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Sensory differentiation of shrimp using a trained descriptive analysis panel

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Abstract

A trained descriptive analysis panel evaluated raw and cooked sensory attributes for both fresh and frozen commercially available shrimp. While significant differences in sensory attributes existed among the type of frozen shrimp evaluated (Georgia white, Georgia brown, Gulf white, Gulf brown, Gulf pink, Honduras white, Belise white, Columbia white, and Burma black tiger), only appearance attributes could uniquely differentiate a specific type of frozen shrimp. Flavor and texture attributes were not unique to one type of frozen shrimp, hence no single attribute could be used for branding of shrimp. While frozen shrimp had greater intensities of cooked shrimp flavor and aroma, fresh shrimps were characterized as being sweeter and juicier than frozen shrimp. Both juiciness and sweetness decreased in Georgia white shrimp when stored on ice.

Keywords: Shrimp; Fresh; Frozen; Iced storage; Trained panel

1. Introduction

In 2004, US consumption of seafood rose to 16.6 lbs of edible meat per person (National Marine Fisheries Service, 2005) with shrimp being the overwhelming favorite type of seafood by consumers (4.2 lbs/person). To satisfy this demand for shrimp, imports of primarily farm-raised shrimp have grown to the point that they represent more than 90% of the US supply. Consequently, market prices for domestically harvested product have been dictated by the imported shrimp prices (Chauvin, 2000; Harrison, 1999) from countries such as Thailand (27% of the US imported supply), China (16% of the US imported supply), Viet Nam (11% of the US imported supply), India (9% of the US imported supply), Ecuador (7% of the US imported supply), and Mexico (7% of the US imported supply). With shrimp arriving from so many different parts of the world, a multitude of shrimp species have entered the US marketplace. These include the black tiger shrimp (*Penaeus monodon*) farmed in Asia, the white shrimp (*Penaeus vannamei* and *Penaeus stylirostris*) farmed in Central and South America, and the pink (*Penaeus duorarum*), brown (*Penaeus aztecus*), and white shrimp (*P. setiferus*) harvested in the South Atlantic and Gulf of Mexico.

Shrimp, in general, are considered to have a mild but distinctive flavor with a texture that is described as tender and delicate. Several studies employing trained descriptive panels have sought to further dissect the sensory attributes of shrimp. Edmunds and Lillard (1979) developed 22 terms to describe cultured and wild shrimp while Bak, Jacobsen, and Jørgensen (1999) developed 14 terms to describe frozen cold-water shrimp (*Pandalus borealis*), and Morita, Kubota, and Aishima (2001) selected 10 terms to describe frozen kuruma prawns (*Penaeus japonicus*) and black tiger shrimp. Chemical and volatile analyses conducted in conjunction with sensory evaluations have demonstrated that both nitrogenous and non-nitrogenous compounds contribute to the characteristic flavor of shrimp. Character-impact aroma compounds that have been identified in cooked shrimp

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include 2,3-butanedione, 2-methyl-3-furanthiol, 2-acetyl-1-pyrroline, 3-(methylthio) propanal, and 2-acetyl-2-thiazoline (Baek & Cadwallader, 1997). A number of other sulfur-containing compounds have also been found in black tiger shrimp and these include dimethyl disulfide, isopropyl thiophene, *cis*- and *trans*-3,5-dimethyl-1,2,4-trithiolane, 2-acetyl- and benzo-thiazole, 3,5,6-trimethyl-1,2,4-dithiazine, and 2,6-dimethyl-4-butyl-1,3,5-dihydrodithiazine (Pan, Tsai, Chen, & Wu, 1997). Since studies often employ different shrimp species, it is unknown whether differences in the volatile profiles between studies represent inherent differences of the shrimp or differences in culture, processing, or storage applied to the samples. For example, free amino acids, the predominant nitrogenous character compounds, varied in shrimp raised in different salinities (Papadopoulos & Finne, 1986; Weng, Cadwallader, Baek, Dabramo, & Sullivan, 1997). Aroma and textural profiles of boiled prawn have also been influenced by marinating or changing the pH of the sample (Morita, Kubota, & Aishima, 2002; Xiong, Xiong, Blanchard, Wang, & Tidwell, 2002) while the impact of iced and frozen storage on shrimp quality has been dependent on the length of storage (Angel, Basker, Kanner, & Juven, 1981; Reddy, Nip, & Tang, 1981) and fluctuations in storage temperature (Jeong, Jo, Lim, & Kang 1991; Srinivasan, Xiong, Blanchard, & Tidwell, 1997).

