

# Utilisation of seafood processing waste – challenges and opportunities.

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## Abstract

During the processing of fish generally only the fillets are retained while the bulk of product (up to 66%) is discarded. Across the seafood industry in south-eastern Australia alone, it is estimated that >20,000 t of fish product waste is produced annually. Some of this fish waste is rendered, but most is dumped to landfill at a cost of up to \$150/t. This practice is coming under increased scrutiny due to environmental issues and is becoming an increasing cost to the seafood industry.

Hydrolysed fish waste composted with rock phosphate, forms an organic solid-phosphate fertiliser. To commercialise this opportunity, working relationships need to be formed between the seafood industry and fertiliser manufacturers. As part of this relationship the seafood industry can provide hydrolysed fish offal as a stable liquid fish concentrate. This is blended with rock phosphate and inoculated with bacteria and fungi using advanced composting technology. This ensures temperatures around 60°C are achieved to produce a pathogen free compost blend. By building up of microbial populations, the availability of phosphorus in the apatite of the rock phosphate can be increased, along with nutrients held in the microbial biomass.

This product has the dual advantages of providing needed nutrients to agricultural crops as well as utilising waste materials otherwise costly to dispose of. Three field trials (processing tomato, irrigated pasture and dry land triticale) are under way to assess the agronomic effectiveness of a fish waste based rock phosphate fertiliser. Processing tomato crop benefited from the application of the fish based rock phosphate fertiliser to the same extent as superphosphate at the end of two seasons.

## Key Words

Fish waste, waste reuse, phosphorus fertiliser, tomato.

## Overview of seafood processing waste

Within the Australian seafood industry, in excess of 20,000 tonnes of fish waste are produced each year by processors and retailers (Gavine *et al.* 2001, Knuckey 2004), as well as the catching sector (Knuckey *et al.* 2001). In processing fish, it is generally only the fillets that are retained and although yields may vary widely (Crapo *et al.* 1993), the fillets of many of the Australian commercial species only usually comprise 30-40% of the whole weight of the fish (Australian Fisheries Management Authority, unpublished). Subsequent to processing, the bulk of the product (60-70%), consisting of head, guts and frame is usually discarded. In some instances this waste product may be taken away from the processor at no cost, but usually processors pay for its removal as garbage that is dumped to landfill at costs up to \$150/t. Due to its high organic content, fish waste is often classified as a certified (prescribed) waste which is even more costly to dispose. This practice is coming under increased scrutiny due to environmental issues (Jespersen *et al.* 2000, Anon 2002) and is becoming an increasing concern and cost burden for the whole seafood industry. At the 2001 Seafood Direction Conference, the Australian Seafood Industry Council highlighted that the utilisation of fish waste was one of the high priority areas that needed to be addressed in the next two years.

With most of Australia's fish stocks near or at full exploitation, it is unlikely that the seafood industry will expand and develop through increased wild-capture harvests. One of the main options to increase profit for the seafood industry is through value-adding the current catch. The Fisheries Research and Development Corporation (FRDC) set up the South East Fishery Industry Development Subprogram to specifically explore such options. The main focus of this Subprogram over the last two years has been to find a solution to the large amounts of fish waste that are discarded by the seafood industry each year.

### **Options for utilisation of seafood processing waste**

At a FRDC workshop in 2001, seafood industry leaders discussed ways to improve the utilisation of fish waste by investigating techniques to process the waste into products such as aquaculture feeds, silage, fertilisers, fish-mince, and fishmeal. After considering a variety of options, it was agreed that processing the waste into valuable fertiliser products was the option that was most feasible at that point in time. This option suited the particular requirements of the processors and the raw product that they produce: it could utilise the bulk of the fish waste and prove cost-effective given the relatively low volume and wide geographical area covered by Australia's seafood industry. It was acknowledged that if the utilisation of fish waste were to be successful on a broad scale, it would require a considerable level of coordination and cooperation, both within the seafood industry supply chain and across a range of different areas. It would also require the sensible use of the current resources as well as investment by the seafood industry into waste utilisation infrastructure.

