Tapioca Crispy Crackers with Ripe Banana Peel: Snack Enrichment with Dietary Fiber and Phenolic Compounds from an Agri-Food Waste

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Abstract

Banana peel is rich in bioactive compounds and dietary fiber. Both tapioca starch and bananas are naturally gluten-free. As a means of waste valorization and snack enrichment, tapioca crispy crackers were enriched with banana peel, with or without flesh. The peel was from cv. *Namwa* bananas are in the final stages of ripening. Phenolic compounds in the ripe banana peel led to the bitterness of the enriched crackers. To increase the amount of banana peel that could be used, the peel was boiled before being incorporated into a formulation of banana peel, at 30 g / 100 g of tapioca starch, and flesh at 8 g/ 100 g of tapioca starch, by weight. The crackers contained no preservative or synthetic coloring or flavoring agent and were assessed without further seasoning. The product was very well-received with 100% acceptance and 93.33% of the respondents were interested in buying it. More than half of the respondents regarded it as being innovative and tasty. Proximate analyses revealed that the optimized formulation contained 2.28% ± 0.08 of total dietary fiber (about 2,280% compared to 0.01% ± 0.02 of the formulation without banana) whereas no significant increase in protein content was observed. The product contained phenolic compounds at 27.26 ± 0.19 μg TAE/g. Sensory evaluation predicted that the enriched crackers, stored at 35±1 °C in a closed container, were not likely to be rejected due to any unpleasant smell of rancidity for at least 10 days. The phenolic compounds contributed by the boiled banana peel significantly suppressed the rancidification process. The optimized formulation can be used for the development of healthy antioxidant-rich, high-fiber, and high-protein snacks using high-protein food processing by-products.

Keywords: *Namwa* banana, consumer acceptance, natural coloring agent, sensory rancidity analysis, waste valorization

Introduction

Bananas (*Kluay* in Thai) are an important food crop, grown and consumed all over the world. *Namwa* bananas (*Musa* ABB group) are the most common type of banana consumed in Thailand and are available throughout the year in Thailand. When bananas are included in food recipes, usually only the flesh of the bananas is used. Despite its availability in large quantities, banana peel, regardless of cultivars, is considered a waste biomass of limited uses in Thailand. The banana peel has been reported to contain numerous bioactive compounds with potential health benefits (Zaini et al., 2022). The peel is also rich in minerals and dietary fiber. It can, however, be used as an ingredient in healthy or functional foods and banana peel powder has been used to enrich food products (Khoozani et al., 2019; Zaini et al., 2020; Alshehry, 2022). The fiber extracted from banana peel has also recently be used as a supplement in yogurt (Safdari et al., 2021).

Bananas are climacteric fruit, meaning that they continue to ripen after being picked. The flesh of the *Namwa* banana in the final stage of ripening (ripeness stage 8) is softer and sweeter and is used in a variety of food preparations by local Thai people. Ripeness is measured against a predefined scale, and the largest proportion of *Namwa* banana peel available is from ripeness stage 8 (B8), therefore, B8 was used in the present study.

Also called rice crackers, fried crackers, or puff(ed) crackers, tapioca crispy crackers are a local-style crispy cracker that is a common tertiary-processed local snack in Thailand, mainland Malaysia, Malay Archipelago, and Vietnam. Hereinafter simply referred to as cracker(s), they are variously called *Khao Kriab*, *Kerupuk*, *Keropok*, *Krupuk*, *Kropek*, or *Bánh Phồng Tôm* in Thai, Indonesian, Malay, Javanese, Tagalog and Vietnamese. The cracker dough is first cooked by steaming and then thin slices are dried. The dried slices, also called half- or semi-products, are briefly fried to obtain puffed and crispy crackers. The dried slices are easier to store or transport and have a much longer shelf life than the ready-to-eat crackers. Common flavors of crackers in Thailand include fish, shrimp/prawn, pumpkin, and taro. Crackers prepared from a mix of tapioca starch and flour made from the flesh of green bananas have also been reported (Wang et al., 2012; Say et al., 2022).

The primary aim of the present study was the valorization of ripe *Namwa* banana peel which is a cheap and readily available source of dietary fiber. The direct supplementation of untreated B8 peel limits the maximum amount of peel that can be added due to the bitter taste of the enriched crackers. The bioactive phenolic compounds in the banana peel were the focus of our study, as they are the most likely causes of bitter taste. Simple full boiling pretreatment in water was employed to remove excess phenolic compounds. The process of developing banana peel-enriched crackers consisted of 3 sessions of sensory evaluations. The highest potential tapioca starch-based cracker formulation without banana (non-enriched, NE) was selected (see the Supplementary Materials for elaboration on the first step) to enrich with boiled peel alone or with both boiled peel and flesh in the second and third steps. Note that only the flesh amounts were varied in the third step.

An acceptance survey was carried out with a wider group of potential customers. Chemical analyses were carried out for B8 peel and dried slices and crackers of selected formulations. Shelf life was also determined over 60 days of storage.

Methods and Materials

Materials

Namwa bananas of ripeness stage 8 (B8) were obtained from local markets. Bananas at stage B8 are ripe bananas with fairly large to large areas of brown senescent marks on their peel. On sorting the bananas, those with more than 75% of their peel areas turned dark were considered overripe and were not used in the present study. The peel to whole fruit weight ratio and the peel to flesh weight ratio were determined using the pooled weight of every banana in each entire hand (bunch) (n = 3). The term "peel" refers to the banana peel/skin includes the tips and excludes the phloem bundles and the stalks.

Non-enriched cracker recipe

The non-enriched garlic-canola oil formulation (NE2) of tapioca starch-based crackers was used as the base formulation for banana enrichment. The Chinese garlic (without skin) was finely crushed just before the preparation of the dough. The other ingredients were commercially available. They were obtained from a supermarket and used as received. The ingredients of the NE2 and banana-enriched formulations are given in Table 1.

In brief, the dough was prepared from the dry mixture of the ingredients and boiled water (150 mL) and kneaded until smooth. Dough rods wrapped close with clear plastic wraps were steamed for 35 minutes. After being chilled for 15 hr in a refrigerator (at about 4 °C), 2 ml thick slices were prepared and dried at 60 °C for 5 hr. The dried slices were puffed by being fried for 6 to 8 sec in palm olein at 170 – 180 °C. Refer to Figure S1 in the Supplementary Materials for the detailed steps of preparation.

Table 1 Ingredients of the NE2, peel-enriched and peel/flesh-enriched formulations

Ingredients	Formulations						
	NE2	P30/30	P30/45	P30/60	P&F[30+4]	P&F[30+8]	P&F[30+12]
Tapioca starch	250 g						
Table salt, iodized	24.6 g (2 teaspoons, 10 mL)						
Chinese garlic, crushed	9.1 g (2 teaspoons, 10 mL)						
White pepper, ground	2.4 g (1 teaspoon, 5 mL)						
White granular sugar	12.75 g (1 tablespoon, 15 mL)						
Canola oil	5 g						
Boiled water	150 mL						
B8 peel (30-min boiled)	—	75 g	—	—	—	—	—
B8 peel (45-min boiled)	—	—	75 g	—	75 g	75 g	75 g
B8 peel (60-min boiled)	—	—	—	75 g	—	—	—
B8 flesh	—	—	—	—	10 g	20 g	30 g

Banana peel boiling pretreatment

Peel of *Namwa* bananas of ripeness stage 8 (B8 peel) was thoroughly washed and full-boiled (rolling boiled) with distilled water (125 mL/100 g of B8 peel) for 30, 45, or 60 min. Boiling pretreatments were carried out without stirring to limit the loss of dry matter due to fragmentations. The post-boiling weight was determined after 90 min of draining and cooling down and mass loss was then calculated.

