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Yam affects the antioxidative and gel-forming properties of surimi gels†

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Abstract: The antioxidative activities and textural properties of pollock surimi gels containing four different yams were determined to evaluate the potential of using yam as a health ingredient and an alternative source for starch in surimi-based seafoods. Surimi gels containing 20% fresh yam showed higher α,α-diphenyl-β-pricryl-hydrazyl (DPPH) radicals scavenging activities and total phenolic contents than the gels without yam. Two tested cultivars, 70W34 and 70W35, did not show significant reductions in antioxidative activities when used in surimi gel while three other cultivars revealed species-dependant declines in both the DPPH scavenging activities and total phenolic contents. The surimi gel containing the cultivar 70R20 showed the highest breaking forces and deformations. In general, 20% fresh yam could be used to form a yam-containing surimi gel having similar textural properties with a potato starch containing pollock surimi gel. The dried yam powders might be used at the amount of 30% fresh yam equivalent without causing significant losses of the textural properties of pollock surimi gels.

Keywords: yam; surimi; antioxidation; texture

INTRODUCTION

Yam is composed mainly of starch (75–84% of the dry weight) with small amounts of proteins, lipids and most vitamins and is very rich in minerals.[1,2] Yam has been classified as one of the important staples in the diets of many tropical countries because of the carbohydrate it provides. For example, yam is widely grown in West Africa.[3,4] Some yams are also used as medicines in the oriental countries to prevent diarrhea and diabetes.[5,6] Modern researches have shown that the extracts of yams can reduce blood sugar[7,8] and blood lipid,[9] inhibit microbe activity[10–12] and show antioxidative activity.[13,14]

Surimi is a washed fish mince to which cryoprotectants, such as sorbitol and sucrose, are added to maintain protein functionality during frozen storage.[15,16] Surimi can be further processed into various surimi-based gelled products such as artificial crab legs and meats. Starch, such as potato starch, is often added in the range of 8–15% to modify the textural properties of surimi-based seafoods. In this study, the potential of using yam as a health ingredient and an alternative source for starch in surimi seafoods was evaluated by determining the antioxidative activities and textural properties of surimi gels containing fresh yam, freeze or hot-air dried yam powders.

EXPERIMENTAL

Materials

Frozen high-grade Alaska pollock (*Theragra chalcogramma*) surimi was purchased from Kasei Frozen Foods Works Co, Ltd, Taiwan. The surimi was stored at $-20\,^{\circ}$C until use. α,α-Diphenyl-β-pricryl-hydrazyl (DPPH), gallic acid and α-tocopherol (trolox, α-Toc) were purchased from Sigma Chemicals Co (St Louis, MO, USA). Potato starch from Sigma Chemicals Co for determination of amylase activity was used as the control additive in the surimi gel. Four different yams (*Dioscorea alata*) within one week after harvest were purchased from Mingjian Shiang, Nantou County, Taiwan. They were three white yams, TNG1 (Tainung No1), 70W34 and 80W02 ('W' stands for white meat), and one red yam, 70R20 ('R' stands for red skin). The selection of these yams was because they are low costs and high yields in Taiwan. Yams were stored at room temperatures until use. Freeze- and hot-air-dried yams were produced in a local food processing plant. To produce freeze- and hot-air-dried yams, fresh yam was washed, peeled, cut into small chunks with size about 1 cm^3, and then dried to final moisture content of 4 and 6.7%, respectively. The dried yam samples were stored in plastic bags along with a desiccant sachet until use. Before incorporating

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into surimi gel, the dried yam samples were ground into powders and passed through a screener of mesh number of 80.