Distinctions in appearance, texture, and flavor have been noted by trained panelists for cultured and wild sea scallops (Naidu & Botta, 1978), Atlantic and Pacific oysters (Josephson, Lindsay, & Stuiber, 1985), cultured and wild yellow perch (Lindsay, 1980), farmed and wild Atlantic salmon (Farmer, McConnell, & Kilpatrick, 2000), and cultured and wild yellowtail and red sea bream (Hatae, Lee, Tsuchiya, & Shimada, 1989). In the case of shrimp, while the industry advocates sensory differences between shrimp species (Fiorillo, 1999), only a few studies have documented these distinctions in the scientific literature. In 1979, a trained panel consistently differentiated cultured brown shrimp and wild white shrimp from wild brown shrimp and Royal Red shrimp (*P. setiferus*) (Edmunds & Lillard, 1979). More recently, Whitfield, Helidoniotis, Shaw, and Svoronos (1997) compared wild and cultivated black tiger shrimp and found that high concentrations of diet-derived bromophenols contributed to the sensory attributes of briny, ocean- and prawn-like flavors in wild shrimp while cultivated shrimps were described as bland. To address a broader range of species and sources of shrimp, this study sought to characterize through trained descriptive panels the sensory attributes of both raw and cooked commercially available frozen shrimp and iced-stored fresh shrimp. The descriptive terms generated were also used as a basis to determine whether notable differences exist between fresh and frozen shrimp. Utilizing this approach, this study ultimately sought to determine whether one unique descriptive term could be used to brand any one specific type of shrimp.

2. Materials and methods

2.1. Description of samples

Fresh Georgia white shrimp (*P. setiferus*, 26–30 count) were harvested off the coast of Brunswick, Georgia during September and October, 2002. Fresh Gulf pink shrimp (*P. monodon*, 26–30 count) were harvested in the Gulf of Mexico in early October 2002. On the same day as capture, the shrimps were deheaded, placed in an insulated cooler, covered with ice, and transported to Griffin, Georgia. Upon arrival, the cooler was drained and placed in a walk-in refrigerated unit (5 °C).

Two 5-lb lots of frozen shrimp (26–30 count) were obtained from commercial distributors. The samples were identified as Gulf brown shrimp (*P. aztecus*), Gulf white shrimp (*P. setiferus*), Gulf pink shrimp (*P. duorarum*), Georgia brown shrimp (*P. aztecus*), Georgia white shrimp (*P. setiferus*), Burma black tiger shrimp (*P. monodon*), Belise white shrimp (*P. vannamei* or *P. stylirostris*), Columbia white shrimp (*P. vannamei* or *P. stylirostris*), Honduras white shrimp (*P. vannamei* or *P. stylirostris*), and Mexico white shrimp (*P. vannamei* or *P. stylirostris*).

2.2. Storage of fresh Georgia white shrimp

Fresh Georgia white shrimps were packed and held on ice for up to 10 d in insulated coolers placed within a walk-in refrigerated unit (5 °C). The cooler was unplugged and elevated to allow drainage of melted ice. A layer of ice (~5 cm) was maintained above the uppermost shrimp in the cooler. Samples were removed at 1, 3, 7 and 10 d for sensory evaluation.

2.3. Sample preparation

2.3.1. Thawing

Frozen shrimps were thawed under cold running water. They were placed into a container and held in a refrigerator (4 °C) for less than 2 h before being cooked or distributed for raw evaluations.

2.3.2. Raw shrimp

Forty-five raw shrimps were collected, rinsed, and distributed onto 3 white paper plates (15 shrimp/plate). The plates were covered with plastic wrap and held in a refrigerator (4 °C) for less than 1 h before evaluations were conducted.

2.3.3. Cooked shrimp

Thirty shrimps were placed into a strainer. In preliminary cooking trials, a digital temperature probe (HH506, T type, Omega Engineering, Inc., Stanford, CT) was placed into one of the shrimp. The strainer was lowered into boiling water (3 l) containing 60 g uniodized salt (Morton Intl. Inc., Chicago, IL) and the shrimp cooked until approximately half of the shrimp in the batch rose to the

surface of the boiling water bath. Based upon preliminary heating trials, this observation corresponded to an internal temperature of 70 °C. Upon removal from the boiling water bath, the shrimps were immersed in an ice water bath for 5 min. The shrimps were manually deshelled, rinsed, and distributed into 3.25 oz. plastic sample cups (2 shrimps per cup) with lids that had been coded with a three-digit random number. The cups were then placed into insulated coolers containing crushed ice (10 °C) and held for 30–60 min before evaluations were conducted.

