# Plant and fruit waste products as phytogenic feed additives in aquaculture

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**Abstract**. Fish constitutes the fastest growing source of food in the world today. The shift in culture system of some countries from extensive to semi- and intensive farming of fish requires the provision of nutritionally-adequate feeds for the cultured stock. There is also a need to provide additives that will boost health and growth performance of the fish in intensive rearing environment. There are a number of feed additives that are available to improve fish health and growth but these are costly and have issues on leaving residues that pose public health risk and environmental contamination. An alternative approach is to use plant-based products as feed additives for aquaculture, and even better is to utilize plant waste products as sources of these beneficial feed additives. The presence of biologically active ingredients from these plant waste products could be one of the most promising alternatives to the use of synthetic feed additives or antibiotics in aquaculture. The utilization of plant and fruit wastes are of particular interest because this addresses issues on waste recycling, waste reduction as well as competition for human food. These waste materials are recycled by being utilized as raw materials for the production of feed additives; thus, they are brought back to the food chain. Because the sources of the feed additives are waste materials from plants and fruits, the production of these phytogenic feed additives no longer competes as sources of food for human consumption. This review discusses and summarizes the potential use of common fruit and plant wastes and by-products as feed additives for aquaculture. The challenges and opportunities on how to effectively utilize these unwanted yet valuable resources in the context of good health and optimum growth performance of fish and crustaceans are also discussed. The information that is provided will offer avenues for further research along this area and to enable the feed industry to utilize these resources in achieving production of healthy fish and crustaceans towards sustainable aquaculture.
**Key Words**: crustaceans, disease control, fish, health management, phytobiotics.

**Introduction**. The growing need for nutritious and healthy food has driven the demand for fisheries products from both inland and marine sources. However, the productivity of these bodies of water is already compromised due to excessive fishing pressure, growing pollution, toxic contamination, habitat degradation and climate change (Maske & Satyanarayan 2012). The gradual shift from capture fisheries to aquaculture as a source of aquatic products has resulted in the rapid increase in the number of aquatic species being cultured, totalling to 600, that are being farmed worldwide (FAO 2012). The bulk of finfish production comes from the extensive production of carps, however, the intensification in the aquaculture of finfish farming is expanding for both high and low value species (Brudeseth et al 2013). The shift from extensive to semi-intensive and intensive farming of fish, consequently resulted in the increased demand of providing nutritionally complete feeds to the culture stock. The use of nutritionally inadequate feeds may lead in the reduction of growth and production, but more seriously, it can result in nutritional deficiencies or mortality due to higher susceptibility to infectious diseases (Asimi & Sahu 2013).

Fish feed is the most expensive input in aquaculture operations and the bulk of the expenses comes from the purchase of expensive protein sources such as fish meal and shrimp meal (Omoregie 2001). The high cost of feed ingredients can be offset by utilizing other protein sources, such as meat wastes. However, the risk of spreading diseases from feed ingredients to the cultured stock, particularly in land-based farmed animals was a concern for producers. Hence, regulations were enacted to avoid this risk (McChesney 2000). At present, there is a legislation of the European Union (EU) that discourages the use of meat wastes to feed farmed animals (García et al 2005) as they can potentially harbor pathogens that could be transmitted to the cultured stock. Instead, the law only allows the use of wastes as feed ingredients with a minimum microbial and toxic content (Esteban et al 2007). An alternative feed ingredient could be sourced from plant sources that will enhance fish production and at the same time provide the adequate nutritional requirements of the fish (Omoregie & Ogbemudia 1993; Kaur & Shah 2017). These plant ingredients are able to provide the needed nutrients of the fish to produce high quality and safe aquatic products for human consumption but at the same time with minimal effect on environment (Gatlin et al 2007). The use of plant products as protein sources for fish feed has been evaluated from a number of studies involving mostly soybean and to some extent barley, corn, wheat and other grains or legumes with most of these studies showed promising results inspite of the presence of anti-nutritional factors that are inherent to these plant ingredients (Francis et al 2001; Gatlin et al 2007). However, not all components of the plant are utilized as feed ingredients. Some of these end up as waste products, which are of no economic value to the feed manufacturers. Moreover, there are also by-products from these plant sources during processing that are not also used and ended up being discarded.

These plant wastes and by-products during food processing together with uneaten fruit and plant products that are thrown away, contribute to environmental hazards because they may be dumped in landfills or rivers (Wadhwa & Bakshi 2013), causing clogging of waterways and increased incidence of organic pollution. Currently, there is a change in the cropping pattern from cereals to more lucrative fruit and vegetable crops in a number of developing countries (Wadhwa & Bakshi 2013; Wadhwa et al 2015). This shift in the farming system will potentially generate huge quantities of fruit and vegetable wastes in the future. These wastes and by-products have the potential to be recycled and brought back to the food chain by converting them to aquaculture feeds. In addition to being used as feed ingredients for aquaculture, some of these waste products have been tapped as sources of some beneficial bioactive compounds that are added to aquaculture feeds in order to improve health and growth performance of the aquacultured species. Table 1 shows some of the selected plant and fruit waste products that have been used as sources of phytogenic feed additives for both livestock and aquaculture.

