Single Cell Protein: A sustainable approach to meeting the growing protein demand

The rapidly growing demand for livestock, tied to rising populations and standards of living, has placed increasingly unsustainable pressure on current sources of high protein feeds.

Dr. Josh Silverman, Chief Technology Officer, Calysta Inc., describes how the company's protein product FeedKind™, provides a sustainable source of protein that is comparable in many respects to high-quality fishmeal, a critical ingredient for aquaculture. FeedKind protein is sustainably produced via non-GMO fermentation of methane, which has minimal impacts on water and land use and does not compete with any aspect of the human food chain. Extensive safety testing across multiple livestock species has shown beneficial nutritional and health properties, and FeedKind protein is currently approved for use in the EU.

Introduction

Demand for high-quality protein for human consumption is projected to rise dramatically with increasing population and standards of living (Alexandratos, 2012). Aquaculture represents one of the most efficient sources of dietary protein with minimal impacts on arable land and feed conversion ratios significantly more favorable than land-based livestock (Bostock, 2010). However, aquaculture requires a key resource, fishmeal, which is one of the highest quality sources of protein for livestock feed. Fishmeal protein consumption is highly significant, even for herbivorous species where only a small percentage of fishmeal is required in the feed (Cao, 2015). Carnivorous species, which comprise more desirable fish such as salmon, trout, sea bass, eel, yellowtail, etc., require even higher levels of fishmeal protein. World fishmeal production has steadily decreased for the past twenty years, limited by the capacity of natural fisheries (Figure 1). Therefore, a clear conflict is on the horizon as global demand for fishmeal continues to rise in the face of static production levels, resulting in dramatic increases in fishmeal prices over the last decade (Figure 1). Already, over two-thirds of the planet's arable land is devoted to growing feed for livestock (Steinfeld, 2006) which is also hampered by the low protein content of most agricultural crops (Tacon, 2009) and the inherent

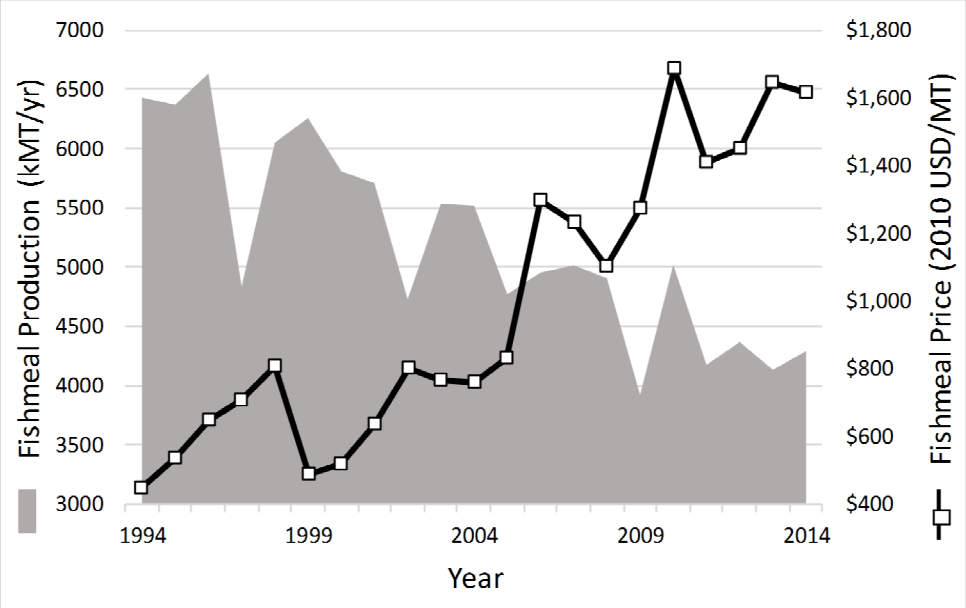

Fig 1: 20 year history of fishmeal production and pricing.