To achieve the above, the Subprogram formed Australian Seafood Co-products (ASCo) during 2002. The goal of ASCo is to add value to the seafood supply chain through the sustainable utilisation of fish and fish co-products that are not traditionally utilised or marketed. ASCo shareholders include the FRDC and numerous major Australian seafood companies from Queensland, New South Wales, Victoria, Tasmania and South Australia. Their initial shareholder contributions have been used alongside Federal government funding to run a number of projects to help get ASCo off the ground. Some of the projects that have been completed to date include a feasibility study on installation of fish silage plants at central fish processing sites, development of a business network plan for ASCo and development of an agreed structure for the operation of ASCo. Although it considered a number of uses for fish waste, ASCo decided that processing of the fish waste into a valuable organic fertiliser was the option that was most feasible at this point in time. As a consequence, ASCo Fertilisers was formed – a partnership between ASCo and Sieber, a New Zealand company that has the proven technology and experience to process fish wastes into fertilisers. ASCo Fertilisers intends to utilise large quantities of fish waste from across south-eastern Australia to produce fish-based fertiliser products that can be potentially used by the farming sector for agricultural crops and can be certified for use in the rapidly growing organic (farming) market. Any research in this area will be an exciting proposition given it is a potential win for the seafood industry, the agriculture industry and the environment.

### **Hydrolysed fish waste**

Hydrolysed fish waste is an inert liquid produced by enzymatic hydrolysis. It is manufactured by first grinding whole fish or fish waste, adding an acid and then agitating the mix until the enzymatic hydrolysis process is complete. Of the acids available Sulphuric acid ( $H_2SO_4$ ) is used, as it is readily available, relatively easily handled, inexpensive and the sulphur (S) content is beneficial to the crop. The  $H_2SO_4$  added (2% by weight), helps initiate hydrolysis of the fish, but its primary purpose is to reduce the pH to prevent microbial spoilage. The hydrolysis process proceeds as the endogenous enzymes in the fish are released from the cells and digest the fish tissue. This process is controlled by temperature and is preferably carried out in an insulated and jacketed tank. This process is exothermic (heat producing). Insulation ensures heat is retained, accelerating the process. A temperature of 30°C provides rapid breakdown of the fish, but higher or lower temperatures will provide good results without degradation of the product. Temperatures >50°C should be avoided to prevent destruction of the enzymes or degradation of the amino acids in the fish nutrient.

Careful control of the pH in the range 3.0-3.5, using an automatic pH meter and acid dosing pump, is essential to avoid bacterial spoilage. Hydrolysis process is usually complete in 48 hours under ideal conditions. The hydrolysed fish waste is then passed through a 1 mm screen to remove any solid material. From a batch of 10 tonnes of fish byproduct there is usually only about 50 kg of solid waste. The hydrolysed fish waste can be stored indefinitely in agitated steel or some plastic containers without spoilage, if the pH is maintained at 3.0 -3.5.

### **Fish-rock phosphate fertiliser (based on Patent PENDING Number 522159)**

Addition of fish-waste, and inoculation with bacteria and fungi to rock phosphate will increase the availability of the P in the apatite by promoting dissolution (During 1984). The bacteria and fungi feed on the fish nutrient and produce acids (Mckenzie 1995), which in turn break down the rock phosphate into forms that are available to plants. This process occurs in the soil but is relatively slow when

compared with its application in a controlled factory environment which results in an increase in the availability of P as a result of the biological activity of the inoculum (Chitralkha *et. al.* 2000).

The Sieber group (now known as Kagree Holdings Limited) has previously manufactured fish-waste rock phosphate fertiliser using 5% by weight of fish waste in a composting process. However, this process was often anaerobic, resulting in off-odours and had the potential to produce pathogenic bacteria, including *Clostridium perfringens*, a spore-forming anaerobe (widespread in the soil), some strains of which can cause enterotoxaemia and "pulpy kidney" in sheep. These problems have been overcome by development of a controlled aerobic low moisture (<10%) composting process, which achieves temperatures >55°C for a period of several days in order to kill potentially pathogenic bacteria. The key to this process is maintaining aeration of the material throughout production and achieving the critical temperature for destroying pathogenic bacteria. This patented process, is initiated by mixing ground rock phosphate with 5% by weight of hydrolysed fish waste (produced as above) to which a mixture of beneficial microorganisms (Table 1) have been added.

