PE7.14 Transport of live Australian abalone: yield and quality changes in raw and cooked product 161.00

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Abstract—Air transport of live abalone is important for many markets so that product can be presented to the consumer in optimal condition. However, transport exposes abalone to physiological stresses and it was the purpose of this investigation to determine what physical/biochemical changes occurred over a 26-hour period of storage/transport and to relate these to quality. Farmed abalone (60) were harvested and commercially packed for transport and either stored at origin, or transported 1800 km by air freight. Abalone were shucked at 0, 6 or 26 h post-harvest. Irrespective of treatment, both groups lost 13 % of their initial weight during the first 6 h. However, losses during the next 20 h were small and not different between treatments. Compared with those shucked at 0 and 6 h, the 26 h group lost only a small amount of haemolymph and fluids resulting in shucked muscle weights being similar (P>0.05). For those attributes measured, there were no differences between the stored at origin and the transported abalone. Further, cooking losses were lower in abalone shucked at 26 h (P<0.05). Muscle glycogen fell slightly with storage time and D-lactate accumulated in muscle tissue at 26 h, indicating metabolic stress during transport. Toughness of cooked abalone also increased after 26 h storage, suggesting an association between high D-lactate concentration and increased toughness.

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***Index Terms*—abalone, D-lactate, live transport, texture, weight loss**

I. INTRODUCTION

THE on-land culture of abalone in Australia is a significant growth industry, in addition to the wild product, and major exports are to south-east Asia. Supplying raw abalone to distant markets, and/or maintaining supply so that they are available in prime condition, is difficult. Apart from the cooked, canned product, abalone is usually exported as live, chilled or frozen. With each of these, there may be quality issues dependent upon the various processes used.

Live abalone reaching overseas markets commands higher prices, typically in the range of US$30-40 per kg [1] compared with other product forms of abalone, but they must survive the transport. There are several important factors known for reducing mortalities during live transport of abalone, including temperature, oxygen availability and accumulation of carbon dioxide, during transport and post-transport periods. Lowering the temperature during transport decreases the metabolic rate, maximizing survival. Abalone have adapted their physiology and have a distinctive metabolism which enables them to continue metabolic processes at a reduced level during exercise or exposure to air [2].

Metabolic activity and stress associated with harvest and transport can negatively affect meat quality in a variety of meat animal species, including abalone [3, 4]. These deleterious effects on quality are usually associated with increased anaerobic metabolism. Compared to vertebrates where L-lactate is produced during anoxia, mollusks accumulate other pyruvate reductase end products of anaerobic glycolysis. These include D-lactate and tauropine [5, 6]. In fact, it has been reported that abalone possess only tauropine dehydrogenase and D-lactate dehydrogenase as pyruvate reductases in the foot and adductor muscles and evidence suggests that lactate is the preferred product during environmental hypoxia and tauropine during functional hypoxia (e.g. exercise) [2, 6]. D-lactic acid has therefore been used to assess the physiological state of abalone under different environmental conditions [2, 7].

Olley and co-workers [8, 9] have investigated links between taste and texture and biochemical indices based on amino acid and nucleotide composition of abalone meat. They also showed an association between low pH and high concentrations of D-lactate and increased toughness and textural changes of abalone meat [3]. The

composition of abalone meat is important in determining final texture and overall quality of the abalone product, but also, subsequent processing treatments have a large impact on quality attributes. Changes in rheological properties and structure of abalone meat were reported after cooking (3h, boiled) of abalone meat [10]. During cooking, abalone meat shrank, lost water and water-soluble components as drip and decreased in weight. Further work [11] investigated the type of cooking method on textural changes and it was found that structural changes in myofibrils were greatest in boiled meat compared with steamed meat of *Haliotis discus* adductor muscle.

In this study, we have examined the effects of live transport stress on the quality, in terms of yield and texture, of both raw and cooked (steamed) abalone meat.

II. MATERIALS AND METHODS

A. Treatment groups and processing

A total of 60 hydrid (*Haliotis laevigata* x *H. rubra)* abalone (shell length 95.9 ± 2.43 mm) were harvested at a local abalone farm in Tasmania.

Twelve abalone were sampled immediately (0 h). The remaining 48 abalone were distributed among 4 polyboxes, within sealed plastic bags containing 100 % oxygen and chill packs, as per standard industry practice for live transport of abalone. The temperature was maintained at 15°C. Two boxes of abalone were retained at origin and the remaining two were transported by commercial air freight to Brisbane (destination), a distance of about 1800 km.

