Growth, Processing Measurements, Tail Meat Yield, and Tail Meat Proximate Composition of Male and Female Australian Red Claw Crayfish, *Cherax quadricarinatus*, Stocked into Earthen Ponds

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ABSTRACT. Small (0.7 g) juvenile red claw, *Cherax quadricarinatus*, were stocked in earthen ponds (0.04 ha) in Kentucky and grown for 86 days so that measures of growth, survival, processing characteristics, and proximate composition of tail muscle in male and female Australian red claw crayfish could be obtained. A commercial marine shrimp was fed to all red in two separate feedings, each consisting of one-half of the total daily ration between 0800-0830 and between 1530-1600 hours for the duration of the culture period. Total weight and number of red claw from each pond were recorded at the harvest.

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Forty red claw from each sex were randomly sampled, chill-killed by lowering the body temperature in an ice-bath, and frozen (−20°C) for processing measurements and proximate composition. Red claw were removed from the freezer, thawed, individually weighed to the nearest 0.01 g, and then were hand-processed so that weights of chelae, tail, and tail muscle were obtained to the nearest 0.01 g. After 87 days, red claw had a final average individual weight of 59.6 g, weight gain of 8,413%, survival of 64.0%, yield of 903 kg/ha, and feed conversion ratio (FCR) of 4.63. When analyzed by sex, males had significantly ($P < 0.05$) higher final individual weight (71.05 g) compared to females (53.65 g); higher ($P < 0.05$) chelae weight (13.1 g for males compared to 6.84 g for females); higher tail weight (25.53 g for males compared to 20.38 g for females); higher tail muscle weight (18.99 g for males compared to 14.89 g for females); and higher cephalothorax weight (32.41 g for males compared to 26.44 g for females; Table 2). There were no significant differences ($P > 0.05$) in the percentage moisture, protein, lipid, fiber, and ash in the tail muscle of male and female red claw when analyzed either on a wet-weight basis and averaged 81.0%, percentage protein averaged 16.46%, percentage lipid averaged 0.16%, fiber averaged 0.1%, and percentage ash averaged 1.42%. Results from the present study indicate that red claw can be grown as a commercial aquaculture species in locations with limited growing seasons, and that male red claw grow larger, have larger chelae, and higher tail muscle weights compared to females so that it might be economically advantageous to stock all-male populations of red claw in ponds to achieve maximum production. Further research on growth and processing yields of red claw should be conducted to assist the industry.

KEYWORDS. Red claw, *Cherax quadricarinatus*, growth, processing traits, ponds

INTRODUCTION

Australian red claw crayfish, *Cherax quadricarinatus*, is a tropical species found in the river systems of northern Queensland and the Northern Territory, Australia, and Papua New Guinea. Red claw have a fast growth rate, are tolerant of a wide range of water temperatures, can achieve high (600 g) maximum weights, are tolerant of crowded conditions, do not have a larval stage which eliminates the need for expensive

hatcheries, and newly-hatched individuals can consume prepared diets reducing or eliminating the need to feed live foods (Webster et al. 1994; Masser and Rouse 1997). There are some difficulties in farming red claw in the United States, especially production of crayfish in earthen outdoor ponds. Water temperatures must be maintained between 23-32°C to achieve maximum growth potential; water temperatures below 20°C reduce growth rates while water temperatures below 10°C are lethal causing a limitation for farmers in less temperate regions. As a result, producers growing red claw outdoors in the U.S. will be constrained to a 4-7 month grow-out season.

Condition indices are widely used in aquaculture to determine the effects of treatments on cultured fish and crustaceans. These indices usually measure relative tissue mass on proximate composition. In crustaceans, hepatopancreactic indices have been mainly used as an indication of culture conditions (Huner et al. 1985, 1990; Schirf et al. 1987; Ackefors et al. 1997; Jussila 1997, 1999). However, while these conditions indices may be useful, producers are more interested in processing characteristics of an aquaculture species (e.g., fillet yield, amount of tail meat, or percentage of edible muscle in relation to body weight). It has been reported that the percentage of tail meat in red claw comprises 22% of body weight (Jones 1989); however, little data on other processing measurements on this species are in the literature.