2.4. Training of panelists

Panelists (13) were recruited from a pool of panelists trained in descriptive analysis using the Spectrum® intensity scaling method (Meilgaard, Civille, & Carr, 1987) and standard references. Training consisted of five 2-h sessions during which panelists developed a ballot (150-mm semi-structured line scales) containing descriptors of both raw and cooked shrimp (Tables 1a and b, respectively). References for these descriptors were also defined and intensity ratings for these references were established by consensus of the panel. The ratings for a calibration sample (fresh Georgia white) were also established by consensus of the panel. During the training, a variety of shrimp samples representing different species and stages of storage were presented to the panelists. Individual panelists who did not rate an attribute within 10 points of the mean rating for the entire group of panelists were asked to evaluate the sample again and to adjust their ratings until consensus was obtained.

2.5. Descriptive analysis testing by trained panelists

Testing consisted of eight 2-h sessions with panel calibration and roundtable discussion during the first-hour followed by evaluation of the test samples (Plemmons & Resurreccion, 1998). Panelists were presented two samples and a control (fresh Georgia white shrimp), in duplicate, for evaluation in any one session. The samples were presented to the panelists in randomized sequential monadic order and ratings were recorded on paper ballots. Panelists rated the attributes of raw samples in an open space within the sensory laboratory. Ratings of cooked samples were conducted in environmentally controlled partitioned booths under white incandescent light.

Table 1a
Standard references and ratings used in descriptive analysis of raw shrimp samples

Category	Attribute	Definition	Reference/source	Rating
Raw aroma	Ocean/seawater	Aromatic associated with the ocean or seawater, from slight to strong	Clam juice (Doxsee All Natural, Snow's Food Co., Portland, ME)	60–70
	Shrimp	Aromatic associated with raw shrimp, from slight to strong	Raw fresh shrimp was used as the qualitative descriptor while taste solutions (see Table 1b.) were used as a reference for intensity of this attribute	
	Old shrimp	Aromatic associated with old fish, from slight to strong	Shrimp powder	75
Raw meat appearance	Plumpness	The appearance of being plump at the head, from flat to round		
	Brown color	The brownness of the meat near the head (cross-section at cut end), from white to brown	White bond paper ($L = 84.77$, $a = 5.65$, $b = -4.20$)	0
			Light brown paper (Beckett Paradox, $L = 65.62$, $a = 8.12$, $b = 10.18$)	35
			Chocolate syrup	150
Raw shell appearance	Darkness	The intensity of the shell color, from light to dark	White bond paper	0
			Black	150
	Stripe darkness	The darkness of the stripes on the shell, from light to dark	White bond paper	0
			Black	150
	Brown color	The brownness of the shell, from white to brown	White bond paper ($L = 84.77$, $a = 5.65$, $b = -4.20$)	0
			Light brown paper (Beckett Paradox, $L = 65.62$, $a = 8.12$, $b = 10.18$)	35
			Chocolate syrup	150
	Blotchiness	The amount of coverage of dark spots on the surface of the meat, from not blotchy to blotchy	None	0
			Fully covered	150
	Glossiness	The amount of light reflected from the shell, from dull to glossy	White bond paper	0
			Laminated card	140
	Tail iridescence/ rainbow	The appearance of rainbow-like colors on the tail, from slight to extreme	Ribbon curl	150

Table 1b
Standard references and ratings used in descriptive analysis of cooked shrimp samples

