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Effect of Velvet Tamarind (*Dialium cochinchinense* Pierre) Residues on Properties and Structure of Mackerel Fish Crackers

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Velvet tamarind residue (VTR), a secondary product of velvet tamarind (VT) juice production, is predominantly found in the southernmost provinces of Thailand. This study explored the impact of incorporating VTR at 0, 3, 6, 9, 12, and 15% on the characteristics of mackerel fish crackers. The findings demonstrated that VTR addition significantly ($p \leq 0.05$) altered the fish cracker's color parameters (*L, *a**, and *b**). The hardness of the crackers increased significantly ($p \leq 0.05$) with higher VTR inclusion. Sensory evaluations revealed that crackers with 3% VTR scored the highest (7.86, moderately like) in panelist preference. Notably, VTR-enhanced crackers exhibited reduced total energy (550.70 *vs.* 486.16 kcal) and total fat (34.38 g/ 100 g *vs.* 22.16 g/ 100 g) compared to non-VTR fish crackers. The VTR fish crackers were also enriched with minerals – including calcium (70.39 mg/ 100 g), sodium (1180.46 mg/ 100 g), and iron (0.79 mg/ 100 g). Additionally, the cross-sectional analysis of VTR fish crackers had larger pores than non-VTR fish crackers. In summary, VTR is potentially beneficial as a novel healthy dietary supplement.**

Keywords: fish cracker, physical-chemical properties, scanning electron microscope, sensory evaluation, velvet tamarind residues

INTRODUCTION

The consumption of snacks such as fish crackers is widespread across Southeast Asia. This delicacy is prepared by cooking and drying the crackers, which are later deep-fried, causing the crackers to expand rapidly and uniformly before serving (Farkas 1994; Farkas *et al*. 1996). The porous structure of fish signifies superior quality, characterised by their light texture, crispiness, and optimal volume expansion (Nguyen *et al*. 2013). The fish cracker is also a special delicacy uniquely formulated in three southern provinces of Thailand. The fish cracker industry serves as the backbone of many small and medium enterprises (SMEs) at Muang, Narathiwat and Yaring in Pattani, Thailand (Saah *et al*. 2015). Consumers often consume fish crackers as a protein-rich snack, but this cracker has a low fiber content. The fried crackers typically contain 8–12% protein and 30–35% fat (Rohani *et al*. 2010). Incorporating fiber into this product could enhance its nutritional profile, potentially transforming it into a healthy, functional food (Borderías *et al*. 2005).

Velvet tamarind (VT) is unique to Thailand's southern provinces (Chedoloh and Chemalee 2019). The pulp is sweet, aromatic, and rich in fiber and ascorbic acid

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(Okudu *et al*. 2017), besides offering a valuable source of antioxidants and minerals (Afolabi *et al*. 2018). The local SMEs in these areas reported that VT residues (VTR) comprise approximately 20% of the wet weight from VT juice processing (VT: water, 1:10 g). The mixture is blended thoroughly and filtered, resulting in large quantities of white, thin VTR. Fish crackers are traditionally made by combining fish meat with starch – followed by shaping, cooking, slicing, and drying the mixture before frying. Currently, SMEs have not incorporated VTR in fish crackers, and the use of VTR as a dietary fiber supplement has not been studied. Therefore, this study proposed the inclusion of VTR in this snack to improve its fiber content, which could positively impact the physical quality, sensory, structure, and nutritional value and potentially benefit human health.

MATERIALS AND METHODS

Raw Materials and Chemicals

Fresh rastrelliger fish (*Rastrelliger brachysoma*) was purchased from the Lammai market in the Muang District of Yala Province, Thailand. Ingredients used in the fish cracker recipe were purchased from the Yala Market – including cassava flour, garlic, sugar, salt, black pepper, and egg. Subsequently, the fish was prepared once removed from the ice container, washed, and graded according to size, and the head and gut were removed. Meanwhile, the VTR was washed thrice with water. The flesh was then grounded using a blender (pore size: 4 mm) (tc12-c model, Champ amci., Thailand). Once the flesh was mixed with other ingredients and shaped, the raw fish crackers were deep-fried in palm oil. All the chemicals and reagents used in this study were sourced from Sigma Chemical Co., USA, and were of analytical grade.

