

SENSORY AND PHYSICOCHEMICAL ASSESSMENT OF WILD AND AQUACULTURED GREEN AND BLACK LIP ABALONE (*HALIOTIS LAEVIGATA* AND *HALIOTIS RUBRA*)

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ABSTRACT Abalone is a highly valued food product in many countries, in large part a result of its unique sensory properties. Wild and cultured abalone both attract premium prices, but generally this is not based on sensory characteristics. Yet, abalone aquaculture is developing to provide an alternative to a dwindling supply of wild abalone, and this provides an opportunity to optimize the sensory properties if they are better understood. In most natural food products, farming practices and growing environment are responsible for the sensory properties of the final product; therefore, the comparison of both wild and aquacultured abalone's sensory characteristics could contribute to a better understanding of the impact of the growing and farming practices on the sensory properties. Our study focused on the development of a descriptive sensory analysis methodology to measure abalone sensory properties, and the observation of differences among the abalone sampled. Wild and aquacultured abalone were prepared according to a standardized cooking protocol. A sensory panel of trained assessors developed and defined a descriptive vocabulary and a method of assessment, and then quantified the sensory properties of abalone. A vocabulary of 16 terms describing aroma, texture, flavor, and aftertaste of the abalone was developed. Very significant differences were found between abalone sourced from the wild and aquacultured abalone from different sources. The wild-caught blacklip abalone, which were larger in size, were perceived as more firm, springy, and chewy, but also rated significantly higher in aroma, flavor, and aftertaste impact as well as earthy and metallic flavors. Significant differences in sensory properties were also found between cultured abalone fed different diets. Compositional analysis showed significant differences between abalone in their content of glycogen (range, 4.8%–23.2% of dry weight (DW)), moisture (69.4%–73.7% live weight), and taste-active free amino acids, especially glycine (3.4–18.2 mg/g DW) and glutamate (1.0–3.6 mg/g DW). Correlations were found between sensory attributes and some chemical compounds. This study indicates that growing conditions as well as growing techniques may have a large influence on abalone sensory characteristics. However, because the design of the study was not balanced for key growth or production variables, additional studies are required to identify and quantify which factors were most influential. The descriptive sensory method developed was successful in measuring the sensory properties of abalone and can now be applied more broadly.

KEY WORDS: sensory descriptive analysis, compositional analysis, free amino acid, black lip abalone, green lip abalone, aquaculture, diet, Australia, *Haliotis laevigata*, *Haliotis rubra*

INTRODUCTION

During the past few decades there has been significant progress in the development of abalone aquaculture, as wild fisheries have progressively declined in many countries (Flores-Aguilar et al. 2007). Both forms of product (i.e., wild-caught and aquacultured abalone) attract a premium price in the marketplace, because of the slow-growing nature of abalone (and hence high production cost) and its unique sensory properties, which contribute to a strong demand, particularly within Asian regions (Gordon & Cook 2001). Optimizing the sensory properties of the cultured abalone may be possible through manipulating the grow-out environment, the feed, and harvesting systems. To do this requires a greater understanding of the variability in the sensory properties and the impacts of the culture environment on them.

Descriptive sensory analysis is a technique that is applied to identify, describe, and quantify the sensory properties of a food product. A panel of trained assessors, screened for their sensory acuity, develop a method of assessment and a defined objective vocabulary of attributes to describe the product. The panel quantifies the perceived intensity of these attributes for each

product. The data collected allow differences to be determined between products based on their sensory properties. Descriptive analysis is a robust and reproducible measurement of sensory properties, and its application should be distinguished from subjective (quality) measurements carried out by consumers or experts. The robustness of the data allows the testing of potential relationships with compositional data.

Abalone may be delivered to the market in live or freshly shucked form, but also in a variety of processed or preserved forms. The latter includes product that is frozen, canned, salted, dried, stored under modified atmosphere, or high-pressure processed (Olley & Thrower 1977, Sanguandekul et al. 2008, Briones et al. 2010).

Measurement of the sensory properties of abalone has been limited to a few studies, and only in 1 case has descriptive analysis using a trained panel been applied. Sanchez-Brambila et al. (2002) studied canned *Haliotis fulgens* and *Haliotis cracherodii* abalone, which underwent a tenderization treatment. A vocabulary of 18 descriptive terms was developed for texture (springiness, cohesiveness, hardness, and chewiness), flavors (briny, decaying, metallic, crustacean, fishy, cardboard), and basic tastes, and afterfeel/aftertaste (metallic, astringent, oily, and starchy). Application of their method found no significant differences between untreated abalone, but found that tenderization treatment increased the perceived bitterness and sourness