Category	Attribute	Definition	Reference/source	Rating
Aroma	Ocean/seawater	Aromatic associated with ocean or seawater, from slight to strong	Clam juice	65
	Cooked shrimp	Aromatic associated with fresh cooked shrimp, from slight to strong	Fresh cooked shrimp was used as the qualitative descriptor while taste solutions (see below) were used as a reference for intensity of this attribute	
	Old shrimp	Aromatic associated with stored cooked shrimp, from slight to strong	Shrimp powder	75
Appearance	Red/orange color	The redness of the surface, from white to red orange	White bond paper ($L = 84.77$, $a = 5.65$, $b = -4.20$	0
			Salmon bond paper ($L = 70.80$, $a = 31.84$, $b = 25.75$)	60
			Red/Orange paper ($L = 50.68$, $a = 46.76$, $b = 31.87$)	150
	Brown color	The brownness of the meat near the head (cross-section at cut end), from white to brown	White bond paper ($L = 84.77$, $a = 5.65$, $b = -4.20$)	0
			Light brown paper ($L = 65.62$, $a = 8.12$, $b = 10.18$)	35
			Chocolate syrup	150
	Blotchiness	The amount of coverage of dark spots on the surface of the meat, from not blotchy to blotchy	None	0
			Fully covered	150
	Glossiness	The amount of light reflected from the meat, from dull to glossy	White bond paper	0
			Laminated card	140
Flavor	Cooked shrimp	The flavor associated with cooked shrimp, from slight to strong	Fresh cooked shrimp was used as the qualitative descriptor while taste solutions (see below) were used as a reference for intensity of this attribute	
Tastes	Bitter	The intensity of the taste associated with caffeine solutions	0.05/100 g caffeine	20
			0.08/100 g caffeine	50
			0.15/100 g caffeine	100
	Salty	The intensity of the taste associated with salt solutions	0.2/100 g NaCl	25
			0.35/100 g NaCl	50
			0.5/100 g NaCl	85
	Sour	The intensity of the taste associated with citric acid solutions	0.05% citric acid	20
			0.08% citric acid	50
			0.15% citric acid	100
	Sweet	The intensity of the taste associated with sugar solutions	2 g/100 g sugar	20
			5 g/100 g sugar	50
			10 g/100 g sugar	100
			16 g/100 g sugar	150
Mouthfeel	Sliminess	The feeling of a slimy film in the mouth, from not slimy to slimy	Boiled okra, Publix (Lakeland, FL)	137.5
Texture	Firmness	The amount of force needed to deform the head-end of the shrimp meat by first biting through skin with incisors, then chewing with molars (skin side toward molars), from not chewy to chewy	Cheddar cheese, Kroger sharp (Cincinnati, OH)	45
			Hebrew National beef hot dog (Hudson, WI)	70
	Juiciness	The amount of moisture to masticate sample to a consistency acceptable for swallowing	Surimi, Louis Kemp (Downer's Grove, IL)	30
			Pineapple, Dole chunk (Westlake Village, CA)	125
			Water	150
	Chewiness	The time required to masticate sample to a consistency acceptable for swallowing	Raw peanuts	30
			Dots gum drops (Tootsie Roll Industries, Chicago, IL)	125
			Tootsie roll (Tootsie Roll Industries, Chicago, IL)	150
	Crispness	The amount of force exerted during first incisor bite that generates a high pitched sound, from slight to high	Pineapple, chunk	15
			Saltine cracker (Nabisco Premium, East Hanover, NJ)	35
	Fibrous	The presence of individual muscle fibers in the shrimp meat, from not fibrous to fibrous	Pineapple, chunk	100
Aftertaste	Iodine	Aftertaste associated with the chemical iodine, from slight to strong	Iodized salt water, 0.2/100 g	15

2.6. Statistics

Statistical software (SAS Institute, Inc., 1987) was used to analyze all data results. Cluster analysis (PROC VARCLUS) was used to determine if any of the trained panelists were outliers (Malundo and Resurreccion, 1992). Analysis of variance using the general linear model (PROC GLM) procedure was conducted to determine any significant differences in a sensory attribute between shrimp samples (main effect) and where statistical differences were noted ($P<0.05$), differences among sample means were determined using Fisher's least significant difference test (LSD). Differences in sensory attributes between fresh and frozen samples was conducted using a paired-comparison *t*-test (PROC UNIVARIATE). Prediction models for cooked sensory attributes from raw mean sensory attributes were determined using forward stepwise regression (PROC STEPWISE). Regression analysis (PROC REG) on stored shrimp samples was conducted to determine those sensory attributes that were impacted by storage.

3. Results and discussion

Trained panel assessment of 10 different frozen samples of commercially available shrimp revealed significant differences in all raw attributes and 17 of the 19 cooked attributes ($P<0.05$) (Tables 2 and 3). Despite these differences, the attributes could not distinguish Georgia brown, Gulf pink, or Honduras white shrimp from all of the other shrimp samples. Attributes that did distinguish one type of commercially available shrimp from all the other samples were always associated with appearance. In the case of Burma black tiger shrimp, distinguishing features were shell darkness and stripe darkness of the raw product and red/orange color of the cooked meat product. Belise white shrimp, on the other hand, were noted for their muted shell color having significantly lower shell and stripe darkness than other shrimp samples while high brown meat color scores differentiated Columbia white shrimp from other shrimp. Georgia white shrimps were unique from other shrimp samples in the high iridescence displayed in the tail of the raw product. In fact, iridescence of Georgia white shrimp was nearly twice that observed in the other shrimp samples including Gulf white shrimp (the same species of shrimp but harvested from a different location). Surprisingly, despite commercial claims that Georgia white shrimps are sweet (Fabian Seafood, 2002), the highest sweetness ratings were found in Burma black tiger shrimp. Georgia white shrimps were characterized as having the highest cooked shrimp flavor but the ratings were not significantly different from Gulf brown, Georgia brown, Gulf pink, or Mexican white shrimp.