Composition determination

The analysis of the protein, fat, moisture, ash, fiber and starch content of each yam was performed according to standard AOAC methods.[17] The total sugar content was determined according to the method reported by Dubois *et al*.[18] About 0.5 g of sample was homogenized at 15 000 rev min^{-1} for 2 min with 10 ml of 80% ethanol. The ethanolic extraction was heated at 70 °C for 30 min. After cooling, the extraction was centrifuged at 4000 rev min^{-1} for 10 min. The supernatant was collected and the amount of total sugar was measured by the phenol–sulfuric acid method.[18]

Surimi gel preparation

The frozen surimi was merely partially thawed at room temperature for approximately 2 h to prevent the rapid increase of sample temperature during the subsequent blending procedures. Surimi was blended with 2% NaCl and predetermined amounts of yam (20 or 30% for fresh yam) in a mixer (Model AT7, Moulinex Co, Ecully, France) for 4 min to produce a mixture with total weight of 1 kg. Ice-water was also added during mixing to adjust the final moisture content to 78% while maintaining the temperature of the mixture in the range of 5–10 °C. When yam powders were used to substitute fresh yam, dry weights of the powders were equal to those of fresh yam. The mixture was stuffed in the stainless-steel cooking tubes (inside diameter 3.0 cm, length 15 cm), and surimi gels were then produced by heating in a 90 °C water-bath for 20 min, followed by cooling in ice–water at about 1 °C for 10 min. Surimi gels were stored in ziplock bags and refrigerated at about 5 °C. The gels were removed from refrigerated storage within 48 h, left at room temperature for 1 h, and then cut into small sections (diameter 3.0 cm, length 3.0 cm) for textural measurements.

Gel strength measurement

The gel properties were measured by a texture analyzer (Model TA-XT2, Stable Micro systems, Haslemere, UK) using a ball plunger with a diameter of 5 mm at a constant punch speed of 4 cm min^{-1} with a maximum punch distance of 15 mm. The results were expressed as breaking force (g) and deformation (mm). Breaking force was the force required in grams to break the gel and deformation was the distance in millimeters traveled by the ball plunger from the surface of the gel at the point of breakage.

Measurement of rheological properties

For measuring the rheological properties of four tested yams, the yams were freeze-dried, ground into powder, passed through a screener with mesh number of 80 and then adjusted to a final moisture of 75%. The rheological measurements were performed on a Carri-Med CSL 500 Rheometer (TA Instruments Ltd, Leatherhead, Surrey, UK) equipped with a cone-plate geometry. The gap size, temperature and the range of shear rate were set at 61 μm, 25 °C, and 0–500 (1/s) respectively. The shear stress and shear rate were recorded and fitted into a power function: shear stress $= K(\text{shear rate})^N$.

Measurement of DPPH radical-scavenging activity

The DPPH radical-scavenging activity of yams were measured according to the method of Yamaguchi *et al*.[19] Samples (fresh yams, yam powders, and surimi gels with the addition of fresh yams or yam powders) were blend with 50% ethanol, and then the aliquot of the mixture (100 μl, 200 mg sample per ml 50% ethanol) was further mixed with 100 mM Tris-HCl buffer (400 μl, pH 7.4) and then added to 1 ml of 500 μM DPPH in ethanol (final concentration of 250 μM). The mixture was shaken vigorously and left in the dark at room temperature for 20 min. The absorbance of the resulting solution was measured spectrophotometrically at 517 nm. Trolox (α-Toc) ($0.04 \sim 1.25$ mg ml^{-1}) was used as the standard for the calibration curve, and the DPPH radical-scavenging activities were expressed as μmol trolox equivalents per gram of tested samples.

Total phenolic content determination

The total phenol content was analyzed using the Folin–Ciocalteu's reagent method.[20] Samples (fresh yams, yam powders, and surimi gels with the addition of fresh yams or yam powders) were blend with 50% ethanol, and then the aliquot of the mixture (0.5 ml, 200 mg sample per ml 50% ethanol) was further mixed with 0.5 ml of Folin–Ciocalteu's reagent and 0.05 ml of 10% Na_2CO_3, and the absorbance was measured at 735 nm after 1 h of incubation at room temperature. Gallic acid was used as the standard for the calibration curve, and the total phenolic contents were expressed as mg gallic acid equivalents per gram of tested samples.

Statistical analysis

One-way analysis of variance (one-way ANOVA) was conducted using a SAS package (SAS Institute Inc, Cary, NC). Duncan's multiple ranges test was used to determine the significant difference between different treatments.