Fish Cracker Formula

Fish cracker formulas were prepared as follows: minced fish (42.63%), cassava flour (42.59%, weight by weight, w/w), salt (2.36%), black pepper (0.16%), sugar (5.79 %), and egg (6.47%). The VTR was incorporated at 0, 3, 6, 9, 12, and 15% relative to the total weight of all ingredients (Chedoloh 2017; Mekarat *et al.* 2019). First, the minced fish was thoroughly mixed with other ingredients such as salt, black pepper, egg, sugar, and VTR. Then, the dough was prepared by adding cassava flour and hot water at 100 ºC (the hot water used in ingredients was 8.5% by weight of all ingredients) and kneaded well. The resulting dough was shaped into cylinders (15 cm × 2 cm) (Figure 1) and allowed to sit for 5 min. Subsequently, the cylindrical doughs were boiled for 30–40 min until floating to enhance the starch gelatinization. The fish crackers were cooled for 30 min at room temperature before being refrigerated (4–7 ºC) overnight. The fish crackers were cut into thin slices (2.10–2.50 mm) before being dried at 55–60 ºC in a dehydration machine (Unique Tools; tray dryer, Thailand) for 3 h. The moisture content analysis (AOAC 2004) indicated that the final moisture content of the raw fish crackers was approximately around 8–9%.

Frying Process

The frying process was performed using an electric fryer (commercial deep fryer; Thailand), where the fish crackers were deep fried in palm oil at 180 °C for 15 s (Chedoloh 2017). Prior to this stage, a preliminary experiment was conducted to determine the optimal frying period to achieve the desired puffiness and appearance. Once fried, oil content was reduced from the fish crackers by placing them on a layer of tissue. Finally, the fish crackers were stored in airtight plastic bags until use.

Physical and Texture Analyses of VTR

The color of each fish cracker sample was assessed using three parameters in the color space, established by the International Commission on Illumination: *L** (lightness/darkness value), *a** (green/red value), and *b** (blue/yellow value). In addition, texture analysis was performed with Brookfield's CT*3* texture analyser, where the breaking force was recorded in Newton (N). The texture analyser program utilised five separate scans from each fish cracker sample to generate hardness and crispness data. The texture analyser was configured with a stainless steel ball probe (TA-18) with a diameter of 0.25 cm and a 25 kg load cell for force/displacement measurement. The fish

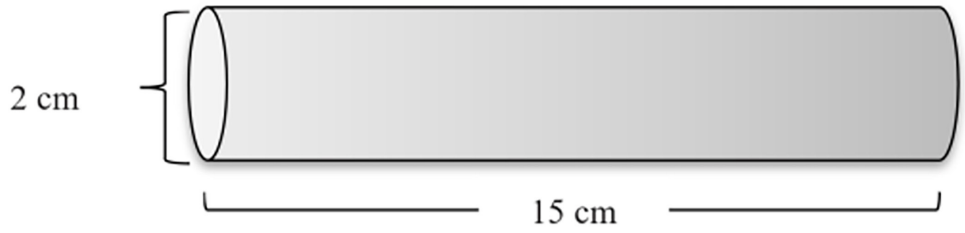

Figure 1. The VTR-reinforced fibers in fish crackers.

crackers were tested at a speed of 1 mm s^{-1}, a trigger force of 1 N, and a probe travel distance of 15 mm. At the end of the experiment, the fish cracker samples were against commercialized fish crackers.

Sensory Evaluation

Yala Rajabhat University's Sensory Laboratory was the facility used to perform the sensory testing. Fifty (50) untrained panelists (25 males and 25 females) were asked to judge the formulated fish crackers based on appearance, color, flavor, taste, crispness, and overall liking. Each attribute was rated using a nine-point hedonic scale (1 = extreme dislike, 9 = extremely like) (Meilgaard *et al*. 2018).

