Review article

Title: Existing fish diet formulation practice and its limitation for aquaponics system

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Introduction

Aquaculture is farming of aquatic organisms including fish (principal component), crustaceans, mollusks etc… in controlled or semi-controlled manner with human intervention for increased yield for human consumption either as dietary, ecological or as an ingredient for other products. It is characterized by higher production capacity coupled with environmental problem due to higher discharge of nutrient loaded waste to the environment. The major constitutes of these waste water are nitrogen, calcium and phosphorus. However, these elements are major nutrient constitute of hydroponic production systems. Hydroponic is a technology which enables to increase plant production by supplementing the major nutrient requirement of the plant. The major issue on hydroponics dissemination to developing world is its nutrient solution preparation cost next to installation cost. Hence, the ancient technology which utilized by Azetic people believed to be a possible alternative for aquaculture and hydroponic existing technical and economical issue and recently called as Aquaponics. Aquaponics combine aquaculture and hydroponic systems and enable to produce two crops (fish and plant) with a single input (fish feed) in closed confinement or open system without hampering the yield potential of independent systems (aquaculture and hydroponics). Fish (aquaculture) deliver nutrients for the plant (hydroponic) and plants filter the water for the fish (Rakocy 2012). Hence, the waste water treatment cost will decrease and the production level will increase. The major nutrient input for the system is fish feed and it is expected that the feed will contain sufficient nutrients in available form for best growth of fish and plants. Aquaponics components include fish rearing tank where the feed administered, solid waste removal unit (where solid waste from fish tank trapped and either removed or used as a bioflock source), biofilter (major seat for microbs) and hydroponic trough (where nutrient uptake by plant will take place). Irrespective of the design variation all aquaponics units utilize feed as a major nutrient source. Nutrient availability from fish feed for plant depends on system operational nature, design, crop type and feed quality. Mineralization and demineralization of nutrients from uneaten feed and fishes feces mainly determined by physical, chemical and biological nature of the system. Generally, in well managed aquaponics unit the mineralization process should be take place in separate compartment and nutrients should leach to main plant production unit. Without shifting from conventional thinking of plants as a secondary crop aquaponics productivity might not be enhanced. Therefore, new feed formula appropriate for aquaponics system should be developed. In addition, extracellular product of plant roots released to the system should be characterized based on the wellbeing of fish and microorganisms.

Background

Different fish species irrespective of their thermo tolerance (warm and cold water fish) and feeding behavior (carnivore to herbivore fish) have been tested for different aquaponics system. Irrespective of the variation between diet formulas in a function of fish biology the major nutrient in all diets is Nitrogen in the form of protein. Usualy the feed efficiency in aquaculture is expressed in the performance of fish biomass build up per unit of feed administered. Fish thermal adaptation will affect system performance due to different temperature need of bacteria and plant Therefore, having best feed efficiency on fish in aquaculture will not dictate the efficiency of feed for aquaponics total yield unless all system crops (fish, bacteria and plant) performance is considered.

In aquaponics feed takes the highest operational expense hence looking for best feed quality with respect to feed efficiency in biomass production with respect to fish, microbes and plant will be needed. From the total nutrients in fish diet Nitrogen is the dominant and the expensive one. In conventional aquaponics production context, feed quality is expressed in terms of protein content. Higher protein content will give higher fish yield however it will not guarantee for higher plant yield. In most cases commercial fish diet are used for aquaponics production but this is wrong because the feed originally developed and produced considering only the fish growth but in aquaponics plant growth should also be considered. In commercial fish diets there exists an addition of vitamins, amino acids, preservatives, attractants and minerals. Among several additives for the highest yield of fish, some antimicrobials additives are commonly used; sorbic acid, propionic acid and sodium benzoate. Even if the purpose of additives is for preservation, their impact on the microflora of biofilter in aquaponics should be investigated.

