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Recent Innovative and Technological Developments in Aquaculture

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Abstract

In recent years world aquaculture production has been increased with innovative and technological developments within fisheries sector and scaled up in world total fisheries production. This increasing aquaculture production quantity depends on production of new species in aquaculture, new raw material production and processing techniques in fish feed manufacturing, innovative production systems and technologies, biotechnological developments. Aim of this paper is to review innovations and technological developments in aquaculture engineering in recent years. These technological and innovative developments are production of egg and fry from eel (*Anguilla sp.*) and bluefin tuna (*Thunnus sp.*) at experimental conditions, production of new marine and freshwater species like meagre (*Argyrosomus regius*), wreckfish (*Polyprion americanus*), pikeperch (*Sander lucioperca*) etc., new raw material, additives, enzymes in fish feed, improved digestibility, biological and technological developments in recirculating aquaculture systems as part of filtration especially nitrogen and phosphorus removal, technological innovations in cage aquaculture, new genetic selection and breeding techniques.

Key words: Aquaculture engineering, innovations, technological developments

1. Introduction

Today the world population of 7.3 billion and it is estimated that it will reach 8,5 billion in 2030 and 9,7 billion in 2050 [1]. Aquaculture is a vital source of nutrients in meeting the rapidly growing population's need for animal protein [2]. Currently, a total of 199,702 million tons of aquaculture production is provided by 106 million tons by aquaculture production. It is expected that in 2030 more than 60% of the amount of aquatic products separated by human consumption will be supplied by aquaculture production [3]. However, considering the world animal meat production, the production of aquaculture is clearly higher than all other animal meat sources and it is estimated that this situation will continue until 2030 [4].

Considering that the production of aquatic products will increase and a significant part of the production will be from aquaculture, new technologies and production methods will be needed. The aim of innovations is not only to achieve high production quantities, but also to minimize environmental impact. With sustainable production, it will be able to reach the minimum level of impact on the environment while achieving future production targets. In this article, information will be given on new technologies and production methods to be used for intensive production and high sustainability.

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2. Production of egg larvae and fry from new species

Difficulties and restrictions on supplies and prices of glass eels are serious problems in the eel culture industry. Therefore, the development of artificial breeding techniques for the eel is desired developments from aquaculture industry. The first production in captivity achieved in 2003 by Japanese researchers Tanaka et al. [5] Then Abe et al. [6] developed an in vitro culture system for producing eel larvae from immature ovarian follicles in Japanese eel (*Anguilla japonica*). After that production of egg and larvae of anguillid eel took forward by other researchers [7, 8, 9].

In 1986 Nippon Formula Feed Manufacturing Company, Ltd. (now called Maruha Nichiro Holdings, Inc.) in 1987 became involved in tuna farming and succeeded in the spawning of 4 year-old broodstock [10]. After that Kinki University has consequently succeeded in describing the full life cycle of the Pacific bluefin Tuna (*Thunnus sp*.) in captivity, and also achieved its aquaculture life cycle [11].Nevertheless, solutions are needed for the remaining technological issues of Pacific bluefin larviculture, such as sinking death on the bottom of the tank in the early life stage, called ‘sinking syndrome’, the search for appropriate food (kind, size, and nutrition) for tuna larvae between the larvae and juvenile stages, cannibalism, bumping against walls, malformation, virus diseases, and other problems [12]. In addition De Metrio et al. [13] published first larval rearing efforts on bluefin tuna.

Meagre (*Argyrosomus regius*) is a teleost fish species that belongs to the Sciaenidae family [14]. This species has been proposed as a candidate for marine finfish diversification on commercial aquaculture in Mediterranean and Eastern Atlantic coasts, mainly related to their fast growth rate and flesh quality [15, 16]. Studies on reproduction of meagre studied by several authors [17, 18].

Wreckfish (*Polyprion americanus*) was studied to diversify European aquaculture and successful results achieved by European researchers supported with EU projects [19, 20].

Pikeperch (*Sander lucioperca*) egg and larvae was studied by several authors but remarkable improvements ensued with EU projects by using recirculating aquaculture systems recently [21].

