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CULTURE OF THE AUSTRALIAN RED-CLAW CRAYFISH (*CHERAX QUADRICARINATUS*) IN ISRAEL

IV. CRAYFISH INCORPORATION INTO INTENSIVE TILAPIA PRODUCTION UNITS

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Abstract

This study tested the suitability of the Australian red-claw crayfish *Cherax quadricarinatus* for rearing in an intensive culture system as a supplement to *Oreochromis niloticus*. Fish were grown in twelve 5.5 m³ tanks at high density (33/m³) for 133 days, alone or with crayfish at two stocking densities (10/m² and 20/m²) with added shelters or with crayfish at the lower density (10/m²) without shelters. Tilapia survival ranged 90.3-95.0% with no significant differences among treatments. The growth rate of the tilapia raised with crayfish (2.05 g/day) was significantly higher than that of tilapia grown alone (1.88 g/day) probably because the fish were feeding on part of the crayfish pellets. Among treatments, there were no significant differences in fish yield. Crayfish survival was extremely low in the 'no shelter' treatment (2.9±2.7%) but reasonable (approximately 60%) when raised with shelters. The growth rate of the crayfish raised with shelters was significantly higher at the lower density (0.21 g/day) than at the higher density (0.18 g/day). Further research is needed on rearing tilapia and crayfish to market size in intensive systems, to establish the economic profitability of this culture strategy.

Introduction

Various combinations of polyculture of freshwater crayfish with fish have been studied. Most of the research on northern hemisphere crayfish was conducted on the red swamp crawfish (*Procambrus clarkii*) cultured with hybrid grass

carp (*Ctenopharyngodon idella* x *Cyprinus carpio*; Merkowsky and Avault, 1977), buffalo fish (*Ictiobus* sp.), paddlefish (*Polyodon spathula*), golden shiner minnows (*Notemigonus crysoleucas*; Green et al., 1979) and channel catfish

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(*Ictalurus punctatus*) fingerlings (Huner et al., 1983). Research on polyculture involving southern hemisphere crayfish (Fam. Parastacidae) focused mainly on the red-claw crayfish (*Cherax quadricarinatus*) cultured with silver perch (*Bidyanus bidyanus*; Jones and Ruscoe, 1996), tilapia (*Oreochromis niloticus*; Brummet and Alon, 1994; Rouse and Kahn, 1998), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*; Karplus et al., 1995a) and grass carp (*Ctenopharyngodon idella*; Medley et al., 1993). All these studies were carried out in earthen ponds with low stocking densities of both fish and crayfish, typical of extensive aquaculture systems. So far, no research has been carried out on the joint culture of *Cherax quadricarinatus* and fish at high densities in recirculating culture systems.

Intensive recirculating culture systems are characterized by very high stocking densities and a monitored and controlled environment. These systems include biological filtration, solids removal and aeration (van Rijn, 1996). The main advantage of these systems is the ability to maintain the specific temperature and oxygen saturation levels in the culture medium needed for optimal growth of the cultured species. The major disadvantages of intensive culture systems are the high costs of construction and maintenance. The economic profitability of these systems depends, to a large extent, on the market value of the cultured species.

Tilapia is the second most commonly cultured fish species in Israel, with an annual production of more than 6000 tons (36.7% of the total 1997 freshwater fish production, Sarig, 1998). Tilapia are produced in Israel in shallow earthen ponds, deep-water irrigation reservoirs and intensive culture systems. Culture of tilapia in intensive systems has become more common because of the increasing water shortage in our region and the need to conserve high-quality water for urban use. The profitability of raising tilapia in intensive systems is marginal because of the relatively low price (\$3-4 per kg) these fish fetch at the farm gate. The addition of a high priced secondary species to the system could increase economic profitability.

The Australian tropical freshwater crayfish, *Cherax quadricarinatus* is being evaluated for Israeli aquaculture (Karplus et al., 1995a, b, 1998; Sagi et al., 1997). Several traits of the crayfish, such as rapid growth (especially of males), wide range of temperatures for optimal growth, ease of breeding in captivity and raising juveniles in nurseries, possibility of live shipment in humid air, high market price (2-4 times the price of tilapia) and heavy demand, make it an attractive candidate for aquaculture. So far, growout of the crayfish in Israel has been tested in earthen ponds in monoculture (Karplus, unpublished) and polyculture with fish (Karplus et al., 1995a).