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of both abalone, and increased the metallic flavor of *H. cracherodii* only. Postharvest treatments are known to affect sensory properties of shellfish (Murchie et al. 2005); therefore, to compare in an objective way the intrinsic properties of abalone, it is necessary to develop a reproducible method that enables the study of the sensory properties of abalone without risking masking or altering them. Sensory and consumer studies were recently conducted on unprocessed or minimally processed abalone (Preece 2006, Smit et al. 2010). Using a triangle test, no differences were found between steamed aquacultured abalone (*Haliotis iris*) fed 2 different artificial diets (Preece 2006). Small differences were found between both raw and boiled aquacultured and wild abalone (*Haliotis midae*) (Smit et al. 2010) using a panel of abalone experts and consumers. Further understanding could be gained from an objective assessment with a trained panel that will describe abalone using a consensus vocabulary.

There have been many reports on the compositional qualities of abalone, focusing on components thought to contribute to taste or nutritional quality (i.e., certain free amino acids (FAAs) such as glycine, glutamic acid, glycine-betaine, arginine, taurine; adenosine-5'-monophosphate; glycogen; fatty acid profiles; and collagen) (Watanabe et al. 1992, Bewick et al. 1997, Chiou et al. 2001, Allen et al. 2006, Guest et al. 2008). Abalone composition varies according to season (Chiou et al. 2001, Watanabe et al. 1992, Hatae et al. 1995), diet (Chiou & Lai 2002), metabolic stress (Braid et al. 2005), species, age, and weight (Oleachea et al. 1993). Konosu (1973) used abalone muscle extracts to investigate the relationship between composition and flavor of abalone with an omission test. The study revealed that glutamic acid and adenosine-5'-monophosphate were responsible for umami taste, and glycine for sweet taste. Omission of taurine or arginine did not affect flavor perception. However, the omission of glycogen seemed to affect the flavor impact of the extract. Subsequent studies with several other species of abalone have not supported these findings universally on the roles that glycogen, arginine, and taurine play in determining sensory properties (Bewick et al. 1997, Chiou et al. 2001, Carefoot et al. 1993). Abalone is characterized by a tough texture attributed in part to high collagen content (Oleachea et al. 1993). Abalone collagen content is known to vary as a result of a series of factors, including season and age (Hatae et al. 1995).

An experimental approach that measures both the sensory properties and chemical composition of the same individual abalone can enable direct relationships between composition and sensory properties to be determined. This approach will likely provide new understanding that is of value to the abalone industry.

The objective of this study was to apply descriptive sensory analysis to Australian abalone and to demonstrate the applicability of the methodology to measure differences, to establish relationships between sensory properties and physicochemical measurements, and to indicate potential differences between species, environment, or diet. A range of samples, which differed in treatment by diet, species, and whether the abalone were aquacultured or wild were tested. Sampling did not follow a strict factorial design, hence the underlying drivers behind many of the differences observed could not be determined unequivocally; interpretations are therefore often generalized.

MATERIALS AND METHODS

Sourcing of Abalone for Experiments.

Five abalone batches (i.e., 4 aquacultured and 1 wild harvested) were sourced from commercial suppliers from locations on the south coast of Australia. Each abalone batch was representative of its farm or fishery of origin and was the result of their normal practices. Abalone had been harvested between January and November 2009 and were immediately frozen by the suppliers using their standard commercial processes. Abalone were frozen rather than kept live, canned, or dried because this strategy provided a better management of the stock for the experiment and was expected to limit the alteration to the original flavor profile of each sample. The hybrid abalone were generated from a cross between *Haliotis laevigata* × *Haliotis rubra* and are hereafter referred to simply as hybrids. The aquacultured animals were cocktail size (approximately 80 mm with shell) whereas the wild-caught abalone ranged from 70–110 mm without shell. In this study, we did not attempt to match aquacultured and wild abalone for size and weight, because this would not have been representative of what consumers receive (Table 1).

TABLE 1.
Description and source of abalone used in the study.

| Site | Code | Species | Growing condition | Diet* | Harvesting date | Freezing method |
|-----------------|--------------|--|-------------------|------------|-----------------|--------------------------|
| South Australia | SA-Cult-Art | Greenlip (<i>Haliotis laevigata</i>) | Cultured | Artificial | January 2009 | Chilled nitrogen vapor |
| Victoria | Vic-Cult-Art | Hybrid (<i>H. laevigata</i> × <i>Haliotis rubra</i>) | Cultured | Artificial | October 2009 | Chilled nitrogen vapor |
| Victoria | Vic-Cult-Nat | Hybrid (<i>H. laevigata</i> × <i>H. rubra</i>) | Cultured | Natural | October 2009 | Chilled nitrogen vapor |
| Tasmania | Tas-Cult-Art | Greenlip (<i>H. laevigata</i>) | Cultured | Artificial | March 2009 | Ice/brine |
| Tasmania | Tas-Wild-Nat | Blacklip (<i>H. rubra</i>) | Wild | Natural | November 2009 | Chilled ethanol solution |

* The composition of the diet was different for each site. Details of the nutrient profiles of the artificial diets used by commercial operators were not available because of commercial-in-confidence reasons. Art, artificial; Cult, cultured; Nat, natural; SA, South Australia; Tas, Tasmania; Vic, Victoria.