RESULTS AND DISCUSSION

Composition and antioxidative property

The compositions of four tested yams are shown in Table 1. The crude protein, starch, ash and total sugar contents showed significant differences among the yams. TNG1 and 70W34 had higher total sugar contents than 70R20 and 80W02, while the order of crude protein levels followed:

Table 1. The compositions of four different yams

	70R20	70W34	TNG1	80W02
Crude protein	30.5 ± 0.7^{c}	42.7 ± 1.1^{b}	18.6 ± 0.9^{d}	45.3 ± 0.5^{a}
Crude fat	0.8 ± 0.1^{a}	0.7 ± 0.1^{b}	0.5 ± 0.1^{c}	0.5 ± 0.1^{c}
Ash	12.6 ± 1.5^{b}	13.1 ± 0.1^{ab}	8.6 ± 1.3^{c}	14.6 ± 0.3^{a}
Crude fiber	5.2 ± 0.6*	4.3 ± 0.3	4.8 ± 1.5	5.2 ± 0.2
Total sugar	35.8 ± 2.7^{b}	68.8 ± 2.0^{a}	67.9 ± 0.2^{a}	34.7 ± 0.7^{b}
Starch	46.1 ± 2.1^{a}	40.4 ± 1.1^{c}	42.5 ± 0.8^{bc}	45.2 ± 2.0^{ab}
Moisture content	747 ± 15*	757 ± 40	780 ± 36	743 ± 49

The values are mean ± standard deviation, with the unit of $g\,kg^{-1}$ yam.
* The values in the same row were not significantly different.
The values in the same row followed by different superscripts were significantly different ($p < 0.05$).

Table 2. The scavenging activities toward α,α-diphenyl-β-pricryl-hydrazyl (DPPH) radical and total phenolic contents of five fresh yams and pollock surimi gels containing 20% fresh yam

	DPPH scavenging activity (trolox $\mu mol\,g^{-1}$)		Total phenolic content (gallic acid $mg\,g^{-1}$)	
	Yam	Surimi gels (with 20% yam)	Yam	Surimi gels (with 20% yam)
70R20	9.46 ± 0.54^{b}	1.30 ± 0.27^{ab} (2.57)*	0.93 ± 0.08^{b}	0.14 ± 0.03^{a} (0.24)*
70W34	5.70 ± 0.51^{c}	1.41 ± 0.22^{ab} (1.82)	0.46 ± 0.05^{c}	0.13 ± 0.02^{ab} (0.15)
TNG1	15.60 ± 2.73^{a}	1.43 ± 0.25^{ab} (3.80)	1.24 ± 0.17^{a}	0.14 ± 0.01^{a} (0.30)
80W02	4.65 ± 0.53^{c}	1.09 ± 0.15^{bc} (1.61)	0.43 ± 0.02^{c}	0.09 ± 0.01^{bc} (0.14)
Surimi gel (without yam)		0.84 ± 0.07^{c}		0.07 ± 0.00^{c}

The values are mean ± standard deviation.
The values in the same column followed by different superscripts were significantly different ($p < 0.05$).
* Estimated value based on the data of fresh yam and surimi gel without yam, the calculation equation = 0.8 * the value of surimi gel + 0.2 * the value of fresh yam.