The aim of the present study was to evaluate the suitability of *C. quadricarinatus* for rearing in an intensive culture system as a supplement to tilapia. Emphasis was put on the effects of crayfish density on tilapia performance and crayfish yield. The need for shelters was evaluated in light of available knowledge of their importance for growth and survival of crustaceans, particularly at high densities (van Olst et al., 1975; Mason, 1979; Fielder and Thorne, 1990; Du Boulay et al., 1993; Karplus et al., 1995b; Karplus et al., 2000; Jones and Ruscoe, 2001) and the obvious inconvenience they inflict on tilapia management in intensive systems.

Materials and Methods

Tilapia were grown in the presence or absence of crayfish. The effects of crayfish at two densities (10 or 20/ m²) with added shelters, and of crayfish at 10/m² without shelters on survival and growth of tilapia and crayfish were tested. The experimental design included four treatments in a randomized design with each treatment replicated in three tanks: (a) tilapia (33/m³) in monoculture (control); (b) tilapia (33/m³) with crayfish at low density (10/m²) without shelters; (c) tilapia (33/m³) with crayfish at low density (10/m²) with shelters; (d) tilapia (33/m³) with crayfish at high density (20/m²) with shelters.

A batch of 840 juvenile *C. quadricarinatus* of similar sizes (mean weight 7.1 g), purchased from a commercial crayfish farm, was selected for this study. Only hard-shelled intact males

were stocked. Sex was visually determined according to gonopore position. Crayfish were weighed in lots of 10 and randomly assigned to treatments. Among treatments, there were no significant differences in crayfish mean weights at stocking ($F_{2,6}=0.465$; $p>0.6$).

A batch of 2160 juvenile red *Oreochromis niloticus* of similar sizes (mean weight 20.6 g), purchased from a commercial fish farm, were selected for this study. Most fish were males (>95%) because of a hormonally-induced sex reversal by means of methyl testosterone (80 ppm) orally administered for a period of 45 days. Fish were weighed in lots of 10 and randomly assigned to treatments. Among treatments, there were no significant differences in tilapia mean weight at stocking (Table 1).

The study was carried out for 133 days at the Ein Yahav Desert Aquaculture Research Station, in the central Arava, south of the Dead Sea (30.46°N, 35.15°E). The dual culture of tilapia with crayfish was tested in a closed intensive recirculating system consisting of 12 circular tanks (5.5 m³) connected to a biological filter. Water from the filter entered each tank at a flow rate of 18 l/min, creating a slow circular motion in the water. The floor of each tank (7 m²), slightly sloping towards its center, had a central drain connected to a standpipe that was lowered twice daily to remove accumulated solids. Seven large airstones continuously provided compressed air to each tank. The tanks were covered by a net to prevent escape of the crayfish. Shelters were black polyethylene pipes (25.0 cm long, 7.0 cm diameter) tied together in bundles of ten. One pipe was provided for each crayfish in both stocking densities.

Food for fish was provided manually twice a day (morning and midday, half the ration each time) in the form of floating pellets (4 mm diameter) according to high-density tilapia feeding tables (Zohar, 1986). The proximate analysis of the fish pellets was protein 35%, fat 4.9%, calcium 1.3%, phosphorus 1.0%, ash 8% and crude fiber 4.5%. The crayfish were fed sinking pellets (4 mm diameter) manually, at a level of 4% of the crayfish biomass four days per week, every other day, twice each feeding day (half the ration each time) immedi-

Table 1. Mean values ($\pm$ s.e.) of weight at stocking and harvest, daily growth rate, survival, feed and FCR (food conversion ratio) of *Oreochromis niloticus* (33/m³) following 133 days of culture with or without crayfish.

Treatment	Mean weight at stocking (g)	Mean weight at harvest (g)	Daily growth rate (g/day)	Survival (%)	Yield (kg)	Feed* (kg)	FCR*
Fish	20.65 $\pm$ 0.04	271.41 $\pm$ 2.76 ^b	1.89 $\pm$ 0.02 ^b	95.0 $\pm$ 0.64	42.67 $\pm$ 1.15	72.88 $\pm$ 1.19	1.71 $\pm$ 0.02
Fish & crayfish (10/cm ²)	20.66 $\pm$ 0.02	301.07 $\pm$ 5.33 ^a	2.11 $\pm$ 0.04 ^a	90.3 $\pm$ 4.06	45.18 $\pm$ 2.35	76.86 $\pm$ 0.61	1.70 $\pm$ 0.04
Fish & crayfish (20/cm ²)	20.47 $\pm$ 0.07	293.70 $\pm$ 0.93 ^a	2.05 $\pm$ 0.01 ^a	92.4 $\pm$ 1.88	45.16 $\pm$ 1.49	75.50 $\pm$ 2.20	1.67 $\pm$ 0.04

Values with different superscripts differ significantly at $\alpha=0.05$.

