Background
Traditionally, fish meal has been the most common protein source used in aquatic feeds due to its optimum amino acid profile and digestibility. However, due to the reduction in supply and increase in cost of fishmeal during the last few years, nutritionists have started to incorporate vegetable-based protein sources like soybean meal and corn gluten meal in the diets of aquatic species. However, the amino acid profile of the vegetable protein sources is not adequate for the high demands of these commercially grown aquatic species and synthetic amino acids like lysine and methionine need to be added to the diet. One of the concerns in the addition of synthetic amino acids to the aquatic diets is the solubility of these amino acids and the related potential for water pollution.

Objective
The objective of this study was to determine the solubility of ALIMET® feed supplement and DL-methionine when included in extruded aquatic feeds. The type of protein source used in the aquatic feeds, as well as the floating characteristics and size of the extruded pellet were also evaluated for solubility for ALIMET and DL-methionine.

Materials and Methods
ALIMET and DL-methionine were added to six different extruded aquatic feeds at approximately 0.5 percent. The six extruded aquatic feeds were selected to represent diets commonly fed to four commercial aquatic species (catfish, salmon, shrimp, and trout), differing by floating characteristics (floating, slow-sinking, and sinking), pellet sizes (2, 3, 6 and 9 mm), and protein sources (soybean meal and fish meal).

Table 1 describes the comparison made among specific extruded aquatic feeds to evaluate the effect of protein source, pellet size and floating characteristics on ALIMET and DL-methionine solubility. The effect of protein source on ALIMET and DL-methionine solubility was evaluated by comparing solubility between 6 mm pellet-size salmon diet (Diet 3) and 6 mm pellet-size and trout diet (Diet 5). The effect of pellet size on ALIMET and DL-methionine solubility was evaluated by comparing solubility among the different pellet sizes of the salmon diet (Diet 2, 3 and 4). The effect of floating characteristics of the pellet on ALIMET and DL-methionine solubility was evaluated by comparing solubility among floating, slow-sinking and sinking pellets as described in Table 1.

Key Findings:
• ALIMET and DL-methionine have very similar solubility in the extruded aquatic feeds evaluated in this study.
• ALIMET and DL-methionine solubility rate averaged 1.50 percent and 1.43 percent per minute, respectively.
• Several factors impact the solubility of ALIMET and DL-methionine, including pellet size, fat content of the pellet, and floating characteristics of the pellet.
Results

ALIMET and DL-Methionine Solubility across All Extruded Aquatic Feeds

Within each extruded aquatic feed, no differences were found in the amount of ALIMET or DL-methionine released from the pellet. It appears that in extruded aquatic feeds, DL-methionine and ALIMET have similar solubility (Figure 1).

Solubility of ALIMET and DL-Methionine over Time

The amount of ALIMET, DL-methionine and soluble protein released from the pellets increased over time following a diminishing return curve. The amount of nutrients in solution increased rapidly during the first 15 minutes of incubation and slowly during the last 30 minutes of incubation. All diets showed a similar pattern (Figure 2).

Solubility Rate of ALIMET and DL-Methionine

Pellets are usually consumed quickly after they are offered to the fish. Therefore, the amount of ALIMET and DL-methionine released from the pellets during the first 15 minutes will be the most relevant for practical applications. If ALIMET and DL-methionine solubility is assumed to be linear during the first 15 minutes of incubation, a solubility rate (% soluble/min) can be determined. ALIMET and DL-methionine solubility during the first 15 minutes of incubation averaged 22.44 percent and 21.44 percent, respectively (Table 1). When solubility was expressed per minute, similar solubility rates were found for ALIMET and DL-methionine.

Factors Affecting the Solubility of ALIMET and DL-Methionine

1. Type of Protein Source Used in the Extruded Aquatic Pellets

The effect of type of protein used in the diet (fish meal vs. soybean meal) on nutrient solubility was evaluated. ALIMET and DL-methionine solubility in trout pellets (45% soybean meal and 12% fish meal) was compared to solubility in salmon pellets (45% fish meal and 12% soybean meal) within the same pellet size. It was found that nutrients solubility in salmon pellets was lower than in trout pellets, suggesting that fish meal could reduce nutrients solubility (Figure 3). However, when all diets were evaluated, a positive correlation was found between levels of fat in the diet and ALIMET and DL-methionine solubility during the first 15 minutes of incubation (Table 2, Figure 4). This correlation suggests that the higher content of fat in fish meal might reduce ALIMET and DL-methionine solubility.
2. Pellet Size of the Extruded Aquatic Pellets
As the fish grow, the size of the pellet fed to the fish also increases. In order to evaluate the effect of pellet size on nutrient digestibility, three sizes of pellets (3, 6 and 9 mm) were chosen within a diet. It was found that as the pellet size increased, the solubility of the nutrients decreased, probably due to the increase in the surface area of the pellet (Figure 5 and 6). When all diets were evaluated a similar inverse correlation was found between pellet size and solubility during the first 15 minutes of incubation (Figure 7).

