INTRODUCTION

By-products from tofu processing, sometimes known as soybean-curd lees or tofu-cake, are left over when tofu (soybean curd) is made from soybeans. Fig. 1 shows the processing of tofu. The filtrate, which contains protein and fat, and is made from milled and boiled soybean mash, is called soy-milk, while tofu wastes are the residue.

The total production of tofu wastes in Japan is estimated at 677,000 mt per year (1989). About 70% of this amount is used as feed for cattle and swine. Nearly all the rest is used as fertilizer or as food for human beings, although 2.3% of the total is simply thrown away or burnt in incinerators. About 85% of the tofu wastes used as feed are raw when they are shipped from the manufacturer. The rest are delivered after being dried or fermented (Central Association of Livestock Industry 1992).

There still remain a high level of nutrients in tofu wastes after they have passed through a filter press. Since they have a water content of over 80% and a high protein content, as shown in Table 1, they quickly deteriorate. Moreover, as Table 1 also shows, different batches of tofu-wastes vary considerably from each other in their chemical components.

From the physical point of view, tofu wastes are a compressive and adhesive material. This makes them difficult to handle, while they tend to clog any handling equipment.

Cost

The price of tofu wastes is relatively low, though their transport requires time and labor. When raw tofu wastes are used as feed, 13% are sold to livestock farms for a fee, 49% are given free, while the manufacturers pay a disposal fee of US$0.02-0.08*/kg, for the rest (The Central Association of Livestock Industry, 1992). Livestock farms pay US$0.06/kg for raw tofu wastes, including the cost of delivery from the factory to the farm (National Association of Food Industries, Japan 1992). Dried tofu waste (water content < 10%) is sold at US$0.22-0.38/kg.

Assuming that the price of raw tofu wastes is US$0.06/kg, this makes the cost per kilogram of TDN (Total Digestible Nutrients) US$0.37. This is lower than the TDN cost of feed concentrates (US$0.63/kg TDN).

Keywords: Drum silo, drying, ensiling, livestock feed, soybean curd lees, tofu wastes
Fig. 1. Flow chart of the production of tofu and tofu wastes

Source: Morimoto et al. 1985

Table 1. Variation in chemical composition of tofu wastes (in %FM)

<table>
<thead>
<tr>
<th>Method of Utilization</th>
<th>Water content</th>
<th>Crude protein</th>
<th>Ether extract</th>
<th>Nitrogen-free extract</th>
<th>Crude fiber</th>
<th>Crude ash</th>
<th>Digestible crude protein</th>
<th>Digestible nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of Raw Tofu Wastes</td>
<td>Max. 85.53</td>
<td>7.52</td>
<td>4.09</td>
<td>13.84</td>
<td>5.45</td>
<td>2.28</td>
<td>6.39</td>
<td>26.21</td>
</tr>
<tr>
<td></td>
<td>Min. 71.55</td>
<td>2.42</td>
<td>0.72</td>
<td>3.81</td>
<td>1.91</td>
<td>0.52</td>
<td>2.06</td>
<td>12.31</td>
</tr>
<tr>
<td></td>
<td>Average 79.34</td>
<td>5.39</td>
<td>2.33</td>
<td>8.82</td>
<td>3.26</td>
<td>0.86</td>
<td>4.58</td>
<td>18.77</td>
</tr>
<tr>
<td>S.D.</td>
<td>2.26</td>
<td>0.92</td>
<td>0.71</td>
<td>1.26</td>
<td>0.62</td>
<td>0.17</td>
<td>0.78</td>
<td>2.28</td>
</tr>
</tbody>
</table>

Source: Inoue et al. 1989
n = 197

METHODS OF UTILIZATION

At present, there are three ways of using tofu wastes as feed. They can be used raw, they can be ensiled for a while and used after fermentation has taken place, or they can be dried and used as a component in formula feed.

Use of Raw Tofu Wastes

Aerobic deterioration begins within half a day in summer, if raw tofu wastes are left untreated. Once spoilage has begun, tofu wastes are less palatable, and can cause diarrhea and ketosis.

Tofu factories are mostly located in urban areas, while livestock farms tend to be in more remote parts of Japan. With long-distance transport, the risk of deterioration and the cost of transportation increase. Therefore, the use of raw tofu wastes is restricted to users who live fairly near suppliers.

If tofu wastes are not consumed on the same day, they should be stored in impermeable containers and compacted by trampling, so that deterioration is delayed.