In the U.S., crayfish are marketed in the form of whole live, or frozen (cooked and uncooked), hard-shelled crayfish, soft-shell crayfish, or fresh or frozen tails. Meat yield from crayfish is generally reported to be approximately 15% by weight; however, large crayfish may have yields of less than 10% due to the weight of the exoskeleton being higher in larger individuals (Huner 1994). Tail meat is usually eaten from whole, cooked crayfish in the U.S., or is sold already removed from the shell (exoskeleton). However, with its large size, red claw can provide a significant amount of claw meat which could be consumed if whole individuals are served, although it may not be considered economically feasible to extract claw meat on a commercial basis from red claw that are smaller than 100-150 g.

While there have been a few reports on the meat yield of several commercially-important crayfish species (Huner et al. 1988; Lee and Wilkins 1992; Huner 1993, 1994; Harlioglu and Holdich 2001), there has been little data on processing data in adult red claw. While expressing meat yield as a percentage of whole animal weight can be useful for comparing various crayfish species, there are numerous factors that must be known when these comparisons are made, such as age of cray-

fish, season, sex, weight, and mineralization of the exoskeleton (Rhodes and Holdich 1984; Huner and Lindqvist 1985; Huner et al. 1988).

The purpose of the present study was to stock small juvenile red claw in earthen ponds and measure growth, survival, processing characteristics, and proximate composition of tail muscle in male and female Australian red claw crayfish so as to provide data on the species' growth and processing characteristics.

MATERIALS AND METHODS

Description and Stocking of Ponds

Ponds were located at the Aquaculture Research Center, Kentucky State University, Frankfort, KY. The surface area of all experimental ponds was 0.02 ha and the average water depth was approximately 1.1 m. In May, ponds were drained and treated with two applications of liquid fertilizer (10:34:0) at an initial rate of 9.0 kg/ha of phosphorus to achieve an algae bloom.

Juvenile red claw were obtained from spawns at Auburn University, Auburn, and stocked into ponds on June 15, 2001. On the stocking date, the mean stocking weight was determined from a sample of 25 red claw that were individually weighed and was 0.7±0.1 g. Two replicate ponds were stocked with 1000 red claw. Upon arrival to the Aquaculture Research Center, the styrofoam shipping containers were opened, red claw inspected, and were taken to the pond and tempered with pond water for 30 minutes before being stocked into the ponds. A 1/2-HP electric aerator was placed into each pond and run continuously throughout the duration of the study. No water quality data were measured based upon past experience with growing fish and crustaceans at our facility when continuous aeration was used.

Diet and Feeding Rates

A commercial marine shrimp diet (35% protein; Rangen Inc., Buhl, Idaho[1]) was fed to all red claw for the culture period of 86 days. Two separate feedings, each consisting of one-half of the total daily ration, were distributed over the entire surface of each pond between 0800-0830 and between 1530-1600 hours for the duration of the culture pe-

1. Use of trade or manufacturer's name does not imply endorsement.

riod. Red claw were fed a percentage of body weight based upon a feeding chart devised by C. D. Webster (unpublished data). Survival was assumed to be 100%. Feeding rates were adjusted every two weeks based on an assumed feed conversion ratio of 3:1 throughout the study. Red claw were fed 4% of estimated body weight with an assumed harvest weight of 150 g. While this feeding rate would most-likely be in excess of what could be consumed, it was decided that diet should not be a limiting factor in the study and that growth of red claw should be optimized considering the short growing period in Kentucky.

Harvest

Ponds were harvested on September 11, 2001. Two days prior to harvest, water levels in ponds were lowered to approximately 0.5 m at the drain end. On the day of harvest, the standpipe in each pond was lowered so that all water was completely drained from the pond. All red claw were manually harvested from the pond. The entire pond bottom was then searched for any red claw hiding in depressions or under algae. Total weight and number of red claw from each pond were recorded at the harvest. Specific growth rate (SGR) and feed conversion rates (FCR) were calculated as follows:

SGR (%/day) $-[(\text{Ln } W_f - \text{Ln } W_i) / T] \times 100$; where W_f is the average final individual weight, W_i is the average initial weight at stocking; and T is the culture period in days; FCR = diet fed (kg)/net weight gain of red claw (kg).

