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Interactions Between Economy and Fish Welfare in Aquaponics Systems

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ABSTRACT

Fish are considered to be sentient and capable of perceiving and experiencing pain. Fish welfare in farming conditions can be interpreted with regard to ethics, economic viability, legal issues and consumer's perspectives. Fish welfare is directly related with the economic inputs such as stocking density, mortality and growth rate, affecting the profitability of the aquaponics systems. Therefore, fish welfare has a strong economic dimension in an overall sustainability of aquaponics systems. Thus, there is a growing understanding of a link between fish welfare and feasibility of the fish production systems. The economic achievement of aquaponics production may be linked to fish welfare, particularly with regard to preclude the fish diseases. Sustainable and profitable production of aquaponics can be challenged by poor welfare of fish. The poor welfare might lead to higher yield variation, resulting in poor economic gain. The strategies that can be adopted to protect fish welfare can increase profits and productivity of the aquaponics systems. Fish welfare practices should be considered to improve the production performance in aquaponics.

Keywords: Fish welfare; economy; aquaponics

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The Outlook For The Fish Welfare In Aquaponics

The problems of climate change, decrease in soil fertility, scarcity of resources, and the shortage of water, the stakeholders in agro-food are in pursuit of new and improved solutions for food production and consumption. Food production with aquaponics systems is of potential to solve these problems by controlling the environment. Aquaponics, basically combines two technologies: recirculation aquaculture systems (RAS) and hydroponics (plant production in water, without soil) in a closed-loop system (Junge et al., 2017). The aquaponics ecosystem stands on the three living components: bacteria, plants, and fish. Understanding the function of each component namely, fish, bacteria and plant production in the system is essential for each farmer to be successful.

The segmentation based on economic aspects of the fish welfare in aquaponics may emerge as a key attention point from the angle of producer. Animal welfare in production system may affect economic sustainability (Valenti et al., 2018). In terms of fish welfare, it may be difficult for a business to be conscious of the direct benefits of fish well-being, whereas aquaponics farmers should take into consideration fish welfare. Fish welfare is linked to key productivity indicators and additional effects on the value chain and changes in consumer perception (Kankainen et al., 2012). It may also support a market advantage through more effective, ethically based production strategies (Kadri et al., 2012). In parallel to consumers, sensitivity to the welfare of the animals produced for human beings the demand for the fish produced in good welfare conditions is increasing and may be of significance in niche markets. Consumers particularly in developed countries are willing to pay a premium price for welfare-assured seafood (Alfnes et al., 2017). Fish welfare interacts with the economic sustainability criteria in fish production systems, that applies to the aquaponics systems. A growing recognition that manipulating fish in a humane manner is the first and central issue in fish welfare issues. However, the economic dimension of the fish welfare in the aquaponics needs to be enlightened for the farmers. The aquaponics industry has been growing in complexity and intensity due to its multi-discipliner structure. Consolidation of the aquaponics systems, along with the control of each input and output, will speed up its acceptance as sustainable robust food production technique. The food production in aquaponics systems needs to be focused on more and more on cost in order to generate returns for its investors. Aquaponics is a combined system, which means that both the costs and the benefits are magnified. Somerville et al., (2014) underlined that aquaponics systems are not low-cost because a complete RAS and a hydroponic system need to be set-up and this is the unique most significant element to consider the venture of an aquaponics. The focus of this review is on the interactions between the welfare of fish in the aquaponics and the profit.