Table 1

Commonly used plant wastes and by-products as feed additives or ingredients in the animal feed industry

| *Common name* | *Scientific name* | *Parts utilized* |
|---|---|---|
| Anise | *Illicium verum* | Seeds |
| Banana | *Musa acuminata*/*Musa paradisiaca* | Peels |
| Cinnamon | *Cinnamomum* spp. | Bark |
| Citrus | *Citrus* spp. | Peels and pulp/rind |
| Papaya | *Carica papaya* | Peels |
| Passion fruit | *Passiflora edulis* | Peels and rind |
| Pineapple | *Ananas comosus* | Peels and core |

Adapted from Olusola et al (2013) and Steiner & Syed (2015).

This review discusses and summarizes the potential use of common fruit and plant wastes and by-products as feed additives for aquaculture. In a recent survey conducted by FAO, the various stakeholders and industry players placed high priority on the use of food wastes as animal feed (Makkar & Ankers 2014). Hence, the challenges and opportunities in effectively utilizing these valuable feed additives in the context of good health and optimum growth performance in aquaculture are also discussed. This information is expected to provide avenues for further research along this area and to enable the feed industry use these resources in achieving production of healthy fish and crustaceans for sustainable aquaculture.

**Classification of phytogenic feed additives**. Phytogenics are plant-derived products that are added to the feed with the purpose of improving health and growth performance of the animal. These are widely tested as additives in the manufacture of feeds for livestock, and recently these are being evaluated in the diets for fish and crustaceans in aquaculture (Citarasu 2010). The evaluation of phytogenics in aquaculture is a relatively new area of research showing promising results (Coutteau et al 2011). The mode of action of most phytogenics is still not fully elucidated (Upadhaya & Kim 2017), however, these plant-based products possess the following properties: antioxidant, antimicrobial, anticarcinogenic, analgesic, insecticidal, antiparasitic, growth promoters, appetite enhancement, stimulant of bile secretion and digestive enzyme activity (Asimi & Sahu 2013; Sutili et al 2018). Phytogenics comprise a wide range of substances and are classified according to botanical origin, processing, and composition (Jacela et al 2010). These plant-based feed additives are classified either as: herbs, which are non-woody flowering plants known to have medicinal properties; spices, which are herbs with intense smell or taste and are commonly added to human food; essential oils, which are aromatic oily liquids derived from plant materials such as flowers, leaves, fruits, and roots; and oleoresins, which are extracts derived by non-aqueous solvents from plant materials (Windisch et al 2008). These products are residue-free and are generally considered safe to be used as ingredients or additives in the food industry and as ideal growth promoters in animal diets (Hashemi et al 2008).

Food additives are substances when added to food result in preservation of flavor and enhancement of taste and appearance (Mathe 2015). Owing to their popularity, plants are being utilized by the food industry as sources of spices, condiments and culinary herbs. Plant-based food additives are also utilized as preservatives for some food preparations because they have antimicrobial properties (Davidson et al 2005). Because of these benefits, plants have been used to develop healthy and safe food for humans as well as feeds for livestock, and also these are potential alternatives to the use of synthetic antimicrobials in animal feeds (CODEX Alimentarius 2014).

The content of processed fruit waste is highly dependent on the type of fruit and the part of the fruit that forms the main mass of the waste (Spalvins et al 2018). If the waste is mainly whole fruit, then a large amount of monosaccharides and disaccharides will be available in the waste, as it is in the case with banana wastes, where 5 to 30% of harvested bananas are discarded as waste due to export regulations (Baldensperger et al 1985). If the fruit waste is mostly composed of outer and inner shells, peels and seeds, then the products are predominantly structural polysaccharides (Scerra et al 1999; De Gregorio et al 2002). Table 2 shows some of the bioactive compounds that are present in fruit and plant wastes and by-products that confer beneficial effects to the host when used as feed additives.

Table 2

Bioactive substances derived from selected fruit and plant wastes and by-products and their actions in the host animal

| *Bioactive substance* | *Action* | *Reference* |
|---|---|---|
| Anthocyanidins (from roots of banana) | Anti-parasitic | Anosa & Okoro (2011) |
| Caffeic acid (from coffee shells) | Anti-oxidant; anti-bacterial | Marinova et al (2009) |
| Cinnamaldehyde (bark of cinnamon) | Antibacterial; anti-parasitic; appetite stimulant | Yan & Kim (2012) |
| Limonene, linalool and flavonoids (from peels and pulp of lemon/orange) | Antibacterial | Caccioni et al (1998) |
| Oleanenoic acid (from leaves of olive tree) | Anti-inflammatory; anti-oxidant | Abbas et al (2012) |
| Papain (leaves and peels of papaya) | Anti-parasitic | Bozkurt et al (2013) |
| Tannins (from seeds of grapes) | Anti-oxidant | Abbas et al (2012) |

Adapted from Sethiya (2016).