World production of fishmeal has dropped by approximately 30% over the past 20 years, coupled with an approximately 300% increase in price. Data are presented for world production and pricing, averaged annually for each year shown. Fishmeal production levels are inclusive of all reported grades (data: USDA, 2015). Fishmeal price is averaged per year over all grades of fishmeal and is reported in 2010 US dollars (data: World Bank, 2015).

competition with agricultural food production. Protein resources simply being moved from one food source to another (with losses) is an unsustainable approach that cannot address the vast new demand of expanding human population. In contrast, creating protein from sustainable, non-food sources, thereby actually growing the protein supply, represents an attractive strategy. However, any novel protein feed ingredient must meet stringent quality and functional criteria to achieve the high performance necessary to represent a true replacement for high quality protein sources such as fishmeal.

Fishmeal substitutes

Given the strong demand for novel protein sources, a number of new products have been proposed as fishmeal substitutes. A comparison of the general composition of some selected protein sources is shown in Figure 2. In general, a high percentage of protein is preferred for feed formulations as it improves blending flexibility and increases the nutritional value of the final blended feed product. Two grades of fishmeal (anchovy and herring) are included to provide a range for comparison. The data show that FeedKind™ *Aqua* protein falls in between the two fishmeal sources in terms of both protein and lipid content, while containing less undesirable

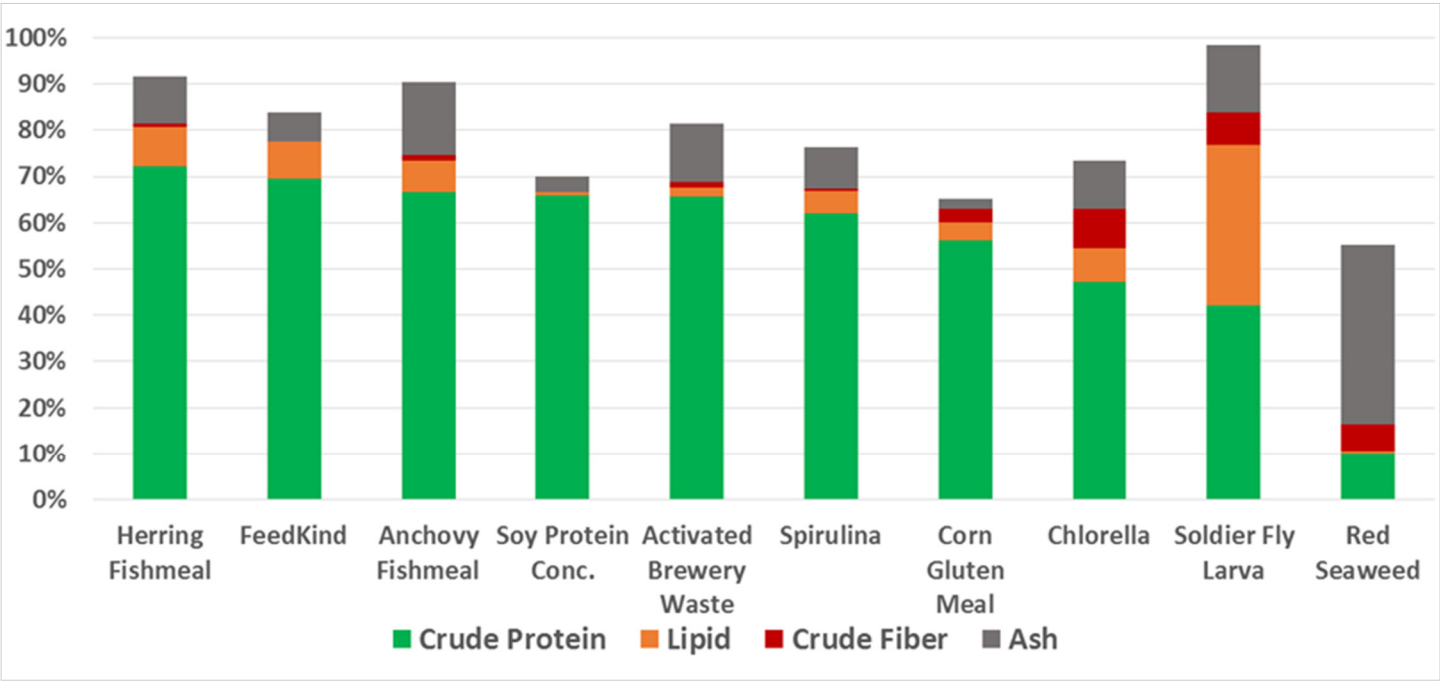

Fig 2: Comparison of current high protein feed ingredients and new alternatives under development.