Fish Welfare Context and Concept From The Angle Of Farmer

Animal welfare is expressed in the ‘five freedoms’, in general. The ‘five freedoms’ is the well-respected ground to judge on the animal welfare. These five freedoms include the negative feelings; *i)* freedom from feelings of hunger and thirst; *ii)* freedom from discomfort; *iii)* freedom from pain, injury or disease; *iv)* freedom to express normal behavior; *v)* freedom from fear and distress (Anonymous, 1979). As a guide, these freedoms give some information to be able to make a decision about welfare. In fish welfare these freedoms are used to form an opinion about the welfare status. The interpretation of fish welfare can be harder than other animals because fish do not have the markers such as facial movements, vocalization and signal emitting to indicate the pain (Levenda, 2013). Although the feelings of fish are the crux in welfare issues, fish are capable of nociception and can feel the pain or have the capacity for at least a limited range of feelings (Ellis et al., 2012a). Due to the incompetence in understanding the feelings of fish, the stress response is used to assessing the presence of negative feelings. The underlying assumption is that the negative feelings appear in the stress response (Ellis et al., 2012a). Stress is a challenge for fish welfare and fish health. Nevertheless, stress, health, and welfare are intertwined subjects in fish production. Ultimately, to interpret the interaction of these terms and the economic results in the aquaponics it is needed to understand each.

Dykes (2012) has identified the welfare context from the producer's perspectives within aquaculture. These components are compatible with the fish production in the aquaponics systems: *i)* Welfare for legislative context; *ii)* Welfare for advantage in the market; *iii)* Welfare for business success.

Welfare for legislative context

Welfare standards and recommendations issued by EC and EFSA that must be adhered to in terms of legal necessity. The main regulations and opinions are included in Council Directive 1998 (98/58/EC), EU-regulations on transport (Council Regulation EC 1/2005) and on slaughter (Council regulation EC 1099/2009) in the panel of Animal Health and Welfare of EFSA (EFSA 2004). The welfare of farmed fish for five main farmed fish species (Atlantic salmon, common carp, rainbow trout, European sea bass, and gilthead sea bream) regarding the transport and slaughter practices were published by European Commission (Anonymous, 2017).

Welfare for advantage in the market

It is clear that the consumer confidence should be ensured for sustainability of aquaponics. Fish welfare is the topic especially in developed countries and the consumers in these countries pay attention to the animal welfare produced for human consumption. Based on the scientific evidence it is certain that fish are sentient animals and can feel pain. Combining the claim of the Treaty of Lisbon to pay full regard to animal welfare and scientific evidence fish are sentient and it is concluded that fish welfare needs to be considered in any farming practice and any ethical consideration of increased aquaculture (Röcklingsberg, 2015). Hence, higher animal welfare standards for sentient animals became the topic to be discussed for the developed countries citizens. Particularly, the slaughter methods are in the focus of interest for the consumers. An ideal slaughter method is expected to include fish welfare and meat quality.

The slaughter methods with positive effect on consumer perception may cost in the market-driven welfare economy. The effect of slaughter method on the flesh quality has also received considerable attention. Viegas et al. (2012) reported that the procedure of stunning/slaughter by electric shock, percussion and anesthetic, as long as proper practice, cause little pain and better meat quality. The slaughtering of fish by asphyxia in air or ice, gas narcosis and salt exposure, except for some cases, cause much stress and poor meat quality. Thus, killing methods such as asphyxia on ice are not recommended by EFSA. In the current condition, there is no inexpensive, simple, and humanely stunning/killing methods matching with the fish welfare requirements. As meat quality is one of the indicative factors for the market prices, the slaughter methods would always be important both for flesh quality and welfare issues. Poli (2009) reported that the proper pre-slaughter and slaughter practices have to be achieved not only from an ethical perspective but also for the quality of the flesh.

Although the humanely killing methods are prominent in welfare issues, it is still in need of improvement of the application at the farm level. Humane slaughter regulations are applied in some Nordic countries to prevent fish from suffering from pain (Röcklinsberg, 2015). Aside from humanely slaughter practices, the welfare of fish during transport is one of the remarkable subjects, nevertheless, the welfare in transport is not central for the consumers.

Another point of fish welfare perception by the consumer is the taste of fish. According to the study by Feucte & Zander, (2015) that the fish would taste better if they were reared in accordance with their natural requirements and fish welfare is an indication of quality. Solgaard & Yang (2011) asserted that consumers who were interested in eco-friendly production of welfare fish, freshness, and animal welfare tend to be willing to pay extra.