Notable differences that occurred in aroma or basic taste attributes could be ascribed to variations in processing applied to the commercially available shrimp sample. For example, old shrimp aroma in the raw product was

Table 2
Sensory ratings of frozen shrimp evaluated raw[a]

Attribute class	Sensory attribute	Shrimp sample									
		Georgia brown	Gulf white	Gulf brown	Gulf pink	Burma tiger	Columbia white	Belise white	Honduras white	Mexican white	Georgia white
Aroma	Ocean/seawater	43.3 ab	37.2 de	38.8 c–e	42.1 bc	42.0 bc	46.5 a	36.4 e	38.8 c–e	41.2 b–d	43.1 ab
	Shrimp	42.7 ab	33.5 d	39.4 bc	40.5 ab	43.2 a	42.9 a	36.3 cd	40.3 ab	40.3 ab	41.4 ab
	Old shrimp	3.8 cd	5.5 bc	6.7 b	3.5 cd	8.0 b	7.5 b	7.7 b	3.2 cd	10.7 a	2.3 d
Meat appearance	Plumpness	109.8 ab	100.0 c	113.0 a	110.9 ab	98.5 c	91.5 d	93.2 d	109.7 ab	107.5 b	110.1 ab
	Brown color	8.9 bc	8.3 cd	8.0 cd	8.5 c	11.8 a	8.8 bc	11.3 ab	6.5 cd	6.8 cd	5.8 d
Shell appearance	Shell darkness	47.2 b	35.1 c	45.2 b	47.8 b	63.0 a	46.2 b	27.7 d	46.1 b	45.4 b	46.5 b
	Stripe darkness	51.6 b	37.5 c	48.7 b	51.2 b	101.8 a	50.4 b	30.3 d	49.1 b	52.7 b	48.9 b
	Brown color	34.9 a	20.4 de	29.5 b	29.9 b	36.2 a	16.9 e	22.2 cd	23.2 cd	26.7 bc	15.7 e
	Blotchiness	5.9 b–d	3.2 de	8.1 bc	9.4 b	8.4 bc	5.2 cd	3.7 de	1.2 e	18.7 a	4.2 de
	Glossiness	119.0 ab	118.0 ab	116.5 b	118.8 ab	119.8 ab	116.7 b	117.5 b	121.4 a	121.5 a	117.5 b
	Tail iridescence	25.6 b	24.7 b	9.7 d	10.9 d	19.9 bc	25.5 b	20.0 bc	21.6 bc	14.4 cd	40.7 a

[a]Means within the same row not followed by the same letters are significantly different ($P\leqslant0.05$).

Table 3
Sensory ratings of frozen shrimp evaluated cooked[a]