At harvest, forty red claw from each sex were randomly sampled, chill-killed by lowering the body temperature in an ice-bath, and frozen ($-20°C$) for processing measurements and proximate composition. Red claw were removed from the freezer, thawed, individually weighed to the nearest 0.01 g, and then were hand-processed so that weights of chelae, tail, and tail muscle were obtained to the nearest 0.01 g. Weight of cephalothorax was calculated as the difference between the whole-body weight and the weights of the chelae and tail.

After removing the exoskeleton from the tail to obtain the tail muscle for weighing, five tail muscles from each sex were randomly selected, minced, placed into freezer bags, and frozen ($-20°C$) for subsequent proximate analysis. Each pond had 3 replicates of five tail muscles per sex. Moisture was determined by placing the sample in an oven (100°C) to be dried until constant weight was achieved; protein was determined by nitrogen analyzer (AOAC method 990.03); lipid was determined by ether extraction; ash was determined by placing a sample into a muffle

furnace (600°C) for 4 hours until constant weight; and fiber was determined by the fritted glass crucible method (AOAC 1990).

Statistical Analyses

Growth performances, survival, feed conversion, processing characteristics, and proximate composition are measured in terms of final individual weight (g), percentage weight gain, percentage survival, total yield (kg/ha), SGR, and FCR processing measurements and proximate composition of tail muscle. Data were analyzed by t-test (SAS 1999). Duncan's multiple range test was used to compare treatment means. All percentage and ratio data were transformed to use six values prior to analysis (Zar 1984). All statistical computations were performed at the $P = 0.05$ probability level.

RESULTS

After 87 days, small (0.7 g) red claw stocked into earthen ponds had a final average individual weight of 59.6 g, weight gain of 8,413%, survival of 64.0%, yield of 903 kg/ha, feed conversion ratio (FCR) of 4.63, the percentage of males harvested was 33.3%, and percentage of females harvested was 66.7% (Table 1). When analyzed by sex, males had significantly ($P < 0.05$) higher final individual weight (71.05 g) compared to females (53.65 g); higher ($P < 0.05$) chelae weight (13.1 g for males compared to 6.84 g for females); higher tail weight (25.53 g for males compared to 20.38 g for females); higher tail muscle weight (18.99 g for males compared to 14.89 g for females); and higher cephalothorax weight (32.41 g for males compared to 26.44 g for females; Table 2).

As a percentage of total body weight, males had a significantly ($P < 0.05$) higher percentage comprised of their body weight by chelae (16.2%) compared to females (12.1%); however, there were no differences ($P > 0.05$) in the percentage of total body weight comprised of tail, tail muscle, and cephalothorax, and these averaged 37.6%, 27.7%, and 48.4%, respectively (Table 2).

There were no significant differences ($P > 0.05$) in the percentage moisture, protein, lipid, fiber, and ash in the tail muscle of male and female red claw when analyzed either on a wet-weight basis or a dry-matter basis (Table 3). When analyzed on a wet-weight basis, percentage moisture averaged 81.0%, percentage protein averaged 16.46%, per-

TABLE 1. Means (±SE) for final individual weight, percentage weight gain, percentage survival, feed conversion ratio (FCR), percentage of males harvested, and percentage of females harvested of red claw, *Cherax quadricarinatus*, grown in earthen ponds.

Final individual weight (g)	59.6±4.7
Weight gain (%)	8413±670
Survival (%)	64.0±12.0
Yield (kg/ha)	903±99
FCR	4.63±0.51
Males (%)	33.3±4.9
Females (%)	66.7±4.9

TABLE 2. Means (±SE) of individual, chelae, tail, tail muscle, and cephalothorax weights, and their percentage of total body weight for male and female red claw, *Cherax quadricarinatus*, grown in ponds. Values in the same row with different letters are significantly different ($P < 0.05$).