Sample Preparation

Animals from each batch were deemed to share the same sensory properties and therefore could be prepared at the same time and interchangeably. The day before test day, required quantities of frozen abalone from each batch were placed at 4°C to thaw for 24 h. Each test day, abalone were removed from refrigeration and, within 2 h, were shucked, cleaned, and washed with tap water. Wild abalone were cut in half to obtain pieces the size of cocktail abalone so the same process could be followed with those samples. A maximum of 3 animals of the same batch were steamed at the same time for precisely 3 min at 100°C with a domestic steamer (BFS400 HealthSmart Food Steamer; Breville). This process ensured that the core of the abalone had reached a temperature of at least 72°C, and most common pathogens were destroyed. The steamer was cleaned after each use to prevent potential contamination and to clear the steaming basket of any remaining flavor residue. Thereafter, each batch was left to cool to room temperature to undergo the following preparation for serving. The epipodium (Fig. 1, part A) was removed from each animal, and a 1-cm-wide lateral cross-section was prepared and kept at -18°C for chemical analysis (Fig. 1, part B). The adductor muscle was removed from the remaining piece of abalone (Fig. 1, part C), which was (Fig. 1, part D) cut into 3 uniform pieces of dimension 1 × 2.5 × 0.5 cm.

A serving consisted of 2 pieces of abalone from the same batch sealed in a transparent coded plastic container closed with a lid and served at room temperature.

Sensory Descriptive Analysis

The CSIRO-trained sensory panel participated in the descriptive sensory analysis experiment over a 2-wk period. The panel consisted of 9 trained assessors (1 male, 8 females) with extensive experience in descriptive analysis of food products, including seafood. All sensory testing took place in the sensory laboratory at CSIRO's North Ryde facility, which is designed in accordance with International Standards on Sensory Analysis (ISO 1985). Seven training sessions of 2 h each were held to develop the method of assessment, and to generate and define the specific sensory vocabulary that best described the sensory properties of the abalone included in the experiment (Table 2). During the training days, the panel was presented multiple times with animals from each batch to familiarize themselves with the products and to generate an extensive vocabulary that expressed differences between products. To clarify more completely some of the descriptive terms in the vocabulary, the panelists nominated reference standards (e.g., boiled chicken

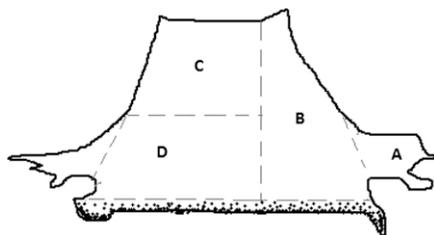


Figure 1. A cross-sectional view of the abalone muscle. A, epipodium; B, section kept for chemical analysis; C, part of the adductor muscle; D, part used for sensory analysis.

TABLE 2.
Abalone sensory vocabulary.

| Term | Definition |
|---------------------|---|
| Odor impact | The initial intensity of the overall aroma |
| Savory odor | The intensity of a cooked white-meat smell |
| Earthy odor | The vegetable aroma associated with the remaining water of boiled <i>Brassica</i> |
| Firmness | The force required to break the sample during the first bite with the front teeth |
| Springiness | The degree to which a sample returns to its original shape after partial compression with the molar teeth. |
| Chewiness | The duration required to masticate the sample before swallowing |
| Flavor impact | The overall impression of the intensity of the flavor of the sample |
| Saltiness | The perceived intensity of the salty taste of the sample when in the mouth |
| Sweetness | The sweet flavor released when chewing the sample |
| Savory | The flavor associated with cold, boiled white meat |
| Earthy | The vegetable flavor associated with the remaining water of boiled <i>Brassica</i> |
| Metallic | The flavor associated with an open metal can |
| Aftertaste impact | The residual flavor intensity that remains after the sample has been swallowed |
| Salty aftertaste | The perceived intensity of residual saltiness that remains in the mouth after the sample has been swallowed |
| Sweet aftertaste | The perceived intensity of residual sweet flavor in the mouth after the sample has been swallowed |
| Metallic aftertaste | The perceived intensity of residual metallic flavor in the mouth after the sample has been swallowed |

and crab meat were related to savory flavor). A pilot sensory profile was conducted midway through training to refine the sensory vocabulary and to provide assessors with feedback on their performance.

