Evaluating artificial diets for small Paracentrotus lividus
(Echinodermata: Echinoidea)

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ABSTRACT: Artificial diets are important for sea urchin aquaculture. We studied growth and nutrition parameters of small Paracentrotus lividus fed 3 artificial diets. Three different diet types were used: “vegetable-base” type (low protein - high carbohydrate level), “mixed-base” type (animal and vegetable) (medium protein and carbohydrate level) or “animal-base” type (high protein - low carbohydrate level). We recorded ingestion, absorption, assimilation efficiency and total growth rate. These parameters were recorded monthly over a 9 month period from October 1993 to July 1994. At the end of the experiment, we also recorded gonadic, test, gut and lantern growth rate. Diet type influenced ingestion, absorption, assimilation efficiency and total growth rates. The highest ingestion rate was obtained with vegetable feed. The highest absorption rate was recorded with animal feed, the lowest with vegetable feed. Absorption was negatively correlated with ingestion and carbohydrate level of the food. The assimilation efficiency was lowest with vegetable diet and highest with animal diet. Growth of test and gonad was best for small urchins fed mixed diet.

INTRODUCTION

The world annual consumption of sea urchins has been steadily increasing over the last years and many countries, such as France, are currently confronted with the problem of over-exploitation of stocks. For this reason, sea urchin aquaculture seems to be a promising means of solving this problem in the future (Le Gall & Bucaille, 1987). In France recent research aims have been directed towards the study of Paracentrotus lividus (Lamarck) in order to establish optimal rearing conditions for this species (Le Gall & Bucaille, 1987; Fernandez & Caltagirone, 1994; Grosjean & Jangoux, 1994; Fernandez et al., 1995). One of the essential points for the development of sea urchin aquaculture is the availability of an artificial feed. In nature, Paracentrotus lividus feeds essentially on marine plants although animal material may also be part of its diet (Neill & Pastor, 1973; Verlaque, 1987). In order to maximize the feasibility of sea urchin farming (availability, stocking, etc.), the utilization of artificial feed seems indispensable. Artificial feeds are successfully used elsewhere to rear Echinoidea or maintain them in aquaria (Lawrence et al., 1989; 1992; Klinger et al., 1994). It is therefore necessary to understand how of artificial feeds are utilized by sea urchins. The aim of this study is to monitor parameters of nutrition in small sized Paracentrotus lividus fed different types of artificial feeds measuring ingestion, absorption, assimilation and growth rates.

MATERIALS AND METHODS

Sea urchins, Paracentrotus lividus, were collected in the Urbinu lagoon (Corsica, France, Mediterranean) in September 1993. The size of the urchins collected was between 20 and 25 mm (mean size : 23.2 ± 1.1 mm and mean weight : 5.8 ± 0.9 g; mean ± standard deviation). Urchins were maintained in laboratory in three aquaria filled with running water (ambient temperature and salinity between 38 and 39 %). Aquaria were divided into 10 equal compartments and one sea urchin was placed in each compartment. Urchins were fed artificial feeds during a 9 month period (from October 1st, 1993 to July 1st, 1994). Each group of 10 individuals (each aquarium) was fed a different artificial feed, which differed in quality and biochemical composition. The first feed consists of vegetable meal and vegetable oils: this food is rich in soluble carbohydrates (58%) and is referred to as
« vegetable feed ». The second feed consists of fish meal and vegetable meal in equal quantities mixed with fish oil and vegetable oil and is referred to as « mixed food ». Its biochemical composition is a mix of soluble proteins (29%) and soluble carbohydrates (35%). The third feed consists of fish meal and fish oil and is rich in soluble proteins (47 %) and is referred to as « animal feed ». Sea urchins were always provided surplus food.

Ingestion rates were measured monthly. Ingestion was determined over a three day period and for each feed type, after a given amount of food was provided every 24h to each urchin. The feed not ingested at the end of 24 hours was collected, freeze dried and weighed. Individual ingestion rates were calculated as the difference between the amount of food available and the amount of food not ingested (dry weight). In addition, water content and dissolution rates of 10 blocks of feed were determined. These parameters allowed for an assessment of food biomass losses and were used to correct daily ingestion rates.

