and the sensory score, water retention and thawing water loss rate were used as evaluation indicators to determine the appropriate amount of each factor added.

2.3.5.1. Determination of the amount of purple cabbage vegetable juice added

The amount of soy protein isolate added, the amount of TG enzyme added, and the amount of sweet potato starch added were fixed at 4%, 0.6%, and 8%, respectively, and the amount of purple cabbage vegetable juice added was set to 6%、8%、10%、12%、14% Single-factor experiments were conducted on five gradients, and they were measured in terms The amount of purple cabbage vegetable juice added, the amount of soy protein isolate added, and the amount of sweet potato starch added were fixed at 10%, 4%, and 8%, respectively, and the amount of TG enzyme added was set to 0.%、0.2%、0.4%、0.6%、0.8% Single-factor experiments were conducted on five gradients, and they were measured in terms of sensory score, water retention and thawing water loss rate, and the effects of different TG enzyme additions on the quality of fish balls were studied.

2.3.5.4. Determination of the amount of sweet potato starch added

The amount of purple cabbage vegetable juice added, the amount of soy protein isolate added, and the amount of TG enzyme added were fixed at 10%, 4%, and 0.6%, respectively, and the amount of sweet potato starch added was set to 4%、6%、8%、10%、12% Single-factor of sensory score, water retention and thawing water loss rate, and the effects of different purple cabbage vegetable juice additions on the quality of fish balls were studied.

2.3.5.2. Determination of the amount of soy protein isolate added

The amount of purple cabbage vegetable juice added, the amount of TG enzyme added, and the amount of sweet potato starch added were fixed at 10%, 0.6%, and 8%, respectively, and the amount of soy protein isolate added was set to 0%、2%、4%、6%、8% Single-factor experiments were conducted on five gradients, and they were measured in terms of sensory score, water retention and thawing water loss rate, and the effects of different soy protein isolate additions on the quality of fish balls were studied.

2.3.5.3. Determination of the amount of TG enzyme added

experiments were conducted on five gradients, and they were measured in terms of sensory score, water retention and thawing water loss rate, and the effects of different sweet potato starch additives on the quality of fish balls were studied.

2.3.6. Orthogonal experiment

Based on the results of the single-factor test, the amount of purple cabbage vegetable juice added (A), the amount of soy protein isolate added (B), the amount of TG ENZYME added (C), and the amount of SWEET POTATO STARCH added (D) were used as the investigation factors. Three optimization levels were set for each factor, and the sensory score was used as the evaluation index. The L9(34) orthogonal test table was used for formula optimization design. The level table of orthogonal test factors is shown in Table 2-4.Each group of tests was repeated 3 times, and the results were averaged.

Table 4: Orthogonal test factors and levels

Level	Purple Cabbage Juice Addition	Soy Protein Isolate Addition	TG Enzyme Addition	Sweet Potato Starch Addition
1	8%	2%	0.4%	6%
2	10%	4%	0.6%	8%
3	12%	6%	0.8%	10%

3. Results and discussion

3.1. Effect of the amount of purple cabbage vegetable juice on fish balls

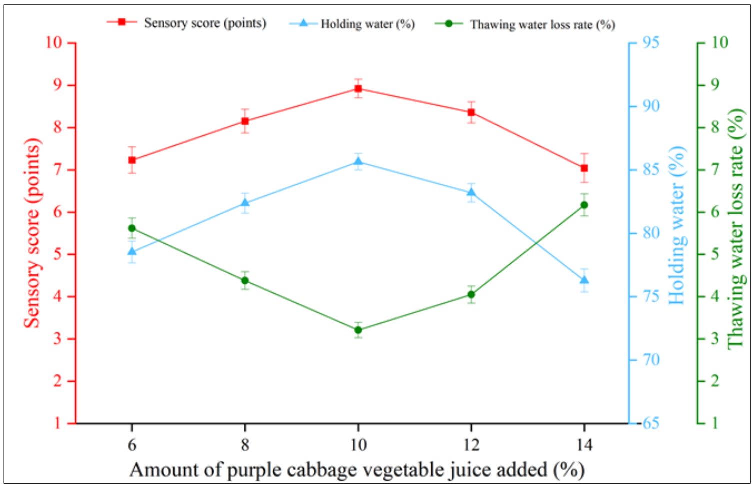

Fig 1: The effect of the amount of purple cabbage vegetable juice added on the sensory score, water retention, thawing and water loss rate of fish balls

The sensory score, water retention and thawing water loss rate of fish balls vary with the amount of purple cabbage vegetable juice added, as shown in Figure 3-1.With the increase of the added amount, the sensory score and water retention both showed a trend of rising first and then falling, while the thawing and water loss rate was the opposite; when the added amount was 10%, the overall quality of the fish balls was the best.The reason may be that the polyphenols and dietary fiber in the appropriate amount of purple cabbage vegetable juice can interact with chymotrypin to promote the formation of a more complete gel network structure, thereby improving water retention and reducing water loss during freezing and thawing. At the same time, it can improve the color of fish balls and enhance the overall acceptance.However, when the amount added exceeds 10%, excessive vegetable juice will dilute the protein concentration in the surimi, weaken the crosslinking effect between protein molecules, and make the gel structure loose, which in turn leads to a decrease in water retention and an increase in thawing water loss rate; In addition, excessive addition will also bring more obvious vegetable jerky taste and slight bitterness, affecting product flavor and sensory quality [11].Therefore, based on various indicators, the appropriate addition amount of purple cabbage vegetable juice is 8% to 12%, and the scope of subsequent orthogonal tests is determined accordingly.