Through abalone familiarization and moderated discussions, the 9-member sensory panel developed a consensus vocabulary of 16 terms that best described the important sensory properties of the abalone. The final descriptive vocabulary categorized the sensory properties identified by odor, flavor, texture, and aftertaste. A standardized method of assessment was developed to ensure the consistency of the evaluation of each attribute by each assessor. Assessors were served with 2 equal-size pieces of abalone in the same container, one to assess texture attributes and the other to assess flavor attributes. Assessors first opened the lid of the container slightly, and smelled the entrapped headspace to assess aroma impact, savory odor, and earthy odor. Assessors placed the first piece of abalone into their mouth and rated the texture attributes firmness, springiness, and chewiness. While chewing naturally the second piece of abalone, assessors rated flavor impact, saltiness, sweetness, savory, earthy, and metallic flavors. After swallowing, assessors rated aftertaste impact, salty aftertaste, sweet aftertaste, and metallic aftertaste.

Assessors proceeded to the evaluation of each sample in triplicate following a randomized complete block design to ascertain assessor-to-assessor variation. Therefore, each assessor was presented with a serving from each batch for assessment every day. Test samples were blind coded with random a 3-digit code and were served monadically. The order of presentation was randomized for each assessor to account for first-order and carryover effects. The experimental design was produced using the design generation package CycDesign (Whitaker et al. 2002). Each descriptive attribute was rated on 100-mm unstructured line scales anchored at 5% and 95%. Assessors were seated in individual sensory booths with appropriate ventilation and lighting, and data were collected using automated data acquisition software (Compusense *five*, release 5.2, Compusense Inc., Guelph, Ontario, Canada).

A 5-min interstimulus interval was imposed between samples to prevent carryover effects. Plain water and diluted apple juice were provided as palate cleansers to prevent assessor fatigue.

Chemical Analysis

Abalone (Fig. 1, part B) were transferred to small plastic sample bags and refrozen at -20°C . Samples were transported frozen to CSIRO's Marine and Atmospheric Research Laboratory in Hobart. Samples were weighed and then dried for 3 days using a Labconco Freezone freeze-drier system (Kansas City, MO). It was not feasible to measure the composition of all the abalone samples subjected to sensory analysis for practical reasons; nevertheless, the analyses incorporated replicates within each batch of $n = 9$ or 10 for glycogen and moisture, and $n = 6$ for FAA. Moisture content of abalone meat was estimated from the weight loss after drying. Dried samples were finely grated using a cheese grater, transferred to sample vials, and stored at -80°C for 1–4 wk prior to additional chemical analysis.

Glycogen was estimated from 50-mg subsamples after extraction with 0.1 M trisodium citrate buffer pH 5.0, conversion to glucose by overnight incubation at room temperature with 0.5% amyloglucosidase and color development using Trinder reagent (Biotron Diagnostics Inc., Hemet, CA) (Braid et al. 2005).

For FAA analysis, 100-mg samples were first extracted with 7% trichloroacetic acid, containing homoarginine as an internal standard, then the extracts were washed with diethyl ether to remove trichloroacetic acid (Konosu et al. 1974). Sample aliquots (0.6 mL) were transferred into Vectaspin Micro units (Whatman, 12,000 M.Wt cutoff) and centrifuged at 5,000g for 45 min. Resultant filtrates were derived with phenylisothiocyanate, and analyzed for FAA by reverse-phase high-performance liquid chromatography (Bidlingmeyer et al. 1984).

Data Analysis

The sensory and compositional data were analyzed separately using General Linear Model analysis of variance (ANOVA).

Each assessor's rating on the unstructured line scale was converted to a value between 0 and 100. The quantitative ratings for each sensory attribute were collated and analyzed using ANOVA with batch ($n = 5$) and assessor ($n = 9$) as main fixed treatment factors, and attributes as dependant variables.

Interactions between the fixed terms were calculated to examine the integrity of the overall data set. The mean scores, F value, P value, and standard error difference were taken from the ANOVA table of the General Linear Model. Twice the standard error difference can be taken as a conservative estimate of the least significant difference, which is an indication of the minimum value (intensity) necessary for significant differences between sample means. For all analyses, a confidence interval of 5% was chosen as the criterion for statistical significance ($P < 0.05$) and all data were analyzed using XLSTAT (v2009.4.02; Addinsoft, Paris, France).

The quantitative data for each chemical measurement ($n = 9$ or 10 for glycogen or moisture; $n = 6$ for FAA) were analyzed separately for each batch using 1-way ANOVA. When differences were found, data were analyzed by Tukey's test for pairwise comparison. Analyses were performed using Excel (Microsoft Corporation, Seattle, WA) and Analyze-it software (Leeds, UK).

