Economic Analysis

Introduction and summary

This project has demonstrated the technical feasibility of replacing up to 50% of the fish oil (FO) with high omega-3 soy oil (STA) in the diet of S. rivoliana. The question posed in this part of the study is whether this is likely to be a profitable substitution, and if so, what is the potential size of the world aquaculture market for STA oil and the engineered soybeans required to produce it.

The profitability of substitution depends on the price of STA relative to that of FO, and the physical rate of substitution of one for the other. The growout trial of the project demonstrated that if fish must be fed for a fixed period of 238 days, it requires about 1.24 kg of STA to substitute for 1 kg of FO. (The “oil reduction” trials imply roughly similar rates of substitution.) Thus only if the price of FO is more than 24% above the price of STA would the substitution to be profitable under this fixed 238-day production period.

The price of commercial STA oil will certainly be higher than commodity soy oil because of the strict market segregation required for a genetically engineered product such as this. We estimate that STA oil will sell at a 22–40% premium over commodity soy oil, depending on volume, yield drag and other factors. We also expect that the current 3% FO premium over commodity soy oil is likely to persist. If so, the price of STA oil will be 19–37% higher than FO, which would certainly result in losses from substituting STA for FO in a fixed-period production plan of 238 days.

However, STA oil is probably profitable if the feeding period is optimally adjusted to match the faster growth rate under the STA oil treatment. This experiment showed a 45% higher final weight of the STA-fed fish (1.71 kg vs 1.18 kg), with the usual deterioration in feed conversion ratio as the fish approach maturity. Additional benefits of STA oil could therefore be achieved by reducing the number of days on feed, reducing facilities cost per kg produced and also improving the average feed conversion ratio. We have no data on facilities costs, but rough calculations indicate that the facilities cost savings could far exceed the losses from feed substitution. The benefits from improved feed conversion would be in addition to the facilities savings. We do not have data on feed consumption and weight gain within the 238-day feeding period, and
therefore cannot estimate the feed conversion benefits. Thus we nonetheless speculate that the net benefits of STA in S. rivoliana aquaculture are positive, despite our calculations of negative benefits under a fixed 238-day feeding strategy.

Aquaculture production of S. rivoliana is small, providing a market for only about 100t of STA oil per year, which could be supplied by a little over 400 acres of STA soybeans. Including other Seriola species, the potential aquaculture market increases to over 20,000t of STA oil, requiring about 80,000 acres of production (one-tenth of one percent of US acreage). If farmed salmon production could also benefit from a similar rate of STA use, the potential market would increase tenfold, to over 200,000t of STA oil, requiring about 850,000 acres of soybean production, or a bit over 1% of US soybean area.

Price relationships among soybean oil, IP soybean oils and fish oil

This project has demonstrated the technical feasibility of substituting high omega-3 soy oil (STA) for fish oil in rations for S. rivoliana. The profitability of this substitution will depend on the prices for the two lipids. There is of course no market for STA, so our analysis uses various sources of information to estimate the price premium, relative to oil from commodity soybeans, that would be required to bring forth a supply of STA. We then exploit the correlation of fish oil (FO) prices with the price of commodity soy oil to determine the likely relative prices between STA and FO.

Price premiums for oils from identity preserved and segregated (IPS) soybeans relative to commodity soy oil

Soybean varieties with enhanced STA content would most likely be produced under an integrated closed loop system (Ebehri, p7, T3) in which identity preservation (IP) controls extend to the farm, and where processing facilities would either be owned by the integrator or be contracted. Production would occur under contract with farm producers involving a premium over market price, with midseason inspections, similar to that described by Darroch, et al. (Fig 2, p. 101), for the high oleic acid soybean supply chain. Current farm-level production premiums range from $0.50-2.00/bu, with the lower premiums for common IP varieties such as high-linoleic, and the higher premiums for varieties that may be grown on a smaller scale, may require greater contamination security measures, or may have higher yield drag. These higher costs will be reflected in higher prices for the IP oils. Industry sources report that current premiums for IP soy oils themselves are $0.10-0.15/lb ($0.22-0.33/kg). As a percent of average 2011 FOB Gulf commodity soy oil prices ($1275/t)\(^1\), these represent premiums of about 16% and 24%, respectively.