80W02 > 70W34 > 70R20 > TNG1. Table 2 shows the scavenging activities toward α,α-diphenyl-β-pricryl-hydrazyl (DPPH) radical and total phenolic contents of four fresh yams and pollock surimi gels containing 20% fresh yam. All the tested yams showed DPPH scavenging activities, and TNG1 had the highest DPPH-scavenging activity followed by 70R20, while no significant difference was found between 70W34 and 80W02. When fresh yam was added in an amount of 20% to pollock surimi gel, all the yam-containing gels except 80W02 showed significantly higher DPPH-scavenging activities than the gel without yam. The DPPH-scavenging activities of surimi gels containing 20% fresh yams were also estimated based on the data of fresh yams and surimi gel without yam, and the estimated values are also shown in Table 2. There were significant differences between the experimental values and estimated values of the DPPH-scavenging activities in 70R20, TNG1 and 80W02, but the difference in 70W34 was not significant. It was suspected that the losses in the DPPH-scavenging activities might be due to the interactions between the phenolic compounds in the yam and the proteins of the surimi gel, the complexation of phenolic compounds and proteins might have reduced the antioxidative activity of the phenolic compounds. The estimated values of total phenolic contents of four fresh yams and pollock surimi gels containing 20% fresh yam were also higher than the experimental data (Table 2), suggesting that complexation of phenolic compounds and fish proteins might hinder the extraction of phenolic compounds by ethanol solution, thus reducing the analytical values of phenolic contents. However, there are no relevant data reported in literature so far to support our suggestion. Furthermore, it might be worth to look into whether the gel preparation procedures, such as heating at 90 °C and adding 2% NaCl, could cause the reduction of phenolic contents in the final gel. All surimi gels containing 20% fresh yam had higher total phenolic contents than surimi gel without yam except the 80W02-containing surimi gel. We also found species dependent losses of the total phenolic contents in TNG1-, 70R20- and 80W02-containing gels with the order TNG1 > 70R20 > 80W02, but no significant losses were found in 70W34-containing gel. To further demonstrate the species dependent reduction in yam-containing gel, the DPPH-scavenging activity and total phenolic content of a species, 70W35, closely related to 70W34, were determined. The DPPH-scavenging activities and total phenolic contents of 70W35 and surimi gel containing 20% 70W35 were 5.05, 0.44 and 1.62, 0.14, respectively, and the estimated values for surimi gel containing 20% 70W35 were 1.69 and 0.14, respectively. Like 70W34, 70W35 showed no significant reduction in the antioxidative ability.

Effect of drying on antioxidative property

According to the results shown in Table 2, two yams, TNG1 and 70W34, that showed different antioxidative responses before and after incorporating into pollock surimi gels, were selected to further study the effects of two drying methods on their DPPH-scavenging activities and total phenolic contents. TNG1 showed the highest DPPH-scavenging activity and total phenolic content among five tested yams, but it also suffered the most significant losses after incorporating into pollock surimi gel. 70W34 was selected because it did not show significant losses in both the DPPH-scavenging activity and total phenolic content. Table 3 shows the effects of freeze and hot-air drying methods on the DPPH-scavenging activities and total phenolic contents of 70W34 and TNG1. In 70W34, both the DPPH-scavenging activities and total phenolic contents were no significant differences among fresh, freeze and hot-air dried yams. However, in TNG1, drying process did significantly decrease both the DPPH-scavenging activities and total phenolic contents. The lack of losses in 70W34 during drying perhaps was due to the initial low values. There was significant difference between freeze and hot-air-dried TNG1 in total phenolic content but no significant difference was found in DPPH-scavenging activity. Thus, TNG1 suffered significant loss in antioxidative ability due to not only surimi gel processing but also drying processing, while 70W34 did not show significant losses.

Effect of yam on the rheological property of surimi

In order to compare the texture properties, the final moisture of all the surimi gels was adjusted to 78%. At the moisture level, the breaking force and deformation of the pollock surimi gel were 522 ± 37 g and 14.7 ± 0.7 mm, respectively. The effect of adding fresh yam on the textural properties of pollock surimi gels is shown in Table 4. The surimi gel contained potato starch with the amount (dry weight basis) equal to that of fresh yam was used as the control. When adding 20% fresh yam to surimi gel, the breaking force, an indicator of gel hardness, of 70R20-containing gel was higher than that of the control, while other three yams showed lower breaking force values than the control. All surimi gels containing 30% fresh yam showed lower breaking force values than the control. It was noted that the increase of fresh yam levels from 20 to 30% caused a significant decrease in the breaking force in all yam-containing surimi gels, but no significant change was found in potato starch-containing surimi gel as the level of potato starch within 20–30%. The deformation of 70R20 was also higher than that of the control, while other three yams showed no significant differences with the control. Again, the increase of fresh yam levels from 20 to 30% resulted in a significant decrease in the deformation in all yam-containing surimi gels, but no significant difference was observed in the control. Our results indicated that the textural properties of surimi gels containing yam in the level of 20% might be acceptable, but weaker surimi gels were obtained as the level of fresh yam reaching 30%. Among the four tested yams, 70R20 showed significant higher breaking force and deformation regardless its relative lower crude protein and total sugar contents (Table 1).

