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FLY PROTEIN PRODUCTION FROM MECHANICALLY MIXED ANIMAL WASTES

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A B S T R A C T

Maggots of the house fly, ***Musca domestica*** L., can be used to convert 100 kg of wet poultry or cow feces to 2-3 kg of protein feed supplement and 50-60 kg of semi-dry, practically odorless soil conditioner.

INTRODUCTION

Attempts to reduce environmental pollution by reduction of livestock wastes were begun in 1968 at the Agricultural Research Center, USDA, Beltsville, Md. Subsequently, Calvert, Morgan and Martin (1970) demonstrated a process of aerobic decomposition of these wastes that resulted in useful by-products; wastes that were objectionable because of odor and residue toxicity were reduced to acceptable products by larvae of the house fly, *Musca domestica* L. Also, 200-g samples of wet poultry feces reduced in less than 8 days by house fly maggots retained ca. 20% less nitrogen than similar samples reduced by hot air drying, a significant difference that could affect the eutrophication of run-off water. Finally, the maggots that accomplished the reduction as they grew, developed into pupae which, when dried and pulverized, contained 63% protein and 15%. fat (linoleic acid, essential in animal diets).

In another test, Morgan, Calvert and Martin (1970) placed 4-5 kg of manure and house fly larvae in specially designed trays and again obtained denitrification, moisture

(1) Mention of a commercial or proprietary product in this paper does not constitute an endorsement of this product by the USDA.

reduction, and improved larval growth. The floors of these trays were made of no. 8 mesh screen (2.38 mm openings), to expose the medium to air circulation from above and below; they were also continually illuminated from above with 40-w daylight fluorescent lamps. The negatively photo-tactic mature maggots were thus encouraged to migrate downward through the screen, caught in metal collecting trays and held for pupation. Laboratory conditions included an air temperature of 20-25°C and RH < 45%.

Despite successes in the laboratory, conversion of this process of larval reduction of poultry feces from exploratory tests to practical application presented several difficulties: (1) the space required for shallow trays that could hold the daily output of feces from a commercial poultry farm (12 m^2/metric ton) was prohibitive; (2) trays with screen floors could not support the weight of deep loads of wet feces; (3) feces placed deeper than 7 cm in trays were not uniformly reduced because the larvae acted only in the upper 5-7 cm; medium below that depth remained wet where it became anaerobic; and (4) air circulation through or around the medium is apparently necessary for maximum larval development. We believed that air circulation through the medium was the key to successful production of fly larvae during reduction of large volumes of manure. We felt that forced aeration or stirring of the medium might improve larval penetration (and insure more thorough bioreduction). The result would then be increased production of protein.

We therefore made a series of tests in which we tried to devise a practical method of producing protein from large quantities of livestock wastes. In general, we were concerned with the reduction of poultry feces, but in some tests feces from dairy cows were used.

MATERIALS AND METHODS

A matched pair of portable concrete mixers, each of 6 ft^3 capacity, were used as the waste reduction and protein production chambers. Each mixer was belt-driven by a 1/2-hp, 1725-rpm electric motor at a sustained rate of ca. 15 rpm. To prevent damage to the larvae from excessive tumbling, we controlled the mixers by two electric timing switches, that, when wired in series, permitted mixing for as little as 12 sec, the equivalent of ca. 3 revolutions. The 2nd timer also

made it possible to cycle the mixing for intervals ranging from 15 min. to 24 hr. In these tests, fly eggs masses were weighed, and 3 g eggs (ca. 16000 eggs/g) were seeded for each 16 kg manure. Mixing was begun 3 hr after the medium was seeded.

Temperature was of concern, as fly embryos and young maggots may be killed by sudden temperature changes, and temperatures below 10°C and above 40°C are lethal. Larvae more than 1 day old tolerate a wider range of temperatures, from 5 to 55°C, but become lethargic below 15°C and may die before maturing, especially if the cold persists for several days. Should temperatures exceed 55°C, they must crowd to the margins of the manure for relief, or else die. However, within this wide range there is a rather narrow optimum range of air temperature (25-35°C) at which larvae will mature in 4.5-5 days. For each day that air temperature drops below 20°C the larvae require an additional day to mature.