Variable	Male	Female
Individual weight (g)	71.05±5.85a	53.65±3.14b
Chelae weight (g)	13.10±1.66a	6.84±0.72b
Tail weight (g)	25.53±1.88a	20.38±1.14b
Tail muscle weight (g)	18.99±1.39a	14.89±0.83b
Cephalothorax weight (g)	32.41±2.441a	26.44±1.52b
Chelae (% of body weight)	16.2±1.09a	12.1±0.7b
Tail (% of body weight)	36.9±0.5a	38.2±0.5a
Tail muscle (% of body weight)	27.4±0.4a	27.9±0.5a
Cephalothorax (% of body weight)	46.9±0.7a	49.8±0.7a

centage lipid averaged 0.16%, fiber averaged 0.1%, and percentage ash averaged 1.42% (Table 3). On a dry-matter basis, percentage protein, lipid, fiber, and ash averaged 86.70%, 0.82%, 0.51%, and 7.47%.

DISCUSSION

Results from the present study indicate that red claw can be grown to a commercially-viable size in a temperate climate with a limited (4

TABLE 3. Means (±SE) of percentage moisture, protein, lipid, fiber, and ash of tail muscle of red claw grown in earthen ponds. Means in the same row with the same superscript not significantly different ($P > 0.05$).

Variable	Male	Female
Moisture (%)	80.37±0.45a	86.61±0.68a
Protein (%)	16.71±0.33a	16.20±0.66a
Lipid (%)	0.14±0.02a	0.17±0.02a
Fiber (%)	0.10±0.0a	0.10±0.0a
Ash (%)	1.41±0.08a	1.42±0.056a
Dry-matter basis		
Protein (%)	85.36±2.59a	88.04±1.21a
Lipid (%)	0.70±0.10a	0.94±0.11a
Fiber (%)	0.50±0.0a	0.52±0.02a
Ash	7.18±0.35a	7.75±0.35a

month) growing season. Average final weight (59.6 g) in the present study was similar to, or higher than, other reports. Brummet and Alon (1994) reported an average final individual weight of 56.1 g when red claw were stocked into ponds (initial weight of 2.0 g) and grown for 170 days. Karplus et al. (1995) stocked 3-g red claw into ponds and stated that males had a final average weight of 34.5 g, while females had a final weight of 31.9 g after 92 days. In the present study, red claw were stocked smaller (0.7 g) than other pond studies and thus, the percentage weight gain reported here (8,413%) is higher than in other studies (Karplus et al. 1995; Rouse and Kahn 1998; Jones and Ruscoe 2000). No attempt to sort harvested red claw by sizes as this was the first time red claw had been grown in Kentucky and it was determined, based upon interest by local and regional markets, it was more important to determine the overall average weight that would be representative of a single-season, one-batch production system.

Mean survival rate of red claw in the present study (64%) is similar to other reports: 36% (Brummet and Alon 1994); 50% (Salame and Rouse 2000). Total yield of red claw in the present study (903 kg/ha) was similar to values reported for freshwater prawn, *Macrobrachium rosenbergii* (Tidwell et al. 1993) and red claw (Salame and Rouse 2000).

FCR value reported in the present study (4.6) was similar to other reports for feeding red claw in ponds. Rouse and Kahn (1998) reported

FCR values averaging 8.0, while Jones and Ruscoe (2000) stated FCR values between 1.4 and 7.4 for red claw stocked into pens.

In the present study, the sex ratio for red claw harvested was skewed towards females, 66.7% compared to 33.3% for males. This is in contrast to other reports where a 1:1 ratio was reported (Karplus et al. 1995; Pinto and Rouse 1996). No explanation can be offered as to a reason for the preponderance of females harvested. It could be that males suffered a higher mortality than females during the study. At stocking, all red claw received were stocked and there was no effort to sex individuals at stocking.