Values for all feeds taken from Tacon, 2009 except for soy protein concentrate which was taken from the specification for Arcon SPC produced by ADM as a representative example.

Table 1. Composition and specification of FeedKind protein.

Source: Calysta, Inc. product specification.

Composition	%
Crude Protein	70.6
Crude Fat	9.8
Ash	7.1
Crude fiber	0.7
N-free extract	11.8
Total	**100%**

Amino acids	g/kg
Lysine	45.6
Methionine	19.8
Cysteine	4.5
Threonine	32.9
Tryptophan	15.7
Leucine	54.9
Isoleucine	33.6
Valine	44.8
Tyrosine	26.0
Phenylalanine	32.9
Histidine	18.0
Arginine	43.8
Alanine	51.9
Aspartic acid	65.1
Glutamic acid	77.1
Glycine	35.7
Proline	31.7
Serine	26.6
Total	**660.6**

Energy	MJ/kg
Gross energy	22.1

Minerals	
Phosphorus	19.5 g/kg
Chloride	7.6 g/kg
Sulphur	5.4 g/kg
Calcium	4.7 g/kg
Potassium	3.7 g/kg
Magnesium	2.1 g/kg
Sodium	0.9 g/kg
Iron	216 mg/kg
Copper	91 mg/kg
Zinc	17 mg/kg
Arsenic	0.051 mg/kg
Selenium	0.017 mg/kg
Cobalt	3.4 mg/kg
Nickel	2.0 mg/kg

Vitamins	mg/kg
Nicotinic acid	130.0
Riboflavin B2	73.0
Inositol	30.0
Thiamin B1	12.1
Vitamin E	<5.0
Vitamin B12	1.7
Biotin	2.8

Other data	
Color	Light brown
Flavor	Neutral
Particle size	150-200µm
Moisture content	6 %

ash and fiber. In contrast, chlorella algae and soldier fly larvae, both of which have recently been touted as low-cost protein sources (Makkar, 2014; Safi, 2014), show dramatically lower protein content than either fishmeal comparator or FeedKind *Aqua* protein.

FeedKind protein

FeedKind protein is a branded family of animal nutrition products, the first of which is FeedKind *Aqua* for the aquaculture industry. The detailed composition of FeedKind *Aqua* protein is shown in Table 1. The lipid fraction is comprised primarily of C16:0 and C16:1 fatty acids (Øverland, 2010). Importantly, FeedKind protein is derived from a fully-defined microorganism culture, allowing stringent standards on quality and reproducibility to be met. Further, the use of methane as the starting point for FeedKind protein provides a fully scalable process that can grow to meet the needs of the livestock industry. In contrast to other novel protein products which generally focus on technologies currently limited to small scales.

FeedKind protein is well tolerated in monogastric animals in general, and shows attractive properties in terms of digestibility, animal performance, and animal health (Øverland, 2010). In particular, due to the high similarity of Feedkind *Aqua* protein composition with high-quality fishmeal, many studies have focused on the effects of FeedKind *Aqua* protein in farmed Atlantic salmon. These studies have shown that FeedKind protein in salmon feed can complement and replace other protein sources such as fishmeal and soy protein concentrate. Although initial studies reported an inhibition of growth of salmon at high FeedKind protein inclusion levels (Berge,