Preparations of banana-enriched crackers

The PE crackers were the NE2 crackers with B8 peel supplementation. The boiled B8 peel thin paste was first prepared by blending the boiled peel with hot boiled water (75 g boiled peel/150 mL distilled water; Table 1) and then used to prepare the dough instead of the usual boiled water only. This resulted in the addition of boiled B8 peel at 30% by weight relative to tapioca starch. The rest of the preparation steps were followed unaltered. Three formulations of PE crackers (P30/*xx*) were prepared, where "*xx*" is the boiling time (30, 45, or 60 min).

The PFE crackers were the P30/45 PE crackers with B8 flesh supplementation. The peel/flesh paste was used as an ingredient rather than the peel paste. To prepare the peel/flesh paste, a thin paste of the B8 peel that had been boiled for 45 min was first prepared as described above. Thin slices of B8 flesh were blended with the peel paste. The flesh was added at 10, 20, or 30 g for every 75 g of boiled B8 peel (Table 1). The relative amount of the B8 flesh was 4, 8, or 12% by weight relative to tapioca starch. Three P&F[30+*x*] formulations were investigated, namely: P&F[30+4], P&F[30+8], and P&F[30+12].

Questionnaire surveys

Ethical approval for the involvement of the human subjects was granted on January 20, 2020, by Phranakhon Rajabhat University's Research Ethics Committee, Reference No. 01.049/63.

Five sensory attributes were evaluated by the sensory panel, including Overall Appearance (*Ap*), Color (*Cl*), Aroma (*Ar*), Taste (*Ts*), and Texture (*Tx*). Overall Satisfaction (*OS*) was also evaluated as the sixth criterion. All sensory evaluations were conducted using crackers without further seasoning.

Product development

During the development of the banana-enriched crackers, the bipolar 9-point scale, i.e. whole number scores from −4 to 4, was employed. The sensory panel consisted of 70 untrained members (18 males and 52 females; aged between 19 and 52) selected from the students, staff, and lecturers in the Home Economy Program.

Sensory scores of cracker formulations evaluated at the same time were grouped according to the panellist to ensure that the survey followed the randomized complete block design (RCBD), i.e. with 70 blocks.

Rancidity analysis

The same bipolar 9-point scoring scheme was employed. The panelist panel consisted of 30 untrained members (5 males and 25 females; aged between 19 and 52) selected from the Home Economy Program's students, staff, and lecturers. The NE2 and P&F[30+8] crackers were prepared and kept separately in closely sealed plastic boxes without any desiccant. The boxes were stored at 35±1 °C without direct exposure to sunlight. The evaluations for the absence of the unpleasant smell of rancidity were carried out at 0, 2, 4, 6, 8, and 10 days of storage.

Customer Acceptance

In the Sensory Evaluation section of the customer acceptance survey, the bipolar 5-point scale (−2, −1, 0, 1, 2) was employed. For comparison with the sensory panel's scores, the "equated" scores (−4, −2, 0, 2, 4) were used. The 150 respondents who participated in the acceptance survey were the University's students, staff, lecturers, and researchers, of which 43 were males and 107 were females and their ages were between 18–50 years.

Total phenolic contents and pH

The Folin-Ciocalteu colorimetric assay was carried out according to Vallverdú-Queralt el al. (2011) with modifications. Without any pretreatment, sample powder/pulp was extracted with deionized water (5 mL/g sample) via vertex mixing (90 secs at higher speed) and sonication (5 minutes). The supernatant was collected by centrifugation (4,000 rpm at 4 °C). A single round of repeated extraction of the sediment was carried out and the supernatants were pooled together and mixed well. No cleaning-up procedure was carried out. The assays were carried out in triplicate with 3 samples/formulations used and the total phenolic compounds concentration ([Total Phenolics]) was determined at 760 nm with a UV/Vis spectrophotometer (UV2-100, UNICAM, UK) using tannic acid as the standard. All samples and standards were handled without exposure to sunlight. The supernatant was also used in pH measurements with the ST3100-B benchtop pH meter (OHAUS Instruments, China).

Proximate analyses and physical characteristics

Moisture, crude protein, crude fat, total dietary fiber, and ash contents were determined using the methods described in or based on AOAC's standard methods (AOAC International, 2011). The remaining dry matter of each sample was taken as the non-dietary fiber carbohydrate.

The sample colors were determined with a benchtop spectrophotometer (CM-3500d, Konica Minolta, Japan) using d/8° measurement geometry and an 8-mm aperture. CIE $L^*a^*b^*$ color coordinates under D65 illuminant and 10° standard observer were recorded. The chroma (C^*), hue angle (h), and color saturation (s; $100 \times C^*/L^*$) were calculated. Yellowness indices (YIE_{313}; per ASTM Method E 313) were also calculated using the corresponding CIE XYZ Tristimulus values of each $L^*a^*b^*$ coordinates via the equation $YIE_{313} = (100/Y) \times (1.3013X - 1.1498Z)$ (Choudhury, 2014).

Pre- and post-puffing weights were recorded ($n = 3$) to calculate the cooking yield (weight increase after frying). Sample apparent volumes (pre- and post-puffing volume) were determined ($n = 5$) with a solid displacement method modified from AACC 10-05.01 by using sesame seeds as the filling material (AACC International, 2010). Sample bulk densities and volume expansions (of the fried crackers) were calculated using the apparent volumes. The latter was defined as the ratio of the volume increase after frying to pre-puffing volume.

Puncture tests were carried out for the optimized formulation using the CTX Texture Analyser (AMETEX Brookfield, USA). Crackers were mounted individually on a support rig with 5-cm space between the left and right parallel edges. The load was applied centrally using a spherical probe (5-mm diameter). Test settings were test speed of 1 mm/s, trigger force of 50 g and travel distance of 5 mm. The maximum forces at break of 10 samples was recorded and used as an indicator of sample hardness. Crackers that were kept in closely sealed zipped bags, were tested within 2 hr of frying.

Statistical analyses

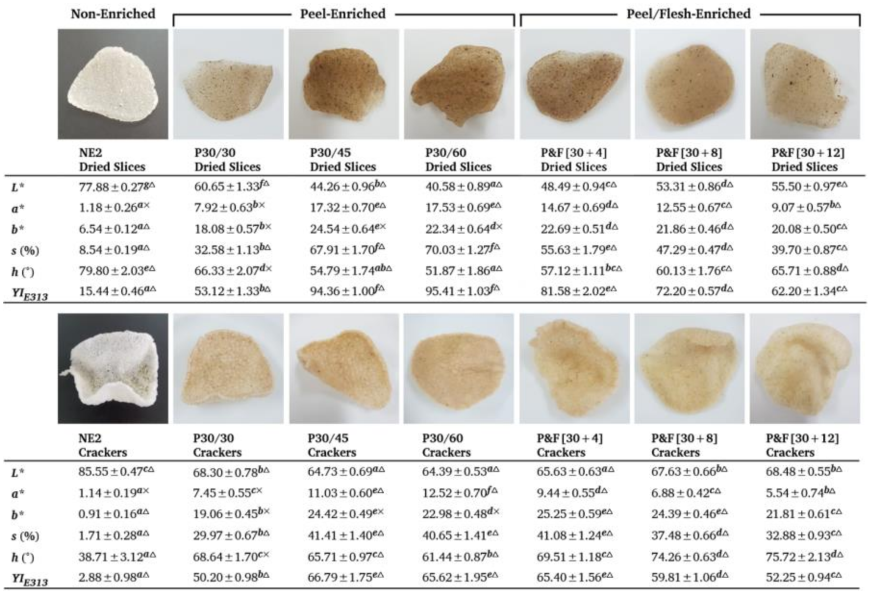
The general linear model/Univariate was employed to analyze the data related to sensory evaluations whereas one-way ANOVA was employed on the other data. *Post hoc* multiple comparisons were carried out following the Ryan-Einot-Gabriel-Welsh (REGW) F method. All statistical analyses were interpreted at $\alpha = 0.05$.