In the case of transgenic soybeans, segregation costs would be required to insure that germplasm does not escape from the controlled STA beans, anywhere along the production and processing chain. Thus the extra costs of producing an identity preserved

and segregated (IPS) crop will be larger than IP costs for organic soybeans, for example, that do not pose a contamination threat and thus do not incur segregation costs.

In the absence of information from market participants regarding premiums for IPS soybeans, we make the rough approximations below, first with respect to farm-level production and then with respect to transportation and processing.

The extra costs to farm producers of IPS soybeans must be reimbursed via premiums that are sufficient to achieve the scale of production required. As previously mentioned, for the 2011-2012 seasons, premiums offered to farmers for producing IP and other specialized soybean varieties range from $0.50 to $2.00/bu. It is not possible to know in advance the yield drag associated with high STA varieties. Release of germplasm is likely to be considered consequential. To be conservative, we conclude that the producer premium would need to be at the higher end of premiums currently offered, about $2.00/bu. If the STA variety has an average oil content of 17.5% and we allocate this entire premium to the oil, a production premium of $2.00/bu is equivalent to an oil premium of $380/t ($0.19/lb), or roughly 30% of current commodity oil price.

Extra processing costs are not so easily observed. The crush margin for commodity soybeans, however, provides an estimate of normal processing and related costs. It varies seasonally and by year, but in recent years it has averaged in the vicinity of $0.90/bu (the margin has averaged somewhat lower in the current year). The crush margin for IPS soybeans would need to be higher than this because equipment and premises need to be thoroughly cleaned both before and after the IPS beans are processed. This process might require as much as a half day of down time both before and after processing the IPS batch. For a one-day or two-day processing batch, as would seem likely for the scale of the aquaculture market, this effectively increases the processing cost by 67% or 100%, an extra $0.60-0.90 per bushel. For this study, we estimate that this extra processing cost would be $0.75/bu. Again allocating this extra cost to just the STA oil implies a processing premium of $143/t ($0.07/lb), or roughly 11% of current commodity oil price.

Together, these estimated premiums for production and processing the IPS soybeans total $524/t ($0.26/lb), equivalent to 40% of the recent FOB Gulf coast value of commodity soybean oil, our base estimate of the price premium for STA oil.

It is conceivable that with sufficient volume, the premium for STA oil could be reduced to $1.00/bu for growers and perhaps extra segregation and processing costs as little as $0.50/bu, which would translate to a total STA price premium no lower than about $0.14/lb, or 22% of FOB Gulf commodity soy oil. Given the novelty and relatively small scale of STA soy oil, this range of estimates (22-40%) compares plausibly to reported premiums for IP soy oil of $0.10-0.15/lb (16%-24%).

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2 Consult [http://www.soybeanpremiums.org/](http://www.soybeanpremiums.org/) for a list of firms that offer premiums for IP soybeans, many of which post current premiums being offered.

The previous section ties the expected price of STA oil to FOB Gulf soy oil. It is useful to tie expected price of FO to the same base. For this we use data from the OilWorld archive cited above. From Fig. E2 depicting average monthly prices, it is evident that CIF NW Europe fish oil and FOB Gulf soy oil have been highly correlated over the past decade. Bypassing the chaotic 2008 oil markets, FOB Gulf soy oil and FOB Peru fish oil have shown a correlation of 0.87 between June, 2009, and September, 2011. Clearly there are variations in the fish oil market (due to variations in the fish catch) that are not related to the soy oil market, but we can nonetheless use this correlation to make inferences about expected premiums for fish oil relative to soy oil.