Welfare for business success

Aquaponics systems are influenced by a multitude of variables, therefore, cost: benefit tools are difficult to use in the aquaponics systems. In the case of aquaculture or RAS the Key Performance Indicators (KPIs) are outstanding indicators for the business. KPIs such as growth rate, mortality, and feed conversion ratio (FCR) are easy to measure and can be utilized in decision instead of complicated economic models (Dykes, 2012). The producer can realize the profit gain after welfare actions using principal KPIs and these indicators are directly related to welfare improvements and profitability of the production. Improvement in fish welfare practices may be correlated with an increase in economic performance, thus, good welfare actions may end with high productivity. Valenti et al. (2011) and Feucht & Zander, (2015) highlighted the necessity for the inclusion of animal welfare elements in sets of sustainable aquaculture indicators in terms of economic, environmental and social aspects. Valentini et al., (2011) emphasized that animal welfare has not been included in these three dimensions of sustainability, emphasizing that each should have involved the fish welfare context. It is normally expected from the aquaculture business to be productive and profitable with optimizing the use of capital and natural resources, conserving the environment. Aquaponics does not differ from the aquaculture regarding the basic economic principles of sustainability. Aquaponics systems as the new food production technique are not explicit regarding the return of the profit to the farmer/producer due to differences in systems, products, market value, etc. The profit increase against the fish welfare action in aquaponics systems is indeterminate yet. However, it is known from the experience of the aquaculture that the improvements in fish welfare have been proceeded by the economic gain to keep the Key Performance Indicators (KPIs) normal (Dykes, 2012). In the process of maturing of aquaponics industry, the effects of welfare actions on the profit would be clearer. One of the best examples of this has been within the field of water quality. Elevated concentrations of carbon dioxide in water detected as a serious risk factor for both growth and feed efficiency in Atlantic salmons. It is reported that, if the carbon dioxide stripping technology is used to decline the carbon dioxide in the water, the profit is recorded due to an increase in the productivity (Kadri et al., 2012). Basically, the requirement to develop common standard welfare indices for fish in culture in order to assess and improve any deviation from the normal physiological state of the fish in their aquacultural holding devices (Moshood, 2014). This is the reality for the aquaponics.

The Relation Between Fish Welfare Elements and The Profitability Of The Aquaponics Systems

In the aquaponics systems fish and plant requirements do not always match perfectly (Somerville et al., 2014). This may include challenges of different aquaponics operating systems. Maintaining the optimal water quality characteristics is crucial for the welfare and health risks of various aquaculture operations. It is highlighted that the potential risk of pathogen in RAS technologies can only be eliminated with appropriate inputs, including water that requires purification to the high standard required for efficient re-use (Murray et al., 2014).

In aquaponics, a production format for co-cultured species (aquatic organisms and plants) can impair the physiological status of the fish. This may be mainly caused by abnormal water conditions, which are disrupting the welfare conditions through complex interactions between water quality parameters and fish physiology (Yildiz et al., 2017).

In aquaponics the water quality parameters for fish are within a similar range with the plants exempt from water temperature and pH. It is known that these two important water parameters have impact on optimization of aquaponics production, hence, the fact is that fish welfare/health issues are interrelated with the water quality. As fish are ectotherms, they can not keep their body temperature constant; fish body temperature is basically the same as surrounding water temperature. The implication of water temperature is that fish are dependent on exposure to suitable range of water temperatures for proper functioning (Huntingford & Kadri, 2014). The water temperature as a welfare indicator is a significant correlate of tolerance limits and temperature preferences of the fish (Stien et al,. 2013). As significant KPIs such as growth rate, feed intake, FCR, and stomach evacuation rate were under the effect of water temperature and fish size as stated by Handeland et al. (2008), the water temperature in aquaponics should be included in the economic aspects of the welfare. The pH stabilization is vital in aquaponics systems, because pH is critical to all living organisms within a cycling system that includes fish, plants and bacteria. The optimal pH for each living component is different (Goddek et al., 2015). Optimal pH range may vary in fish species and be within the range of 6.5-8.5. Water pH higher than 11 or lower than 4 is lethal to most fish species. pH changes cause stress in fish. Gill tissue in fish is mirror for water quality and low pH affects the sensitive gill tissue. Low pH can cause acidosis and stimulate the mucus production in the gills, resulting in osmotic stress. Chronic acidosis is associated with impaired growth and FCR. Moreover, pH is related to other water chemistry parameters such as ammonia. Water temperature and pH are the important factors having an impact on fish welfare and the efficacy of production in aquaponics. In profitability aspects of the aquaponics systems, the linkage between water quality and fish welfare should be taken into consideration, especially water temperature and pH. In RAS systems, which are analog systems to aquaponics, fish welfare can be disrupted by exposure of fish to various stressors, particularly in relation to stocking density, chronic exposure to poor water quality and metabolic by-products due to water treatment technology in low standard or inexperienced management (Murray et al., 2014).