3. Fish Feed

Recent years fish feed industry focused on alternative raw materials to improve digestibility and fish feed quality. Recent studies published on plant protein sources [22], insects [23], other animal byproducts [24], protection of feeds with antioxidants [25], and herbal biomedicines to improve fish health [26]. In addition some authors studied on feed manufacturing types like silages [27] and fermented feeds [28]. On the other hand fish feed additives [29] and enzymes [30] used for better digestibility and fish health.

4. Technological Innovations in Cage Aquaculture

In the aquaculture production, the use of net cages for aquaculture activities, which allow the use of different aquatic environments, except for limited terrestrial facilities, first started in the Southeast Asia region in the 1800s [31]. In the early days, net cages built in enclosed basins, in closed coves and gulfs at sea, and lakes in fresh waters, consisted of small size (5x5x5) galvanized steel, wood and plastic bins to provide buoyancy [32]. Technological developments have begun to use high-volume plastic cages that are resistant to challenging offshore conditions, reaching a diameter of 200 m, along with the need for systems to be used on open seas and larger capacity systems.

Figure 1. The first net pen cages used in aquaculture and the latest technological systems

Currently, only functional and high production capacity is aimed at net cage cultivation which is the most beneficial system for production of aquatic products from technology and engineering. In the days when the environmental impact of aquaculture is being debated, the future of mesh cage systems is likely to focus on portability and sustainability. The next generation mesh cage systems that are in the design stage, being manufactured or being used are mentioned below.

4.1. Aquapod

The system, which started to be used in 2011, is a circular structure formed by joining triangular net parts. It is very suitable for aquaculture in open sea conditions due to the structure of sinkable and it is completely surrounded by nets. When the air in the system is filled and emptied, the position of the water column and the water level are adjusted. In the system, the feed is made by float pipes which communicate with the water surface. Divers and electronic devices keep the system under constant control [33].

Figure 2. Aquapod

4.2. Smart Floating Farms

The intelligent floating farm model is a highly productive system where the technological top point is used in aquaculture. There are many layers in the system. On the top floor there are solar panels to meet systems energy needs, areas where vegetable production is made in the middle layer and pools where fish production is made in the bottom layer. With the Aquaponic production, the wastewater from the fish ponds is used in vegetable production, while the vegetable products can be used in feeding fish. The system, including the energy field, is capable of self-sustaining and highly sustainable production. In addition, thanks to the packaging units located in the middle section, harvested products can be shipped directly. This system is especially good for cities with a high population [34].

Figure 3. Smart floating farms

4.3. Ocean Farms

The Norwegian company was developed by Salmar. The system with steel construction has a diameter of 110 meters and a depth of 42 meters. The presence of the control room and feed reservoir in the system minimizes the logistic need from the shore, and every stage of production can be controlled and intervened if necessary. With the volume it has, 8 times more production can be realized in the system than standard net pen systems [35].

Figure 4. Ocean farms

4.4. Nordlaks Havfarm

The ocean farm looks like a big ship. The system with steel construction has 6 net pen cages with dimensions 50mx50mx60m. When fully operational, 10,000 tons of production can be done. The system is fixed to the floor by the head and its position changes towards the wave direction with the help of the propellers on the rear side. The desired time allows for displacement. All operations such as feeding, moving fish and harvesting are carried out in the system using mechanization. The system will be used for the first time in 2017 [36].

Figure 5. Hayfarm

5. New Eco-friendly Aquaculture Practices

Aquaculture production is rapidly increasing day by day in response to increasing animal protein needs. In parallel, an increase in the environmental impact from aquaculture will also be seen. As the most basic entry in the aquaculture, the fish meal is dispersed to the water environment in particulate and dissolved form, as the inedible feed and metabolic debris, and creates an environmental load. 72% of nitrogen, 79% of carbon and 82% of phosphorus in fish feed are distributed in the water environment [37]. Highly enriched nutrient inputs into the system have many negative effects, from degradation of water quality to eutrophication [38]. By eliminating all of this environmental impact, sustainable production techniques have emerged that minimize the environmental impact. These techniques are currently used in closed circuit systems, aquaponic and integrated multi-trophic aquaculture systems (IMTA).