3. Floating Characteristics of the Extruded Aquatic Feeds
The different floating characteristics (floating, slow-sinking and sinking) of the aquatic diets are achieved by changing the extruder conditions. Floating and slow-sinking pellets are obtained by preconditioning the feed with high steam and temperature prior and at the mid-point of the extruder. The combination of steam and temperature gelatinizes the starch of the feed, reducing the density of the pellet and the solubility of the nutrient. The sinking pellets have less steam and temperature during preconditioning and extrusion, resulting in higher dense pellet (Table 3). ALIMET and DL-methionine solubility in the sinking pellets (shrimp diet) was the highest of all diets. However, the pellet size of the shrimp diet was also the smallest (2 mm). In general, the more expanded the feed is, the lower the nutrient solubility and, therefore, ALIMET and DL-methionine solubility (Figure 8 and 9).

**TABLE 2.**
Correlation between ALIMET and DL-Methionine Solubility during the First 15 Minutes and Dietary Content of the Diets

<table>
<thead>
<tr>
<th>Type of Diet</th>
<th>ALIMET Solubility during First 15 min, %</th>
<th>DL-Methionine Solubility during First 15 min, %</th>
<th>CP in Diet, %</th>
<th>Dietary Fat, %</th>
<th>Fish Meal, %</th>
<th>Soybean Meal, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catfish Diet, 6 mm</td>
<td>23.00</td>
<td>20.35</td>
<td>32.04</td>
<td>5.2</td>
<td>5</td>
<td>30</td>
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<tr>
<td>Salmon Diet, 3 mm</td>
<td>30.57</td>
<td>30.78</td>
<td>38.49</td>
<td>25.44</td>
<td>45</td>
<td>12</td>
</tr>
<tr>
<td>Salmon Diet, 6 mm</td>
<td>10.34</td>
<td>10.60</td>
<td>38.49</td>
<td>25.44</td>
<td>45</td>
<td>12</td>
</tr>
<tr>
<td>Salmon Diet, 9 mm</td>
<td>9.7</td>
<td>10.27</td>
<td>38.49</td>
<td>25.44</td>
<td>45</td>
<td>12</td>
</tr>
<tr>
<td>Trout Diet, 6 mm</td>
<td>16.96</td>
<td>16.88</td>
<td>37.54</td>
<td>14.98</td>
<td>12</td>
<td>45</td>
</tr>
<tr>
<td>Shrimp Diet, 2 mm</td>
<td>44.05</td>
<td>39.75</td>
<td>38.72</td>
<td>3.08</td>
<td>15</td>
<td>43.5</td>
</tr>
</tbody>
</table>

Figure 3. Effect of Type of Protein in the Diet on ALIMET and DL-Methionine Solubility

Figure 4. Effect of Fat Content in the Diet on ALIMET and DL-Methionine Solubility

Figure 5. Effect of Pellet Size on ALIMET Solubility in Salmon Diets

Figure 6. Effect of Pellet Size on DL-Methionine Solubility in Salmon Diets
Conclusion

- ALIMET and DL-methionine have very similar solubility in the extruded aquatic feeds evaluated in this study. ALIMET and DL-methionine solubility during the first 15 minutes of incubation averaged 22.44 percent and 21.44 percent, respectively. ALIMET and DL-methionine solubility rate averaged 1.50 percent and 1.43 percent per minute, respectively.

- Several factors can influence ALIMET and DL-methionine solubility:
  - Pellet size: The smaller the pellet the higher the solubility of ALIMET and DL-methionine.
  - Fat content of the pellet: The higher the fat content of the diet, the lower the solubility of ALIMET and DL-methionine.
  - Floating characteristics of the pellet: The process of expanding the feed to achieve floating and slow-sinking pellet characteristics reduces ALIMET and DL-methionine solubility.

### Table 3

<table>
<thead>
<tr>
<th>Type of Diet</th>
<th>Floating Characteristics</th>
<th>ALIMET Solubility during First 15 min, %</th>
<th>DL-Methionine Solubility during First 15 min, %</th>
<th>Preconditioning Steam Flow, kg/h</th>
<th>Preconditioning Temperature, °C</th>
<th>Steam in Extruder, kg/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmon Diet, 3 mm</td>
<td>Slow-sinking</td>
<td>30.57</td>
<td>30.78</td>
<td>50</td>
<td>93</td>
<td>9</td>
</tr>
<tr>
<td>Salmon Diet, 6 mm</td>
<td>Slow-sinking</td>
<td>10.34</td>
<td>10.60</td>
<td>35</td>
<td>89</td>
<td>11</td>
</tr>
<tr>
<td>Salmon Diet, 9 mm</td>
<td>Slow-sinking</td>
<td>9.7</td>
<td>10.27</td>
<td>40</td>
<td>93</td>
<td>6</td>
</tr>
<tr>
<td>Trout Diet, 6 mm</td>
<td>Slow-sinking</td>
<td>16.96</td>
<td>16.88</td>
<td>34</td>
<td>78</td>
<td>6</td>
</tr>
<tr>
<td>Catfish Diet, 6 mm</td>
<td>Floating</td>
<td>23.00</td>
<td>20.35</td>
<td>52</td>
<td>92</td>
<td>13</td>
</tr>
<tr>
<td>Shrimp Diet, 2 mm</td>
<td>Sinking</td>
<td>44.05</td>
<td>39.75</td>
<td>20</td>
<td>64</td>
<td>0</td>
</tr>
</tbody>
</table>

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