Depending on the species type dietary protein content vary and the ration varies based on the growth stage of the fish. Usually the daily ration is calculated based on total fish biomass in the system but recently aquaponics specialists developed a calculation scheme for aquaponics based on the plant growing area and plant size. But all calculations should be revised based on the integration of fish and plants under specific climatic and operational conditions. Nile tilapia feeding ratio varies based on the fish size and feed type; B-MEG Tilapia diet recommends 15-20% (0.01-2g), 7-10%% (2-15g), 5.9-7% (16-37g), 4.4-5.8% (38-83g), 4.4-5.8% (91-1000g) while Vitarich diet recommend 6-13% (3-15g), 5-6% (22-62g), 3-4% (77-105g) and 2-3% (130-250g) (FAO 2014). Studies suggest that higher feed frequency per day increases feed efficiency in recirculating aquaculture system and this will work aquaponics too (FAO 2014). The major feeding issue in aquaponics is not the ration and frequency rather is nutrient availability for fish, plant and microbs in the system from the feed. Since the original intension for commercial fish diet factory is to increase fish biomass per unit feed, the nutrient for the plant is not considered and needs to be addressed critically. There are some practices in developing fish diet from plant materials by replacing the most expensive nitrogen source (fish meal). This will increase the possibility of obtaining higher nutrient concentration in fish waste but the proportion of these minerals for optimum plant growth will be another challenge.

Fish diet commonly formulated based on the proportion of Protein, Lipid, Energy content, vitamin and mineral composition. The common ingredients includes fishmeal, blood bone meal, meat meal, worms, invertebrates, insects, oil seed (soya bean, sesame, pea nut, cotton seed, sunflower etc…), duckweed, jatropha, moringa etc…(Astuti, Becker et al. 2009, Akinleye, Kumar et al. 2012). Mineral and vitamin will be added in the required proportion based on species types but the existing practice focuses only fish need hence the mineral excreted from fish might not be sufficient to support the plant growth. The commonly used viramin-mineral premix (mg/Kg) contains 300 mg Iodine, 30,000 mg Iron, 60,000 mg Manganese, 4,000 mg

Copper, 100 mg. Cobalt, 100 mg Selenium, 50,000 mg Zinc, 3,000 g Calcium Carbonate and the usually used proportion in fish diet preparation is 2% by feed weight. To increase water stability of diet, different binders are commonly incorporated including wheat grain(FAO 2014). These binders usually contain highe carbon than nitrogen. Carbon to nitrogen (C/N) ratio in fish feed determine the bioflock development in the system. In optimum C/N ratio, bioflock will be developed in the system this might have dual impact (positive and negative). The bioflock that will possible developed due to the intentional use of high carbon to nitrogen ratio for protein supplementation for fish might create root scavenging problem(Meriac, Eding et al. 2014).

Different fish feed quality is expressed as per the water stability of the feed but this might be problem when aquaponics is considered. If feed is too stable in the water possibility of the nutrients to leach in to the water for the plant in dissolved form is reduced that will possiblly cause nutrient deficiency for plants. Issue of managing water stability in aquaponics is still not addressed. The presence of higher cellulose and starch in the fish diet might create suitable environment for the development of plant root pathogens like Pythium and Fusarium. The presence of such pathogens might challenge aquaponics productivity and profitability therefore water stability issue in the current commercial fish feed production system should be perceived in different ways for aquaponics fish feed production.

Since fish is the major biological converter of nutrient in feed for plant growth nutrients, its ability to digest the feed material is critical. In most cases fish ingest only 20-25% of feed administered to the system and the rest will be accumulated in the water column of the system and will wait for microbial actions. The release of nutrients in feed to the water in accessible form for plant use also depends on the digestibility status of the feed, assimilation efficiency of fish and water stability of feed and feces. Plants need to have nutrients (macro and micro nutrients) in available form and sufficient amount for their best growth. The macro nutrients are nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. These elements are needed in large proportions than micronutrients. Availability of these nutrients in aquaponics in sufficient amount in useable form determines the system performance. The amount and proportion of nutrients can vary based on plant species type and size. Leafy vegetable use similar nutrient proportions throughout their growth but fruiting and flowering plants will need to have different nutrient proportion through their growth. Addressing the plant need based on growth scale only through feed adjustment will be a challenge for aquaponics and still it needs scientific investigations.