Results and Discussion

Formulation optimizations of banana-enriched crackers

The process of developing banana enriched crackers consisted of 3 sessions of sensory evaluations. Nine formulations were prepared and investigated in total. The NE1, NE2, and NE3 were non-enriched ones. The selection of the non-enriched NE2 formulation as the base formulation for banana enrichments is given in detail in the Supplementary Materials. In brief, the NE2 formulation was superior to the other NE formulations in every sensory attribute except the color. In terms of taste, the NE2 ingredients provided a better balance between saltness and sweetness. In terms of aroma, the NE2 also contained garlic in addition to white pepper. However, the NE2 aroma and color were relatively weak (*Ar*-score < 2.00; *Cl*-score < 1.50) compared to the other 3 sensory attributes.

Photograph images along with CIE $L^* a^* b^*$ color coordinates and corresponding saturation, hue angles, and yellowness indices of the NE2 and the 6 enriched formulations are given in Fig. 1.



	NE2 Dried Slices	P30/30 Dried Slices	P30/45 Dried Slices	P30/60 Dried Slices	P&F [30+4] Dried Slices	P&F [30+8] Dried Slices	P&F [30+12] Dried Slices
L^*	$77.88 \pm 0.27^{g\Delta}$	$60.65 \pm 1.33^{f\Delta}$	$44.26 \pm 0.96^{b\Delta}$	$40.58 \pm 0.89^{a\Delta}$	$48.49 \pm 0.94^{c\Delta}$	$53.31 \pm 0.86^{d\Delta}$	$55.50 \pm 0.97^{e\Delta}$
a^*	$1.18 \pm 0.26^{a\times}$	$7.92 \pm 0.63^{b\times}$	$17.32 \pm 0.70^{e\Delta}$	$17.53 \pm 0.69^{e\Delta}$	$14.67 \pm 0.69^{d\Delta}$	$12.55 \pm 0.67^{c\Delta}$	$9.07 \pm 0.57^{b\Delta}$
b^*	$6.54 \pm 0.12^{a\Delta}$	$18.08 \pm 0.57^{b\times}$	$24.54 \pm 0.64^{e\times}$	$22.34 \pm 0.64^{d\times}$	$22.69 \pm 0.51^{d\Delta}$	$21.86 \pm 0.46^{d\Delta}$	$20.08 \pm 0.50^{c\Delta}$
s (%)	$8.54 \pm 0.19^{a\Delta}$	$32.58 \pm 1.13^{b\Delta}$	$67.91 \pm 1.70^{f\Delta}$	$70.03 \pm 1.27^{f\Delta}$	$55.63 \pm 1.79^{e\Delta}$	$47.29 \pm 0.47^{d\Delta}$	$39.70 \pm 0.87^{c\Delta}$
h (°)	$79.80 \pm 2.03^{e\Delta}$	$66.33 \pm 2.07^{d\times}$	$54.79 \pm 1.74^{ab\Delta}$	$51.87 \pm 1.86^{a\Delta}$	$57.12 \pm 1.11^{bc\Delta}$	$60.13 \pm 1.76^{c\Delta}$	$65.71 \pm 0.88^{d\Delta}$
YI_{E313}	$15.44 \pm 0.46^{a\Delta}$	$53.12 \pm 1.33^{b\Delta}$	$94.36 \pm 1.00^{f\Delta}$	$95.41 \pm 1.03^{f\Delta}$	$81.58 \pm 2.02^{e\Delta}$	$72.20 \pm 0.57^{d\Delta}$	$62.20 \pm 1.34^{c\Delta}$

	NE2 Crackers	P30/30 Crackers	P30/45 Crackers	P30/60 Crackers	P&F [30+4] Crackers	P&F [30+8] Crackers	P&F [30+12] Crackers
L^*	$85.55 \pm 0.47^{c\Delta}$	$68.30 \pm 0.78^{b\Delta}$	$64.73 \pm 0.69^{a\Delta}$	$64.39 \pm 0.53^{a\Delta}$	$65.63 \pm 0.63^{a\Delta}$	$67.63 \pm 0.66^{b\Delta}$	$68.48 \pm 0.55^{b\Delta}$
a^*	$1.14 \pm 0.19^{a\times}$	$7.45 \pm 0.55^{c\times}$	$11.03 \pm 0.60^{e\Delta}$	$12.52 \pm 0.70^{f\Delta}$	$9.44 \pm 0.55^{d\Delta}$	$6.88 \pm 0.42^{c\Delta}$	$5.54 \pm 0.74^{b\Delta}$
b^*	$0.91 \pm 0.16^{a\Delta}$	$19.06 \pm 0.45^{b\times}$	$24.42 \pm 0.49^{e\times}$	$22.98 \pm 0.48^{d\times}$	$25.25 \pm 0.59^{e\Delta}$	$24.39 \pm 0.46^{e\Delta}$	$21.81 \pm 0.61^{c\Delta}$
s (%)	$1.71 \pm 0.28^{a\Delta}$	$29.97 \pm 0.67^{b\Delta}$	$41.41 \pm 1.40^{e\Delta}$	$40.65 \pm 1.41^{e\Delta}$	$41.08 \pm 1.24^{e\Delta}$	$37.48 \pm 0.66^{d\Delta}$	$32.88 \pm 0.93^{c\Delta}$
h (°)	$38.71 \pm 3.12^{a\Delta}$	$68.64 \pm 1.70^{c\times}$	$65.71 \pm 0.97^{c\Delta}$	$61.44 \pm 0.87^{b\Delta}$	$69.51 \pm 1.18^{c\Delta}$	$74.26 \pm 0.63^{d\Delta}$	$75.72 \pm 2.13^{d\Delta}$
YI_{E313}	$2.88 \pm 0.98^{a\Delta}$	$50.20 \pm 0.98^{b\Delta}$	$66.79 \pm 1.75^{e\Delta}$	$65.62 \pm 1.95^{e\Delta}$	$65.40 \pm 1.56^{e\Delta}$	$59.81 \pm 1.06^{d\Delta}$	$52.25 \pm 0.94^{c\Delta}$

Regarding the color parameters of dried slices or crackers between different formulations (i.e. in the same row), the superscript $^{a, b, c, \text{etc.}}$ indicated *post hoc* homogeneous subsets (values with no letter in common are significantly different).

Regarding the color parameters between the dried slices and crackers of the same formulations (i.e. corresponding values in the same column), the symbols "△" and "×" marked significant and non-significant differences, respectively.