At time of harvest, the 0 h group was weighed and shucked immediately after removal from the tanks (on-farm). The muscle was then cut in half vertically and snap-frozen in liquid nitrogen and stored at -80°C for later analysis for glycogen. The remaining abalone were maintained in the storage/transport conditions in the polyboxes and held at 15°C. At 6 and 26 h post-harvest, at origin and destination, abalone were removed from the polyboxes and shucked and processed as below.

After weighing whole, the abalone were shucked and individual components reweighed. The muscle was put on ice for 20-25 min and a sub-sample taken for D-lactate content (frozen in liquid nitrogen and stored at -80°C). The remainder of the sample was stored at 4°C overnight for texture analysis the following day. The group allocated to the cooking treatment was stored overnight at 4°C, cooked the next day, and measurements recorded for cook loss and texture.

B. Texture analysis

All textural measurements were made on a Lloyd instruments LRX Materials Testing Machine fitted with a 500N load cell (Lloyd Instruments Ltd., Hampshire UK). Texture profile analysis (TPA) was conducted on the raw and cooked abalone slices using a cylindrical plunger of 6 mm diameter, at a cross-head speed of 100 mm/min and 60% compression. Two or three replicates were possible on each slice.

Warner-Bratzler (WB) shear force and compression was also recorded on raw and cooked slices using the Lloyd instrument at a cross-head speed of 50 mm/min.

C. Muscle glycogen and D-lactate content

Glycogen was determined on freeze-dried meat samples [12]. D-lactate was assayed using commercial test kits for the enzymatic determination of D-lactate and L-lactate (Roche) for meat products.

D. Cooking procedure

The abalone meat was steamed in bamboo trays over boiling hot water for 10 min and then cooled in tap water for 10 min. Samples were equilibrated at room temperature for 20 min prior to reweighing and preparation for texture analysis.

III. RESULTS AND DISCUSSION

At time of harvest (0 h), abalone had a mean weight of 134.8 g. Six hours later, the mean weights of those stored at origin, or subjected to transport by commercial air freight, were only 119.9 or 116.6 g respectively (Table 1), having lost about 13 % of their initial weight. This large loss may have resulted mainly from a loss of gut contents and urine as muscle weights were not different. During a further 20 h of storage, there were additional weight losses but these were somewhat smaller than the losses observed during the initial 6 h. There were no differences (P>0.05) in weights between those transported and those kept at origin. When shucked, the initial mean muscle weights at times 0 and 6 h were not different (53.1 to 55.1 g) but by 26 h of storage/transport, the initial muscle weight was significantly less (42.9 to 45.7 g).

For abalone transported to destination, the muscle weights were also measured after allowing 20 min for haemolymph and other fluids to drain from flesh. Abalone shucked at 6 h lost 10.3 mL fluid (24.6 % of initial muscle weight) compared with those shucked at 26 h which lost just 1.8 mL (1.8 %) resulting in essentially identical muscle

weights (40.3 g). It would appear therefore that those abalone maintained live from 6 to 26 h lost fluid, either as mucous or through evaporation from their soft tissues [13] and therefore there were only very small losses on shucking.

Cooking of abalone muscle resulted in further small weight losses. Although raw muscle weights from the 6 and 26 h groups were identical, when cooked, abalone shucked at 6 h had a significantly greater cook loss (6.44 %) than those shucked at 26 h (3.24 %).

In terms of overall yield, it would appear therefore that the duration of storage/transport (6 or 26 h) does not affect the final weight of the raw muscle. However, there was a slight benefit in terms of cook yield.

Texture measurements performed on abalone product at destination indicated that Warner-Bratzler peak shear force was similar for raw abalone at both 6 and 26 h and was also similar to that of cooked abalone at 6 hours post-harvest (Table 2). However, for cooked abalone following shucking at 26 h, the shear force required was significantly greater (P<0.05), indicating that delayed shucking and presumably more stress, resulted in increased toughness of the flesh. The observations for compression followed a similar trend except that, compared with raw, cooking resulted in an increase in compression force (P<0.05) in samples shucked at both 6 and 26 h and the force was nearly twice as high in the 26 h samples.

Texture profile analysis indicated that Hardness 1 decreased in raw abalone when shucked at 26 hours compared with 6 hours post-harvest and also, cooking reduced this attribute (Table 2). However, Cohesiveness and Springiness both increased in cooked samples irrespective of time of shucking. Findings for Gumminess and Chewiness were both affected by time of shucking of raw abalone but did not differ once cooked (Table 2).