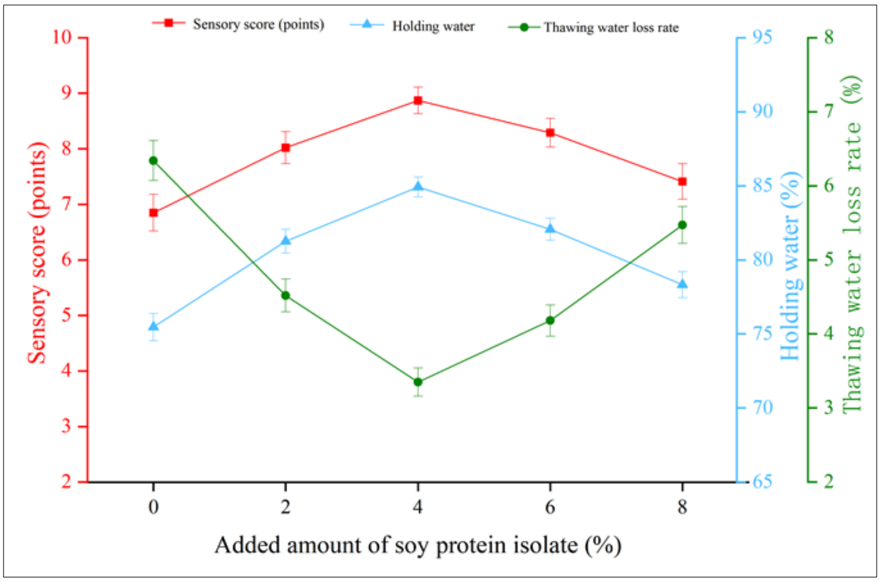

Fig 2: The effect of the addition of soy protein isolate on the sensory score, water retention, thawing and water loss rate of fish balls

3.2. Effect of soy protein isolate addition on fish balls

The changes of the sensory score, water retention and thawing water loss rate of fish balls with the addition of soy protein isolate are shown in Figure 3-2.As the amount of addition increased, the sensory score and water retention both showed a trend of rising first and then falling, while the thawing water loss rate showed a trend of falling first and then rising; when the amount of addition was 4%, the indicators reached the best.The reason may be that an appropriate amount of soy protein isolate can be used as a substrate for TG enzyme action to promote the formation of a more stable gel network structure of chymotrypsin, thereby improving water retention and reducing freeze-thawing water loss, while improving the elasticity and texture characteristics of fish balls, and improving sensory quality.However, when the amount added exceeds 4%, excessive vegetable protein will affect the crosslinking and aggregation of chymotrypin, resulting in loose gel structure, decreased water holding capacity, and increased thawing and water loss rate; in addition, it will produce a significant bean smell, making the product taste hard and rough tissue, thereby reducing the sensory score [5].Therefore, based on various indicators, it is determined that the appropriate addition amount of soy protein isolate is 2% to 6%, which is used for subsequent orthogonal test design.

The changes of the sensory score, water retention and thawing water loss rate of fish balls with the amount of TG enzyme added are shown in Figure 3-3.With the increase of the amount of TG enzyme added, the sensory score and water retention showed a trend of rising first and then falling, while the thawing water loss rate showed a trend of falling first and then rising; when the amount added was 0.6%, the overall quality of fish balls was the best.The reason may be that the right amount of TG enzyme can catalyze the formation of heteropeptide bonds between chymotrypsin and soybean protein isolate, promote protein molecular crosslinking, and build a denser and more stable gel network structure, thereby improving water holding properties, reducing freeze-thaw and water loss, and improving the elasticity and texture characteristics of fish balls.However, when the amount of TG enzyme added exceeds 0.6%, the protein is over-crosslinked, resulting in the gel structure is too tight and the phenomenon of shrinkage and hardening occurs, causing the water in the system to be squeezed out, resulting in a decrease in water retention and an increase in thawing water loss rate; At the same time, the texture of the fish balls hardens, lacks softness, and the flavor is also affected to a certain extent, thereby reducing the sensory score [6].Therefore, based on various indicators, it is determined that the appropriate addition amount of TG enzyme is 0.4% to 0.8%, which is used for subsequent orthogonal test design.