Likewise, relative humidity should be 40% or less for larval activity and growth. Higher relative humidity reduces the effective release of moisture from the manure, especially when the maggots are tunneling to aerate and improve their living conditions. When relative humidity stays above 60% for several days, the medium becomes anaerobic and all maggots die.

To facilitate separation of fly larvae from the reduced media, we designed a mechanized larval recovery system that utilizes the maggots' negative phototactic response. The system consisted of (1) a feed hopper for containing the reduced media-larvae mixture, (2) an endless screen belt that conveyed the mixtrue under a battery of fluorescent lamps, (3) sloping teflon-coated metal trays beneath the screen to catch falling maggots, and (4) a hopper for receiving the larvae-free media and an auger to convey it to a disposal point.

For Test 1, the mixers were housed in the same temperature-controlled room as the hens, and feces that accumulated beneath the hen cages on plastic sheets were collected every 3-4 days, weighed, and placed in one of the mixers. The room air temperature and the temperature of the feces at a depth of 10 cm were measured by a thermocouple probe, both before and after the 1st mixing of each batch (the third day after seeding). Thereafter, the timers were set to mix every 4 hr beginning at 0900 hr. On the 5th day after seeding the temperatures were measured, and the feces inspected for larval

stage of development. Maggots seen crawling about the chambers or on the surface of the media were considered mature, and the batches were transferred to the separation trays where the larvae were collected, held through pupation and weighed as pupae.

For Test 2, the mixers were moved outdoors to a fly-proof screened cage, and feces from a commercial poultry farm were used. The change served 3 purposes: (1) this medium did not have uniform consistency, primarily because of the effect of fluctuating air temperature on water intake of the hens during the warm summer months; (2) the mixers and contents were exposed to the wide range of daily fluctuating temperatures; and (3) sufficient feces were available so both mixers could be loaded with a single batch. Since such commercially produced hen feces tended to be much wetter, sawdust (10 and 20% of the total weight of the mixture) was added in an attempt to improve living conditions for the maggots. However, the weight of fly eggs used for seeding continued to be based on the weight of the medium. Temperature was measured at 0900 hr the 3rd and 5th days of bioreduction (after seeding), and mixing was done at 4-hr intervals beginning at 0800 the 3rd day.

Tests 3 and 4 were repetitions of tests 1 and 2 except that dairy cow feces were used and temperature measurements were omitted.

Finally, in test 5, the ability of bioreduced cow feces to support subsequent generations of fly larvae was determined by reseeding 2 batches of bioreduced media. No additional sawdust or water were added.

In operation, a 1 to 1.5-cm-deep layer of the media-larvae mixture was spread to gravity-flow through a narrow opening (2.5 x 115 cm) at the convergence of the V-shaped hopper floor. The depth of the mixture was regulated by hopper elevation above the screen belt (1.22 m wide and made of no. 12-mesh polyester screen with reinforced edge). A short distance from the point, the mixture was deposited onto the belt and a set of vertical steel fingers was mounted across the belt to rake the mixture into a uniform thickness. (When the mixture was allowed to pass under the lamps as an irregular layer, the larvae tended to cluster in the denser areas and would not migrate away from the light and downward through the screen). Immediately after the mixture was passed

through the rakes, it began to pass beneath eight 40-w daylight fluorescent lamps, evenly spaced in 2 parallel rows for 2.5 m at an elevation of 22.5 cm above the belt. The mesh belt moved the mixture at the rate of 0.67 m/min.

While the mixture was under the lamps, the maggots burrowed downward, through the belt and dropped to sloping metal trays below. The trays, teflon-coated to reduce larval traction, caused the larvae to tumble downhill into teflon-lined tubs. When the tubs contained all the maggots from 1 batch of bioreduced medium, they were removed to an insectary.

As the maggot-free media reached the end of the mesh belt, a cylindrical nylon brush, with a length equal to the width of the belt and rotating counter to the movement of the belt, brushed the media from the belt into the receiving hopper and auger below. The manure biological processing plant is graphically shown in Fig. 1.