Attribute class	Sensory attribute	Shrimp sample									
		Georgia brown	Gulf white	Gulf brown	Gulf pink	Burma tiger	Columbia white	Belise white	Honduras white	Mexican white	Georgia white
Aroma	Ocean/seawater	34.7 a–c	32.0 c	33.8 bc	32.9 c	33.3 bc	38.1 a	33.7 bc	31.2 c	33.0 bc	36.9 ab
	Cooked shrimp	36.8 a–c	35.1 b–d	39.3 a	39.3 a	37.8 ab	39.5 a	31.5 d	33.8 cd	39.4 a	38.1 ab
	Old shrimp	3.2 cd	7.4 a	4.6 b–d	3.8 b–d	4.5 b–d	5.1 a–c	6.1 ab	3.8 b–d	4.1 b–d	2.4 d
Appearance	Red/orange color	58.2 b	47.1 d	52.4 c	60.4 b	71.7 a	56.7 b	50.0 cd	52.2 c	46.3 d	48.0 d
	Brown color	5.8 bc	5.3 b–d	6.1 bc	6.1 bc	6.6 b	8.6 a	3.9 d	4.1 d	5.4 b–d	4.6 cd
	Blotchiness	1.1 b	0.3 b	0.3 b	1.8 b	1.1 b	2.0 b	1.1 b	0.3 b	11.0 a	0.3 b
	Glossiness	116.0 ab	114.8 a–c	112.4 b–d	113.9 b–d	114.2 a–d	111.2 cd	112.6 b–d	117.7 a	111.0 d	113.2 b–d
Flavor	Cooked shrimp	48.0 ab	43.6 b–d	49.9 a	51.1 a	46.8 a–c	42.0 d	47.1 a–c	43.1 cd	50.0 a	51.4 a
Basic tastes	Bitter	2.8 de	0.9 e	6.4 a	4.3 b–d	2.5 de	5.0 a–c	2.5 de	2.4 de	6.4 ab	3.9 cd
	Salty	21.0 c	64.0 a	34.2 b	39.2 b	21.1 c	18.2 c	21.3 c	20.3 c	22.9 c	22.9 c
	Sour	0.4	0.7	2.1	0.9	0.4	1.3	1.4	1.0	0.3	0.3
	Sweet	18.1 c	13.9 d	17.0 c	17.9 c	22.2 a	19.1 bc	21.0 ab	18.8 bc	19.1 bc	17.6 c
Aftertaste	Iodine	4.6 c	7.5 ab	8.9 a	5.3 c	5.8 bc	4.7 c	6.1 bc	4.6 c	5.4 bc	5.6 bc
Mouthfeel	Sliminess	3.2 d	9.8 a	6.7 bc	5.7 c	5.4 cd	8.1 ab	6.5 bc	7.0 bc	5.0 cd	5.3 cd
Texture	Firmness	71.8 ab	62.5 f	63.2 ef	67.7 cd	72.5 a	63.8 ef	71.5 a–c	68.3 b–d	73.3 a	66.9 de
	Juiciness	35.7 d	39.2 bc	37.6 cd	37.0 d	40.2 b	36.1 d	43.1 a	39.9 b	35.6 d	36.5 d
	Chewiness	49.2	44.5	45.1	46.6	51.9	47.0	52.2	50.5	47.1	48.9
	Crispness	22.2 a	21.1 ab	20.1 b	21.0 ab	22.6 a	21.4 ab	22.0 ab	21.9 ab	20.8 ab	20.3 b
	Fibrous	60.3 a–c	56.6 d	58.9 cd	59.4 b–d	62.7 ab	60.3 a–c	63.3 a	61.1 a–c	61.9 a–c	59.1 b–d

[a]Means within the same row not followed by the same letters are significantly different ($P \leqslant 0.05$).

significantly higher in Mexican white shrimp than other shrimp samples. At the same time, blotchiness ratings were also significantly higher in Mexican white raw and cooked shrimp suggesting that the shrimp had been held for some period of time prior to freezing. Another variation in processing that was also perceived by the trained panel was the addition of the additives, sodium tripolyphosphate and sodium bisulfite, in Gulf shrimp. In fact, salty scores in Gulf pink shrimps were nearly twice those of other shrimp while their sweetness scores were 20% lower than other shrimp.

While consumers use raw characteristics for purchase of shrimp, their ultimate criteria of acceptance and hence repurchase is dependent on cooked characteristics. Identifying relationships between these two product forms therefore would assist in defining a grading scale for raw product that would relate to consumers' preferences. Consequently, ratings for three of the nineteen cooked attributes could be predicted with a significant R^2 value >0.9 using raw attribute ratings. Cooked glossiness scores could be defined using old shrimp aroma, shell glossiness, blotchiness, and shell brown color ratings of the raw product ($R^2 = 0.949$). At an R^2 of 0.930, cooked red/orange color ratings were predicted using the raw attribute ratings of shell darkness, meat brown color, and old shrimp aroma. Cooked ocean/seawater aroma ratings were described with an R^2 of 0.918 using glossiness, ocean/seawater, and iridescence ratings. Texture, flavor, and taste attributes of the cooked product, on the other hand, were not as successfully predicted using raw attributes. In fact, no significant relationship with raw attributes could be found for sour, sweet, firmness, chewiness, fibrousness, and iodine cooked attributes. Bitter ratings correlated significantly with raw blotchiness ratings ($R^2 = 0.466$) while cooked shrimp flavor ratings correlated significantly with meat plumpness ratings ($R^2 = 0.368$). Slightly higher predictive relationships could be found for juiciness and crispness attributes using raw ocean/seawater aroma ratings and meat brown color ratings, respectively ($R^2 = 0.560$ and 0.541, respectively).