Table E2 presents the ratio of average prices of interest. The most relevant FO price for aquaculture is the FOB Peru price, since Peru supplies well over half of the world's fish oil, and represents an FOB price relevant to potential aquaculture users. During the period of relatively high correlation since June, 2009, the average Peru FO price was 2.6% higher than FOB Gulf soy oil. Dating back to the origin of the Peru price series, it has averaged 9.7% higher. It appears from the CIF NW Europe price in Fig E2 that the FO price has become more closely related to Gulf soy oil price during the last half of the decade, giving some confidence that the 3% Peru price premium of recent years may provide a reasonable expectation of the expected price relationship in the future.
Table E2. Ratios among average monthly oil prices for alternative time periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>Price of:</th>
<th>Soybean oil, U.S., FOB Decatur</th>
<th>Soybean oil, US, FOB Gulf</th>
<th>Fish oil, CIF N.W. Europe</th>
<th>Fish oil, FOB Peru,</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1/2000-9/1/2011</td>
<td>Soybean oil, U.S., FOB Decatur</td>
<td>1.000</td>
<td>1.060</td>
<td>1.286</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Soybean oil, US, FOB Gulf</td>
<td>0.943</td>
<td>1.000</td>
<td>1.213</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Fish oil, CIF N.W. Eur</td>
<td>0.778</td>
<td>0.824</td>
<td>1.000</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Soybean oil, US, FOB Gulf</td>
<td>0.935</td>
<td>1.000</td>
<td>1.213</td>
<td>1.097</td>
</tr>
<tr>
<td></td>
<td>Fish oil, CIF N.W. Eur</td>
<td>0.771</td>
<td>0.825</td>
<td>1.000</td>
<td>0.905</td>
</tr>
<tr>
<td></td>
<td>Fish oil, Peru, FOB</td>
<td>0.852</td>
<td>0.912</td>
<td>1.106</td>
<td>1.000</td>
</tr>
<tr>
<td>6/1/2009-9/1/2011</td>
<td>Soybean oil, U.S., FOB Decatur</td>
<td>1.000</td>
<td>1.075</td>
<td>1.252</td>
<td>1.103</td>
</tr>
<tr>
<td></td>
<td>Soybean oil, US, FOB Gulf</td>
<td>0.930</td>
<td>1.000</td>
<td>1.164</td>
<td>1.026</td>
</tr>
<tr>
<td></td>
<td>Fish oil, CIF N.W. Eur</td>
<td>0.799</td>
<td>0.859</td>
<td>1.000</td>
<td>0.882</td>
</tr>
<tr>
<td></td>
<td>Fish oil, Peru, FOB</td>
<td>0.906</td>
<td>0.974</td>
<td>1.134</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Profitability of substituting STA oil for fish oil

To determine the profitability of substituting STA for FO, we first focus on just the physical rate of substitution between the two lipids as determined in the experiments. This combined with their price ratios will determine the profitability of substitution. It is not necessary to examine the entire cost of the rations, as the other components and their cost do not change with this substitution. An appraisal based on the cost of the entire ration would have exactly the same result as this partial budgeting approach.

While the substitution of STA for FO in the ration itself is 1:1, the substitution per unit of fish gain tells a different story, as indicated by Table E1. In the growout trials, the change from the control diet to the 50:50 diet reduced FO requirement per kg of fish gain from 0.2227 kg to 0.1233 kg, for a reduction of 0.0995 kg of FO, while STA increased from zero to 0.1233 kg. The rate of substitution in producing a given amount of fish in this experiment was thus 1.24 kg STA per kg of FO. This rate of substitution is unfavorable for STA, and it is important to note that it results in part from the much higher final weight of the fish in the STA treatment. This is probably responsible for the 11% more feed fed per kg of gain (.247 vs .223 kg lipid/kg gain).

Table E1. Returns from substituting STA oil for fish oil; price premiums
relative to soy: 40% for STA, 3% for FO.