Relationships between sensory and compositional data were found using Pearson's correlation (XLSTAT, v2009.4.02).

RESULTS

Comparison of Abalone Sensory Properties

All sensory attributes discriminated significantly among the abalone batches ($P < 0.005$; Table 3), apart from sweet aftertaste.

Very significant differences were found between the wild blacklip abalone and the aquacultured abalone sampled. The wild blacklip abalone was perceived as significantly higher in flavor and aftertaste impact, mainly driven by earthy and metallic characters. Significant flavor differences were also observed between batches of aquacultured samples. Victoria cultured natural abalone (Vic-Cult-Nat) had significantly higher metallic and earthy odors and flavors compared with the other aquacultured samples. Nevertheless, these abalone, fed a natural diet, were perceived as less metallic and earthy than wild blacklip abalone. Aquacultured abalone fed with formulated diets showed similar flavor characteristics to one another. Small between-site batch differences were observed. Tasmania cultured artificial abalone (Tas-Cult-Art) was perceived with significantly higher flavor impact, savory odor, salty taste, and savory flavor than Vic-Cult-Art and South Australia cultured artificial abalone (SA-Cult-Art). Texture of wild blacklip abalone was very different to that of the aquacultured abalone sampled. Wild abalone were perceived as more chewy, springy, and firm compared with their aquacultured counterparts. Texture differences were observed between different cultured batches, but this was not reflective of the diet. Hybrid abalone from the same site but fed different diets (Vic-Cult-Art and Vic-Cult-Nat) had similar texture and were perceived as more firm, springy, and chewy than aquacultured abalone sampled from other farms. South Australian-Cult-Art and Tas-Cult-Art were very close from a texture point of view, and SA-Cult-Art was less springy. Using Pearson's correlations, correlations were found between sensory attributes. Sweetness correlated negatively to firmness ($r = -0.897$), chewiness ($r = -0.900$), metallic flavor ($r = -0.966$), and metallic aftertaste ($r = -0.911$). Earthy and metallic flavors were correlated to one another ($r = 0.926$).

TABLE 3. Estimated means and significance for abalone sensory characteristics.

| | Odor impact | Savory odor | Earthy odor | Firmness | Springiness | Chewiness | Flavor impact | Saltiness | Sweetness | Savory flavor | Earthy flavor | Metallic flavor | Aftertaste impact | Salty aftertaste | Sweet aftertaste | Metallic aftertaste |
|--------------|-------------|-------------|-------------|----------|-------------|-----------|---------------|-----------|-----------|---------------|---------------|-----------------|-------------------|------------------|------------------|---------------------|
| SA-Cult-Art | 53.54 | 42.98 | 34.07 | 38.80 | 32.72 | 33.35 | 49.59 | 37.15 | 35.26 | 51.93 | 23.98 | 17.78 | 46.63 | 27.67 | 22.57 | 16.59 |
| Tas-Cult-Art | 58.87 | 55.56 | 33.33 | 43.20 | 44.22 | 42.82 | 65.33 | 62.91 | 36.67 | 59.67 | 20.48 | 12.02 | 62.54 | 54.63 | 25.91 | 13.59 |
| Vic-Cult-Art | 43.41 | 39.82 | 22.20 | 55.78 | 54.11 | 56.76 | 49.52 | 40.17 | 32.85 | 58.30 | 17.24 | 16.56 | 44.44 | 28.43 | 21.56 | 14.83 |
| Vic-Cult-Nat | 65.78 | 40.41 | 45.63 | 54.06 | 53.76 | 57.00 | 54.19 | 40.93 | 28.13 | 51.76 | 27.57 | 33.32 | 49.19 | 28.57 | 17.98 | 26.00 |
| Tas-Wild-Nat | 66.44 | 46.69 | 63.06 | 78.48 | 67.04 | 77.89 | 73.63 | 40.15 | 24.78 | 50.30 | 65.28 | 50.82 | 66.17 | 35.48 | 21.41 | 49.19 |
| F value | 9.77 | 3.76 | 15.86 | 19.75 | 18.83 | 30.69 | 26.66 | 18.43 | 3.09 | 3.06 | 42.34 | 29.43 | 21.95 | 31.97 | 1.42 | 26.77 |
| P value | <0.001 | 0.008 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.022 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.237 | <0.001 |
| LSD | 8.67 | 8.57 | 10.46 | 9.98 | 9.52 | 9.73 | 5.82 | 7.10 | 7.64 | 6.78 | 9.76 | 8.31 | 6.21 | 6.36 | 6.50 | 8.15 |

Art, artificial; Cult, cultured; LSD, least significant difference; Nat, natural; SA, South Australia; Tas, Tasmania; Vic, Victoria. In bold, the statistical values (*P*-, *F*- and LSD values). *P*-value < 0.05 indicate significant differences between samples for this attribute.