Composition Analysis of End products

The fish crackers were assessed based on their physical and chemical properties. The physical properties evaluated the cracker's color, whereas the chemical properties include moisture, ash, protein, fat, fiber, carbohydrate, and water activity (a_w). All analyses were conducted gravimetrically according to AOAC methods (2019): cholesterol [in-house method TE-CH-143 based on AOAC (2019, 976.26)], sugars (AOAC 2019, 925.35), sodium [in-house method TE-CH-143 based on AOAC (2019, 984.27)], calcium [in-house method TE-CH-143 based on AOAC (2019, 984.27)], and iron [in-house method TE-CH-143 based on AOAC (2019, 984.27)]. Samples were first cut and fixed onto an aluminium tube using double-sided adhesive tape, followed by sputter-coating with old palladium using an Edward S150A sputter coater to enhance the thermoelectrical conductivity. Subsequently, the prepared samples were scanned using a Quanta 400 scanning electron microscope (SEM) (FEI, Czechina), and the micrographs of the surfaces and cross-sections were captured at 100× magnification.

Statistical Analysis

This study employed a completely randomized design to determine the physical and chemical properties of fish crackers (triplicates). Meanwhile, the sensory tests were conducted using the randomized complete block design. The Statistical Package for Social Sciences or SPSS software (IBM, USA) was used to establish a linear mixed model for the purpose of analyzing different treatments. Duncan's new multiple-range tests were carried out to compare treatment means and identify significance differences ($p \leq 0.05$). Finally, the end product was analyzed using the t-test.

RESULTS AND DISCUSSION

Effect of Oil Type on Physical Properties

The VTR inclusion in fish crackers at varying levels significantly influenced ($p \leq 0.05$) the L^* (brightness value), a^* (red value), and b^* (yellow value) of the end product (Table 1). Precisely, L^* and b^* values decreased as VTR inclusion in the fish cracker increased (Figures 2 and 3), resulting in a darker color. In contrast, the * values varied as VTR inclusion increased. Fish crackers without VTR had a^* value of 5.28, appearing less red. Meanwhile, the red hue became more pronounced with increased VTR supplementation at 3% (9.04), 6% (11.71), 9% (13.82), 12% (14.86), and 15% (16.12) (Table 1). The color of fried fish crackers was influenced by several factors – including the fish-starch proportion, starch and additives, thickness, fish type, and the Maillard reaction (Huda *et al*. 2010; Idris *et al*. 2018). Furthermore, structural changes in starch granules and protein caused by heat from deep frying may cause color alterations in fish crackers. The Maillard reaction, caramelization from heat, and shifts in pigment concentration resulting from dehydration and expansion could also determine the cracker's color (Wang *et al.* 2013). Moreover, the changes in a^* and b^*

Table 1. Effect of velvet tamarind residues on the color of fish crackers.

Velvet tamarind residues (%)	Color		
	L^*	a^*	b^*
0	61.08 ± 1.50^{a}	5.28 ± 0.42^{f}	26.09 ± 0.54^{a}
3	56.75 ± 0.81^{b}	9.04 ± 0.29^{e}	23.81 ± 0.39^{b}
6	46.20 ± 0.76^{c}	11.71 ± 0.16^{d}	21.34 ± 0.64^{c}
9	41.35 ± 0.69^{d}	13.82 ± 0.10^{c}	21.41 ± 0.66^{c}
12	38.22 ± 1.87^{e}	14.86 ± 0.12^{b}	20.79 ± 0.56^{c}
15	32.05 ± 0.96^{f}	16.12 ± 0.67^{a}	19.02 ± 0.88^{d}

Different alphabets indicate significant differences ($p \leq 0.05$) between groups; the experiment was conducted in triplicates

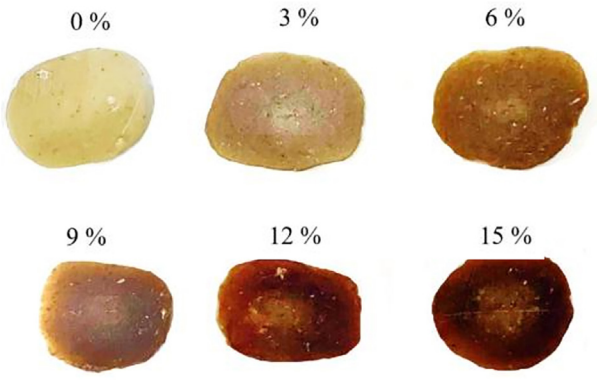

Figure 2. Appearance of raw fish crackers.

Figure 3. Fried fish crackers supplemented with different levels of VTR.

values may be linked to myoglobin oxidation and starch gelatinization and swelling, respectively (Yang and Park 1998; Trespalacios and Pla 2007).