<table>
<thead>
<tr>
<th>Trial</th>
<th>treatment</th>
<th>fish oil</th>
<th>STA oil</th>
<th>fish oil</th>
<th>STA oil</th>
<th>Total</th>
<th>$ per kg gain</th>
<th>$ per kg STA oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growout</td>
<td>control</td>
<td>0.2227</td>
<td>0.0000</td>
<td>0.322</td>
<td>0.000</td>
<td>0.322</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>50:50</td>
<td>0.1233</td>
<td>0.1233</td>
<td>0.178</td>
<td>0.243</td>
<td>0.421</td>
<td>-0.099</td>
<td>-0.800</td>
</tr>
<tr>
<td>Oil reduction</td>
<td>50:50</td>
<td>0.0952</td>
<td>0.0952</td>
<td>0.138</td>
<td>0.187</td>
<td>0.325</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>75:25</td>
<td>0.0510</td>
<td>0.1530</td>
<td>0.074</td>
<td>0.301</td>
<td>0.375</td>
<td>-0.031</td>
<td>-0.201</td>
</tr>
<tr>
<td></td>
<td>90:10</td>
<td>0.0196</td>
<td>0.1760</td>
<td>0.028</td>
<td>0.346</td>
<td>0.375</td>
<td>-0.026</td>
<td>-0.146</td>
</tr>
</tbody>
</table>

As Table E1 further shows, at our base estimate of relative prices (STA at 40% above soy oil, FO at 3% above soy oil - see the previous section), the substitution of STA for FO is unprofitable, increasing the cost of gain by $0.099/kg of fish produced.

Table E1 shows similar results from the oil reduction trials. The substitution rates, units of STA per unit of FO, between the 50:50 and 75:25 treatments and between the 75:75 and 90:10 treatments are 1.31 and 1.07, respectively. These bracket the 1.24 substitution rate from the growout trial, and are likewise unprofitable at base price estimates. Henceforth we will ignore the substitution rates revealed in the oil reduction trials because they were of much shorter duration (66 vs 238 days) in the middle of the life cycle examined in the growout trial.

The profitability indicated in Table E1 is unique to the base prices used there. With the lower estimate of STA premium (22%), the growout trial still remains quite unprofitable, increasing the cost of gain by $0.067/kg.

To extend the analysis, we calculate, using the rates of technical substitution from the growout trial data in Table E1, the relationship between price premiums needed to make STA profitable. That breakeven line is:

\[ P_{\text{STA}} \leq -0.193 + 0.0807 \times P_{\text{FO}} \]

Fig. E1 plots this breakeven price line. Both prices are expressed as a premium relative to a common commodity soy oil price. \( P_{\text{STA}} \) premiums above the line are too high for STA to be profitable. Or, alternatively, FO prices to the left of the line indicate that FO price is so low that STA cannot compete. For example, the base price estimates used in Table E1 are FO premium of 0.03 and STA premium of 0.40, a point far above the breakeven line. One can observe that at this low FO price premium of 3% above soy oil, STA price would need to be at least 17% below the soy oil price (a negative premium) for STA to be profitable. Or, at this STA premium of 40%, the FO price would have to be at least 74% above soy oil for STA to become profitable. Alternatively, at a lower STA premium of 22% (our minimum expectation), the FO premium would have to exceed 50% for STA to be profitable.
To determine the likelihood that price premiums would fall into the profitable area shown in Figure E2, we depict in Figure E2 the frequency with which FO prices have fallen below given levels. We have determined above that the STA oil premium will be at least 22%, probably near 40% initially. For the lower STA price premium of 22%, STA will be profitable only if the FO premium exceeds 50%, which we can see from the Peru fish oil line in Fig E2 occurred virtually 1% of the months during 2007-2011. (A NW Europe FO price premium of 50% occurred about 15% of the time during 2000-2011, but this is a delivered price not directly relevant to producers choosing between Peru fish oil bought at Peru ports and STA oil purchased from Gulf ports.) For the higher estimate of STA premium (40%), the FO price would need to exceed 73%, which has never occurred.
Thus it seems quite clear from these price and feed conversion data that STA oil will not be able to compete with fish oil. But this is based on a rate of substitution under a fixed 238-day feeding period. If the feed conversions could be adjusted to reflect the earlier stages of growth within the experiment, it seems likely that feed conversion could be improved sufficiently that STA would be a favorable substitute. These data are not available to us, so we are not able to make such calculations. In the next section we comment further on this issue.

Adjusting feed conversion for the different growth stages observed in the experiment

We have established the sets of prices that would make STA a profitable substitute for FO, based on the rates of substitution as revealed in the growout trial. However, the feed conversion rates for the STA treatment were low at least in part due to the much higher growth rate that resulted in poorer feed conversion as the fish reach maturity. Had the STA fish been harvested when they reached the 1178g weight that the FO fish attained in 238 days, the unfavorable feed conversion rate for the STA treatment would have been reduced, perhaps reversed. Feed consumption data at relevant points during the trial were not available to us at the time of this analysis, so we were unable as yet to pursue that issue.

