White Worms *Enchytraeus albidus* as a Live Feed and in Formulated Aquafeeds

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Marine invertebrates can provide a valuable substitute or supplementary nutritional source that may decrease the demand for fishmeal in the production of aquafeeds. Large-scale production of live aquatic worms and other invertebrates also may be useful for marine or estuarine stock enhancement and sea ranching efforts, as well as for aquarium, terrarium, laboratory and hobby maintenance of fishes, amphibians, reptiles, birds and larger invertebrates. Ideally a mass cultured invertebrate is fast-growing, precocious, fecund, easy to rear and able to thrive at high densities (Ivelva 1973). White worms *Enchytraeus albidus* are 2–4 cm long, globally distributed, intertidal oligochaetes that feed on decaying organic matter. They are found on a wide variety of moist terrestrial soils, in fresh and brackish waters, in the marine littoral zone and on aquatic plants washed ashore. They have even been found in large densities within the gravel filters of irrigated fields as well as in urban water pipes (Ivelva 1973). Their ease of culture may enable the production of a natural, sustainable feed for marine aquaculture.

White Worm Productivity

Experimental work on the mass culture of invertebrates for production purposes began in Russia at the end of the nineteenth century (Ivleva 1973). White or pot worm cultivation was developed in the 1940s as a result of expanding fish culture programs in the former USSR. Studies on the biology, nutrition and cultivation of white worms are reported in Russian-language publications but few have been translated into English (Vedrasco *et al*. 2002). Published reviews describe rooms of wall-to-wall racks stacked with wooden boxes (50 x 40 x 12 cm) of worms (100 - 300 g/box). Many fish breeding facilities maintained over 1,000 of these boxes and produced 500 kg to several tons of white worms per season to feed 2.5 to 3 million juvenile sturgeon (Ivelva 1973, Memiş *et al*. 2004).

Peak production biomass can be 2–3 kg/m^2 with mean production of 1.2 kg/m^2 (Ivleva 1973). An individual white worm can produce approximately 1,000 viable eggs over the course of its lifetime (L_{50} = 200 d), of which 93-95 percent will develop successfully. The species has a high survival rate at all growth and developmental stages.

Although some aquarium hobbyist and research organism suppliers produce white worms on a small-scale for use as feed by hobby aquarists and for biological and toxicological studies, currently no targeted, large-scale production is occurring. The reasons for this are unclear, but the cessation of production appears to correspond with the breakup of the Soviet Union and perhaps the increased availability of formulated feeds there.

Worm Feeds

White worms are composters and feed on decaying plant- and animal-based organic matter under natural conditions. Thus, these worms can be cultured on a variety of feeds considered wastes, including the byproducts of brewery, bakery and other food processing industries, as well as proteolyzed yeasts prepared in paper and pulp plants (Ivelva 1973). This dietary flexibility provides the culturist with the potential to develop mutually beneficial local partnerships and generate favorable publicity. The use of wastes as worm fodder keeps materials that would normally end up in a landfill within a sustainable food production system. These wastes provide the culturist with an inexpensive and easily obtained food supply for worm production.

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Instructions for the small-scale production of white worms to feed ornamental fish (e.g., discus, bettas, angelfish, and killifish) can be found widely on the Internet. However, mass culture is successful only in exceptional cases, with the difficulty lying in the transition from a satisfactory, modest production to an efficient, large-scale operation expected to produce hundreds or thousands of kilograms (Ivleva 1973).

Culture Methods at UNH

For small-scale production at the University of New Hampshire, worms were reared in clear plastic shoeboxes (34.5 x 20.25 x 12.75 cm) filled 5-7 cm high with damp organic potting soil (Walsh 2012). Feeding and moistening of the soils of all cultures (up to 25) took less than one hour, once per week. Feed, such as stale formulated fish pellets, baby cereal flakes, hot dog rolls, a mixture of moistened dry dog food with oil, was distributed against the bottom of containers and covered