The tolerance of fish to water quality limits the diversity of fish species to be grown in aquaponics systems. This is another point in terms of aquaponics feasibility, thus, in order to meet the welfare standards tolerant fish is entailed in selecting the fish species such as tilapia. These fish species may be low-cost, causing poor economic returns. The fact remains that species-specific welfare definition still does not exist and the topic to be in need of more work (Dykes, 2012). More research is needed to manage the cycling of nutrients (especially nitrogen and phosphorus), and pH levels, so that aquaponics can be economically viable, which will also affect its overall sustainability.

In aquaponics the growth rate is conditional and depends on some factors specific to aquaponics such as water change, filter success, and stocking rate. The increase in the stocking density of fish results in an increase in revenue, however, this is directly related with the suitable water change and filters. If the filters do not function properly higher stocking density may result in economic failure (Karimanzira et al., 2017). High stocking density is in demand by the producers, partly for the reason that operating at higher stocking densities can make production costs less. Decreased stocking rate leads to increased production and the labor cost, eventually increase in the price of the fish. Thus, economic sustainability and profitability for farmer should be taken into consideration in estimating the stocking density.

On the other hand, higher stocking density is considered stressor in aquaculture and related with the well-being of fish. High stocking density can impair the well-being of fish in aquaculture. Higher stocking density has a negative impact on the fish health status and economic consequences (Huntingford & Kadri, 2014). There is extensive literature on the stocking density and the welfare of fish, e.g., disease problems increased in *Senegalese sole* rearing at high stocking densities as reported by Costas et al., (2008). Liu et al., (2017) reported that the salmon raised in low stocking density had higher special growth rate (SGR) and lower FCR in comparison to high stocking density. Higher density in salmon aquaculture caused stress and impaired welfare, as reflected in some blood parameters such as blood glucose, hematocrit, and hemoglobin. Nevertheless, too low fish density may also impair welfare. There is no exact optimal density in aquaculture because it may be varied in fish species, the size of fish, culture techniques (i.e. RAS, sea cage, pond etc.). Van de Nieuwegiessen et al., (2009) emphasized that stocking density is an impact on the welfare of African catfish, clearly, stocking ensity is the factor with many interacting elements that affects fish wellbeing. In aquaponics, the plant productivity interacts with the stocking density regarding the nutrients amounts from the fish culture part. The stocking density can not be too low in aquaponics to ensure enough nutrients for the plants. Consequently, the stocking density in the aquaponics is the matter of fish welfare and economy of the system, both for plant and fish.