Product Texture

The VTR fish crackers with the best volume expansion were compared to the non-VTR fish crackers (Table 2) and demonstrated significant ($p \leq 0.05$) differences in hardness and crispness. Precisely, the hardness of crackers increased with rising levels of VTR and low levels of fish meat. In this study, the VTR 15% group was harder than 0, 3, 6, and 12% fish crackers. Likewise, Chedoloh (2017) reported that fish crackers increased in hardness with rising levels of rice bran inclusion (100:00, 90:10, 80:20, 70:30, 60:40, and 50:50), ranging from 6.15 ± 0.12 to 18.84 ± 0.04 N. Zzaman *et al*. (2017) reported similar findings for fried fish crackers, whose hardness ranged between 12.11–15.32 N. Texture is one of the factors determining the food quality, particularly for fish crackers (Idris *et al*. 2018).

Table 2. Effect of VTR on hardness and crispness of fish crackers.

VTR (%)	Hardness (N)	Crispness (N)
0	7.24 ± 0.84^{d}	1.94 ± 0.36^{c}
3	8.59 ± 0.57^{c}	2.11 ± 0.35^{bc}
6	8.91 ± 0.77^{c}	2.64 ± 0.14^{ab}
9	9.24 ± 0.83^{c}	2.96 ± 0.42^{a}
12	10.91 ± 0.60^{b}	2.80 ± 0.34^{a}
15	16.82 ± 0.44^{a}	2.95 ± 0.26^{a}

Different alphabets indicate significant differences ($p \leq 0.05$) between groups; the experiment was conducted in triplicates

Sensory Evaluation

The sensory parameters are crucial properties of food products. The study findings indicated significant ($p \leq 0.05$) differences in preference scores (appearance, color, flavor, taste, crispness, and overall liking) between the fish crackers supplemented with different levels of VTR (0, 3, 6, 9, 12, and 15%) (Table 3). Fish crackers with 3% VTR obtained better sensory scores than groups with higher VTR inclusion (6, 9, 12, and 15%). Meanwhile, the overall liking score for fish crackers with 0, 3, 6, 9, 12, and 15% VTR were 6.96, 7.86, 6.90, 6.80, 5.80, and 5.86, respectively – which reflected the overall acceptance of panelists towards the fish crackers. The 3% VTR group recorded the highest at 7.86 (moderate preference) (Table 3). Furthermore, the panelists gave the highest crispness score of 7.90 (moderate like) to the 3% VTR, indicating that the texture was acceptable for the panelists. Cereal fiber also influences the sensory acceptability and physicochemical properties of instant fish crackers (Rohani *et al*. 2010). Therefore, it could be concluded that adding different ingredients to fish crackers affects the texture and flavor differently. Incorporating these ingredients in the fish cracker formulation should not alter the original taste of the product.

Analysis of the Final Product

Physicochemical properties. The L^* values in this study ranged from 56.75–60.08, whereas the fiber content was approximately 1.87 g/ 100 g for the VTR fish crackers. Meanwhile, the moisture content and a_w values in different VTR-inclusion fish crackers were 1.96–2.53 g/ 100 g and 0.31 - 0.34, respectively. As the VTR fiber is saturated with water, its inclusion in fish crackers increases the moisture content of the end product. Furthermore, VTR contains soluble fiber and is insoluble in water as a constituent. In cracker manufacturing, it is vital to ensure that the cracker is heated to cook and gel at 100 °C, thus producing soluble fibers while boiling. As a result, the fibers in the structure of the gel crackers become hygroscopic.

The protein content of the VTR fish cracker was 8.47 g/100g (Table 4), which was lower than the non-VTR fish cracker. This finding indicated that fish fillet was not the only source of protein in fish crackers. Zzaman *et al*. (2017) reported that the protein levels in fish crackers depend on the freshwater fish species used in the recipe, ranging from 13.79%–16.19%. Meanwhile, Rohani *et al*. (2010) revealed that the crude protein from oat fiber-enriched crackers was 9.70%, almost similar to the current study and Zzaman *et al*. (2017). Thus, low levels of VTR inclusion are more suitable for fish crackers to avoid the reduction in protein content. The fat content of VTR-supplemented fish crackers in this study was 21.36% (Table 4). The VTR fish crackers had slightly lower fat contents (32.06 %) compared to the original

Table 3. Effect of VTR on the sensory evaluation of fish crackers.