The majority of edible muscle in crayfish comes from the tail, and sometimes the claws. Amounts depend upon the size of the crayfish, maturity, and condition of the individual(s). No determination of the weight of the hepatopancreas or ovaries was made in the present study, although both can be considered, and sometimes prized, part of the edible portion of freshwater crayfishes. The present study was interested in the weight of the tail muscle because the majority of the local and regional markets were only interested in tail size and weight of harvested red claw.

Relating meat yield to body weight has been reported to be misleading since larger individuals may have a greater weight attributed to the exoskeleton (Harlioglu and Holdich 2001). Furthermore, the degree of mineralization can vary among individuals, populations, and species (Huner and Lindqvist 1985). However, calculating muscle weight as a percentage of total body weight does allow relative comparisons to be made; something that cannot be done when simply using weight of muscle due to the differences in size among various populations and species. For instance, Harlioglu and Holdich (2001) reported that a 7.5-g total muscle yield for male *Pacifastacus leniusculus* corresponded to 13.7% of the total body weight (wet-weight basis); however, a 3.3-g muscle yield for male *Astacus leptodactylus* corresponded to a similar percentage of total body weight (12.6%) because the exoskeleton of *P. leniusculus* is more heavily mineralized.

Sexual maturation can influence growth rate, survival, and meat quality. In freshwater crustaceans, differences between the sexes in the relative growth of chelipeds and abdomen usually coincide with sexual maturation (Holdich and Lowey 1988). In males, there is a dramatic increase in the relative size of chelae and chelipeds, while females increase the relative size of the abdomen (Gu et al. 1994). Chelae (claws) were believed to function in the acquisition and manipulation of food, for defense against predators, and possibly in courtship rituals. Stein

(1976) reported that *Orconectes propinquus* males with larger chelae were more successful in mating with larger, more fertile females than males with smaller chelae. This could allow for propagation of these males' offspring to be present in the gene pool. In the present study, males had significantly larger chelae than females with males having greater claw weight and a higher percentage (16.2%) of their total body weight comprised of chelae while females had 12.1% of their body weight comprised of chelae. The values from the present study are lower than stated by Gu et al. (1994) who reported that mature male red claw had 22.6% of their body weight comprised of chelae and that females had 14.2% of their body weight comprised as chelae.

While males had significantly higher weights of tail and tail muscle compared to females, in relation to the percentage of the total body weight comprised by tail muscle of male and female red claw, there were no statistical difference between the sexes found in the present study. However, Gu et al. (1994) reported the abdomen (tail) provided a greater percentage contribution to body weight in mature females (37.5%) than mature males (32.1%) with more muscle in the tails of females (28.6%) compared to 24.5% for males. The percentage of body weight compared by tail muscle of red claw is higher than reports of other crustaceans. In those reports, the percentage of total muscle weight to total body weight was reported, not tail muscle solely. The total muscle percentage of total body weight was reported to be 23% for females and 27% for males of *Austropotamobius pallipes* (Rhodes and Holdich 1984); 24% for both sexes of *Orconectes limosus* (Dabrowski et al. 1966); and 23% for females and 24% for males of *Astacus astacus* (Dabrowski et al. 1968). Tail muscle comprised between 16.4% (intermolt) and 20.0% (postmolt) of body weight of marron, *Cherax tenuimanus* (Jussila 1999), while another report had wet muscle somatic indices of marron at 22.4% (Fotedar 1999).

There were no differences in any of the proximate analyses of tail muscle of male and female red claw. Tail muscle of red claw is a high-protein, low-fat product that would be beneficial for consumers interested in reducing dietary fat intake. Further, the low percentage of lipid in tail muscle might allow for long-term frozen storage with minimal loss of product quality (Tseng et al. 2002).

This study has generated data that may be useful for producers from temperate regions interested in growing red claw as a commercial aquaculture species, as well as interest to processors who need to know the meat yield of red claw. In contrast to the suggestion by Gu et al. (1994) that female red claw should be grown, since male red claw grow

larger, have larger chelae, and higher tail muscle weights compared to females, it might be economically advantageous to stock all-male populations of red claw in ponds to achieve maximum production. Further research on growth, production, and processing characteristics of red claw need to be conducted so that its full potential as an aquaculture species might be assessed.

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