One of the KPIs, the growth rate in fish has been used as a marker for the welfare conditions in aquaculture. Reduced growth rate may be a signal of reduced welfare. Stress disrupts the balance between energy intake and energy utilization. Growth is reduced through a negative effect on energy balance due to activation of the HPI axis for a long period (Ellis et al., 2002; Huntingford et al., 2006). Moreover, stress has suppressive effects on the secretion of growth hormones in fish (Pickering, 1993), hence, stress has a direct link with the growth. The effects of stocking density on growth, formulating as mean weight or length at the end of an experimental period, the proportion of weight to length, individual or mean specific growth rates have been previously discussed (Ellis et al., 2002; d'Orbcastel et al., 2009). The contradictory findings for the correlation between stocking density and the fish growth exist in the literature. While in some studies higher fish density with increased growth was reported (Hecht & Appelbaum, 1988; Kaiser et al., 1995; Hecht & Uys, 1997), no significant effect of stocking rate was detected in others (van de Nieuwegiessen et al., 2009). In the aquaponics systems, the stocking rate is also associated with fish growth to plant productivity in the context of total biomass. Yildiz and Bekcan, (2017) reported that fish stocking density has an impact on total biomass, considering the fact that the maximum growth in tilapia corresponding to maximum plant biomass (tomato plant) was recorded in the high stocking density (50 kg/m^3) in one-loop aquaponics systems. The lower fish density resulted in decreasing plant biomass. The suboptimal nutrient supply for the plants may be related to the inappropriate stocking rate (Herman et al,. 2006). It should be emphasized that low stocking densities are not considered in the commercial fish production by the producers. The stocking rate in aquaponics can be poised to obtain maximum fish growth and plant growth. It is an explicit that the interaction among the fish density, growth performance and welfare conditions should be holistically evaluated to optimize the whole dual (fish and plant) aquaponics system. Goddek et al. (2015) reported that each plant and fish species in the aquaponics have different nutritional needs that are also dependent on the growth stage/life-cycle and external factors, which can be critical in fish growth. Although the optimal stocking density matching normal fish growth and fish welfare can not be easily predicted in aquaponics due to the system complexity the welfare of fish in aquaponics should be shown using the various welfare indicators. In addition, stocking density is not the only possible reason for variation in growth rates; environmental stressors such as fluctuations in pH and temperature, as well as insufficient dissolved oxygen can be used to explain the deviations from the normal growth rate, as stated by Huntingford et al., (2006). Two critical factors in aquaponics in terms of providing the requirements of the plants; water temperature and pH can act as a stressor and may retard the growth in fish. As an example, it has been found that the increase in water temperature constituted a stress factor in olive flounder and affected the fish growth negatively, reflected by decreased feed intake, total length, and body weight (Hur et al., 2008). As a matter of the fact, water temperature is the critical factor to be considered both for fish and plant requirements in the aquaponics as explained above. Similarly, lower pH may affect the growth rate of fish. The tolerance of fish to acidity varies to fish species, however in general, the growth may decelerate in low pH values. Ultimately, growth rate relating to the profitability of the aquaponics systems may reflect the welfare status of the fish.

The economy of the aquaponics seems highly vulnerable and can be affected by the loss of the fish. As profitability in fish farming is directly related to survival, the mortality is normally being remarked by the farmers. Mortality, one of the KPIs, is of great potential as a welfare indicator (Ellis et al., 2012b). Because mortality is an essential determinant of the profitability of any farming operation, farmers take notice of monitoring and reducing the mortality. The true situation in fish farming business is that large fish represent a much more financial investment related with the feed consumed in a period of time than small fish. Thus, mortality of large fish is typical of a considerable economic loss (Ellis et al., 2012b). The cost of mortality increases with fish size and time elapsed in relation to the inputs such as feed consume and energy spend during the production cycle (Kankainen et al., 2012b). Although the mortality is conceived in the aquaponics systems, there is a scarcity in robust data on mortality rates and causes within the aquaponics systems. The reason for the high mortality in fish production may have resulted from disease problems. Hence, another point interrelating with minimizing production losses in the aquaponics systems is to keep the fish healthy. As the use of antimicrobials in aquaponics systems is improper, maintaining the fish in good health with the biosecurity applications seems to be the most rational way. Health parameters can be used in monitoring welfare as good health is completely necessary for good welfare and vice versa, poor welfare conditions lead to impaired health (Segner et al., 2012).