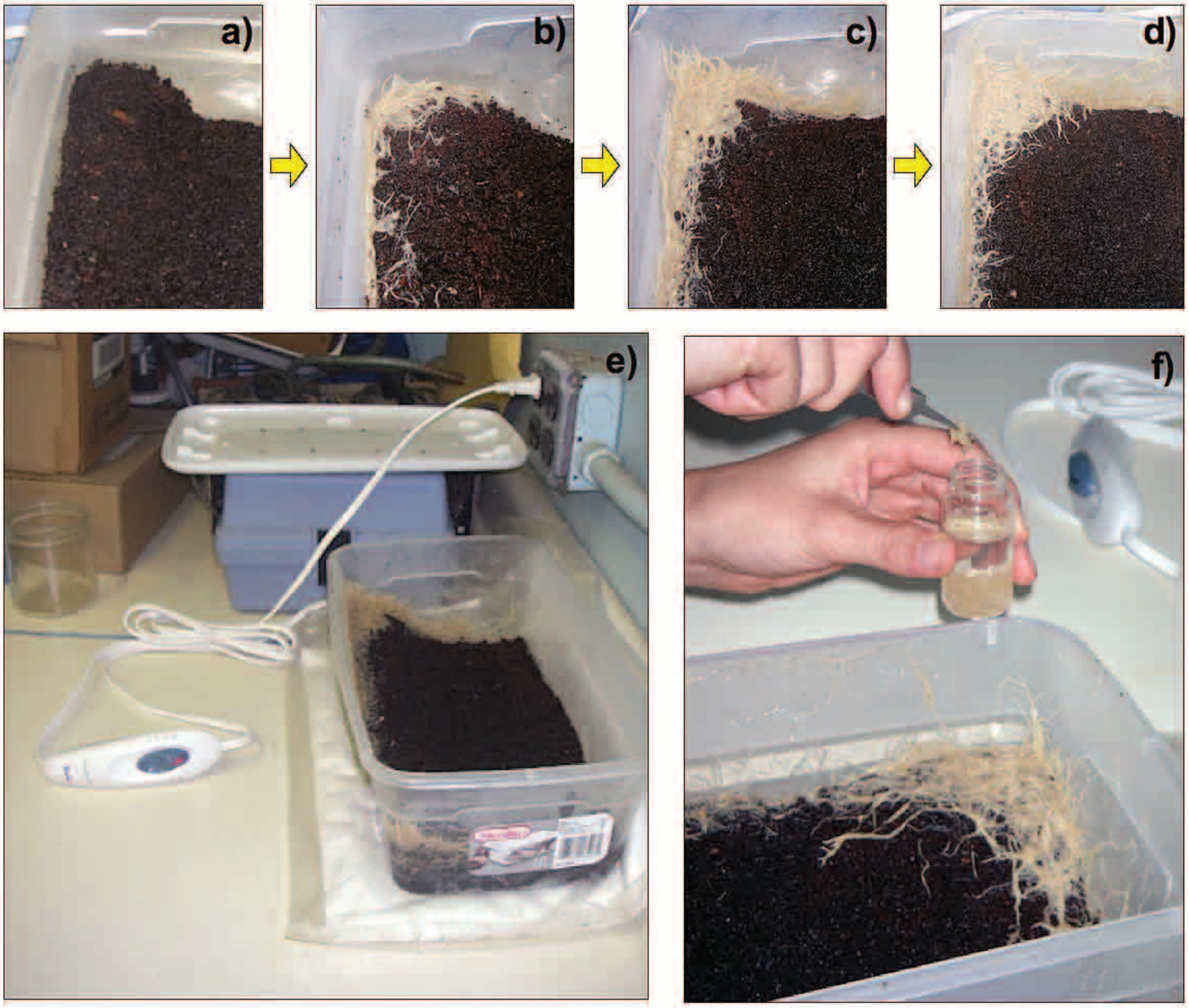

FIGURE 1. *Small-scale white worm harvest procedures at the University of New Hampshire. Thermophobic worms progressively move to the surface and up the sides of the container (a-d) after being placed on a heat source, in this case, a heating pad (e). Worms are then easily and cleanly collected from the surface (f). Photos: M.Walsh.*

with soil to minimize infestation by mites or small flying insects. Feed levels could be monitored simply by viewing the underside of the clear container and replenishing feed when necessary.

Worms were easily harvested by placing the rearing container on a heat source, such as a heating pad (Fig.1). A small mound of rearing soil was made adjacent to the side of the container and, over the course of 1-2 hours, the thermophobic white worms migrated to the surface and even up the sides of the plastic container, where they were easily and cleanly harvested.

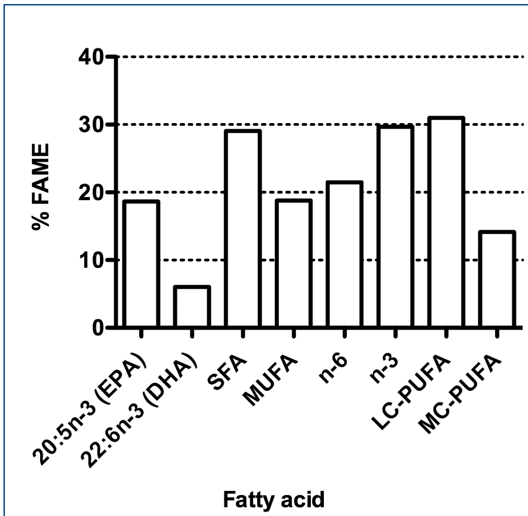

FIGURE 2. *Percent fatty acid methyl ester (FAME) composition of white worms. Analyses conducted for M. Walsh by J. Trushenski of Southern Illinois University at Carbondale.*