An additional economic advantage of the STA treatment is that the faster growth rate allows more production per year in a given set of pens. Specifically, it appears from Figure 3 that the fish in the STA treatment would have reached the final weight of the
fish in the FO treatment (1178g) about 75 days before the end of the trial, or 30% less

time occupying the facilities. We can only speculate on the economic benefit, since we

have no data on the monthly cost of maintaining cage facilities. Suppose, for example,

that total production costs are $7.00/kg, and that 30-40% of these costs are for facilities

(capital costs, labor, etc.). Then a reduction of 30% in the time use of these facilities

would represent a 10% reduction in total production costs, or about $0.70/kg. This

saving would dwarf the $0.099/kg extra feed cost for the STA treatment as estimated in

Table E1 above.

It is clear that reducing the feeding period for the STA fish would have increased

the economic benefit of STA in two ways: the overall feed conversion rate would be

improved, enhancing the rate of substitution of STA for FO; and the faster growth rate

would reduce the cost of facilities used.

Of course, the optimal harvest size for these fish is not likely to be either the

1176g achieved in 238 days by the FO treatment or about 163 days by the STA treatment,

nor the 1710g achieved by the STA treatment in 238 days. The basic optimization

criterion is to choose the harvest age that maximizes annualized net revenue to the

facilities. Net revenue in this case is basically the value of total gain minus feed,

fingerling and marketing costs. The very significant effect of the STA treatment on

growth rate implies that the ultimate economic benefit of STA would result from the

increase in annualized revenues to the cage facilities, which we are not able to identify

without further data on feed consumption and other enterprise budget information.

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**Potential size of the STA oil aquaculture market**

The total annual production of Kona Blue, Seriola rivoliana, is about 827 tons. At

rates of STA oil used in the growout trial, the potential market for this species is limited
to about 100t, requiring annual production of 572t of STA soybeans, which could be

produced on about 400 acres if the STA soybeans have average yields.

But STA oil would presumably be as useful in diets of other Seriola species.

Table E2 lists the 2008 worldwide production of a number of similar species, according
to the FAO⁴. By far the largest production is of S. quinqueradiata, which has a potential
market of about 17,262t of STA oil, which added to S. rivolana brings the total market to

17,364t as shown in column 2 of Table E2, and a total soybean acreage of 71,403 as

shown in the final column. All Seriola production brings the potential market to about

20,000t of STA oil, produced on about 82,000 acres of soybeans

If STA oil would have production responses in salmon production, the total

potential market would be 200,000t of oil annually, requiring nearly 850,000 acres of

soybeans, still only a bit over 1% of total US soybean acreage.

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Table E2. Potential market size for STA oil for deep water mariculture

<table>
<thead>
<tr>
<th>species</th>
<th>annual farmed production (tons)</th>
<th>cumulative market size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STA oil (t)</td>
<td>Raw soybeans for STA oil (t)</td>
</tr>
<tr>
<td>Kona Blue, S. rivoliana (longfin amberjack, kahala)</td>
<td>827</td>
<td>102</td>
</tr>
<tr>
<td>S. quinqueradiata (hamachi, yellowtail)</td>
<td>140,000</td>
<td>17,364</td>
</tr>
<tr>
<td>S. spp (other)</td>
<td>20,792</td>
<td>19,928</td>
</tr>
<tr>
<td>S. Ialandi (California Yellowtail, goldstribed amberjack)</td>
<td>1,100</td>
<td>20,063</td>
</tr>
<tr>
<td>S. dumerili (greater amberjack)</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Salmo salar (Atlantic salmon)</td>
<td>9,000</td>
<td>21,173</td>
</tr>
<tr>
<td>All farmed salmon</td>
<td>1,500,000</td>
<td>206,123</td>
</tr>
</tbody>
</table>

bCalculated at 0.1233 kg STA oil per kg produced