3.3. Effect of TG enzyme addition on fish balls

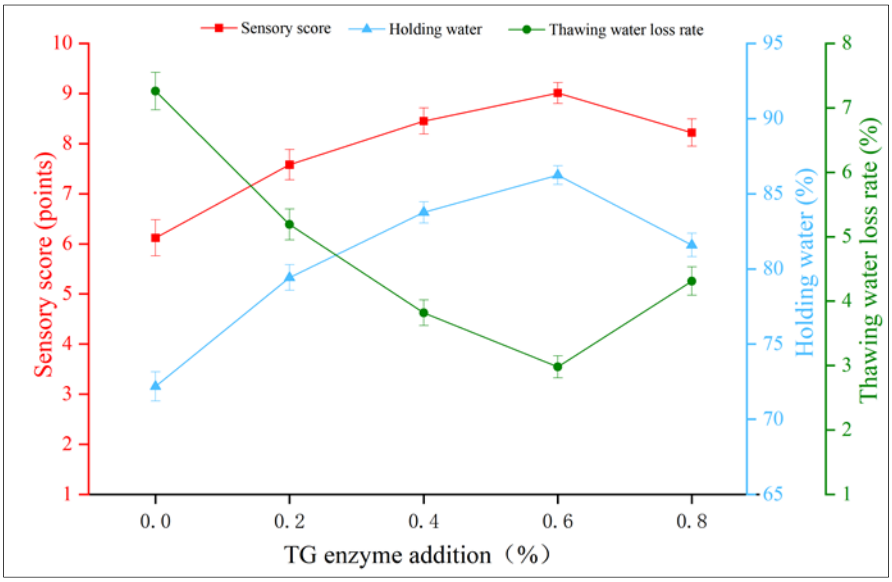

Fig 3: The effect of the amount of TG enzyme added on the sensory score, water retention, thawing and water loss rate of fish balls

The changes of the sensory score, water retention and thawing water loss rate of fish balls with the amount of sweet potato starch added are shown in Figure 3-4.As the amount of addition increased, the sensory score and water retention both showed a trend of rising first and then falling, while the thawing water loss rate showed a trend of falling first and then rising; when the amount of addition was 8%, the indicators reached the best.The reason may be that an appropriate amount of sweet potato starch gelatinizes during heating, which can absorb and fix the moisture in the system and fill the voids in the surimi gel network, thereby improving the water holding capacity and reducing freeze-thawing water loss, while improving the elasticity and taste of fish balls, and improving sensory quality.However, when the added amount exceeds 8%, the excess starch will compete for moisture with chymotrypin, affecting protein crosslinking and gel structure formation, resulting in a decrease in water retention and an increase in thawing water loss rate; at the same time, the taste of fish balls is sticky, elasticity and brittleness decrease, and the starch taste is too heavy, thereby reducing the sensory score [8].Therefore, based on various indicators, it is determined that the appropriate amount of sweet potato starch is 6% to 10%, which is used for subsequent orthogonal experimental design.

From the extremely differential analysis results, it can be seen that the main sequence of the influence of four factors on the sensory quality of compound vegetable quick-frozen fish balls is: C (TG enzyme addition) > A (purple cabbage vegetable juice addition) > B (soy protein isolate addition) > D (sweet potato starch addition).Among them, the amount of TG enzyme added has the most significant impact on the sensory quality of the product, and the amount of sweet potato starch added has the least impact. The results are consistent with the single-factor test law, indicating that the test results have good reliability.

By comparing the k values of different levels of various factors, it was determined that the optimal formula for compound vegetable quick-frozen fish balls is A3B2C2D1, which is 12% purple cabbage vegetable juice, 4% soy protein isolate, 0.6% TG enzyme, and 6% sweet potato starch.There is a difference between this result and the best level obtained from the single-factor test, which shows that the orthogonal test comprehensively considers the synergy between the various factors and is more in line with the actual production conditions.

In order to verify the feasibility of the optimal solution, three repeated tests were carried out under the conditions of the formula.The results showed that the sensory score of the fish balls obtained reached 9.15 points, which was higher than the highest score in the orthogonal test (8.95 points), and the product had natural color, elastic organization, and good taste, indicating that the optimization plan is reasonable and feasible, and has practical application value.

In addition, in the optimal combination obtained by the orthogonal test, the level of each factor is within the appropriate addition range determined by the single-factor test.Among them, 0.6% of the TG enzyme is the optimal level in the single-factor test, which can effectively ensure the gel quality and water retention performance of the product; the other factors, under the synergistic action, are conducive to achieving a comprehensive balance of product color, flavor, texture and water retention performance

4. Conclusion

This study optimized compound vegetable quick-frozen fish balls using grass carp surimi, purple cabbage juice, soy protein isolate, TG enzyme, and sweet potato starch. The results showed that proper addition improved sensory quality, water-holding capacity, and freeze-thaw stability, while excessive amounts weakened gel structure and flavor. Orthogonal testing indicated that the main influencing factors were TG enzyme, purple cabbage juice, soy protein isolate, and sweet potato starch, in that order. The optimal formula was 12% purple cabbage juice, 4% soy protein isolate, 0.6% TG enzyme, and 6% sweet potato starch, achieving a sensory score of 9.15. The product had a natural color, firm texture, good elasticity, and low thawing loss, showing good practical application value.

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