Significant differences were noted by the trained panel between fresh and commercially available frozen shrimp (Georgia white and Gulf pink) for 18 of the 30 sensory attributes ($P<0.05$) (Table 4). In terms of appearance, fresh shrimps were glossier than frozen shrimp for both the raw and cooked products. The most notable change in appearance for the raw product, however, was the loss in tail iridescence. The most notable change in appearance for the cooked product was a loss of red/orange color on the shrimp surface. Frozen shrimp had more intense desirable flavors and aromas (cooked shrimp flavor, cooked shrimp aroma, and ocean/seawater aroma) than fresh shrimp whereas no difference in the undesirable aroma (old shrimp aroma) was noted. While the changes in flavor and aroma upon freezing could be considered advantageous, the textural changes noted upon freezing would be considered detrimental. More specifically, shrimp that had been frozen were firmer and less juicy than fresh shrimp. These differences contrast to the findings of Nip and Moy (1981) who described the absence of notable differences in texture and flavor acceptance of fresh and frozen prawns (*Macrobrachium rosenbergii*). Since frozen shrimps were commercially obtained in this study, the period of time they had been in frozen storage is unknown. Hence, recrystallization may have occurred during storage and influenced the extent of cellular damage and loss of product quality. Loss of soluble components in thaw exudates in frozen shrimp samples could explain the decrease in sweetness in frozen shrimp whereas the higher salty intensities observed in frozen shrimp may be attributed to the addition of sodium tripolyphosphate and sodium bisulfite to frozen pink shrimp.

Iced storage of fresh Georgia white shrimp for up to 10 d led to notable changes in the appearance and in the aroma of raw product (Table 5). While tail iridescence decreased significantly during storage, attribute ratings for shell blotchiness, meat brown color, and old shrimp aroma increased significantly. In contrast, Angel et al. (1981) did not detect the presence of spoilage odors in freshwater prawn until after 16 d on ice while Alvarez and Koberger (1979) reported that objectionable odors had developed after 11 d storage on ice. More recently, Jeyasekaran and Ayyappan (2002) noted the absence of perceptible changes in odor for freshwater prawn and attributed differences in odor profiles of stored marine and freshwater shrimp to differences in microbial flora of the product. Increased meat brown ratings in this study corresponded to the observation noted in the seafood quality classification study of Ellis, Silva, and Lee (1997) that as storage progressed, raw flesh went from translucent whitish-gray to opaque whitish-yellow in color.

Significant differences following iced-storage among cooked sensory attributes included cooked shrimp and old shrimp aromas, red/orange and brown colors, blotchiness, bitter and sweet tastes, sliminess, and juiciness (Table 6). Firmness and crispness, on the other hand, did not change for Georgia white shrimp over the 10 d of iced storage in contrast to the development of mushiness observed in freshwater prawn (Angel, Weinberg, Juven, & Lindner, 1985; Nip & Moy, 1988). In the latter studies, delays in deheading or aquacultural practices inducing stress during growth and harvest may have facilitated the migration of proteolytic enzymes from the hepatopancreas to the tail muscle and subsequent degradation of the tissue. Juiciness, on the other hand, was a textural attribute for Georgia white shrimp that decreased significantly during early stages of iced storage in this study. Similarly, red/orange appearance ratings decreased during early stages of storage then leveled off. While blotchiness ratings of cooked product in this study were slightly lower than the raw product, changes during storage in the raw and cooked blotchiness attributes paralleled each other. Decreases in quality of stored shrimps were also marked by the decrease in cooked shrimp flavor and sweetness ratings, although

Table 4
Comparison of fresh and frozen shrimp (Georgia white and Gulf pink) for raw and cooked sensory attribute ratings

State of shrimp	Sensory attribute	Fresh	Frozen	*P* value
Raw	Ocean/seawater aroma	38.46±8.98	42.63±5.88	0.0003
	Shrimp aroma	37.71±7.71	40.96±4.23	0.0005
	Old shrimp aroma	2.55±4.01	2.87±3.88	0.6047
	Meat plumpness	109.76±14.73	110.50±7.01	0.6272
	Meat brown color	8.23±14.15	7.14±4.02	0.5102
	Shell darkness	51.65±18.39	47.15±8.12	0.0397
	Stripe darkness	51.37±23.79	50.03±8.79	0.6209
	Shell brown color	17.19±14.46	22.81±11.35	0.0003
	Shell blotchiness	5.35±7.32	6.81±6.60	0.1409
	Shell glossiness	121.18±8.72	118.18±6.37	0.0007
	Tail iridescence/rainbow	42.67±19.52	25.81±18.10	<0.0001
Cooked	Ocean/seawater aroma	32.32±9.64	34.92±8.05	0.0378
	Cooked shrimp aroma	32.36±8.59	38.69±7.63	<0.0001
	Old shrimp aroma	3.73±4.97	3.08±4.79	0.3874
	Red/orange color	65.99±17.49	54.23±8.99	<0.0001
	Brown color	4.83±4.22	5.33±2.98	0.2956
	Blotchiness	1.33±3.65	1.01±2.21	0.4472
	Glossiness	116.55±7.92	113.58±6.38	0.0018
	Cooked shrimp flavor	48.16±11.24	51.25±5.96	0.0441
	Bitter	2.26±3.84	4.09±4.42	0.0022
	Salty	20.53±4.47	31.03±18.81	<0.0001
	Sour	0.86±3.27	0.58±2.20	0.4733
	Sweet	19.23±4.18	17.76±4.91	0.0477
	Sliminess	8.34±4.96	5.45±4.17	<0.0001
	Firmness	64.82±7.28	67.31±5.99	0.0127
	Juiciness	40.92±6.70	36.76±3.43	<0.0001
	Chewiness	49.62±7.48	47.74±4.98	0.0478
	Crispness	20.69±3.77	20.60±3.04	0.9572
	Fibrous	58.17±10.04	59.26±6.69	0.2072
	Iodine aftertaste	6.09±3.75	5.43±3.77	0.1851