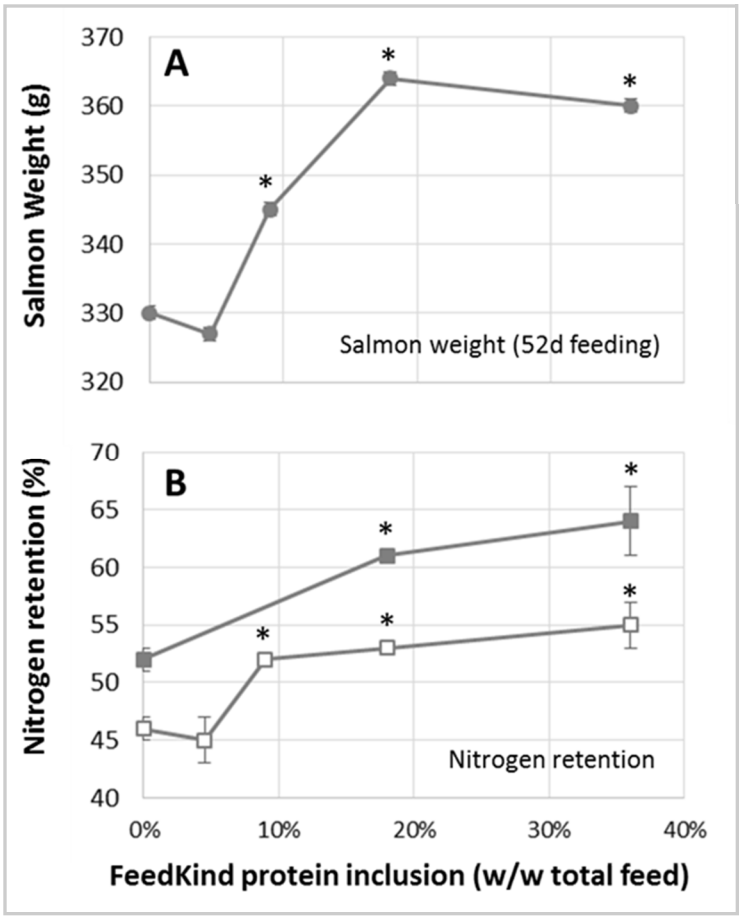

Fig 3: Results of 52 day feeding study in Atlantic salmon.

Data is taken from the Aas, 2006. FeedKind protein was included at the indicated ratios in total feed, replacing primarily fishmeal while keeping constant protein and energy levels. Data points showing statistically significant ($p<0.05$) differences relative to the 0% value in each data set are designated with an asterisk. A) Ending weights +/- SEM after 52 day feeding trial of juvenile Atlantic salmon (n=3 per group). Average weights of all groups at the start of the feeding trial were 169-170g with no significant differences between any group. No mortality was observed in any group during the trial. B) Nitrogen retention of total ingested feed (open symbols) and digested feed (closed symbols) +/- SEM after 52 day feeding trial of the same groups shown in panel A.

2005; Storebakken, 2004), these studies suffered from several issues unrelated to the FeedKind protein itself, including high general mortality and low growth across all groups (including the control), as well as poor control of feed pellet size (Aas, 2006). More recent studies have contradicted the initial results and show that FeedKind protein supports improved growth and performance in Atlantic salmon even over a normal fishmeal diet (Fig. 3) . In addition, FeedKind protein has also been shown to have significant positive impacts on the gastrointestinal health of both fish and mammals (Romarheim 2011, Kleiveland 2013), although the mechanism of action is currently under investigation. FeedKind protein is currently approved in the European Union for inclusion in all livestock feeds (Commission Regulation (EU) No 575/2011).

Sustainability

FeedKind protein is produced by the biological conversion of methane into single cell protein. Methane is abundantly available from a number of sources including anaerobic digestion, landfills, and natural gas. Methane is also a significant greenhouse gas, with an impact on climate warming over 28 times greater than CO_2 (IPCC, 2014). FeedKind protein provides an efficient method to capture methane from a wide variety of sources, thus preventing its release into the atmosphere. Furthermore, methane represents a source of carbon that is independent of the human food chain and does not impact arable land, native environments such as rainforests, or natural water resources. At the same time, replacing fishmeal with FeedKind protein is expected to both reduce pressure on wild catch fisheries, as well as to increase availability of forage fish to feed wild fish populations.