The rheological properties of the yam pastes (75% moisture content) was investigated in order to explain the differences in textural properties of the surimi gels containing different yams. It was found that the parameters, K and N, derived from fitting the shear stress and shear rate data into a power function of 70R20 also showed the unique rheological properties (Table 5). All tested yams showed shear-thickening (dilatent) behavior with the values of N greater than 1. However, 70R20 showed a higher N value than other yams. It is known that the dilatant behavior is often found in suspensions of high solids content. When the

Table 3. The scavenging activities toward α,α-diphenyl-β-pricryl-hydrazyl (DPPH) radical and total phenolic contents of fresh-, freeze- and hot-air-dried yams

	DPPH scavenging activity (Trolox μmol g^{-1})	Total phenolic content (Gallic acid mg g^{-1})
70W34		
Fresh yam	5.70 ± 0.51^{cd}	0.46 ± 0.05^{c}
Freeze-dried yam	4.91 ± 0.23^{cd}	0.53 ± 0.01^{c}
Hot-air-dried yam	4.27 ± 0.36^{d}	0.48 ± 0.03^{c}
TNG1		
Fresh yam	15.60 ± 2.73^{a}	1.24 ± 0.17^{a}
Freeze-dried yam	7.78 ± 0.41^{b}	0.75 ± 0.03^{b}
Hot-air-dried yam	6.49 ± 0.51^{bc}	0.57 ± 0.07^{c}

The values are mean ± standard deviation.
The values in the same column followed by different superscripts were significantly different ($p < 0.05$).

Table 4. Textural properties of surimi gels containing fresh yam

	Breaking force (g)		Deformation (mm)	
	20%	30%	20%	30%
70R20	352 ± 53^{a}	162 ± 19^{b}	11.5 ± 1.1^{a}	8.2 ± 0.5^{a}
70W34	186 ± 11^{c}	116 ± 4^{c}	9.0 ± 1.0^{bc}	6.5 ± 0.4^{b}
TNG1	200 ± 4^{c}	103 ± 4^{c}	8.5 ± 0.4^{c}	5.8 ± 0.2^{c}
80W02	207 ± 17^{c}	121 ± 14^{c}	9.6 ± 0.5^{b}	6.1 ± 0.5^{bc}
Potato starch	288 ± 25^{b}	267 ± 25^{a}	8.9 ± 0.6^{bc}	8.7 ± 0.7^{a}

The values are mean ± standard deviation.
The values in the same column followed by different superscripts were significantly different ($p < 0.05$).

Table 5. The K and N values of the power functions represented the relationship between the shear stress and shear rate

	K	N
70R20	0.10 ± 0.07^{c}	2.02 ± 0.22^{a}
70W34	0.54 ± 0.23^{b}	1.70 ± 0.21^{b}
TNG1	1.40 ± 0.31^{a}	1.43 ± 0.07^{c}
80W02	0.40 ± 0.10^{bc}	1.79 ± 0.15^{ab}

Power function: shear stress = K(shear rate)^{N}.
The values are mean ± standard deviation.
The values in the same column followed by different superscripts were significantly different ($p < 0.05$).

Table 6. Textural properties of surimi gels containing fresh yam, freeze-dried yam, and hot-air-dried yam

	Breaking force (g)		Deformation (mm)	
	20%	30%	20%	30%
70W34				
Fresh yam	186 ± 11^{c}	116 ± 4^{d}	9.0 ± 1.0^{ab}	6.5 ± 0.4^{d}
Freeze-dried yam	279 ± 25^{b}	187 ± 7^{c}	8.7 ± 0.6^{b}	7.1 ± 0.2^{d}
Hot-air-dried yam	303 ± 16^{ab}	211 ± 34^{bc}	9.7 ± 0.4^{a}	7.9 ± 0.6^{bc}
TNG1				
Fresh yam	200 ± 4^{c}	103 ± 4^{d}	8.5 ± 0.4^{b}	5.8 ± 0.2^{e}
Freeze-dried yam	203 ± 35^{c}	219 ± 19^{b}	8.4 ± 0.2^{b}	7.8 ± 0.4^{c}
Hot-air-dried yam	321 ± 17^{a}	286 ± 14^{a}	9.7 ± 0.5^{a}	8.5 ± 0.4^{ab}
Potato starch	288 ± 25^{b}	267 ± 25^{a}	8.9 ± 0.6^{ab}	8.7 ± 0.7^{a}