Figure 1 Photograph images and the color parameters of cracker formulations prepared in the present study

With regards to colors, the hue angle/color system used by Jonauskaite et al. (2016) was adopted: provided that chroma (C^*) was > 5, hue angles (h) in the range of 346° – 40° were considered as red, those in the range of 40° – 72° were considered orange, and those in the range of 72° – 105° were considered yellow. Pure red was observed at a hue angle of 25°, orange was observed at a hue angle of 57°, and yellow at 87°. Colors with chroma ≤ 5 were considered achromatic (more or less in grayscale) tone regardless of hue angle and chroma values.

Bananas of ripeness stage 8 and peel boiling pretreatment

The relative weights of the *Namwa* B8 peel varied considerably between bananas obtained from different markets. The peel to whole fruit weight ratio was 20.60% ± 4.31 whereas the peel to flesh weight ratio was 26.19% ± 6.88. In an 8-stage classification of *Namwa* banana ripening, the presence of a small number of senescent spots or flecks on the peel marks the beginning of ripeness stage 7 whereas a fairly large area of enzymatic browning on the peel indicates the ripeness stage 8 (Chapai et al., 2018). Wang et al. (2014) divided banana ripening into 7 stages and the B8 will be classified as being in the final stage of ripening, i.e. stage 7. The senescent spots or flecks were caused by the enzymatic browning reaction. This indicates that polyphenol oxidase activity (PPO) was very high in the B8 peel.

Phenolic compounds were still present in the untreated B8 peel (see Fig. 4. for more details). The direct supplementation of B8 peel at 30% of tapioca starch weight resulted in bitter crackers (data not shown). The B8 peel was first boiled in water to remove a significant portion of phenolic compounds. To develop high-fiber crackers, we fixed the boiled B8 peel's relative amount and varied the pretreatment boiling time and prepared the PE (P30/*xx*; *xx* = 30, 45, or 60 min) crackers for evaluation.

The outer surfaces of the boiled peel turned dark all over during the boiling pretreatment. Polyphenol oxidase released from damaged peel tissue during prolonged boiling catalysed the oxidation of monophenols in the peel into *o*-diphenols. A polymerization reaction then converts o-diphenols to *o*-benzoquinones. Synthesized from the benzoquinones, melanin pigments were responsible for the dark color (Kaewjumpol et al., 2021). Compared to the NE2 dried slices or crackers, it is evident from Fig. 1. that pigments provided by the supplemented boiled peel gave rise to brown color of the banana-enriched crackers.

Cracker enrichments with boiled banana peel

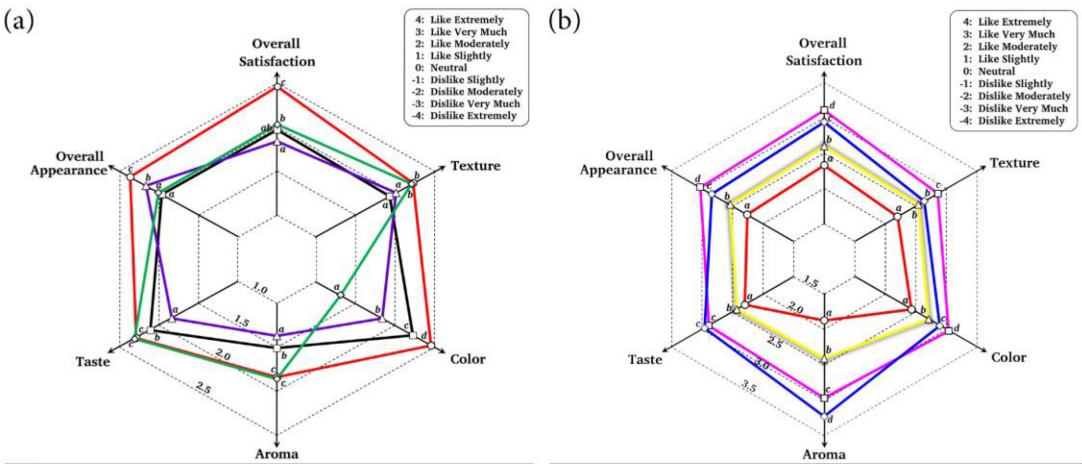
All PE (P30/*xx*) formulations were superior to the base formulation in terms of color. The NE2 dried slices were yellow in color (72° < h = 79.80±2.03 < 105°) but exhibited extremely low saturation (s = 8.54%±0.19) while the NE2 crackers were almost white (i.e. achromatic (C^* = 1.46±0.24) and very light in color (high lightness, extremely low saturation (s = 1.71%±0.28)).

The supplementation of boiled peel resulted in color shifts toward an orange tone (40° < h < 72°). As the color saturations were low to very low, the PE dried slices were brown, i.e. low-saturation orange. Longer boiling time resulted in darker and more saturated brown color. Kasar et al. (2019) reported that treating potato slices with acarbose (an α-amylase inhibitor and anti-diabetic drug) at 200 ppm for 30 min resulted in a reduction in PPO by 62% and sugar content by 8%. The inhibitor treatment also led to a dramatic reduction in the yellowness index (*YI*) and a dramatic increase in the whiteness of potato chips. The increases in *YI*s in the PE dried slices suggest that the majority of pigments provided by the boiled peel were melanin pigments formed during boiling pretreatment.

Apart from the lighter and lower-saturated colors of the crackers, frying the PE-dried slices resulted in hue shifts from orange towards yellow. The PE crackers had a light yellowish-brown color (high lightness, low-saturation yellowish orange ($57° < h < 72°$). It is obvious from the images given in Fig. 1 that, in terms of color and over appearance, boiling the peel for 45 min also made the P30/45 crackers look better than the P30/30 crackers which were too pale. Both the color saturations, lightnesses, and *YI*s of the P30/45 and P30/60 crackers were comparable but the P30/45 crackers displayed a slightly yellower hue.

The NE2 crackers were repeatedly evaluated together with 3 PE crackers and the average scores are given in Figure 2a. As expected, all the PE crackers received higher *Cl*-scores than those of the NE2 crackers. The P30/45 received the highest *Cl*-score and won the NE2 by a large margin of 1.15 units (9-point scale). Because of the bitter taste that was caused by a high amount of phenolic compounds, the P30/30 received the lowest *Ts*-score owing to the bitter taste left at the base of the tongue after consuming only a small amount of the crackers. No panelist mentioned the bitter taste of the P30/45 or P30/60 crackers. Therefore, boiling the peel for 45 min was sufficient for the enrichment with B8 banana peel at 30% of starch dry weight.

The P30/45 was the only PE formulation that was not statistically inferior to the base (NE2) formulation in every aspect of the sensory profile. It was quite unexpected that the supplementation of 45-min boiled B8 peel had no significant detrimental effect on the sensory attributes of the P30/45 formulation. Furthermore, the sensory profile of the P30/45 crackers was improved in terms of overall appearance and color. Alternatively, lengthening the peel boiling pretreatment time to 60 min resulted in inferior *Ar*-, *Ts*- and *Tx*-scores compared to those of the base formulation. As the *Ar*-score of the P30/45 crackers was relatively low (<2.0), we continued to further optimize the P30/45 formulation with the addition of B8 flesh.