* Only floating pellets, intended for tilapia, were included in the computation of feed and FCR.

ately following the fish feeding. The proximate analysis of the crayfish pellets was protein 40%, fat 8%, calcium 1.3%, phosphorus 1.1%, ash 8% and crude fiber 4.5%. On the remaining three days of the week, the crayfish were fed three different feeds (sliced carrots, wheat and maize), one type per day, at a level of 4% of their biomass.

Approximately once every five weeks, the tanks were drained and the tilapia and the crayfish were weighed and counted. The crayfish were individually weighed and the number of individuals with missing claws was noted. The tilapia were weighed in lots of 10. Rations were adjusted following the weighing of fish and crayfish.

Water quality was monitored every morning. Minimum and maximum water temperatures were recorded with two immersed thermometers. Water temperatures were high and stable (29-30°C) during the first two months of the study (Fig. 1). From mid-October, the temperature gradually fell, reaching 20°C in mid-December. During the last part of the study,

water temperatures were suboptimal for *C. quadricarinatus* growth (Jones, 1990). Oxygen and pH were measured with portable meters. Throughout the entire study, levels of dissolved oxygen were high ($80.6 \pm 1.9\%$ saturation). Water pH was stable and slightly alkaline (7.70-8.20). Total ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-), determined with Hach kits, were relatively low (Fig. 2) and acceptable for commercial recirculating systems (Kamstra et al., 1998). Unionized ammonium levels, for our pH and temperature values, were low (<0.06 mg/l) and nontoxic.

The data were analyzed with the JMP statistical package, version 3.1.5. Descriptive statistics (mean and standard error) were computed from the raw data. One-way ANOVA and the Tukey-Kramer test were applied for contrasting tilapia and crayfish at stocking and harvest. Repeated measurements two-way ANOVA was applied to analyze changes over time in survival, mean weight and biomass of crayfish. Percentage data were arcsin transformed and the daily weight gain was log transformed.

Fig. 1. Daily minimum and maximum water temperatures in the intensive recirculating culture system used to grow *Oreochromis niloticus* with *Cherax quadricarinatus*.

Fig. 2. Daily ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) concentrations in the intensive recirculating culture system used to grow *Cherax quadricarinatus* with *Oreochromis niloticus*.

Results

Survival of tilapia at 19 weeks was higher than 90% for all treatments (Table 1). There were no significant differences among treatments, although tilapia reared alone had a slightly higher survival than those reared with crayfish (95.0% vs. 90.3% and 92.4% respectively).

Tilapia reared with crayfish (at both densities) had significantly higher growth rates than tilapia raised alone. However, there were no significant differences in yield between tilapia grown with crayfish or alone. Similarly, there were no significant differences in FCR for tilapia among the treatments (based on floating pellets only), which was low in all treatments (1.71–1.67).

Survival of crayfish reared without shelters declined rapidly, reaching $2.9 \pm 2.7\%$ after only 14 weeks (Fig. 3a). No further monitoring of this group was carried out because of the extremely low survival. Comparison of survival of all three groups of crayfish over 14 weeks revealed highly significant effects of treatment ($F_{2,6}=51.98$; $p<0.0002$), time ($F_{3,18}=379.63$; $p<0.0001$) and interaction of time and treatment ($F_{6,18}=31.81$; $p<0.0001$). No significant differences ($F_{1,4}=0.217$; $p>0.6$) were found in survival at harvest (after 19 weeks) between crayfish raised at low density and those raised at high ($59.5 \pm 5.7\%$ and $56.6 \pm 2.5\%$, respectively). Contrasting the changes in survival of these two groups revealed a similar pattern of decline in survival with time ($F_{4,16}=165.4$; $p<0.0001$), but no effect of treatment ($F_{1,4}=0.33$; $p>0.59$) or significant interaction of treatment and time ($F_{4,16}=0.58$; $p>0.6$) was found. About 89% of the crayfish reared with shelters in both densities were intact, namely possessed two claws.