Summary

FeedKind protein represents a high-quality, sustainable protein source which is well tolerated across multiple livestock species. For aquaculture in particular, FeedKind Aqua protein has been demonstrated to perform significantly better than fishmeal in promoting growth and health in Atlantic salmon. The composition of FeedKind Aqua protein is comparable to fishmeal, and superior to many novel protein sources under development. The FeedKind production process has been validated at commercial scale in conjunction with European Union product approval, and product is expected to be available in the marketplace in late 2017.

References

Aas TS, Grisdale-Helland B, Terjesen B, Helland S. **Improved growth and nutrient utilization in Atlantic salmon (*Salmo salar*) fed diets containing a bacterial protein meal.** Aquaculture. 2006 May; 259: 365-376.

Alexandratos, N. and J. Bruinsma. 2012. **World agriculture towards 2030/2050: the 2012 revision.** ESA Working paper No. 12-03. Rome, FAO.

Berge GM, Baeverfjord G, Skrede A, Storebakken T. **Bacterial protein grown on natural gas as protein source in diets for Atlantic salmon, *Salmo salar*, in saltwater.** Aquaculture 2005; 244: 233 -240.

Bostock J, McAndrew B, Richards R, Jauncey K, Telfer T, Lorenzen K, Little D, Ross L, Handisyde N, Gatward I, Corner R. **Aquaculture: global status and trends.** Philos Trans R Soc Lond B Biol Sci. 2010 Sep 27;365(1554):2897-912.

Cao L, Naylor R, Henriksson P, Leadbitter D, Metian M, Troell M, Zhang W. **Global food supply. China's aquaculture and the world's wild fisheries.** Science. 2015 Jan 9;347(6218):133-5.

COMMISSION REGULATION (EU) No 575/2011 of 16 June 2011 on the Catalogue of feed materials. (PDF)

IPCC, 2014: **Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change** [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kleiveland CR, Hult LT, Spetalen S, Kaldhusdal M, Christofferesen TE, Bengtsson O, Romarheim OH, Jacobsen M, Lea T. **The noncommensal bacterium Methylococcus capsulatus (Bath) ameliorates dextran sulfate (Sodium Salt)-Induced Ulcerative Colitis by influencing mechanisms essential for maintenance of the colonic barrier function.** Appl Environ Microbiol. 2013 Jan;79 (1):48-56.

Makkar H, Tran G, Heuzé V, Ankers P. **State-of-the-art on use of insects as animal feed.** Animal Feed Science and Technology, Volume 197, November 2014, pages 1-33

Øverland M, Tauson AH, Shearer K, Skrede A. **Evaluation of methane-utilising bacteria products as feed ingredients for monogastric animals.** Arch Anim Nutr. 2010 Jun;64(3):171-89.

Romarheim OH, Øverland M, Mydland LT, Skrede A, Landsverk T. **Bacteria grown on natural gas prevent soybean meal-induced enteritis in Atlantic salmon.** J Nutr. 2011 Jan;141(1):124-30.

Safi, C., Zebib, B., Merah, O., Pontalier, P. Y., & Vaca-Garcia, C. (2014). **Morphology, composition, production, processing and applications of Chlorella vulgaris: A review.** Renewable and Sustainable Energy Reviews, 35, 265-278.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. **Livestock's long shadow: Environmental issues and options.** FAO, Rome 2006.

Storebakken T, Baeverfjord G, Skrede A, Olli JJ, Berge GM. **Bacterial protein grown on natural gas in diets for Atlantic salmon, *Salmo salar,* in freshwater.** Aquaculture 2004; 241: 413-425.

Tacon A, Metian M, Hasan M. **Feed ingredients and fertilizers for farmed aquatic animals.** FAO fisheries and aquaculture technical paper 540. 2009.

USDA, 2015. United States Department of Agriculture Foreign Agricultural Service; Production, Supply and Distribution Online database.

World Bank, 2015. World DataBank Global Economic Monitor (GEM) Commodities.

More information

Josh Silverman, Ph.D., Chief Technology Officer, Calysta Inc.
E: jsilverman@calysta.com