Abalone Chemical Composition

Comparing compositional data of the different abalone batches, total concentrations of FAAs were lower in Tas-Wild-Nat (average, 85.1 mg/g dry weight (DW)) than in any of the cultured abalone. Average values of the latter ranged between 103 mg/g DW (Vic-Cult-Nat) to 116 mg/g DW (Vic-Cult-Art), although these values were not significantly different (Table 4). Individual FAAs showed some significant differences between batches—in particular, the glycine content was 3–5 times greater in abalone fed artificial diets (i.e., SA-Cult-Art, Vic-Cult-Art, and Tas-Cult-Art) than those fed natural diets (i.e., Vic-Cult-Nat and Tas-Wild-Nat; Table 4). Also, Victorian hybrid abalone had significantly more taurine than other abalone. Glycogen percentages in Vic-Cult-Nat were about one quarter of those from other abalone batches; in general, all batches had highly variable glycogen (Fig. 2). Between-group differences were also evident in the moisture content (Fig. 3).

Data from all batches were also collated to provide information on the compositional variation of the sample population as a whole. For FAAs, this highlighted the sample variation in glycine, which ranged from 1.7–26.1 mg/g DW (Table 4). Other specific FAAs showed 2–7-fold differences between minimum and maximum values; total FAAs varied from 75–129 mg/g. Percentages of glycogen ranged from 0.1%–33% DW (average, 17.1 ± 9.3% DW) and moisture ranged from 66.1%–76.9% meat weight (average, 71.6 ± 2.1% meat weight).

Pearson’s correlations, showed interesting relationships between compositional and sensory measurements. Savory odor correlated significantly to glutamate (*r* = 0.884), whereas savory flavor correlated significantly to arginine content (*r* = 0.893). Sweetness correlated to glycine content (*r* = 0.971). Earthy and metallic flavors correlated negatively to the total amount of FAAs (*r* = -0.961 and *r* = -0.891, respectively). Glycogen was not correlated to any attribute.

DISCUSSION

A strict preparation protocol was developed to conduct descriptive sensory analysis of frozen abalone. The abalone were steamed for consumption but otherwise minimally processed, maintaining the integrity of the abalone and reducing the risk of potential microbiological contamination of the tasters. Short-time steaming is deemed to be a heating treatment that is not a severe as canning or extensive boiling; the core of the product reaches 64°C for a very limited time. Smit et al. (2010) reported that boiling affected the sweetness and freshness of abalone. Abalone were described using similar terms to those used for canned abalone by Sanchez-Brambila et al. (2002), in particular by terms such as savory, sweet, salty, metallic, and decaying/earthy notes. The development of a specific and consensual vocabulary and method of assessment in this study removed the subjectivity of the results.

The use of 5 abalone treatments (batches) within this study—differing by growing conditions (i.e., cultured vs wild), species, size, age, harvest date, diet, and freezing method—produced a broad range of sensory and compositional profiles and provided a representation of product types found in the marketplace.

A stricter comparison could be made between Victorian hybrid abalone that were reared in similar conditions but fed

TABLE 4.

Concentrations (measured in milligrams per gram dry weight) of selected free amino acids (FAAs) and total FAAs in the batches of abalone, and summary data for all abalone.

| Abalone batch | Individual FAAs | | | | | Sum other FAAs* | Total FAAs |
|-----------------------|-------------------------|------------|-------------------------|------------------------|--------------------------|--------------------------|-----------------------|
| | Taurine | Arginine | Glycine | Glutamate | Alanine | | |
| Individual batch data | | | | | | | |
| SA-Cult-Art | 54.8 ± 2.6 ^b | 15.5 ± 2.6 | 15.2 ± 2.2 ^a | 2.5 ± 0.6 ^b | 1.4 ± 0.4 ^{bcd} | 17.7 ± 2.3 ^a | 107 ± 11 ^a |
| Tas-Cult-Art | 51.2 ± 5.2 ^b | 18.0 ± 5.2 | 18.2 ± 5.7 ^a | 3.6 ± 0.4 ^a | 1.6 ± 0.3 ^{bc} | 13.4 ± 2.9 ^{ab} | 106 ± 13 ^a |
| Vic-Cult-Art | 63.4 ± 4.7 ^a | 18.4 ± 1.9 | 14.7 ± 4.6 ^a | 1.9 ± 0.6 ^b | 1.9 ± 0.5 ^{ab} | 15.4 ± 3.2 ^{ab} | 116 ± 10 ^a |
| Vic-Cult-Nat | 68.7 ± 3.3 ^a | 16.9 ± 2.3 | 4.4 ± 3.0 ^b | 1.0 ± 0.3 ^c | 1.0 ± 0.2 ^d | 10.8 ± 3.3 ^b | 103 ± 8 ^a |
| Tas-Wild-Nat | 49.8 ± 6.1 ^b | 14.8 ± 2.0 | 3.4 ± 1.4 ^b | 2.7 ± 0.6 ^b | 2.2 ± 0.4 ^{ab} | 12.3 ± 3.0 ^b | 85 ± 9 ^b |
| F value | 18.8 | 1.5 | 19.8 | 21.1 | 10.1 | 5.1 | 7.4 |
| P value | <0.0001 | 0.22 | <0.0001 | <0.0001 | <0.0001 | 0.004 | 0.0005 |
| All sample data | | | | | | | |
| Average ± SD | 57.6 ± 8.6 | 16.7 ± 3.2 | 11.2 ± 7.1 | 2.3 ± 1.0 | 1.6 ± 0.5 | 13.9 ± 3.7 | 104 ± 14 |
| Range | 41.7–72.8 | 11.8–28.2 | 1.7–26.1 | 0.6–4.2 | 0.9–2.6 | 8.1–22.2 | 75–129 |