RESULTS

Fly protein, a useful feed supplement to chick diets and a potential protein supplement to other animal diets, has been grown in aerated poultry and cow feces. The concrete mixers redistributed the larvae during mixing, exposed unused medium to larval activity, and combined the resulting dry upper layer with the wet lower layer. Additional benefits included aeration of the larval medium; the release of ammonia and other potentially toxic gases as well as water vapor; and some (temporary) cooling of the medium.

We found that the fermenting medium, if allowed to stand unmixed for 3 or more days, generated so much heat ($> 60^{o}C$) that maggots were either driven from the container before they matured or died therein. Medium that was mixed frequently after it was seeded was usually warmer than room air temperature by the 3rd day, but it cooled by the 5th day, the day of larval migration.

Wet medium became anaerobic within 3 days without mixing or aeration, and was then lethal to house fly maggots, though some degraded the upper strata and survived to maturity. In such medium, successful pupation and adulthood thus depends, to a considerable extent, on the number of larvae per unit area of medium. If it is seeded at the normal rate of 3 eggs/g

manure, less than 10% of the maggots will survive through pupation because the shallow, upper aerobic surface can support only a few larvae.

Morgan *et al.* (1970) reported that the odor of fresh poultry feces was altered soon after the larvae began tunneling through the medium. In the tests with concrete mixers, the odor was noticeably reduced within 24 hr after seeding and was replaced by a strong odor of ammonia that persisted until the 5th day if the air temperature had remained above 20°C. Then during separation, when the medium with larvae was spread in the screened trays, the combination of lamp heat and increased air circulation through the thin layers enhanced the release of ammonia.

The addition of sawdust to poultry feces had little effect on the production of fly protein. However, with cow manure, production was greatly increased by the sawdust (Table 1). Miller and Shaw (1969) showed that the nitrogen content of decomposed manure was inversely proportional to the weight loss of manure. Calvert *et al.*(1970) found house fly pupae to be mainly protein. Therefore, the feces-sawdust mixture that produced much more (ca. 10x) pupal protein during bioreduction should retain much less nitrogen.

Table 1. Summary of results when house fly larvae were reared in poultry and dairy cow feces with and without sawdust, 3 replicates each.

Wt before bioreduction			Wt after bioreduction	
Feces (kg)	Sawdust (kg)	Fly eggs (g)	Feces (kg)	Pupae (kg)
		Poultry Feces		
23.6	0.0	4.45	16.6	0.54
20.5	2.2	3.86	16.3	.46
20.9	5.2	3.92	17.7	.56
		Cow Feces		
20.7	0.0	3.87	15.6	.073
20.1	2.2	4.16	14.8	.673
19.5	4.3	3.99	14.4	.654

When the thoroughness of feces bioreduction by house fly larvae was investigated in test 5 by reseeding 2 samples of medium reduced in test 4, the medium was still wet enough to support a 2nd generation of young maggots, though much water vapor had been lost during the separation of maggots after the 1st reduction. However, only a few larvae survived 10 days in 1 batch, and none in the other. (Surviving maggots migrated after 10 days in the secondhand medium, but none pupated when they were held in a controlled temperature room (26 ± 2°) for 7 days, though pupation normally occurs within 8-10 days after larval hatch.)