VTR (%)	Appearance	Color	Flavor	Taste	Crispness	Overall liking
0	6.26 ± 1.79^{b}	6.90 ± 1.3^{b}	6.63 ± 1.40^{ab}	6.93 ± 1.11^{a}	7.16 ± 1.23^{ab}	6.96 ± 1.21^{b}
3	7.86 ± 0.68^{a}	7.80 ± 0.99^{a}	7.20 ± 1.12^{a}	7.40 ± 1.13^{a}	7.90 ± 0.75^{a}	7.86 ± 0.93^{a}
6	6.80 ± 1.18^{b}	6.46 ± 1.16^{b}	6.63 ± 1.06^{ab}	6.80 ± 1.09^{a}	7.43 ± 1.25^{a}	6.90 ± 1.24^{b}
9	6.76 ± 1.45^{b}	6.46 ± 1.54^{b}	6.20 ± 1.62^{bc}	6.73 ± 1.55^{a}	7.60 ± 1.49^{a}	6.80 ± 1.56^{b}
12	5.36 ± 1.60^{c}	4.83 ± 1.80^{c}	5.53 ± 1.19^{cd}	5.53 ± 1.19^{b}	6.43 ± 1.75^{b}	5.80 ± 1.68^{c}
15	5.50 ± 1.61^{c}	5.03 ± 1.71^{c}	5.36 ± 2.05^{d}	5.40 ± 1.81^{b}	6.50 ± 1.79^{b}	5.86 ± 1.73^{c}

Different alphabets indicate significant differences ($p \leq 0.05$) between groups; the experiment was conducted among 50 panelists

Table 4. Properties of non-VTR and VTR fish crackers.

Composition	Non-VTR fish cracker	VTR fish cracker
Color		
*L**	61.08 ± 1.50^{a}	56.75 ± 0.81^{b}
*a**	5.28 ± 0.42^{b}	9.04 ± 0.29^{a}
*b**	26.09 ± 0.54^{a}	23.81 ± 0.39^{b}
a_w	0.31 ± 0.03^{b}	0.34 ± 0.02^{a}
Moisture (g/ 100 g)	1.96 ± 0.05^{b}	2.53 ± 0.02^{a}
Ash (g/ 100 g)	1.34 ± 0.03^{b}	3.03 ± 0.02^{a}
Protein (g/ 100 g)	8.47 ± 0.08^{ns}	9.15 ± 0.68^{ns}
Fat (g/ 100 g)	32.06 ± 0.87^{a}	21.36 ± 0.61^{b}
Fiber (g/ 100 g)	0.16 ± 0.01^{b}	1.87 ± 0.03^{a}
Carbohydrate (g/ 100 g)	78.07 ± 3.25^{ns}	77.69 ± 4.50^{ns}

Different alphabets indicate significant differences ($p \leq 0.05$) between groups; the experiment was conducted in triplicates
ns is Non-significant differences ($p>0.05$)

non-VTR fish crackers (21.36%), with a difference of 0.60%. Meanwhile, the fiber content was 1.87% for all crackers in this study.

Nutrition value. The mean nutrient and energy content of the fish crackers are presented in Table 5. The increase of VTR inclusion in fish crackers reduced the total energy (from 550.70 to 486.16 kcal) and total fat (from 34.38 to 22.16 g/ 100 g) in the end product. The amount of fish used, fat content, and fish parts or raw materials used in the formulation may influence the fat content in fish crackers (Huda *et al*. 2010). The VTR fish crackers were also rich in minerals such as calcium, sodium, and iron (mg). The relatively higher calcium (mg/ 100 g) content in the VTR fish crackers demonstrated the potential health benefits of this product. A previous study stated that VTR supplementation in products could help fulfill the nutritional needs of consumers (Ahmed and Abozed 2015). The water activity and moisture content of VTR

Table 5. Nutritional value of non-VTR and VTR fish crackers.