**Table 1. Micro-organisms added to mixture of rock phosphate and fish silage.**

Actinomycetes	<i>Streptomyces</i>
Fungi	<i>Zygomycetes</i>
Phosphate- and other mineral-fixing bacteria	<i>Thiobacillus</i>
Selected archaeobacteria	-
Autotrophic bacteria	<i>Glomus tenuis</i>
Aerobic composting bacteria	<i>Theobacillus</i> <i>Alkaligenes</i> <i>Azotobacter</i> <i>Pseudomonas</i>
Acidophiles and lactic-acid bacteria.	-

As well, 5% by weight of a porous organic material (usually sawdust) is added to the phosphate rock to improve aeration. The presence of coarse sawdust immediately assists circulation of air through the relatively fine rock phosphate, but circulation is progressively enhanced as the sawdust is partially digested, leaving voids in the mixture. The organic material acts as a source of carbon for mopping up free nitrogen. The mixture is then held in a (preferably insulated) concrete bin, through which air is forced to ensure the aerobic process is maintained. It is important to maintain moisture content below 10%, to avoid development of anaerobic zones and loss of valuable nitrogen (as ammonia).

Proliferation of bacteria in the early stage of the process will result in the mixture reaching temperatures of around 60°C, which can be maintained for several days. The temperature then gradually decreases, during which phase there is a proliferation of fungal mycelia through the phosphate mass. These fungi partially absorb phosphate released during production.

The end product from this process comprises a free-flowing powdery or sandy material with 5% to 10% moisture content, containing a variety of dead or living micro-organisms and some secretions, at a pH of about 7 to 7.2 (sometimes pH 6.5 to 7.5, depending on the rock phosphate used). The microorganisms have already begun to solubilise or digest the phosphate rock while being supported by a community of other microorganisms that are converting the nutrients into cellular material.

Depending on the source of rock phosphate, the nutrient (P) analysis is high (Table 2) due to the relatively low (10% by weight) addition of composting ingredients. The end product can be handled through conventional fertiliser storage and distribution facilities and is applied to farms using conventional spreading methods.

The fish-waste rock phosphate fertiliser (BioPhos) is currently marketed to farmers in New Zealand. The product has organic certification in New Zealand (BioGro NZ # 0171).

**Table 2. Typical analysis of biologically activated rock phosphate (Ben Guerir) fertiliser.**

Analyte	Fish-waste rock phosphate fertiliser
Total P (%)	12.5
P as water soluble	n/a
P as citric soluble (%)	3.85
Converted to total product (%)	30.7
Total K	Nil
Total S (%)	0.7
Total Ca (%)	38
Total N (%)	<3
Organic matter (loss on ignition at 550°C)	5

### Agricultural trials

The seafood industry in south-eastern Australia is currently developing BioPhos fertiliser in Australia. This has the potential to reduce environmental impact by utilising problem wastes and could also generate significant financial returns to the seafood industry. The farming sector would also gain an alternative P fertiliser.

Australian soils are generally deficient in phosphorus (P) in their native state. They require the application of P fertilisers to satisfy crop and pasture requirements. Two-year field trials were established at Tatura (northern Victoria) and Dutson Downs (Gippsland) to examine the effectiveness of BioPhos in comparison with traditional P fertiliser (Superphosphate) on processing tomatoes (Tatura), irrigated pasture (Tatura) and dryland triticale (Dutson Downs). Results from the two-year tomato trial are reported here.

### Tomato trial

#### *Materials and methods*

The experiment comprised 3 treatments. These were an unfertilised control (T1), superphosphate (T2) and fish based rock phosphate fertiliser (BioPhos) (T3), replicated 12 times (3x12=36 raised beds) over 4 blocks. Each block comprised 9 raised beds 1.5 m wide x 72 m long. Experimental plots were 8 m long and 3 beds wide with all measurements taken from the central bed. Tomatoes were grown on these beds for 2 consecutive seasons (2002-03 and 2003-04). Phosphorus was surface applied each year (hand spread and raked into the top 10 cm) at the recommended rate (120 kg P/ha) before seedlings were transplanted. Table 3 shows the analyses of P fertilisers applied.