Values for FAAs of individual batch data down the same column and sharing a common superscript are not significantly different ($P > 0.05$).

* Asparagine, aspartate, cysteine, glutamine, histidine, isoleucine, lysine, methionine, ornithine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, and valine. Art, artificial; Cult, cultured; Nat, natural; SA, South Australia; Tas, Tasmania; Vic, Victoria.

different diets. Both batches shared similar characteristics, but abalone fed a natural diet had more intense earthy and metallic characters, which leads us to hypothesize that earthy and metallic characters originate from the diet. Consistent with this, wild blacklip abalone, which graze on macroalgae, also had more intense earthy and metallic flavors. Although Smit et al. (2010), using a panel of consumers, concluded that diet had no effect on the metallic character of South African *Haliotis midae*, our findings with a trained sensory panel suggest that there could be an effect of natural diet on the earthy and metallic character of Australian abalone. Metal concentration in Victorian abalone foot was found to be diet dependant (Skinner et al. 2004). Wild abalone were measured with a higher metal content than aquacultured abalones, which could corroborate this finding.

Small, but significant, differences were observed between aquacultured abalone. Tasmanian-Cult-Art abalone were perceived as the most salty and savory abalone sampled. Tasmanian-Cult-Art abalone were sampled from a deep-water tank system whereas other aquacultured abalone sampled had been sourced from shallow raceway-style tank systems. Tasmanian-Cult-Art were also the only abalone frozen in brine, which leads us to hypothesize that either growing environment or postharvest treatment could have an effect on the salty taste of abalone; however, further analysis is required to confirm this.

Several texture differences were observed among abalone treatments. Wild blacklip abalone was perceived as firmer, chewier, and springier than aquacultured abalone. Hybrid abalone were perceived as firmer, chewier, and springier than greenlip abalone. Correlations between texture and flavor

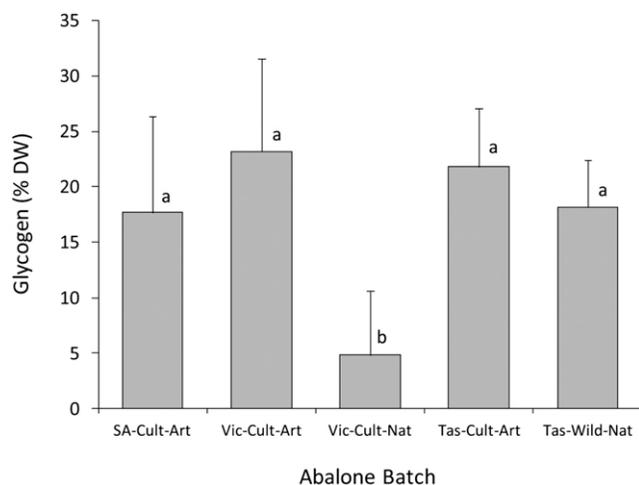


Figure 2. Glycogen in the foot of abalone (\pm SD). Groups that share a common letter do not differ significantly in their glycogen content. Art, artificial; Cult, cultured; DW, dry weight; Nat, natural; SA, South Australia; Tas, Tasmania; Vic, Victoria.