There was an apparent reduction in muscle glycogen during 26 h from 6.2 to 5.1 g/100 g muscle but the changes were not significant. The content of D-lactate in live abalone muscle was relatively low and did not change during the period of 0 to 6 h post-harvest (Fig 1). On this basis it would appear that aerobic metabolism was not markedly impaired during the 6 h storage/transport and the abalone were relatively unstressed. However, during the next 20 hours of live storage at 15°C, there was a large increase (P<0.001) in D-lactate content, signifying a switch to anaerobic metabolism (with slight reduction in glycogen) and therefore indicating stress of the abalone [14]. Wells & Baldwin [2] also found that lactate increased after 24 h air exposure in two New Zealand abalone species (*H. iris* and *H. australis*). Storage of abalone muscle at 0, 5 and 10°C over a longer time (up to 15 days) also showed a marked increase in D-lactate concentration in *H. discus* [15].

IV. Conclusion

Although weight loss of whole abalone increased with time of live storage the actual weight of the raw meat obtained (after accounting for fluid loss on shucking) was similar. Thus if moisture is lost early, it is not available for loss at a later stage. However, it is concluded that cook loss is reduced with longer time of storage, perhaps resulting from coagulation of haemolymph.

Although there were no differences in shear force measurements in raw abalone with storage/transport of either 6 h or 26 h, there were significant differences in gumminess and chewiness with storage time which may impact on overall eating quality. However, storage for 26 h and cooking resulted in tougher meat. The decrease in glycogen and increase in D-lactate contents with 26 h storage suggests some degree of metabolic stress which may be responsible for tougher meat when cooked.

It appears that live transport of abalone (*H. laevigata* x *H. rubra*) does not impact on overall yield of product but may alter some texture characteristics relating to eating quality.

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Table 1: Weight of live abalone and shucked components at time 0, 6 and 26 h after harvest. The 6- and 26-hour groups were packed in poly boxes, gas flushed, and either transported by air to their destination or kept at their origin. Mean ± SD, n=12, except for cook loss where n=6.

Weight parameters	**Time from harvest[1]**				
	0 h	6 h		26 h	
	Origin	Origin	Destination	Origin	Destination
Live weight (g)	134.8 ± 7.70[a]	119.7 ± 9.42[b]	116.6 ± 9.13[b]	111.9 ± 9.13[c]	111.3 ± 10.92[c]
Shell weight (g)	36.3 ± 2.79[a]	35.1 ± 3.49[a]	35.0 ± 2.56[a]	35.9 ± 3.32[a]	36.2 ± 3.11[a]
Muscle weight, initial (g)	55.1 ± 4.59[a]	53.8 ± 4.30[a]	53.5 ± 6.89[a]	45.7 ± 5.72[b]	42.9 ± 4.48[b]
Muscle weight, after fluid loss at 20 min (g)	nd[2]	nd	40.3 ± 4.16[a]	nd	40.3 ± 3.64[a]
Fluid loss (g) and [% of initial muscle weight]	nd	nd	10.25 ± 2.39[a] [24.6%]	nd	1.81 ± 2.06[b] [5.89%]
Cook loss (%)	nd	nd	6.44 ± 2.05[a]	nd	3.24 ± 0.55[b]

[1] Values in rows having different superscripts are significantly different, $P<0.05$

[2] Not determined

Table 2: Warner-Bratzler shear and compression analysis, Texture Profile Analysis on raw and cooked abalone at destination following storage/transport of 6 or 26 hours post-harvest. Mean ± SD, n=6.

	Raw		Cooked	
	6 h	26 h	6 h	26 h
Shear and compression analysis				
Warner-Bratzler Peak Force (N)	71.34±11.03[a]	82.50±22.13[a]	79.99±4.46[a]	117.7±17.34[b]
Compression (N^2m)	46.48±13.45[a]	44.29±16.60[a]	69.89±6.44[b]	139.4±60.48[c]
Texture Profile Analysis				
Hardness 1 (N)	39.12±8.56[a]	20.39±10.53[b]	16.24±1.92[b]	19.11±2.71[bc]
Cohesiveness	0.354±0.109[a]	0.293±0.108[a]	0.565±0.008[b]	0.574±0.018[b]
Springiness (mm)	4.92±0.44[a]	4.67±0.51[a]	5.91±0.62[b]	5.65±0.38[b]
Gumminess (N)	13.19±4.40[a]	5.30±2.51[b]	9.19±1.13[c]	10.94±1.58[c]
Chewiness (Nm)	65.38±21.86[a]	25.50±13.68[b]	54.73±11.89[a]	62.11±12.16[a]

Figure 1: D-lactate and glycogen contents of abalone processed at different storage/transport times post-harvest.