Nutrient	Non-VTR fish cracker			VTR fish cracker		
	Per 100 g	Serving size	% RDI	Per 100 g	Serving size	% RDI
Total energy (kcal)	550.70	170	–	486.16	150	–
Energy from fat (kcal)	309.42	90	–	199.44	60	–
Total fat (g/ 100 g)	34.38	10	15	22.16	7	11
Cholesterol (mg/ 100 g)	29.12	10	3	30.30	10	3
Protein (g/ 100 g)	8.47	3	–	9.15	3	–
Total carbohydrate (g/ 100 g)	51.85	16	5	62.53	19	6
Sugars (g/ 100 g)	1.86	< 1	–	1.45	0	–
Ash (g/ 100 g)	2.55	–	–	2.84	–	–
Moisture (g/ 100 g)	2.75	–	–	3.32	–	–
Calcium (mg/ 100g)	70.39	17.60	2	70.07	17.60	2
Sodium (mg/ 100 g)	1180.46	350	18	1168.06	350	18
Iron (mg/ 100 g)	0.79	0.20	0	0.76	0.20	0

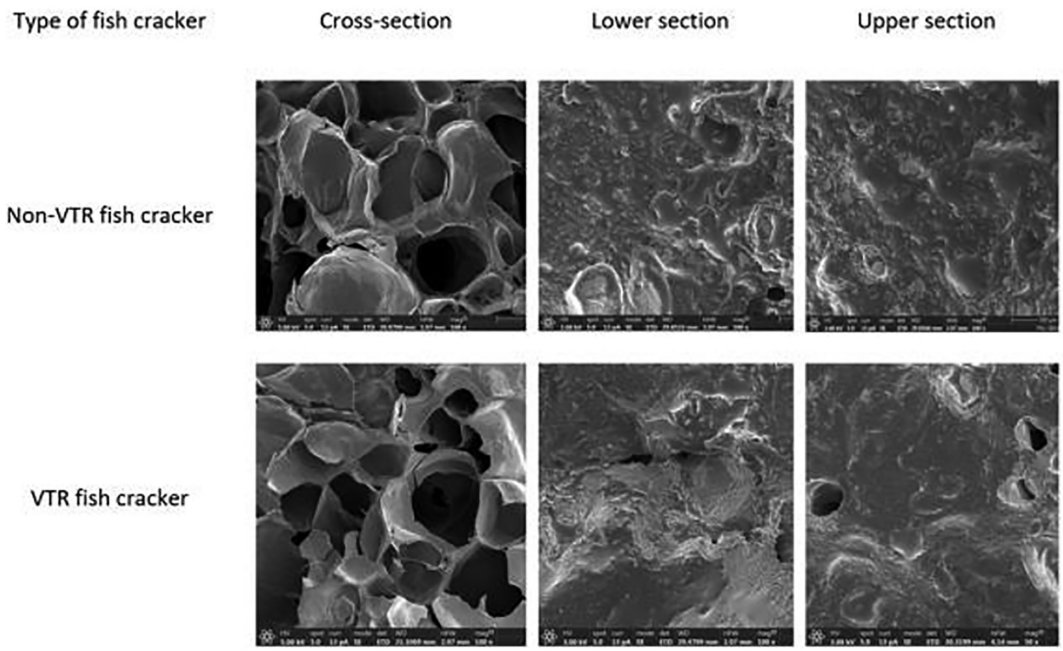

Figure 4. Comparison of SEM images for fish crackers supplemented with different levels of VTR.

fish crackers In this study showed a significant ($p \leq 0.05$) reduction compared to those without VTR. A low a_w is crucial in extending the shelf life of a product (Ibadullah *et al*. 2019). In summary, people of all ages could consume the VTR-supplemented fish crackers, which potentially act as a healthy food to supplement consumers with essential nutrients.

Results of scanning electron microscopy. The structures of VTR and non-VTR fish crackers were characterized using SEM to examine the morphology such as surface shape pattern and size. The 3D cross-section images indicated that the addition of VTR in the crackers had a substantial effect on pore size than the non-VTR fish crackers. In addition, the VTR fish crackers exhibited lower fat content in the lower and upper sections compared to the control sample (Figure 4).

CONCLUSION

The VTR, a by-product of SME activities in Yala province, potentially improves the nutritional profile of fish crackers. Adding VTR to fish crackers may enhance the levels of minerals, fiber, and protein while decreasing calories from fat and carbohydrates, offering health benefits to consumers. Nonetheless, VTR addition adversely impacted the sensory qualities and physicochemical properties of the fish crackers, specifically the texture. Therefore, this study recommends a maximum inclusion of 3% VTR, as this group obtained the highest score from the panelists.

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