(n = 70)	Overall Appearance	Taste	Aroma	Color	Texture	Overall Satisfaction
NE2	2.01 ± 0.86^{a}	2.31 ± 0.93^{c}	1.86 ± 0.91^{c}	1.31 ± 0.97^{a}	2.21 ± 0.98^{b}	2.03 ± 0.90^{b}
P30/30	2.17 ± 1.06^{b}	1.84 ± 1.34^{a}	1.37 ± 1.07^{a}	1.84 ± 1.07^{b}	2.01 ± 1.03^{a}	1.84 ± 1.33^{a}
P30/45	2.37 ± 1.04^{c}	2.29 ± 1.19^{c}	1.84 ± 1.04^{c}	2.46 ± 1.03^{d}	2.23 ± 1.04^{b}	2.46 ± 1.02^{c}
P30/60	1.97 ± 1.05^{a}	2.11 ± 1.06^{b}	1.51 ± 1.07^{b}	2.23 ± 1.04^{c}	1.93 ± 1.01^{a}	1.97 ± 0.99^{ab}

a, b, c, d *Post hoc* homogeneous subsets (values with no letter in common are significantly different)

(n = 70)	Overall Appearance	Taste	Aroma	Color	Texture	Overall Satisfaction
P30/45	2.26 ± 0.94^{a}	2.30 ± 0.84^{a}	1.87 ± 0.88^{a}	2.43 ± 0.89^{a}	2.20 ± 0.93^{a}	2.33 ± 0.86^{a}
P&F[30+4]	2.84 ± 0.90^{d}	2.96 ± 0.82^{c}	3.23 ± 0.73^{d}	2.89 ± 0.88^{c}	2.64 ± 0.90^{b}	2.94 ± 0.85^{c}
P&F[30+8]	3.03 ± 0.85^{c}	2.89 ± 0.84^{c}	2.97 ± 1.02^{c}	3.04 ± 0.95^{d}	2.86 ± 0.84^{c}	3.11 ± 0.73^{d}
P&F[30+12]	2.43 ± 0.86^{b}	2.43 ± 0.86^{b}	2.41 ± 0.97^{b}	2.71 ± 0.82^{b}	2.54 ± 0.88^{b}	2.60 ± 0.81^{b}

a, b, c, d *Post hoc* homogeneous subsets (values with no letter in common are significantly different)

Figure 2 Results of sensory panel evaluations of (a) 3 peel-enriched and (b) 3 peel/flesh-enriched cracker formulations

Cracker enrichments with boiled banana peel and ripe banana flesh

Based on the peel-enriched P30/45 formulation, 3 formulations of PFE crackers supplemented with B8 flesh were prepared (P&F[30+x], x = 4, 8, or 12 g/100 g starch dry weight). The sensory panel evaluated the PFE crackers along with the P30/45 formulation and the average score is given in Fig. 2b.

It was unexpected that the addition of B8 flesh resulted in significant improvements in sensory attributes that were not limited to the aroma but in every aspect of the sensory profile. At 4% of tapioca starch weight, the addition of B8 flesh led to the highest *Ar*-score. While the *Ar*-scores decreased with increasing amounts of B8 flesh added, the *Ar*-score of the P&F[30+12] crackers was still significantly higher than that of the formulation without B8 flesh.

The supplementation of B8 flesh resulted in lower *YI*s of the dried slices since melanin pigments were more diluted in the PFE formulations. As expected, hue shifts towards yellow were observed as the pigments provided by the boiled peel led to a hue shift toward orange. As observed in the case of the PE crackers, frying resulted in paler (higher lightness and less saturated) colors of PFE crackers. Hue shifts towards yellow after frying was also observed. The lightnesses of the +F8- and P&F[30+12] crackers were comparable to that of the P30/45 crackers but their color saturations were significantly higher.

In the P&F[30+4] crackers, the hue was yellowish orange (57° < *h* < 72°) whereas the hues were orangey yellow (72° < *h* < 87°) in crackers with higher amounts of B8 flesh. Even though the color of P&F[30+8] crackers was arguably too pale, banana-enriched crackers received the highest *Cl*-score with 30% and 8% of 45-minute boiled peel and ripe flesh, respectively. The supplementations of B8 flesh posed a constraint on the enriched cracker colors. To make the enriched cracker color more saturated, the hue was less yellow as in the case of the P&F[30+4] crackers. The sensory panel preferred the yellower hue of P&F[30+8] crackers to the more saturated but more orangey color of the P&F[30+4] crackers. This implies the inclination of the panelists towards the color of fried potato chips.

Apart from the aroma and color, the addition of B8 flesh resulted in air cells of smaller sizes that distributed more evenly in crackers. In general, the overall appearances of the PFE formulations were better than those of the PE formulations owing to the former much smoother surfaces. The B8 flesh also enhanced the taste of the crackers. Since only 0.82 – 2.45% of the PFE cracker dry matter was B8 flesh, it is unlikely that the enhanced tastes of the PFE crackers were mainly due to the increases in sweetness contributed by B8 flesh. *Namwa* B8 contained 9.77 ± 0.42, 8.76 ± 0.30, and 44.07 ± 0.33 g/100 g dry weight of fructose, glucose, and sucrose, respectively (Chaipai et al., 2018). Interestingly, at 2.45% of dry matter (in P&F[30+12] crackers), B8 flesh lowered all the sensory scores. The detrimental effects of a too-high volume of banana flesh were more pronounced in taste and aroma than the other sensory attributes.

All the sensory evaluation scores of the P&F[30+8] cracker were higher than 2.75 and its *OS*-score was also the highest. Therefore, the P&F[30+8] (P&F[30+8]) formulation was selected as the highest potential tapioca starch-based crackers containing B8 peel.

Customer acceptance survey

All of the 150 respondents had eaten crackers before but had never heard of banana peel-enriched ones. They mainly had crackers as a snack (49.33%) or as an appetizer (40.00%). 69.33% of them had previously eaten crackers at least once a month. (36.66% of them had eaten crackers every week.) Crackers were consumed as a light meal because they were tasty (43.33%), readily available (35.33%), or cheap (21.34%).

The optimized banana-enriched crackers were very well-received with 100% acceptance. However, 14.67% of the respondents were neutral and thought that, although it was not an inferior product, there was nothing special about the product compared to typical crackers currently available. 93.33% of the respondents were interested in buying the product whereas the remaining were of two minds. This indicates that more than half of the respondents who were neutral about the product were still want to buy it. Among the respondents with positive opinions about the product, they valued the product as innovative (76.67%), tasty (66.33%), interesting (49.33%), and nutritious (38.67%). Even though it was considered nutritious by only 38.67% of the respondents, 66.33% of the respondents thought that the product was tasty.

The respondents gave the product lower scores in every aspect of the sensory profile except for the *Tx*-score which was the highest sensory attribute score (2.87 ± 1.12 *vs* the panelists' 2.86 ± 0.84). The *Ar*-score was relatively low (2.23 ± 1.44). The other scores were 2.56 ± 1.10, 2.61 ± 1.27, 2.71 ± 1.19, and 2.75 ± 1.22 for *Ap*-, *Ts*-, *Cl*-, and *OS*-scores, respectively.

Cooking yield, frying oils uptake, and total energy of crackers

The "as-is" proximate compositions of the B8 peel and selected crunchy cracker formulations (enriched or non-enriched) along with their cooking yields are given in Table 2. The cooking yield of the NE2 formulation was 128.84% ± 0.79, for P30/45, 131.01% ± 0.92, and for the P&F[30+8] formulation, 130.39% ± 0.85. The cooking yields of the NE2 formulation were significantly lower (i.e. less oil uptake) than those of the enriched formulations.