Fish diseases may hinder the entire production of the aquaponics system by wasting the production resources and/or constraining the production output along the same line as the other livestock farm animals (Vetter et al., 2014). One of the issues specific to aquaponics is the bacteria in the system. Bacteria have crucial role in the aquaponics systems due to their inclusion in nitrogen cycling. Nevertheless, microbial profile of aquaponics is still unknown and the existing knowledge is from the similar studies with the microbial characterization on recirculation aquaculture systems (RAS), as reported by Munguia-Fragozo et al. (2015). The identification of microbiome in aquaponics systems is challenging. The risk of the bacteria in the system is related to the probability of the pathogen bacteria existence. The bacterial community can show a variation in different niches of the aquaponics system (Schmautz et al., 2017). In aquaponics, overall suspended organic and nitrogen compounds such as uneaten food, fecal matter found in biofilter can create the suitable environment for microbial growth, because the solids removal and biological filtration are in the same part in the system (Munguia-Fragozo et al., 2015). These compounds associated with the microbes and pathogens in the system, having an impact on fish welfare may impair the fish health or vice versa. As the fish diseases have considerable difficulties in treating with antimicrobial agents in the aquaponics system, it is deemed that the biological control with organisms exerting inhibitory effects on fish and plant pathogens can have potential to prevent the diseases in aquaponics, to avoid the disadvantages of drug or chemical use in the fish production (Sirakow et al., 2016). However, the extent of the preventive effect of biological control is not obvious. Fundamentally, fish diseases pose a risk in the aquaponics systems, resulting in limitation of production by losses due to death, slow growth, improper FCR and totally, lower capacity utilization for both fish and plant production in the aquaponics system as a whole. The majority of losses of fish in aquaculture is accompanying with the predisposing factors such as unfavorable conditions related to environmental factors and the pathogens are not the sole factors for the losses. In general, it has been known that in fish diseases, the pathogens and unsuitable culture conditions function concurrently. From this angle, the fish welfare practices may preclude the resource loss and related expenditure.

In evaluating the economy of aquaponics the context of "organic" is obviously prominent. Quagrainie et al. (2018) reported that economically feasible aquaponics stipulates that the production should have some specific features such as certified organic production. Hence, aquaponics production of vegetables can be considered organic production with higher prices in the market. Although the feasibility of the aquaponics systems is correlated with factors such as quantity produced, seasonality, type of vegetables, fish market etc., organic production can support the economic viability of aquaponics systems. Thus, in the strategy of organic production in the aquaponics systems, good health and good welfare issues become more important. The feasible aquaponics production from the business perspective is linked to fish welfare, particularly to prevent the fish diseases.

In overall outlook, aquaponics offers alternative solution to the water scarcity through water recycling and sludge recovery and reduce aquaculture waste. This can be regarded parallel to the circular economy targets. However, aquaponics systems are extremely sensitive in maintaining the balance among the components of fish, plant and bacteria in the system while re-using the water. Fish welfare and overall fish productivity can be affected by these system characteristics in aquaponics. There are many factors to consider in aquatic species production for profit. This focus should be along with the fish health. One of the keys to success in aquaponics development therefore, lies in keeping fish in good welfare conditions that good welfare defines the good fish health and eventually good fish biomass to sustain the system. There seems to be an interaction between potential profitability of the aquaponics system and welfare of the fish.

Conclusion

The economic gains in aquaponics systems are based on both fish and plant gains, implying that the feasibility of the aquaponics systems is dependent on both plant and fish productivity. This format of the aquaponics makes operations highly sensitive to feasibility. The well-being of fish is affected by the operational input parameters such as fish density and feed consumption. Therefore, the input costs play an important role in an overall economic sustainability of the aquaponics systems. The producers of aquaponics could examine the fish welfare practices for two points of view: 1. The productivity changes of the system after good fish welfare practices; 2. The good welfare practices matching the optimal growth of plant. Fish welfare practices can be an economic burden for the aquaponics farms at the beginning. However, in the long term embarking on the welfare practices returns the profit. It can be foreseen that good fish welfare can make good economic sense in the aquaponics.

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