Absorption rates were also measured monthly. Absorption was determined by collecting fecal pellets produced by 10 urchins every 24 hours during the 3 day feeding period. Food remains, podia and spines were removed from fecal pellets. Pellets were then rinsed with distilled water, freeze dried and weighed. Absorption rates were calculated using the following equation:

\[
\text{Absorption rate (\%)} = \frac{\text{ingested biomass} - \text{defecated biomass}}{\text{ingested biomass}} \times 100
\]

Growth was also recorded monthly by determining the total wet weight (after 1 min drainage on paper towel) of each sea urchin. At the end of the experiment the gonad, gut, test and lantern dry weights for each sea urchin were determined after dissection and drying in an oven at 70° C (to a constant weight). These measurements were also taken at the beginning of the experiment from ten urchins collected at the same time as the experimental animals. The difference in mean weight for each sea urchin part at the beginning and at the end of the experiment was used to estimate growth rate for each organ. From these data the assimilation rates were calculated using followed equation:

\[
\text{Assimilation rate (\%)} = \frac{\text{Ingestion rate}}{\text{growth rate}} \times 100
\]

The nutritional budgets, in dry weight, were then established from all the data obtained. This data is represented in the format used by Hawkins & Hartnell (1983) as modified by Frantzis.

After testing the normality of the data and variance homogeneity, the results were subjected to one-way or two-way ANOVA, coupled with the Tukey test (Zar 1984).

RESULTS

Ingestion

The sea urchins' mean ingestion rates (dry weight/day) differed significantly depending on the feed provided and the time of sampling (two way ANOVA, p<0.05) (Figure 1). Ingestion rates are highest when sea urchins are fed the vegetable feed (Tukey test, p<0.05) regardless of the sampling period. Statistical analysis reveals that the ingestion rate is significantly and negatively correlated to the protein content of the feed (r = 0.55, p<0.05).

Absorption

Absorption efficiency varies significantly with feed type (one way ANOVA, p<0.05) (Figure 2). The lowest absorption efficiency is obtained with vegetable feed, followed by the mixed feed and finally the highest absorption efficiency is obtained with the animal feed (Tukey test, p<0.05). Correlation between absorption efficiencies and the level of soluble protein and soluble carbohydrates of the feeds are r = 0.80 and r = - 0.81,
respectively. The higher the protein content, the greater the absorption efficiency.

![Absorption Efficiency Chart]

**Figure 2**: Mean absorption efficiency (± confidence interval) for *Paracentrotus lividus* fed three food types.

**Assimilation**

Significant differences in gross assimilation efficiencies are observed for the three feed types (one-way ANOVA, p<0.0001). The lowest assimilation efficiencies are observed for the vegetable feed. Vegetable feeds also yield high ingestion rates and low growth rates. Gross assimilation efficiencies are not significantly different for individuals fed the animal and mixed (Figure 4).

![Gross Assimilation Efficiency Chart]

**Figure 4**: Mean assimilation efficiencies (± confidence interval) for *Paracentrotus lividus* fed three food types.

**Growth**

The initial size of the sea urchins was 23.2 mm (5.8 g). At the end of the experiment the final size varied according to the food provided (one-way ANOVA, p<0.05) (Figure 3). Maximal growth was observed for sea urchins fed either mixed or animal feed (Tukey test, p<0.05). Results obtained at the end of the rearing period reveal also that the gonadal, gut and test index increased substantially during experiment; conversely, the lantern index decreased during the nine months of the experiment (two-way ANOVA, p<0.05) (Figure 3).