Table 2 Compositions, pHs, bulk densities, volume expansion ratios, and cooking yields of the B8 peel and selected crackers

Formulations*	Moisture (%)	Crude Protein‡ (%)	Crude Fat (%)	Total Carbo-hydrate‡ (%)	Total Dietary Fiber‡ (%)	Ash‡ (%)	pH	Bulk Density (g/L)	Expansion Ratio (%)	Cooking Yield (%)
(1) B8 peel, untreated	85.55±0.25^{d}	1.12±0.05	0.86±0.02^{a}	10.71±0.26	8.71±0.27	1.76±0.05	7.48±0.05^{e}	*n/d*	*n/a*	*n/a*
(2) B8 peel, boiled†	91.44±0.13^{e}	0.62±0.02	0.80±0.04^{a}	6.18±0.13	5.27±0.21	0.96±0.03	5.91±0.03^{c}	*n/d*	*n/a*	*n/a*
(3) NE2, dried slices	10.45±0.16^{c}	0.37±0.02	1.89±0.08^{b}	85.41±0.28	0.50±0.02	1.88±0.09	6.21±0.02^{d}	527.4±16.0^{b}	*n/d*	*n/d*
(4) NE2, crackers	2.57±0.13^{b}	0.46±0.04	28.58±0.22^{c}	66.95±0.23	0.10±0.02	1.44±0.07	6.16±0.04^{d}	70.4±4.2^{a}	708.75±45.72^{ns}	128.84%±0.64^{a}
(5) P30/45, dried slices	10.73±0.21^{c}	0.43±0.03	2.22±0.09^{b}	84.54±0.15	2.87±0.04	2.08±0.08	5.45±0.03^{b}	543.8±20.3^{b}	*n/d*	*n/d*
(6) P30/45, crackers	1.37±0.11^{a}	0.45±0.02	31.52±0.26^{e}	65.14±0.20	2.16±0.05	1.52±0.05	5.19±0.04^{a}	77.8±4.4^{a}	648.36±41.27^{ns}	131.01%±0.73^{b}
(7) P&F[30+8], dried slices	10.59±0.19^{c}	0.37±0.02	1.96±0.09^{b}	85.17±0.27	3.09±0.04	1.91±0.04	5.46±0.02^{b}	535.6±19.1^{b}	*n/d*	*n/d*
(8) P&F[30+8], crackers	1.35±0.14^{a}	0.49±0.05	30.92±0.24^{d}	65.77±0.28	2.28±0.08	1.47±0.07	5.20±0.04^{a}	75.7±2.7^{a}	658.24±40.94^{ns}	130.39%±0.85^{b}

† 45-minute boiling
‡ ANOVA analysis was not carried out on these "as-is" dry matter data.
a, b, c, etc. *Post hoc* homogeneous subsets (values with no letter in common are significantly different).
ns *Not significantly different*
* All analyses or measurements were carried out using 3 samples (n = 3) except the bulk densities in which n = 5.
n/a Not applicable
n/d Not determined

Deep-fat frying in palm olein at 175 ± 5 °C was employed as the means of puffing the dried slices and, as a result, high frying oil uptake by the crackers was inevitable. Up to 95.12% of the crude fat of the crackers was frying oil. In the P&F[30+8] crackers, frying oil was about 19.5 times the amount of crude fat originally present in the dried slices. The frying oil accounted for 27.14% of the NE2 crackers' weight and 29.41% of the P&F[30+8] crackers' weight. (The estimations of frying oil contents of the crackers were based on the ratio of crude fat to non-fat dry matter of the respective dried slices.)

Crispiness and other organoleptic and sensorial properties of fried foods combine to give a unique experience of eating fried crackers. However, high dietary fat intake is a common health concern. Radiant frying, vacuum frying/puffing (with or without a microwave as a heating source) or spray frying (Udomkun et al., 2020; Wang et al., 2021) are potential alternatives to deep-fat frying that is currently employed.

To reduce the frying oil uptake of deep-fried crackers, composite flour containing flour with higher fiber content was studied. Jiamjariyatam (2019) reported that tapioca starch-based crackers contained about 37% oil. When tapioca starch/riceberry bran mixture (at the ratio of 3:1, 1:1, or 1:3) was used instead, the oil content was reduced to about 23%, 21%, or 16%, respectively. The effect of fiber on frying oil uptake was more complex in the case of fried crackers made from mixed flour composed of tapioca starch (TS), banana (mature green, flesh only) flour (BF), and brown waxy-rice flour (BWRF) (Say et al., 2022). While the reduction in tapioca starch in the flour mixture resulted in lower oil uptake of the crackers, smaller tapioca starch amounts (< 60%) did not always lead to lower oil uptake. In 4 pairs of formulations containing the same relative amount of tapioca starch, 2 pairs of such formulations exhibited lower crackers' oil contents in a formulation with BF:BWRF ratio > 1 compared to that in a formulation BF:BWRF ratio < 1. The other 2 pairs exhibited about the same cracker oil contents regardless of BF:BWRF ratios.

The total energy of each formulation was calculated from total crude fat (9 Cal/g) and total carbohydrate and crude protein (4 Cal/g). The non-enriched NE2 crackers provided total energy of 526.79±1.66 Cal/100 g whereas the P&F[30+8] crackers provided 543.23±1.64 Cal/100 g. The total energies of the crackers were about 147 – 154% of that of the respective dried slices owing to the very large amounts of frying oils left on the crackers. For reference, *Namwa* B8 flesh provided about 389 Cal/100 g (71.61% of that of the P&F[30+8] crackers) of total energy (Chaipai et al., 2018).

Amounts of B8 peel and flesh in dry matter of P&F[30+8] crackers

For peel supplementation at 30%, boiling without stirring for 45 minutes was effective in removing phenolic compounds while most of the peel's dry matter (94.62%) was retained. Boiling the peel also increased the peel's ratio of dietary fiber to non-dietary fiber carbohydrates. On a dry-weight basis, the 45-minute boiled B8 peel contained 63.61% dietary fiber. The effects of boiling pretreatment on the proximate compositions of the boiled B8 peel are discussed in more detail in the Supplementary Materials.

The 45-minute boiled B8 peel contained 91.68% moisture. According to Chaipai et al. (2018), the moisture content of raw B8 flesh was 69.21% ± 0.26. Since the boiled 45-minute B8 peel moisture content was much higher than that of the B8 flesh, the relative amounts (dry weight basis) of the peel and the flesh in dry matter of P&F[30+8] crackers were comparable, i.e. 1.66% and 1.63% of dry matter (including frying oil), respectively. The tapioca starch accounted for 59.32% of the dry matter (including frying oil).

Proximate compositions of the NE2 and P&F[30+8] crackers

The relative amounts of components of dry matter cannot be directly compared between formulations due to different amounts of the frying oil. The relative amounts of the components of non-fat dry matter of the NE2 and P&F[30+8] formulations are given in Fig. 3. The main component of the dried slices and the crackers was non-dietary fiber carbohydrate which accounted for more than 90% of the non-fat dry matter. Despite the relatively small amounts of the B8 peel and flesh present in the dried slices, the B8 peel/flesh enrichment led to about a 2,280% increase in the total dietary fiber and 133% increase in crude protein. The ash contents were not significantly affected by the B8 peel/flesh supplementation. The relative amount of non-dietary fiber carbohydrate of the P&F[30+8] dried slices decreased slightly as the result of the higher crude protein and total dietary fiber contents.