Table 5
Sensory ratings of raw Georgia white fresh shrimp stored for 0, 3, 7, and 10 d on ice[a]

Attribute class	Sensory attribute	Storage (d)			
		0	3	7	10
Aroma	Ocean/seawater	38.3	36.7	41.6	41.8
	Shrimp	38.3 ab	35.1 b	38.2 ab	42.1 a
	Old shrimp	0.9 c	1.5 bc	4.8 b	12.4 a
Meat appearance	Plumpness	108.8	115.5	112.3	112.3
	Brown color	6.1 bc	4.7 c	7.8 ab	9.2 a
Shell appearance	Shell darkness	40.8 c	48.7 a	48.0 ab	44.1 bc
	Stripe darkness	36.7 b	51.5 a	49.9 a	48.6 a
	Brown color	10.8 ab	9.0 b	9.2 b	11.8 a
	Blotchiness	4.0 c	3.5 c	7.6 b	12.8 a
	Glossiness	118.7 a	120.5 a	118.6 a	114.5 b
	Tail iridescence	47.4 a	43.0 a	36.5 b	21.8 c

[a]Means within the same row denoted by different letters are significantly different ($P \leqslant 0.05$).

the changes in the former attribute were not significant. In addition, increased bitterness ratings following 7 d of storage would contribute to adverse quality alterations.

In summary, a diversity of flavors and textures existed among commercially available shrimp, however, no single flavor or textural attribute could be used to distinguish one type of shrimp from all the other sources. Hence, marketing or branding efforts that strive to label one shrimp as superior to all others may not be based on any of these attributes. In contrast, several of the commercially available shrimp samples could be identified on the basis of their appearance attributes. Thus, dependent on consumers' preferences, one or more of the appearance attributes could be used as criteria for branding shrimp. Domestically

Table 6
Sensory ratings of cooked Georgia white fresh shrimp following storage for 0, 3, 7, and 10 d on ice[a]

Attribute class	Sensory attribute	Storage (d)			
		0	3	7	10
Aroma	Ocean/ seawater	34.4	36.5	33.9	32.6
	Cooked shrimp	32.7 b	39.5 a	36.9 a	35.8 ab
	Old shrimp	1.6 b	3.5 ab	5.5 a	3.5 ab
Appearance	Red/orange color	56.6 a	48.5 b	49.8 b	49.4 b
	Brown color	4.1 b	3.2 b	6.0 a	6.5 a
	Blotchiness	1.4 b	0.3 b	2.2 b	5.3 a
	Glossiness	115.8	117.0	114.1	114.8
Flavor	Cooked shrimp	49.2	49.2	47.0	45.0
Basic tastes	Bitter	1.7 b	1.8 b	6.0 a	5.4 a
	Salty	21.7	20.7	22.2	21.0
	Sour	0.7	0.1	0.8	0.6
	Sweet	20.9 a	19.7 a	19.2 a	16.5 b
Aftertaste	Iodine	5.6	4.2	3.9	5.9
Mouthfeel	Sliminess	8.9 a	4.3 b	7.3 a	7.4 a
Texture	Firmness	65.0	66.1	62.5	63.2
	Juiciness	41.9 a	38.6 b	37.3 b	37.2 b
	Chewiness	49.6	48.0	45.0	47.5
	Crispness	19.9	20.6	20.2	19.3
	Fibrous	58.3	59.4	59.0	57.9

[a]Means within the same row denoted by different letters are significantly different ($P \leqslant 0.05$).

caught fresh shrimp may also present a competitive advantage to imported frozen shrimp in that fresh shrimps were juicier and sweeter than frozen shrimp, however, this advantage in these attributes is lost if storage of shrimp on ice extends to 3 and 10 d, respectively. In the case of Georgia white shrimp, tail iridescence could serve as a visual index of storage life and hence quality of the shrimp.

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