The daily growth rate of crayfish reared with shelters was significantly higher ($F_{1,4}=21.02$; $p<0.01$) at the low density (0.21 ± 0.006 g/day) than at the high density (0.18 ± 0.003 g/day). Mean weight (Fig. 3b) at harvest was consequently higher ($F_{1,4}=26.48$; $p<0.007$) in the low density (35.9 ± 0.6 g) than in the high (31.3 ± 0.6 g). Contrasting the changes in mean weight of crayfish reared in low and high densities revealed highly significant effects of treatment ($F_{1,4}=23.43$; $p<0.009$) and time ($F_{4,16}=360.40$;

$p<0.0001$) but the pattern of increase in mean weight with time did not differ significantly between the two densities, as indicated by an insignificant treatment-time interaction effect ($F_{4,16}=2.40$; $p>0.09$).

The changes over time in biomass of crayfish reared at the two densities are presented in Fig. 3c. Highly significant differences in crayfish biomass related to time ($F_{4,16}=116.67$; $p<0.0001$) and treatment ($F_{1,4}=33.10$; $p<0.005$) were found. The different change in biomass with time in crayfish reared at the two densities, mainly attributed to differing growth rates, was revealed by the highly significant interaction of treatment and time ($F_{4,16}=6.37$; $p<0.005$). Computation of crayfish yield at harvest revealed a significant increase in yield with density ($F_{1,4}=8.62$; $p<0.04$), with yields of 1507.9 ± 232.9 g and 989.20 ± 198.2 g per tank at the high and low stocking densities, respectively.

Discussion

The major finding of this study is that incorporation of crayfish in intensive tilapia culture units is possible. The addition of a relatively large number of crayfish (20/m²) and a similar large number of large polyethylene pipes to an intensive culture system did not affect the production of the tilapia, the primary species. Survival and growth of crayfish, the secondary species, were lower in this system than in monoculture in earthen ponds at lower densities (Curtis, 1990; Pinto and Rouse, 1996; Jones and Ruscoe, 2000; Froyman, pers. comm.). Further research is needed on rearing tilapia and crayfish to market size in intensive systems to determine the economic profitability of this culture strategy.

The competition for food between two species reared together at high densities in intensive systems is very different than competition between the same two species reared in earthen ponds in low densities. In balanced extensive polyculture, species are selected on the basis of differing and complementary food preferences, which leads to better use of natural food resources and results in higher yields than monoculture of each species (Rouse and Stickney, 1982; Milstein, 1992). In intensive

Fig. 3. (a) Survival, (b) mean weight and (c) biomass of the Australian red-claw crayfish *Cherax quadricarinatus* reared at different densities (10/m² and 20/m²) with and without shelters, together with *Oreochromis niloticus* (33/m³) in an intensive culture system.

recirculating systems, all the feed is usually supplied in the form of pellets. Because of high stocking densities and the lack of natural food, food competition is amplified. Therefore, to ensure optimal management, each species is usually cultured by itself. The rationale for rearing more than one species in intensive culture systems is mainly the improved use of space (e.g., crayfish use the bottom and fish the water column) to maximize production per water volume. The successful culture of several species together in intensive systems will require the development of means to reduce food competition. In the present study we attempted to reduce interspecific food competition by simultaneously providing the fish with floating pellets and the crayfish with sinking pellets, and by providing the crayfish feeds that are not preferred (or are even avoided) by fish (i.e., carrots, wheat and maize).

In the present study, the growth rate of tilapia with crayfish was higher than that of tilapia grown alone, probably because of a competitive edge of the fish that fed on part of the crayfish pellets. Several researchers have suggested that tilapia (*O. niloticus* and *O. aureus*) out-compete crustaceans such as *C. quadricarinatus* (Rouse and Kahn, 1998), *Macrobrachium rosenbergii* (Rouse and Stickney, 1982) and *Penaeus chinensis* (Wang et al., 1998) because of aggressive feeding habits. Rouse and Stickney (1982) suggested that the competitive edge of tilapia was pronounced in the acquisition of supplemental feed. Observations in aquaria of food competition revealed that relatively large *O. niloticus* were able to prevent crayfish from reaching food patches. Even relatively small fish, which were unable to do that, obtained a significant amount of feed thanks to the rapidity of their visually-guided feeding responses compared to the relatively slow, mainly chemically-guided crayfish responses (Barki et al., 2001).