After making comparisons of the relative amounts of each non-fat dry matter component (Fig. 3) between the dried slices and the crackers of the same formulation, it is found that frying for a brief 6-8 sec in palm olein at 175 ± 5 °C led to significant reductions in total dietary fiber and non-dietary carbohydrate contents. Ash contents exhibited non-significant decreases. The reductions of the relative amounts of these 3 components of non-fat dry matter resulted in significant increases in crude protein contents. Tapioca starch provided a relatively tiny amount of total dietary fiber (presumed to be mainly in the form of resistant starch) which was reduced to about one-third after frying. A much smaller proportion of total dietary fiber was lost by frying in the P&F[30+8] crackers (4.53% compared to 73.68% of the NE2 formulations). We suspect that such a reduction in total dietary fiber occurred mainly to the portion of dietary fiber provided by tapioca starch and the portion provided by the boiled P8 peel was largely unaffected by frying.

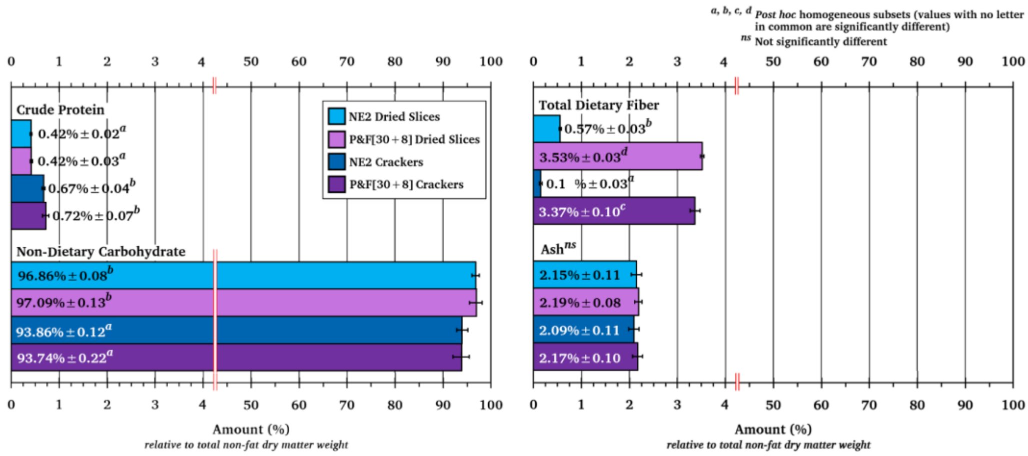


Figure 3 Relative amounts of the components of non-fat dry matter of the NE2 and the P&F[30+8] formulations

Bulk densities, volume expansions, and crispiness

The bulk densities of the NE2, P30/45, and P&F[30+8] dried slices were not significantly different (527.4 – 543.8 g/L). No significant difference was observed among the bulk densities of the crackers (70.4 – 77.8 g/L; Table 1). Jiamjariyatam (2019) also showed that higher amounts of rice berry bran, and hence higher fiber content, result in puffed crackers of higher hardnesses but lower volume expansion ratios. High relative amounts of tapioca starch also resulted in larger linear (thickness) expansion ratios in the study of Say et al. (2022). High relative amounts of banana flour led to lower expansion ratios. The linear expansion ratio of fried crackers prepared with TS/BF/BWRF mixture of 60:20:20 ratio was about 1.5, 2.0, and 9.5. times of those of the crackers prepared with the 46:33:21, 21:33:46, and 21:58:21 mixtures, respectively.

Dried slices of various formulations retained about the same amount of moisture (about 10.5 – 11.0%; Table 1). After frying, the moisture contents of the enriched (P30/45 and P&F[30+8]) crackers were significantly lower than that of the NE2 crackers. The volume expansions of the NE2, P30/45, and P&F[30+8] crackers were not significantly different. However, a significant difference in oil uptake was observed between the enriched (P30/45 or P&F[30+8]) crackers and the NE2 crackers. Even though the relative amounts of the boiled B8 peel and flesh were small, the supplementations of boiled B8 peel alone or along with B8 flesh resulted in about an 8% – 9% increase in frying oil uptake over that of the NE2 formulation.

The crispiness of the crackers was determined by measuring their fracture behavior. The maximum force applied in a puncture test is related to hardness and is used as an indicator of crispiness. A higher hardness value indicates that the material requires a higher force treatment for breaking and this can be explained as brittle. The maximum force at break of P&F[30+8] crackers was 2.35 ± 0.10 N.

Total phenolic contents and pH of B8 peel after thermal treatments

The total phenolic contents are reported as tannic acid equivalent (TAE) and given in Fig. 4a for the total phenolics per gram of sample fresh weight. The direct supplementation of untreated B8 peel at 30% (of tapioca starch weight) resulted in bitter crackers (data not shown). The supplementation of 45-minute boiled B8 peel at 30% did not make the crackers bitter. This suggests that the phenolic compounds responsible for the bitter taste were either (1) lost to boiling water or (2) still present in the boiled peel but converted to smaller compounds. Due to the presence of large amount of frying oil, the [Total Phenolics] was significantly lower than that of the corresponding dried slices, i.e. smaller proportions of the boiled peel in the fresh weights of the crackers. The P&F[30+8] crackers provided about 27 μg TAE/g.

For comparisons between the dried slices and crackers, the total phenolics per gram of the dry weight of the 45-minute boiled B8 peel present in the dried slices or crackers are given in Fig. 4b. The total phenolics contributed by the boiled B8 peel was significantly higher in the crackers than in the dried slices (about 106%) and in the boiled peel (about 140%). These observations suggest that more and more phenolic compounds were released from the breakdown of larger phenolic compounds. It is also evident from Fig. 4b. that the amounts of phenolic compounds contributed by the flesh were negligible since the [Total Phenolics] of the P30/45 and P&F[30+8] dried slices were not significantly different.

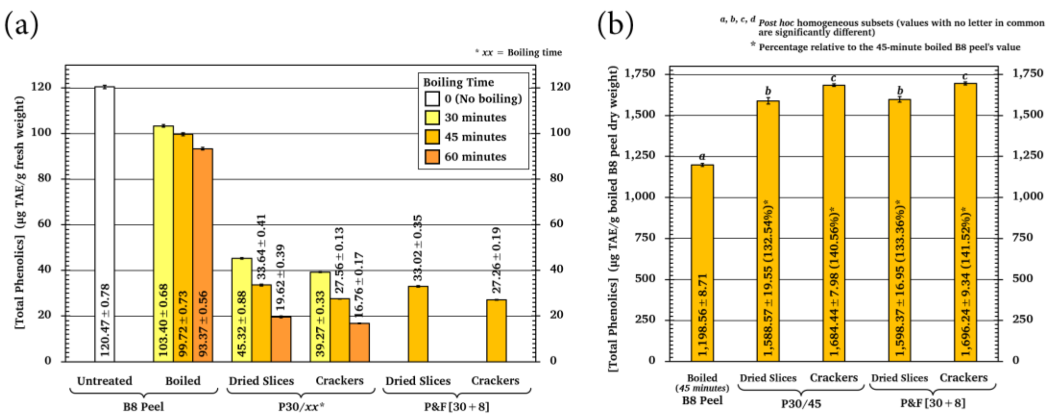


Figure 4 (a) Total phenolic compounds concentrations per gram fresh weight; (b) Total phenolic compounds concentrations concerning the actual amount of the 45-minute boiled B8 peel supplemented in each formulation

The pH values of the enriched dried slices and crackers given in Table 2 suggest the possibility that the (averaged) relative acidity of phenolic compounds in crackers was higher than that of phenolic compounds present in dried slices. This implies that, over the course of frying, the breakdown of larger phenolic compounds resulted in more acidic phenolic products. The other possibility is that larger proportions of phenolic compounds were converted to acidic non-phenolic products during frying. More acidic products from the breakdown of phenolic compoundsaccumulated in the enriched crackers than in the enriched dried slices