Silage Made from Tofu Wastes

If tofu wastes can be stored without spoilage, they do not have to be delivered to farms every day. Ensiling is the most convenient way of preserving tofu wastes at present. Moreover, good silage made from tofu wastes is better than the raw wastes in terms of both digestibility and palatability.

DRIED TOFU WASTES

Characteristics of Fermentation and Deterioration

Table 2 shows the quality of tofu-waste silage made in drum-silos with additives. Butyric acid was not detected in any sample, and pH values were low. The effect of the additives was slight, because fresh wastes were used (4 hours after pro-
duction) with satisfactory compaction. Therefore, good silage is produced by sealing the wastes quickly and compacting them well, as long as they are fresh enough (Ohmomo 1992). However, some additives would be needed if the condition of the raw wastes is not very good.

The changes in pH values and in the organic acid content of tofu-waste silage after the silos were opened are shown in Fig. 2. One silo was sealed tightly after loading, during the ensiling period, while the other silo was left open. Although little change was observed in the quality of samples from either silo two days later, after four and six days the open silo showed a decrease in the lactic acid content and a rise in pH. Thus, it is considered that aerobic deterioration occurred after the third day. On the other hand, these changes were not observed in the sealed silo. Thus, we can conclude that preventing air from entering the silage, by sealing or covering it, is effective in preserving the silage.

Compaction by trampling is important in preventing deterioration of ensiled tofu wastes. The density of tofu wastes is about 520 kg/m³ when they are loaded onto a truck. The density increases to 610 kg/m³ after traveling for one hour, and to 760-970 kg/m³ when ensiled. If compaction is thoroughly carried out, it is possible to increase the density to over 900 kg/m³.

**METHODS OF ENSILING AND UNLOADING**

**Small-Scale System**

Drum silos (made of molded steel or plastic, with a capacity of 0.2 m³, measuring 0.6 m in diameter and 0.9 m in height, weighing 8-20 kg and costing US$70-90 each) are used. Around 135-180 kg of tofu-wastes are packed into each drum.

**Pure Silage**

Drum silos are distributed to tofu manufacturers who store tofu wastes in the silos. At small-scale factories, a single drum can hold all the wastes produced over several days. Collection and delivery of silos is carried out by livestock farmers or by traders once or twice a week. This system is an efficient way of collecting wastes from a number of small factories.

**Mixed Silage**

Tofu wastes are taken to farms by truck, and mixed with conditioners (e.g., beet pulp and/or rice straw), then packed into drum silos. A mixer for this purpose has been developed (Segawa 1991), which consists of a slat conveyer (1.2 m wide, 3.6 m

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**Table 2. Comparison of the quality of tofu-refuse silage ensiled into drums for 15 days**

<table>
<thead>
<tr>
<th>Additives</th>
<th>Water content (%)</th>
<th>pH</th>
<th>Organic acid (% in FM)</th>
<th>Number of lactobacilli (cells/g FM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lactic acid</td>
<td>Acetic acid</td>
</tr>
<tr>
<td>Conditioners*</td>
<td>Glucose** Lactobacilli***</td>
<td>77.31</td>
<td>4.11</td>
<td>0.94</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>77.11</td>
<td>4.00</td>
<td>0.98</td>
</tr>
<tr>
<td>-</td>
<td>+</td>
<td>78.26</td>
<td>3.80</td>
<td>1.34</td>
</tr>
<tr>
<td>+</td>
<td>-</td>
<td>74.09</td>
<td>4.01</td>
<td>0.88</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>73.53</td>
<td>3.97</td>
<td>0.99</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>75.63</td>
<td>3.86</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Source: Ohmomo 1991

* Conditioners: 2% rice straw and 5% beet pulp (FM)
** Glucose: 1% (FM)
*** Lactobacilli: Amount prescribed by the maker.
Fig. 2. Changes in quality of silage made from tofu wastes after the silo has been opened
(a) Silo left open during the test period
(b) Silo sealed tightly every time the silo was loaded with fresh tofu wastes
Source: Ohmomo 1991

long, 10 mm/second feed-rate), a beater, and a belt conveyor (Fig. 3). Tofu wastes, conditioners and preservatives are piled in layers on a slat conveyer that feeds them into the beater.

The different layers are cut and crumbled by the beater, so that they are mixed with each other in a constant ratio. The mixture is then carried by the belt conveyer into a drum silo, where an operator tramples it, and compacts it by his own weight. The equipment can also be used in other types of small silos. In a performance test, this machine could process 1.37 mt/hour, i.e. 4-6 minutes for each drum silo. For an underground silo, the rate was 1.86 mt/hour.