5.1. Recirculating Aquaculture System

In traditional production methods, a flowing water technique is used in cultivation. This technique is based on leaving the plow again using clean water entering the farm. This greatly increases the need for water and causes the discharge of relatively dirty water into the reservoir as a result of the use of the water. After using water in recirculating aquaculture systems, the particle filter, sand filter, biological filter, U.V. Filtration and ventilation, through physical, chemical and biological remediation. Compared with the conventional method, 98% less water is used in recirculating aquaculture systems [39]. In this respect, maximum production of aquatic products is achieved with minimum environmental impact and water use.

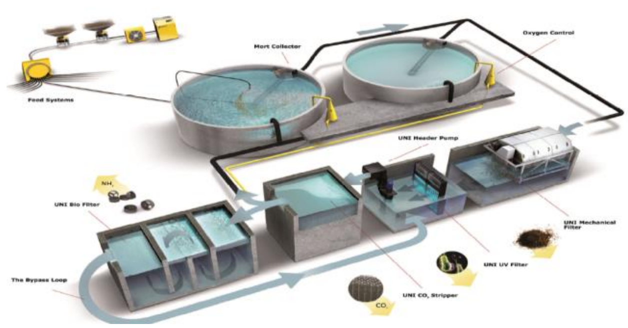

Figure 6. General view of recirculating aquaculture system

5.2. Aquaponics

Aquaponic is a closed circuit aquaculture system in which aquaculture and hydroponic system are used together and agricultural and fish production operates in an integrated manner. In this system, water is circulated between fish tanks and bases where vegetative production is made and can be carried out in both production with the same water [40]. Working principle of systems; Ammonia is released by fish into the water environment as waste. Thanks to the microorganisms present in the medium, ammonia is first converted to nitrite followed by nitrite. While nitrate is used by plants to grow, the level in the aquatic environment also decreases in this way. Thanks to the aquaponic systems, both fish production and plant production are realized with minimum water usage, resulting in low environmental impact [41]. Aquaponic systems have a high sustainability potential due to their advantages such as less water requirement, minimum environmental impact and the ability to grow organic and polycultured fish [42]. However, there are disadvantages such as high installation costs and operating costs [43]. With the widespread use of aquaponic systems, it will be possible to produce water products in areas where water supply is not sufficient for traditional production and agricultural production in less favorable areas.

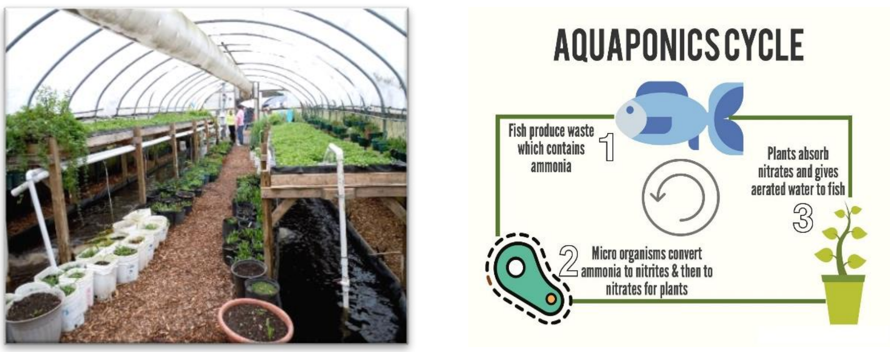

Figure 7. Aquaponic model and aquaponic cycle diagram

5.3. Integrated Multi-Trophic Aquaculture Systems (IMTA)

IMTA is a system based on polyculture and is based on the production of living species which absorb the nutrient waste from aquaculture [44]. In this system, particulate wastes are absorbed by bivalve organisms and echinoderms, while water-soluble wastes are absorbed by water algae. Thus, while the environmental impact from aquaculture has been reduced to a minimum level, fish production, bivalve crustacean production and algae production have been realized, further increasing the economic gain from aquaculture. In research, it was determined that mussels grown integrated with trout farms developed %50 faster and brown moss was %46 faster [45]. In other studies, sea bream fish were integrated with crustaceans and ıt was seen that, reduction in environmental impact from sea bream breeding and %50 reduction in organic sedimentation at cage bottom [46].