The values are mean ± standard deviation.
The values in the same column followed by different superscripts were significantly different ($p < 0.05$).

concentrated suspension is sheared at high rate, the dense packaging particles expand (dilate), increases the voidage. Since there is only limited amount of liquid fill the voidage to lubricate the particles, the increasing voidage would result in insufficient liquid in the system to lubricate the flow of the particles past each other, thus increases the apparent viscosity. It was suspected that the amount and the size of the starch granule, as well as the rheological property of the mucin of 70R20 might be different from those of the other yams, and these characteristics results in a high dilatancy. The unique rheological property of 70R20, in turn, affected the texture of the 70R20 yam-containing surimi gel.

Table 6 shows the textural properties of pollock surimi gels containing fresh yam, freeze-dried or hot-air-dried yam powder. For surimi gels containing freeze- or hot-air-dried yam, the amount (dry weight basis) of yam powder was equal to that of fresh yam. Adding freeze- or hot-air-dried 70W34 powder in surimi gels at the levels of both 20 and 30% fresh yam equivalent resulted higher breaking force values than adding fresh yam, but no significant difference was found between freeze- and hot-air-dried 70W34 powder. As the level of freeze- or hot-air-dried 70W34 powder increased from 20 to 30%, the breaking force decreased significantly. Surimi gel containing freeze-dried TNG1 powder at 20% level showed no significant difference in the breaking force with surimi gel containing 20% fresh yam, but significant difference was found at 30% level. Moreover, surimi gel containing hot-air-dried TNG1 powder had higher breaking force values than freeze-dried TNG1 powder and fresh TNG1 at both 20 and 30% levels. The data of the deformation showed that surimi gels containing freeze-dried 70W34 powder at both 20 and 30% levels had same levels of deformation with the gels containing fresh 70W34. However, the addition of hot-air-dried 70W34 powder showed higher deformation values than freeze-dried 70W34 powder at both 20and 30% levels. For surimi gel containing TNG1, hot-air-dried powder had higher deformation than freeze-dried powder and fresh yam at both 20 and 30% levels. Moreover, surimi gel containing freeze-dried TNG1 powder at 30% level showed higher deformation value than fresh TNG1-containing gel, but no significant difference at 20% level.

The data of the breaking force and deformation indicated that hot-air-dried yam powder was the best form of yam to modify the textural properties of yam-containing surimi gel, followed by freeze-dried yam powder, and fresh yam appeared to be the worst form (Table 6). This finding was not agree with common understanding that freeze-drying is a better drying method than hot-air drying in preserving the nature and textural properties of food materials. It was suspected that fresh yam contained some components that might soften the texture of surimi gel due to their interactions with fish proteins to form a weaker gel matrix. These components might lose their activities during hot-air drying, while the loss of the activities might be less significant in freeze-drying method. A comparison with the textual properties of surimi gel containing potato starch also revealed that dried yam powders might be used at the amount of 30% fresh yam equivalent without causing significant losses of the textural properties of pollock surimi gels.

CONCLUSIONS

The yam TNG1 showed the highest antioxidative activity among the tested cultivars. All yam-containing pollock surimi gel except 80W02 showed significantly higher antioxidative activity than the gel without yam. When incorporating yam into pollock surimi gels, some yams reduced the antioxidative activity of the products. The effect of drying on the antioxidative activity of yam was species-dependant. Among four tested yams, 70R20-containing pollock surimi gel showed the best textural properties. It was also noted that hot-air-dried yam powder was the best form of yam to modify the textural properties of yam-containing surimi gel, followed by freeze-dried yam powder, and fresh yam appeared to be the worst form. When compared to potato starch containing pollock surimi gel, in general, 20% fresh yam can be added without causing significant losses of the textural properties; for dried yam powder, 30% fresh yam equivalent may be used.

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