Issue

In perfectly designed and managed aquaponics system the major nutrient input is fish feed. The existing commercial fish diets are produced considering fish growth and health conditions. Fish diet quality expressed in increased assimilation efficiency and reduced nutrient leakage to the water. Hence using these diets might need to have nutrient supplementation for plant growth. Due to lack of distinct diet prepared for aquaponics all aquaponic operations use fish feed produced for other productive systems. Hence limited growth is observed in different aquaponically produced plants unless supplementary nutrient is added to the system (Rakocy 1997, Seawrighta, Stickney et al. 1998).

Result

Irrespective of diet nutrient composition effluent nutrient composition will show variation with respect to different operational conditions (Table 1). All fish can obtain their mineral need either by direct absorption at their gill or by absorption in digestive tract. Therefore, water stability of feed should be considered in the opposite direction for aquaponics diet formulation.

Different authors report different mineral compositions for different fish in different production systems (Lovell 1991, El-Sayed 1998, FAO 2014). The major nutrient composition varies based on system input (feed) characteristic. Keeping the nutrient requirement for trout in a standard range different nutrient in effluents is found in different amount. If these waste nutrients used to grow tomato the major limiting nutrient will be potassium even if all other nutrients are below the threshold level stated in hydroponic solutions (Trejo-Téllez, Gómez-Merino et al. 2012).

Table 1: Nutrient composition in diet and feces of trout farm (Naylor, Moccia et al. 1999)

Nutrient	Nutrient proportion in feed and effluent of trout farm						
	Feed	Effluent					
N %	7.19	2.83	4.85	3.15	4.8	2.95	1.78
P%	1.15	2.54	1.79	1.34	2.22	0.88	0.38
K%	0.91	0.1	0.15	0.29	0.047	0.05	0.29
Ca%	1.43	6.99			6.1	1.18	0.34
Mg (mg/kg)	0.27	0.53			0.31	0.18	0.35
Na (mg/kg)						11.2	9.3
S (mg/kg)					0.2		
Cl (mg/kg)					0.52	0.006	0.002
Cu (mg/kg)	74.5	33.4	49	47	40		
Fe (mg/kg)	354	1942			769		
Mn (mg/kg)	194.5	487.8			150		
Zn (mg/kg)	336.5	604.9	342	450	458		
Co (mg/kg)	0.99	1.82			0.59		

The nutrient availability is a function of feed ingredients characteristics and amount. Feed ingredients from animal origin had higher nitrogen; phosphorus, Iron, and sodium compositions however plant based ingredients have higher potassium and calcium composition. But the amount of nutrients available in the ingredients is not sufficient even to supplement the fish nutrient requirement hence vitamin mineral premix are frequently used. Therefore in aquaponics nutrients are divided between fish, bacteria and plants and supplementation of additional nutrient or utilization of additional feed might be needed.

Poultry manure contains substantially high amount of nutrients relative to other ingredients except for nitrogen. There are some experimental practices on testing poultry manure as fish feed but it is not yet tested for aquaponics (Al-Salman, Kloor et al. 1991.