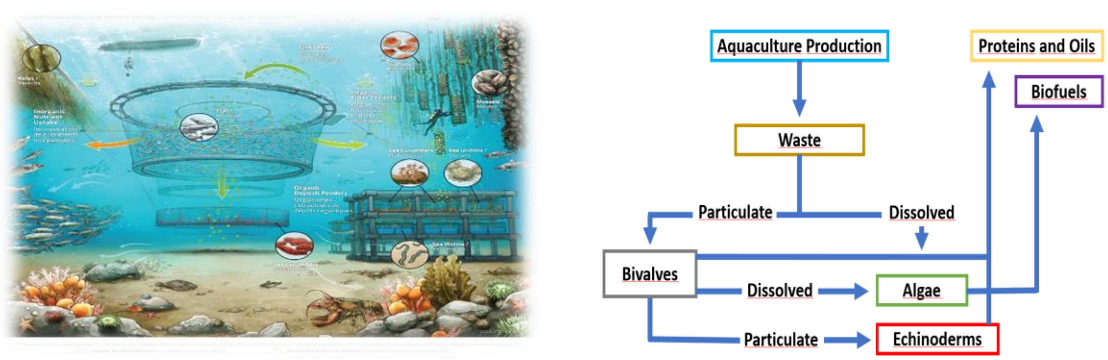

Figure 8. General view of IMTA and IMTA cycle diagram

6. Genetic Selection and Breeding programs

A traditional breeding programs in aquaculture focuses on economically important traits, such as individual growth. Selection for growth in a competitive environment may increase competition, and negatively impact production and animal welfare [47]. Instead of selecting for direct breeding values only, breeders should select for total breeding values. The total breeding value combines direct and social genetic effects, and selection for total breeding value maximizes response to selection in socially-affected traits [48]. As a result breeding selection studies considered social traits in complete perspectives.

Genetic improvement has potential to reduce various environmental impacts simultaneously but this aspect of selective breeding has not been explored so far in fish production. In many fish species, genetic response to selective breeding is high due to high heritability of commercial important traits, high intensity of selection and high genetic variation [49]. Genetic improvement also obtained through selective breeding programs, is a powerful tool to generate cumulative change in animal population. A genetic change in fish performances is expected to improve not only economic benefit of farms [50], but to reduce also environmental impacts, as shown in livestock [51].
As a result genetic improvement and selective breeding studies are directed to social and environmental issues in additional to fundamental principles

7. Conclusion

Aquaculture, from past to present, has evolved along with technological developments in all parts. Cultivation of new species, improved fish feed, enhanced fish health and new production systems is developing at an unprecedented pace. The net cage cultivation in which the production is done intensively is examined, the first systems used are steel-wood structure, low capacity, whereas high capacity integrated systems that are resistant to open sea conditions started to be used together with developing technology. Another technological innovation is the use of recirculating aquaculture systems in aquaculture to reduce environmental impact to a minimum level and the application of environmentally friendly production methods such as aquaculture and Integrated Multi-Trophic Aquaculture Systems (IMTA). With these methods it is aimed to minimize the environmental effect while achieving maximum productivity in fish culture. It also allows for integrated cultivation, allowing more than one species to grow at the same time. Aquaculture will continue to play an important role compensating the rapidly growing population's need for animal protein in the future. To implement this mission, it is very important to follow modern technological developments in all engineering fields and to perform both yield increase and environment friendly production.

References

[1] The United Nations (UN) Department of Economic and Social Affairs. World population

projected to reach 9,7 billion by 2050. Access Date: 11.06.2017. http://www.un.org/en/development/desa/news/population/2015-report.html

[2] Tidwell JH and Allen GH. Ecological and economic impacts and contributions of fish farming and capture fisheries. Access Date: 11.06.2017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1084135/

[3]The World Bank. Fish to 2030 Prospects for Fisheries and Aquaculture. Agricuture and Environmental Services Discussion Paper 03, 2013; p.102.