DISCUSSION

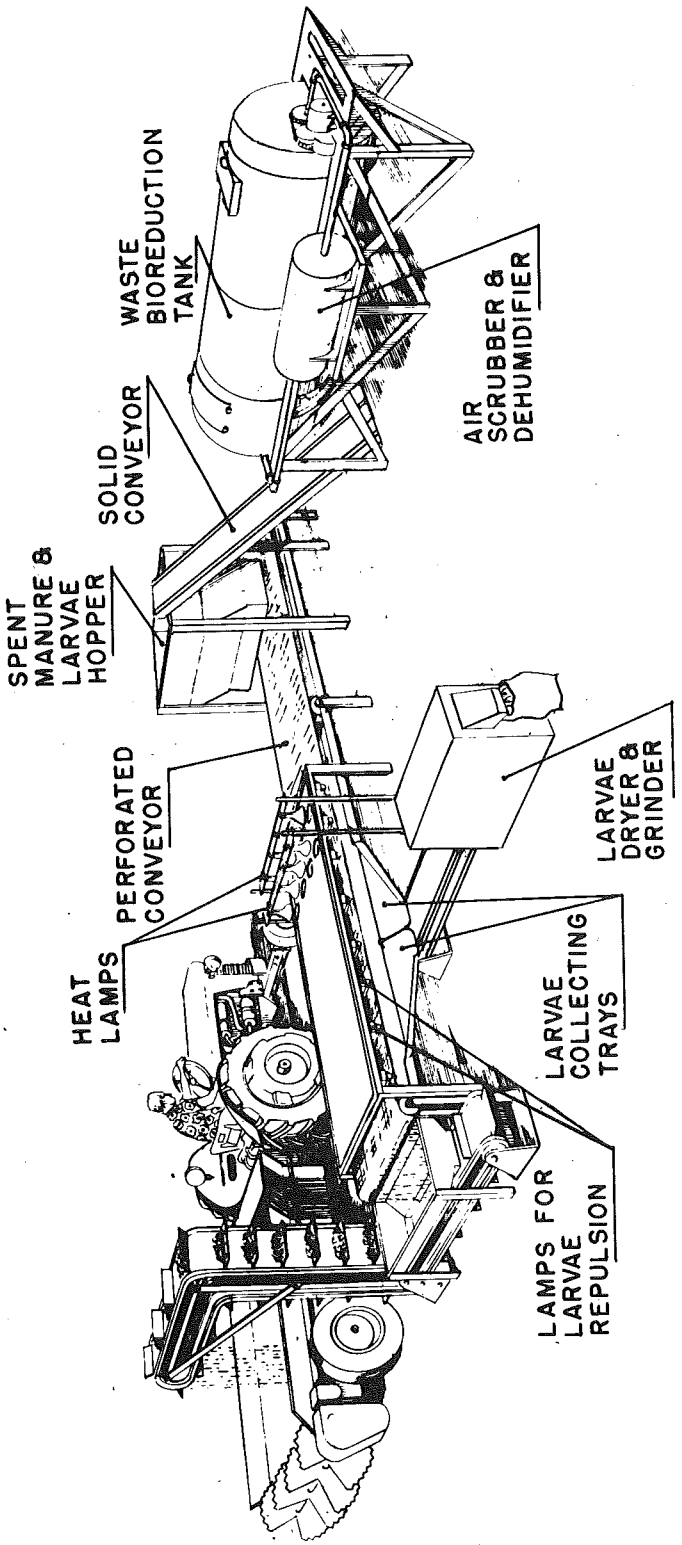
In the reduction chamber, we tried to give the fly maggots a near optimum environment with little or no competition. We were indeed able to mechanically moderate conditions while improving the manure's structure for larval activites. In other words, we used periodical mechanical aeration to release the extreme heat of fermentation produced by bacterial activity, fecal moisture and gases to the atmosphere. With the concrete mixers used as manure reduction cells, we could successfully program medium-mixing to produce mature larvae and a 40% reduction in fecal weight in a minimum of 4.5 days. However, the relative humidity of the room had to be maintained below 40%. With a higher humidity, immature maggots usually migrated from the medium and pupated, but only a few flies eclosed (< 5%). When feces contained more than 70% water, ambient relative humidity of the room was below 40%, and heat from fermentation was above 50°C, the mechanical mixing caused visible vapor to be released from the medium, particularly when air temperature was below 20°C.

The products from the waste reduction program included a protein that has been fed to chicks as part of the growing chick ration, a solid residue that was used as a soil conditioner, and water.

A qualified value for fly protein was established in a 1971 chick feeding program in the USA when soybean meal containing 44% protein was selling for $160/ton and fly-larva meal containing 63% protein was estimated to have an equivalent value of $209/ton. (Calvert *et al.*, 1970).

Fig. 1

MANURE BIOLOGICAL PROCESSING PLANT



The great numbers of maggots and pupae produced by the process could be used in a fly suppression program. The pupae would be sterilized by gamma ray irradiation, and the emerging flies released in fly breeding areas to compete with the native population.

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