Table 2: Nutrient composition of different fish feed ingredients

Nutrient	**Earth worm**	**Blood meal (Feedipedia 2013)**	**Black soldier fly larvae (Bondari and Sheppard 1987)**	**Poultry manure dehydrated (Al-Salman, Kloor et al. 1991)**	**Wheat bran**	**Faba bean**	**Lupin**	**Cotton seed**	**Ground nut**	**Linseed meal**	**Soya bean meal(Feedipedia 2013)**	**Sunflower meal**
Crude protein	61	94	42.1	24.2	17	29	33.8	22	54	34.2	53.5	31.3

(g/kg)												
P (g/kg)	10.2	2.2	9	19.8	11.1	5.5	3.5	5.9	6.2	9	7.9	11.1
K (g/kg)	7.2	3.8	6.9	16.1	13.7	11.5	9.3	12	14.9	11.8	25	16
Ca (g/kg)	5.4	1.3	75.6	50.4	1.4	1.5	2.7	1.5	1.7	4.3	3.6	4.3
Mg (mg/kg)	0.6	0.2	3.9	6.3	4.6	1.8	2	3.6	3.5	5.5	3.4	5.3
Na (mg/kg)	4.4	4.5	1.3	5.9	0.1	0.1	0.5	0.1	0.4	0.8	0.1	0.1
Cu (mg/kg)	29	6	6	69	14	13		10	16	19	18	30
Fe (mg/kg)	357	2186	1370	1444	157	75	57	70	579	175	169	274
Mn (mg/kg)	18	1	246	527	113	10	43	16	41	40	40	43
Zn (mg/kg)		24	108	499	89	34		35	61	19	57	92

Discussion

Nitrogen is the major component of hydroponic nutrient solution and also the major component in fish feed. Different species require different level of nitrogen as crude protein; the common range of crude protein is 26-30% for tilapia, 38-50% for hybrid striped bass and 34-38% for Rainbow trout (Naylor, Moccia et al. 1999, Hargreaves and Tucker 2012). From the total feed 20-30% ingested by fishes depending on feed quality. However, the assimilated nitrogen by fish is mostly less than 20% that means more nitrogen will be released to the water. However, the exiting high quality feed formulation practice tend to decrease the loss of nutrients to water by increasing the feed conversion efficiency and also by increasing the water stability of feces. The practice of replacing fish meal by different plant ingredients due to cost and availability issue decreases the water stability of the feces. In aquaponics water stability is one factor which should be analyzed and scientifically stated. Nutrient load in aquaponics depend on fish and plant biomass but in well proportioned aquaponics system salt build up will be increased through time. According to (Trejo-Téllez, Gómez-Merino et al. 2012) hydroponic solutions contain Ca (150-250 ppm); Mg (50-100ppm); Na (0-20 ppm); K (120-400 ppm); N-NO3 (100-200 ppm); N-NH4 (0-50 ppm); P-PO4 (50-300 ppm); S-SO4 (30-200 ppm); Cl (0-30 ppm); Fe (0-5 ppm); Mn (0.1-1.5 ppm); Cu 0.01-0.1ppm); Zn (0.01-0.6 ppm); B (0.1-0.6 ppm) and Mo (0.001-2.5 ppm). These concentration pattern is higher than the mineral concentration in fish waste water hence shortage of some nutrients are evident if the commercial diet is used for aquaponics system. In contrary the nutrient amount in fish feed is much higher than the hydroponic formula however the availability of these nutrients for the plant depends on the biochemical processes in the system.

Feed ingredients will affect the nutrient availability, if more plant material is used in the diet water stability will decrease and fish waste can easily be dissolved in to water so as to release the nutrient for the plant. Some feed ingredients possibly can be used in aquaponics diets are oilseed cakes, corn grain, wheat grain, wheat bran, rice bran, canola etc….

Nutrient availability for fish and plant will be affected by interactions of other factors like dissolved oxygen, flow rate, temperature, pH and proportion of other minerals. Fish can access dissolved nutrients from water mainly in its gut and through its gill. Therefore increasing the solubility of minerals (nutrients) in feed in aquaponics water might not affect fish growth. But this will be limited for some minerals.

As a conclusion, aquaponics input should be critically optimized based on fish, micro organisms and plant requirements. To increase productivity of aquaponics and to develop reproducible system formula new diet specific for aquaponics might need to be formulated based on specific formulas for aquaponics. In addition feed ingredients, feeding mechanisms, feed property should be reconsidered for aquaponics based on fish, microbs and plant demand.

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