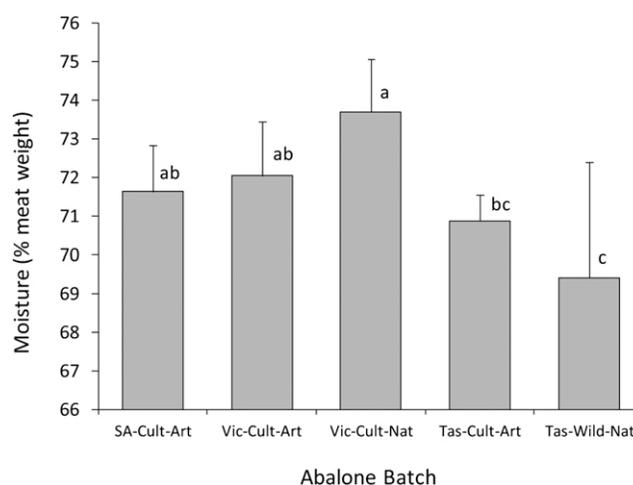


Figure 3. Moisture in the foot of abalone (\pm SD). Groups that share a common letter do not differ significantly in their moisture content. Art, artificial; Cult, cultured; Nat, natural; SA, South Australia; Tas, Tasmania; Vic, Victoria.

attributes were found. Firmness and chewiness correlated negatively with sweetness and correlated positively with metallic flavor, which could suggest a physiological origin for the abalone metallic flavor. A hypothesis would be that, as the animal ages, its meat becomes more chewy and firm, and consequently less sweet. The absence of sweetness changes the balance of flavor and the meat develops a metallic character.

Total concentrations of FAAs, and individual FAAs were in line with other reports for abalone (e.g., with taurine, arginine, and glycine occurring in highest amounts) and other putative taste-active FAAs (i.e., glutamate and alanine in low concentrations) (Bewick et al. 1997, Chiou & Lai 2002). High concentrations of taurine relate to its role in abalone osmoregulation, whereas arginine (through argininophosphate) is linked to muscle energetics (Viana et al. 2007). The high variability in glycogen concentrations (0.1%–33% of DW), also concurs with other reports in which composition of abalone were analyzed across different seasons, and fed either natural or artificial diets (Chiou & Lai 2002, Fluckiger et al. 2011). Because glycogen is the principle energy reserve in abalone, its content is linked to the physiological status of the animal, and hence is influenced by factors including reproductive stage, nutritional condition, diet, stress, and temperature (Chiou et al. 2001, Ponce-Diaz et al. 2004, Braid et al. 2005).

It is important to emphasize that because of the multiple variables associated with the batches of abalone tested (i.e., species, site, season, age, size, diet, growing conditions, and freezing method), it is difficult to make conclusions or generalize on the effect of individual factors on sensory characteristics and composition. The exception was the Victorian hybrid abalone, which were from the same farm and harvested at the same time; hence, the influence of natural versus artificial diet on composition could be compared. Abalone fed artificial diets contained significantly more of the FAAs glycine, glutamate, and alanine, as well as more glycogen. Similarly, Chiou and Lai (2002) found *Haliotis diversicolor* fed an artificial diet contained significantly more glycine, glutamate, and glycogen than similar abalone fed a natural diet. Like our study, Bewick et al. (1997) found glycine to be highly variable—from 0.1 mg/g (based on wet tissue weight) in nonfeeding wild abalone (*Haliotis iris*) to 1.8 mg/g in feeding wild abalone, up to 6.2 mg/g in cultured abalone fed an artificial diet. Variability in glycine content may

be associated with its role in intermediary metabolism, where it may act as precursor for protein and other metabolites (e.g., homarine, which is also a taste-active constituent in abalone) (Bewick et al. 1997). Variable glycine may be related to turnover of the collagen, which contains approximately one third of its residues as glycine (Kimura & Matsuura 1974). The relationship between sweetness and glycine as well as between savoriness and glutamate was established by Konosu (1973) and Chiou and Lai (2002). Tasmanian-Cult-Art abalone used in this study were perceived as higher in sweetness and savory character, and were characterized by a high glycine and glutamate content, which would agree with previous findings. Concentrations of glycine were low in abalone fed a mixed (Vic-Cult-Nat) or natural (Tas-Wild-Nat) diet and, consequently, these abalone were perceived as low in sweetness. Those samples were also perceived as high in earthy, metallic flavors as well as in all the texture attributes. Previous studies have shown that the amount of collagen and the connectivity of the muscle fibers vary with season and increase through an abalone's lifetime such that abalone with increased collagen content have tougher (in our case, more firm) meat (Oleachea et al. 1993, Hatae et al. 1995). Wild abalone were between 70 mm and 110 mm, a size associated with abalone older than 3 y when harvested (Shepherd & Laws 1974), and aquacultured abalone were, on average, ~60 mm, indicating they were approximately 1 y old. This observation corroborates the hypothesis that as abalone age, they become tougher and their taste characteristics change.

CONCLUSION

This study demonstrated that descriptive sensory analysis can measure differences in sensory properties among abalone varying in their rearing conditions. Relationships between sensory and biochemical measurements were established. Diet as well as age seemed to have a high impact on sensory properties of abalone.

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