An Unloader for Drum-Silos

Emptying silage out of drum silos is heavy work if done manually, especially if the silage is well compacted. We therefore developed an unloading-feeding machine for drum silos (Segawa et al. 1992). This machine is composed of a lifting frame onto which a drum silo is mounted, a hand winch, scraping blades and a motor, as shown in Fig. 4. When an open drum silo is lifted up and turned upside down by means of the hand winch, it slides down the frame onto the scraping blade with its open end facing downward (Fig. 5). The scraping blade then rotates and scrapes out silage into the trough. The drum silo continues to slide down onto the blade as the silage is scraped out, until it has been emptied.

A performance test was conducted using silage made of tofu wastes only, mixed silage (50% tofu wastes and 50% straw, on a dry matter basis) and grass silage. The rate of unloading was 0.06-0.14 m³/minute, depending upon the material. The test showed that this machine can be used for grass silage, as well as silage made from tofu wastes.

When this machine is controlled by a timer, it can be used as an automatic feeder. It is inexpen-
Medium Scale System

In this system, tofu wastes are transported to farms by dump truck and loaded into silos. The silos should be constructed so that the wastes can either fall directly from the truck bed into the silo, or be dropped onto a concrete floor, to be later put in the silo by a bucket-loader.

When mixed silage is being prepared, conditioners and preservatives are stacked in flat layers on top of the tofu-wastes lying on the loading platform of the dump truck. An operator then cuts and crumbles the layers of materials as they are dropped into the silo (Fig. 6). Another way is to mix tofu wastes and additives on a concrete floor with a bucket-loader, and to load the mixture into the silo (Fig. 7).

Large-Scale System and TMR Plant

For large-scale systems, tofu wastes transported to farms by a dump truck are dropped into an unloading box and fed into a forage blower at a constant rate of flow. Additives are supplied simul-
Fig. 5. Schematic diagram of the unloading machine's motion

In some TMR (total mixed ration) plants, tofu wastes are mixed with many other ingredients to make TMR. Tofu wastes are loaded from dump trucks into bunker silos and then unloaded by a bucket-loader. The wastes are then fed into a batch mixer, where they are mixed with the other materials. The finished TMR is ordinarily packed into 500 kg bags for delivery to farms.

**Dried Tofu Wastes**

Drying of tofu wastes is carried out by tofu manufacturers, not by livestock farmers. Dried tofu wastes are stable and easy to handle, so can be distributed to relatively distant areas.

Though dried wastes have many good features, they are far from being a profitable product for tofu makers. The market price of dried tofu wastes, according to their nutritional value, is only US$0.28 - 0.39/kg, but to dry the wastes with a dryer costs US$0.67 - 0.78/kg. This figure includes the cost of fuel, electricity, labor, depreciation of facilities, and so on. Dryers of various sizes, with a capability of 20 kg/h to 2 mt/h of raw tofu refuse, are available on the market. The price of a dryer is about US$78,000 for a machine with the drying capability of one ton of raw refuse per day. Reducing the cost of drying so that the product is competitively priced does not seem feasible at this time. It may be necessary to utilize exhausted heat (e.g. heat from the tofu plant itself, heat from waste incineration facilities, etc.) and to develop a new, inexpensive and highly efficient dryer.

**CONCLUSION**

Tofu wastes are a relatively cheap feed resource, considering their nutritive value. The key to their effective utilization as feed is to find an economical way of preventing them from deteriorating. The optimal method for utilization depends on the location and scale of the livestock farm and the tofu factory.

For a steady supply of high-quality feed and to save labor in collection and delivery, it is recommended that tofu wastes be mixed with dry materials and ensiled. It is also recommended that silos be designed in a way to make loading and unloading easy and efficient.

The development of energy-saving, low-cost drying technologies for tofu wastes and other food by-products with a high water content is recommended in future studies. The formation of networks and cooperative organizations which combine tofu-makers, livestock farmers and refuse-traders can also be expected to promote the more effective use of tofu wastes.

**REFERENCES**


Morimoto, H. et al. 1985. Feed. Yokendo,
Fig. 6. A simple method of processing mixed silage, using an auxiliary silo

Fig. 7. Making mixed silage using a bucket loader (medium- to large-scale)
Fig. 8. Diagram of a large-scale processing system for mixed silage
Source: Amaha et al.