[4] Anonymus. Access Date: 12.06.2017. https://www.mla.com.au/prices-markets/market-news/the-worlds-leading-meat-protein-is.--fao/

[5] Tanaka, H., Kagawa, H., Ohta, H., Unuma, T., Nomura, K. The first production of glass eel in captivity: fish reproductive physiology facilitates great progress in aquaculture. Fish physiology and biochemistry, 2003; 28.1: 493-497.

[6] Abe, T., Ijiri, S., Adachi, S., Yamauchi, K. Development of an in vitro culture system for producing eel larvae from immature ovarian follicles in Japanese eel Anguilla japonica. Fisheries Science, 2010; 76(2), 257-265.

[7] Okamura, A., Horie, N., Mikawa, N., Yamada, Y., Tsukamoto, K. Recent advances in artificial production of glass eels for conservation of anguillid eel populations. Ecology of Freshwater Fish, 2014; 23(1), 95-110.

[8] Tanaka, H. Progression in artificial seedling production of Japanese eel Anguilla japonica. Fisheries Science, 2015; 81(1), 11-19

[9] Asturiano, J. F., Sørensen, S. R., Pérez, L., Lauesen, P., Tomkiewicz, J. First production of larvae using cryopreserved sperm: effects of preservation temperature and cryopreservation on European eel sperm fertilization capacity. Reproduction in Domestic Animals, 2016; 51(4), 485-491.

[10] Masuma S. Development on techniques of stock enhancement for Pacific bluefin tuna Thunnus orientalis by the Fisheries Research Agency (Formally, Japan Sea Farming Association). J. Fish. Tech.. 2008; 1:21-36.

[11] H. Kumai, S. Miyashita. Life cycle of the Pacific bluefin tuna is completed under reared condition Nippon Suisan Gakkaishi, 2003; 69, pp. 124-127.

[12] Masuma, S., Takebe, T., Sakakura, Y. A review of the broodstock management and larviculture of the Pacific northern bluefin tuna in Japan. Aquaculture, 2011; 315(1), 2-8.

[13] De Metrio G, Bridges CR, Mylonas CC, Caggiano M, Deflorio M, Santamaria N, Zupa R, Pousis C, Vassallo-Agius R, Gordin H, Corriero A. Spawning induction and large-scale collection of fertilized eggs in captive Atlantic bluefin tuna (Thunnus thynnus L.) and the first larval rearing efforts. Journal of Applied Ichthyology, 2010; 26(4):596-9.

[14] Chao, L.N. Sciaenidae, P.J.P. Whitehead, M-L. Bauchot, J.C. Hureau, E.Tortonese (Eds.), Fishes of the Eastern Atlantic and Mediterranean ¼ Poissons de l'Atlantique du nord-est et de la Me´diterrane´e, Unesco, Paris, 1986; pp. 865-874

[15] Quéméner L. Le maigre commun (Argyrosomus regius): biologie, pêche, marché et potentiel aquacole. Editions Quae; 2002.

[16] Mateos AV. Una nueva especie para la acuicultura marina, la corvina,(Argyrosomus regius). InActas XI Congreso Nacional de Acuicultura. A. Cervino, A. Guerra and C. Pérez (Eds). Actas XI Congreso Nacional de Acuicultura, Vigo, Espana 2007; (pp. 519-522).