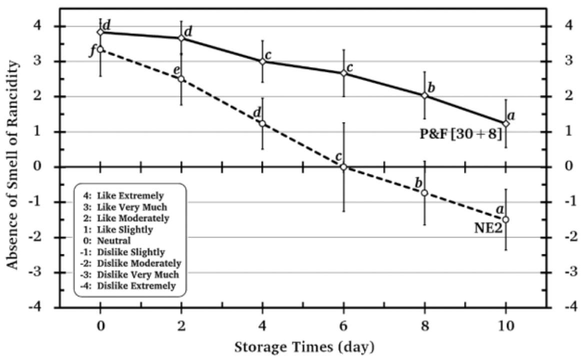
Sensory rancidity analysis

Based on microbiological risk assessment, the shelf life of the optimized formulations was 30 days in closely sealed zipped bags without any desiccant (elaborated in the Supplementary Materials). The results of sensory rancidity evaluation of the NE2 and P&F[30+8] crackers are given in Figure 5. At Day 0, the rancid score of the P&F[30+8] crackers was significantly higher than that of the NE2 crackers possibly due to the aroma of ripe banana flesh. In the NE2 crackers, rancidification progressed rapidly. After 6 days of storage at 35±1 °C, the crackers average score was at neutral satisfaction level (0.00) indicating that a number of panel members was already rejected the crackers. At Day10, the panelist had already dislike the NE2 crackers slightly due to the rancidity.

Despite their higher crude fat contents, the panelist still liked the P&F[8+30] crackers slightly at Day 10. Furthermore, none of the panel members disliked the enriched crackers, i.e. gave a lower score than 5 (data not shown). Therefore, without any desiccant and direct sunlight exposure, the enriched crackers could be stored at

35±1 °C in a closely sealed plastic box without customer rejection. It is reasonable to suggest that the anti-oxidants provided by the B8 peel help to suppress the progression of the rancidification.

Furthermore, in the case of the enriched crackers, a negative quadratic correlation was observed with Pearson's coefficient of determination (R^2) of 0.9923. Predicted using this trend, the enriched crackers are going to be rejected by the majority of customers on Day 13 with their negative rancid scores. The moisture content of the crackers increased from 0.15 to 0.63 and 2.01 wt% within 15 and 30 days of storage, respectively, in closely sealed zipped bags without any desiccant (Table S2 in the Supplementary Materials). The inclusion of a desiccant, such as silica gel (Amarakoon & Navaratne, 2017), may also suppress rancidification and other quality deteriorations and delay consumer rejection.



NE2	3.33 ± 0.76^f	2.50 ± 0.73^e	1.23 ± 0.73^d	0.00 ± 1.26^c	-0.73 ± 0.91^b	-1.50 ± 0.86^a
P&F[30+8]	3.83 ± 0.38^d	3.67 ± 0.48^d	3.00 ± 0.59^c	2.67 ± 0.66^c	2.03 ± 0.67^b	1.23 ± 0.68^a

Figure 5 Results of sensory panel evaluations of the NE2 and the optimized (P&F[30+8]) enriched formulations

Banana-enriched tapioca starch-based crackers as a functional food

Foods with high dietary fiber and/or resistant starch contents are considered healthy ones. Dietary fiber is generally defined as the macromolecules present in the diet which is resistant to digestion by human endogenous enzymes. It can be further classified as water-soluble or water-insoluble. In proximate analyses, it is generally included in the total carbohydrate component of the dry matter. There are 2 groups of dietary fiber: (1) non-starch dietary fiber and (2) resistant starch. Resistant starch is the portion of starch that is digestion-resistant or not absorbed in the small intestine. The colon microorganisms ferment resistant starch and release short-chain fatty acids. In general, the peel of ripe (yellow) bananas contained higher dietary fiber contents while ripe flesh contained higher resistant starch contents (Khoozani et al., 2019). Other non-energy micronutrients along with free sugars and free amino acid contents provided by the boiled B8 peel were arguably negligible since it was very likely that almost all of these small nutrients were lost during boiling pretreatment.

Banana peel is also rich in bioactive compounds. More than 40 of these are phenolic compounds. These compounds were reported to possess useful bioactivities including antioxidant, antimicrobial and anticancer. See Hikal et al. (2022) and Zaini et al. (2022) for a recent review. One apparent benefit of the antioxidant activities of bioactive compounds present in banana peel is free radical scavenging. Free radical reactive oxygen species (ROSs) released in the process of thermal degradation of lipids in frying oil are very reactive. They have proved to be detrimental to human health (Lobo et al., 2010). Phenolic compounds present in frying oil offer good protection of oils against oxidative deterioration without decreasing the sensory properties of fried food (Wu et al., 2019). The direct provision of phenolic compounds to food to be fried can be a better alternative to the supplementation of phenolic compounds in frying oil. Although the dried slices were only briefly fried, more and more ROSs accumulated in the prolonged use of frying oil. Since about 29.5% of P&F[30+8] crackers was frying oil, bioactive compounds with antioxidant activities provided by the boiled peel could help remove a significant proportion of ROSs in frying oil.

Note that banana peel also contains several anti-nutritional factors. Examples of water-soluble anti-nutritional factors in banana peels are tannins, oxalate, phytate, and glycoside. With 45-minute boiling pretreatment and the relatively tiny amount (1.66% of dry matter (frying oil included)) of the incorporated boiled peel, the presence of these anti-nutritional factors should be of little concern.

Tapioca starch provides a small amount of dietary fiber. Unfortunately, a large proportion (two-thirds) of the provided dietary fiber was destroyed during frying. The boiled B8 peel and flesh provided a significant amount of dietary fiber even though their total amount is only 4.59% of the dry matter excluding frying oil. The dietary fiber content of the P&F[30+8] crackers was about 22.5 times of that of the non-enriched base formulation whereas total phenolic content of the P&F[30+8] crackers was about 2.7 mg TAE/100 g crackers. Finally, based on its ingredients, the NE2 crackers are a gluten-free vegan snack. The enriched crackers are also gluten-free owing to the fact that bananas are naturally gluten-free. The P&F[30+8] crackers contained natural coloring and flavoring agents.

Conclusion and Suggestions

Tapioca starch-based crackers were successfully enriched with *Namwa* banana peel in the final ripeness stage. Boiling the peel in water for 45 min was required to ensure that the enriched product was not bitter at 30% by weight (relative to starch weight). All aspects of sensory profiles were improved when ripe banana flesh was supplemented. The optimized formulation contained 8% flesh in addition to the boiled peel. The optimized formulation was very well-received. Based on its ingredients, the banana-enriched crackers are a gluten-free vegan snack that contains dietary fiber, phenolic compounds, natural coloring, and flavoring agents, and no preservatives. In a closely sealed zipped bag without any desiccant, their shelf life was 30 days before being spoiled by an unsafe level of yeasts/molds due to an increase in moisture content.

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Author Contributions

Author 1: Optimizations of banana-enriched crackers, customer acceptance survey, and manuscript drafting;

Author 2: Characterizations of crackers' physical properties and manuscript editing and proofreading; Author 3: Characterizations of crackers' chemical properties, proximate analyses, and manuscript editing and proofreading.

Conflict of Interests

All authors declare that they have no conflicts of interest.

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