**Table 3. Fertilizer analyses (w/w).**

Analyte	Superphosphate (T2)	BioPhos (T3)
Total P	7.52%	9.6%
P as water soluble	6.84%	<0.5%
P as water insoluble but citrate soluble	0.51%	1.6%
P as citrate insoluble	0.17%	7.6%
Total K	6.02%	8%
Total S	11.87%	6.4%
Total Ca	16.24%	25.6%

Soil samples (two per bed) were taken from each plot prior to application of treatments during the first season (2002-03) to assess the initial levels of Olsen-P in the 0-30 cm depth. Seedlings of the standard processing tomato cultivar Heinz 9035 were transplanted in single rows with 30 cm spacing between plants during both the seasons. Irrigation and N fertiliser were applied according to commercial practice, through a buried drip system installed at a depth of approximately 15 cm. Leaf samples were taken to determine P levels during crop establishment and early fruit set stages for the 2 seasons. Fruit samples were taken to determine P levels at harvest for the second season crop only. Total yields (t/ha) were calculated on the basis of fruit weight harvested from a 2 m subplot from within each treated plot. Soil samples (0-30 cm depth in the middle of each plot) were taken at the end of each season to determine Olsen P. Additional 30-50 cm depth soil samples were taken at the end of 2003-04 season.

## Results

The initial Olsen-P levels (0-30 cm depth) ranged from (4-25 mg/kg) and were more variable on T2 plots. There was no relationship between initial Olsen-P and total yield. Average plant P levels at the crop establishment stage were highest for T2 and lowest for T1. Early fruit stage samples showed highest average P levels in leaves for T3. There was no relationship between total leaf P (at either sampling dates) and total yield. When three 'outlying' values were treated as missing, there was a significant effect of treatment on total yield ( $p < 0.01$ ) with mean yield significantly lower for the control treatment (T1) by over 15 t/ha. There was no significant difference between the two fertiliser treatments.

**Table 4. Treatment means from ANOVA (2002-03 season) with three 'outlying' values treated as missing<sup>1</sup> (n=33).**

Assessment	Units	T1	T2	T3	sed	lsd (5%)
Total yield	t/ha	99.7	115.2	115.4	5.30	10.88
Total leaf P (Crop establishment stage)	%	0.283	0.468	0.368	0.016	0.032
Total leaf P (Early fruit set stage)	%	0.174	0.180	0.216	0.009	0.018
Final Olsen-P (0-30 cm)	mg/kg	7.0	5.5	7.0	0.74	1.5

<sup>1</sup>one plot from T2 and one from T3 (both in block 1) excluded due to observed irrigation problems, an additional one plot from T1 (block 2) excluded due to exceptionally high total yield (147.6 t/ha)

In the second season (Table 5), average plant P levels at the crop establishment stage were highest for T2 and lowest for T1, similar to first season. However, early fruit stage leaf samples and fruit samples at harvest showed no significant differences between the treatments. There was no relationship between total leaf P (at all sampling dates) and total yield. There was a significant effect of treatment on total yield ( $p < 0.01$ ) with mean yield significantly lower for the control treatment (T1) by over 22 t/ha. There was no significant difference between the two fertiliser treatments, similar to first season's results.

**Table 5. Treatment means from ANOVA (2003-04 season).**

Assessment	Units	T1	T2	T3	sed	lsd (5%)
Total yield	t/ha	77.3	99.1	107.4	7.39	15.08
Total leaf P (Crop establishment stage)	%	0.243	0.349	0.293	0.014	0.029
Total leaf P (Early fruit set stage)	%	0.140	0.136	0.135	0.010	0.021
Total leaf P (fruit at harvest)	%	0.259	0.288	0.283	0.016	0.032
Final Olsen-P (0-30 cm)	mg/kg	6.6	50.8	10.8	3.45	7.0
Final Olsen-P (30-50 cm)	mg/kg	3.5	21.5	4.4	2.34	4.8

Mean Olsen P for the superphosphate treatment (T2) at the end of the trial was significantly higher than T1 and T3 at both depths (Table 5).

In summary processing tomato crop benefited from the application of fish based P fertiliser to the same extent as traditionally used superphosphate. However, further work would be required in order to validate the results before any general recommendations for fish based rock phosphate fertiliser use could be made.

## Conclusions

The Australian seafood industry is currently developing a fertiliser product by composting rock phosphate with hydrolysed fish waste and selected bacteria and fungi. If this material has wide agricultural application, there are potential benefits to fishermen, farmers and the environment. The fish based rock phosphate P fertiliser produced tomato yields that were statistically equivalent to those achieved with super phosphate in a two year field trial. When compared with the unfertilised control, both fertiliser treatments increased plant growth and yield production. There are therefore grounds for further commercial development of this product, particularly as it may comply with requirements for organic farming practices.

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