**Effects on immune response and growth performance**. Modulation of the immune response of the host as a means to combat infectious diseases has generated a great deal of interest among immunologists. Immunomodulation either stimulates or suppresses the various indicators of cellular, humoral, and nonspecific defense mechanisms of the host (Bakuridze et al 1993). In humans, there is normally a balance between stimulation and suppression of the immune system of an organism (Applegate et al 2010). However, when an organism is exposed to some substances such as plant products, this causes a shift in the immune response. For example, ginseng contains saponins, has an immunostimulatory activity as it stimulates production of pro-inflammatory cytokines and macrophages (Tan & Vanitha 2004). On the other hand, ginko biloba contains flavonoids and terpenes, which mediate production of pre-inflammatory cytokines (Li 2000). Such approach can also be applied to aquaculture and could be one of the most promising methods of strengthening the defense mechanism of fish and crustaceans. This can be done through prophylactic administration of immunostimulants (Citarasu 2010; Lazado & Caipang 2014; Reverter et al 2014).

Thanikachalam et al (2010) showed that the inclusion of garlic peels in feed enhanced the hematological parameters of African catfish, *Clarias gariepinus* fingerlings even at low dosage and enabled the fish to be more resistant to infection with *Aeromonas hydrophila*. Similarly, some humoral and cellular immune responses in common carp, *Cyprinus carpio* were upregulated following the addition of stem and root extracts from Chinese herbs *Astragalus* sp. (Yuan et al 2008). The root extracts of this Chinese herb contains significant amounts of polysaccharides, organic acids, alkaloids, glucosides and volatile oils that could enhance immune functions in the fish (Jeney et al 2009). Specifically, the *Astragalus* polysaccharide (APS) from *A. membranaceus* was able to inhibit the production of reactive oxygen species (ROS) as well as stimulate both the humoral and cellular immune responses (Yuan et al 2008). These results indicate that enriched diets with plant extracts have beneficial effects on fish health and enhance the immune system; hence, they could exert an important role in preventing disease outbreaks in aquaculture systems. However, in most cases, the actual mechanisms responsible for these enhancement in the immune responses are still unknown.

Phytogenics from fruit and plant wastes and by-products also possess beneficial effects in the growth performace of fish (Kaur & Shah 2017). Extracts from herbs and spices (*e.g.*, barks, peels and seeds) are reported to improve animal performance by stimulating action on digestive secretions or by having a direct antibacterial effect on gut as observed in animals fed with diets containing capsaicin and piperine from pepper or with cinnamaldehyde from cinnamon bark (Citarasu 2010). These bioactive substances are able to stimulate salivation through amylase production, thus resulting in improved digestibility and availability of nutrients from feedstuff (Chesson 1987). There is a reduction in the amount of undigested materials that pass through the large intestine; hence, limiting the amount of substrate available for the proliferation of pathogenic bacteria (Citarasu 2010). First feeding of African catfish fry with feeds consisting of lettuce seeds and neem seeds resulted in comparable growth with those fed live *Artemia*, indicating the possibility of using these plant waste materials as feed additives (Enyidi & Nduh-Nduh 2016). Further, the addition of sweet potato (*Ipomoea batatas*) peels up to 15% in the diets of tilapia (*Oreochromis niloticus*) resulted in better growth, feed utilization and some biochemical responses of the fish (Omoregie et al 2009). The significance of the study indicated that sweet potato peels can reduce the production cost in farming of tilapia and at the same time improved growth. In shrimp, diets containing papaya leaf meal resulted in better protein digestion, feed conversion ratio, specific growth rate and weight gain of *Penaeus monodon* postlarvae (Peñaflorida 1995). This improved growth performance in shrimp was due to the presence of the the enzyme, papain in papaya leaves.

**Concluding remarks**. Terrestrial plants have been studied and exploited extensively for many years due to the presence of a diverse array of bioactive compounds from their extracts. The presence of these biologically active ingredients could be one of the most promising alternatives to the use of antibiotics in aquaculture. The utilization of plant and fruit wastes are of particular interest because this addresses issues on waste recycling, as well as competition for human food. These waste materials are recycled by being processed as feed additives; thus, they are brought back to the food chain. Because the sources of the feed additives are waste materials from plants and fruits, the production of these phytogenic feed additives no longer competes as sources of food for human consumption. In spite of the potential use of the phytogenics in the aquaculture feed additives industry, their wide scale application in the feed industry is limited, largely because of their inconsistent efficacy and lack of a comprehensive understanding on their modes of action. As such, a better understanding on the effects of these plant and fruit waste-derived phytogenic compounds on the physiological make-up of the host animals will enable us to fully utilize the use of these phytogenic substances for an economically effective and sustainable aquaculture production.

**Acknowledgements**. The authors gratefully acknowledge the support provided by the administration and staff of the College of Fisheries and Aquatic Sciences, Western Philippines University-Puerto Princesa Campus, Palawan during the preparation of the manuscript. C. M. A. Caipang is supported by the Department of Science and Technology – Balik Scientist Program through the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD).

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Received: 08 December 2018. Accepted: 30 January 2019. Published online: 22 February 2019.
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How to cite this article:
Caipang C. M. A., Mabuhay-Omar J., Gonzales-Plasus M. M., 2019 Plant and fruit waste products as phytogenic feed additives in aquaculture. AACL Bioflux 12(1):261-268.