Use as a Live Feed and in Formulated Aquafeeds

White worms have a high protein (75 percent) and lipid (15 percent) content with relatively low levels of ash (6 percent, Walsh 2012). White worms are a good source of n-3 long chain polyunsaturated fatty acids, though the DHA content may be limiting

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(Fig. 2). Worms provide a balanced supply of essential amino acids including tyrosine, tryptophan, arginine, histidine, cystine and methionine, as well as calcium, phosphorus, iron, carotene and vitamins A and B_2 (Ivelva 1973).

They are readily accepted for direct consumption by juvenile sturgeon (Ivelva 1973) and winter flounder (Klein-MacPhee 1978, Walsh 2012), indicating that, as a feed, white worms provide adequate palatability, amino acid balance, energy and digestibility, all requirements of an appropriate protein source for aquafeeds.

White worms provide distinct advantages over polychaete-based feeds. The small size of white worms allows the option of direct feeding (live) to small or juvenile fishes. White worms can be reared in damp soils or substrates, eliminating the need for a water-based culture system. Terrestrial, air-breathing organisms can congregate at much higher densities than those of aquatic animals (Ivelva 1973). Preliminary work has been conducted to minimize the amount of soil necessary for production by growing white worms on agar plates (Springett 1964).

As a live feed, white worms are effective because they tolerate a wide range of temperature and salinity (Ivelva 1973). Although optimal temperature for growth and reproduction peaks at 15-21 °C, white worms will survive in freezing water temperatures and can persist for over 30 min at 33 °C if necessary. Salinity tolerance spans the spectrum of most natural waters. Worms will continue moving in water, eliciting a behavioral feeding response from predaceous juvenile fish in fresh, brackish-estuarine, and full-strength seawater. Individual oligochaetes can be cut into smaller pieces, if needed, and these pieces will continue to move when submerged. Providing white worms as a live feed can slow the deterioration in tank water quality because any excess feed remains alive and thus does not break down in tanks like other feeds, remaining available and moving until the appetite of the target cultured species returns.

The use of marine worms as a protein source in formulated fish feeds is not a new concept. Dragonfeeds, a subsidiary of UK-based Blue Marine Feeds Limited, combines the cultured polychaete *Nereis virens* with plant proteins to produce a feed with no fishmeal that has an amino acid profile similar to fishmeal. With a 70 percent protein and 2 percent lipid composition, the Dragonfeed product is marketed for finfish and shrimp aquaculture. Aquathrive, manufactured by Reed Mariculture/Reef Nutrition, combines fishmeal and oil with Terebellid polychaetes to produce a 46 percent protein, 11 percent lipid feed that is marketed mainly to aquarium hobbyists.

To summarize, white worms are an interesting candidate for aquaculture feeds because of the following properties:

- Rearing and harvesting ease; that is, worms thrive on neglect.
- Nonselective, composting feeding nature; it is cheap to feed worms.
- Ability to survive in a wide range of temperatures (0–33 °C) and salinities (0–35 ppt), even when cut into pieces.
- Excellent nutritional content (75 percent protein, 15 percent lipid).

Potential Benefits of Use

The potential economic benefits of white worm production for commercial aquaculture might include incorporation into formulated diets or development of alternative organic diets for carnivorous marine fishes. Use of diets that are reared and harvested easily, thrive with minimal maintenance and survive in salt/brackish water for prolonged periods also may decrease overall costs by reducing feed waste and the need for water quality maintenance.

White worms present the potential for mass-scale production, involving mutually beneficial local collaboration with an inexpensive materials cost. In addition, production of white worms as an aquaculture feed or feed ingredient may enable a reduced reliance on fishmeal and the opportunity to culture marine species on a natural, sustainable feed.

The development of systems to grow white worms for freshwater, brackish or marine baitfish and/or fee fishing operations is worth serious investigation, inasmuch as sourcing nutritionally balanced diets for small-scale hatchery and nursery operations is a serious hurdle for many producers. The mass culture of invertebrate live feeds as an advanced diet for juveniles used in estuarine/marine stock enhancement programs for species such as salmonids, flatfish or shad may increase stocking effectiveness, survival and recruitment of released fish. This contributes to potentially greater landings for fishermen and an economic boost for fishing communities.

Notes

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