**Organ allocation**

Assimilated food is allocated first to test production, then to gonadic production, to lantern production and finally to gut production, and that for the three food types (two-way ANOVA, p<0.05) (Figure 5).
Results of the present study reveal that ingested food is mainly used for test and gonadic growth but that the levels allocated to each of these tissues differs depending on food composition (two-way ANOVA, p<0.05). In particular, we observed that animal and mixed feeds enhanced test growth. In addition, the mixed feed allows an allocation of nutrients to gonadal production (one-way ANOVA, p<0.05). Finally, the metabolic activity measured as loss observed (allocated to maintenance such as respiration, excretion and secretion) are highest with the animal feed. These losses decrease for the mixed feed and are lowest with the vegetable feed.

DISCUSSION

The results of this experiment show that food quality influenced feeding parameters and growth.

For ingestion rate, the influence of food type on this parameter has also been reported for Echinoidea as Strongylocentrotus droebachiensis, Strongylocentrotus franciscanus or Paracentrotus lividus fed natural seaweed (Vadas, 1977; Frantzis, 1992). These differences may be due to the characteristics of the foods consumed (Paine & Vadas, 1969; Frantzis, 1992). In the present study, a significant correlation was seen between ingestion rate and protein levels. Our data support the compensatory food intake model which predicts an inverse relationship between ingestion rate and food quality (Frantzis, 1992). We observe an increased ingestion
rate when the level of soluble proteins in the food is low (the level of proteins being an indication of food quality). Other authors have made similar observations namely sea urchins ingest greater quantities of low nitrogen food to obtain the protein necessary for their growth and maintenance (Miller & Mann, 1973; Lowe & Lawrence, 1976). For seasonal variations of ingestion rate, similar observations have already been observed for other Echinoidea: Miller & Mann (1973) observed a significant positive correlation between ingestion rate and water temperature for Strongylocentrotus droebachiensis and Fuji (1967) observed that Strongylocentrotus intermedius feeds very little just prior to and during its spawns.

In the literature, as in our work, absorption efficiencies measured for Paracentrotus lividus vary according to food type (Lawrence et al. 1989, Frantzis, 1992). This last author obtained absorption efficiencies from 26% for Corallina elongata to 96% for Asparagopsis armata. Lawrence et. al. (1989), using artificial foods, obtain values between 8 and 34%. The differences observed could be due in part to the feeds containing vegetable meal which are rich in soluble carbohydrates also contain insoluble carbohydrates. These insoluble carbohydrates are not digested by Echinoidea (Lawrence, 1976) and would therefore lower the absorption efficiency.

Investigations on for other species of echinoids, have provided evidence of the effect of food type on growth (Lawrence, 1975 ; Vadas, 1977 Larson et al.,1980). The good efficiency of feeds contained fish meal in our experiment confirm that P. lividus is omnivorous. The efficiency of an omnivorous diet for sea urchin growth is debated. For Strongylocentrotus droebachiensis, experiments suggested that this urchin grew faster on a diet of kelp than on diet of only mussel (Briscoe & Sebens, 1988) but other experiments suggest that mixed diet (kelp with ectoproct) is more efficiency than kelp alone (Nestler & Harris, 1994). Our experiment as these last experiments suggest that the nutrients available from omnivorous or animal diet allow for optimal growth. This is also true for gross assimilation efficiency. Food composition generally influences gross assimilation efficiency in Echinoidea (Fuji, 1967; Leighton 1968), the gross assimilation efficiencies obtained with animal and mixed feeds are greater than those observed for sea urchins fed a natural marine plant diet. The possibility exist that assimilation could be improved for artificial diets.

Concerning organ allocation, several experimentations have shown that resource allocation varies under different level of nutrition (Ebert, 1996). Generally, when food is scarce, individuals allocated relatively more of their available resources to lantern growth (Ebert, 1980; Black et al., 1982 ; Levitan 1991) and less to gonad and gut growth (Ebert, 1996). Our research also suggests that the quality of food affect resource allocation. When nutritional value is high (rich in protein), sea urchin allocated relatively more energy to test and gonad growth than when nutritional value is lower.

In conclusion, our results suggest a mixed protein/carbohydrate feed provides the best results with a low ingestion rate and high absorption and gross assimilation efficiencies. Test and gonad growth were enhanced with the mixed diet. Therefore we recommend this diet for sea urchin aquaculture.

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