The direct impact of tilapia on red-claw crayfish growth is hard to evaluate from the present study since there was no crayfish monoculture treatment. However, the improved growth of tilapia in the polyculture was probably achieved at the expense of crayfish food. Several studies on the polyculture of *O. niloti-*

cus with red-claw crayfish in earthen ponds reported a decrease in the growth of the crayfish compared to crayfish growth in monoculture (Kotha and Rouse, 1997; Rouse and Kahn, 1998). In the study by Brummet and Alon (1994), growth of crayfish was also lower in polyculture with fish, if the replicate pond with extremely low survival is excluded from the analysis. A study on interspecific food competition between *C. quadricarinatus* and tilapia was carried out in a small recirculating culture system (Barki et al., 2001). Four mixed groups with spatial and temporal separation of feed and two monoculture control groups were studied. Tilapia grew better with crayfish than when reared alone, while crayfish showed the reverse trend, growing better alone than when reared with fish. Feeding the crayfish at night resulted in a 30% improvement in growth. The effect on crayfish growth of feeding crayfish at night and fish during the day should be tested in large intensive culture tanks and, hopefully, implemented in commercial tilapia/crayfish culture. Currently Australian farmers are raising silver perch (*Bidyanus bidyanus*) together with marron (*Cherax tenuimanus*) in earthen ponds. Food is provided for the crayfish during the night and for the fish during the day to reduce food competition (Whisson, pers. comm.).

The inverse relationship between stocking density and growth rate of *C. quadricarinatus* in the present study is typical of crustaceans grown in a variety of systems, including earthen ponds and recirculating systems (Lutz and Wolters, 1986; Keller, 1988; Morrissy, 1992; Whisson, 1995; Karplus et al., 2000). A direct comparison between crayfish performance in intensive systems in the present study and that reported from earthen pond studies is impossible, because of differences in variables (e.g., size at stocking, sex, density, length of grow-out season, and temperature) which affect growth. However, the growth rates (0.21 g/day) obtained in intensive systems seem to be lower than the values for all-male culture in earthen ponds at similar high stocking densities. In a commercial farm in Israel, all-male *C. quadricarinatus* stocked in earthen ponds (mean weight 55 g) at a density of 6/m² had a survival rate of 71% and a growth rate of 0.4 g/day over

a period of 140 days (Froyman, pers. comm.). Curtis and Jones (1995) suggested that the red-claw crayfish growth rate was lower in intensive systems than in earthen ponds because of the lack of natural food, normally provided through pond microbial communities. A comparison of total hemocyte counts and exoskeleton pigmentation in the related marron (*Cherax tenuimanus*) reared in intensive systems and in semi-intensive earthen ponds revealed a nutrition deficiency in intensive systems (Jusila, 1997).

Survival of *C. quadricarinatus* raised with tilapia in intensive systems at very high densities was lower than in monoculture in earthen ponds in controlled studies at lower densities (Medley et al., 1993; Brummet and Alon, 1994; Pinto and Rouse, 1996; Rouse and Kahn, 1998; Jones and Ruscoe, 2000) and in commercial culture of red-claw crayfish (Curtis, 1990). Nevertheless, the relatively high survival in intensive systems, considering the high stocking density, may be due to the large number of added shelters that reduced agonistic interactions and allowed safe retreat during ecdysis. The absolute necessity of shelters for crayfish culture in intensive systems, clearly revealed in the present study, may be due to the lack of any other type of shelter in these culture units. The major losses of crayfish during the present study were probably due to cannibalism when crayfish were in the vulnerable soft-shelled state following ecdysis (Peebles, 1978). Our results are consistent with several reports that shelters increase the survival of cultured crustaceans (van Olst et al., 1975; Mason, 1979; Karplus et al., 2000). Studies on the effects of shelters on *C. quadricarinatus* carried out during the nursery phase revealed their importance for increased survival (Du Boulay et al., 1993) and growth rate (Karplus et al., 1995b). In a recent study, Jones and Ruscoe (2001) compared the effects of five types of shelters and a no-shelter control on the growth, survival and biomass of red-claw during growout under earthen pond conditions. The type of shelter had a significant effect on survival and biomass and no effect on growth. Similar to our results, crayfish survival was very low in the no-shelter control. The design of an optimal shelter for use in intensive culture with

fish is complex, since the impact of the shelter on fish management and water quality has to be considered in addition to its attractiveness to crayfish, construction cost and storability when not in use.

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