[17] Roo, J., Hernández-Cruz, C. M., Borrero, C., Schuchardt, D., Fernández-Palacios, H. Effect of larval density and feeding sequence on meagre (Argyrosomus regius; Asso, 1801) larval rearing. Aquaculture, 2010; 302.1: 82-88.
[18]Mylonas, C. C., Mitrizakis, N., Papadaki, M., Sigelaki, I. Reproduction of hatchery-produced meagre Argyrosomus regius in captivity I. Description of the annual reproductive cycle. Aquaculture, 2013; 414: 309-317.
[19] Peleteiro, J. B., Linares, F., Vilar, A., Fauvel, C., Duncan, N., Rodriguez, C., Mylonas, C. Diversify: results from the first year of wreckfish (Polyprion americanus) culture. In: Aquaculture Europe 2015-Aquaculture, Nature and Society, October 20-23 2015, Rotterdam, The Netherlands. 2015.
[20] Matusse, N. R., Pita, A., Peréz, M., Trucco, M. I., Peleteiro, J. B. Presa, P. First-generation genetic drift and inbreeding risk in hatchery stocks of the wreckfish Polyprion americanus. Aquaculture, 2016; 451: 125-136.
[21] Steenfeldt S, Fontaine P, Overton JL, Policar T, Toner D, Falahatkar B, Horváth Á, Khemis IB, Hamza N, Mhetli M. Current status of Eurasian percid fishes aquaculture. InBiology and Culture of Percid Fishes, 2015; (pp. 817-841). Springer Netherlands.
[22] Bhosale, S. V., Bhilave, M. P., Nadaf, S. B. Formulation of fish feed using ingredients from plant sources. Res. J. Agric. Sci, 2010; 1(3), 284-287.
[23] van Raamsdonk, L. W. D., van der Fels-Klerx, H. J., de Jong, J. New feed ingredients: the insect opportunity. Food Additives & Contaminants: Part A, 2017; 1-14.
[24] Jayathilakan, K., Sultana, K., Radhakrishna, K., & Bawa, A. S. Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. Journal of food science and technology, 2012; 49(3), 278-293.
[25] Hamre, K., Kolås, K., Sandnes, K. Protection of fish feed, made directly from marine raw materials, with natural antioxidants. Food Chemistry, 2010, 119(1), 270-278.
[26] Citarasu, T. Herbal biomedicines: a new opportunity for aquaculture industry. Aquaculture International, 2010; 18.3: 403-414.
[27] Olsen, R. L.,Toppe, J. Fish silage hydrolysates: Not only a feed nutrient, but also a useful feed additive. Trends in Food Science & Technology, 2017.
[28] Özyurt, G., Özkütük, A. S., Boğa, M., Durmuş, M.,Boğa, E. K. Biotransformation of Seafood Processing Wastes Fermented with Natural Lactic Acid Bacteria; The Quality of Fermented Products and Their Use in Animal Feeding. Turkish Journal of Fisheries and Aquatic Sciences, 2017; 17(3), 543-555.
[29] Sutili, F. J., Gatlin, D. M., Heinzmann, B. M., Baldisserotto, B. Plant essential oils as fish diet additives: benefits on fish health and stability in feed. Reviews in Aquaculture, 2017.
[30] Dalsgaard, J., Bach Knudsen, K. E., Verlhac, V., Ekmann, K. S., Pedersen, P. B. Supplementing enzymes to extruded, soybean-based diet improves breakdown of non-starch polysaccharides in rainbow trout (*Oncorhynchus mykiss*). Aquaculture Nutrition, 2016; 22(2), 419-426.
[31] Gopakumar G. History of cage culture, cage culture operations, advantages and disadvantages of cages and current global status of cage farming. National training on 'cage culture of seabass' held at CMFRI, 2009. Kochi
[32] Emre Y, Sayın C, Kiştin F and Emre N. Türkiye'de ağ kafeste alabalık yetiştiriciliği, karşılaşılan sorunlar ve çözüm önerileri. Süleyman Demirel Üniversitesi, Eğirdir Su Ürünleri Fakültesi Dergisi, 2008; Cilt: 4 Sayı: 1-2.

[33] InnovaSea Systems, Inc. Access Date: 17.06.2017. https://www.innovasea.com/ portfolio-item /aquapod-a3600-in-puerto-rico/
[34] Anonymus. Access Date: 17.06.2017. http://smartfloatingfarms.com/
[35] Salmar CO. Access Date: 17.06.2017. http://www.salmar.no/
[36] Nordlaks. Access Date: 17.06.2017.http://www.nordlaks.no/Havfarmene
[37] White, P. Environmental consequences of poor feed quality and feed management. In M.R. Hasan and M.B. New, eds. On-farm feeding and feed management in aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO, 2013; pp. 553–564.
[38] Alvarado, L. Aquafeeds and the environment. CIHEAM Cahiers Options Méditerranéennes; n. 22, 1997; pages 275- 289.
[39] Bregnballe, J. A guide to recirculation aquaculture. An introduction to the new environmentally friendly and highly productive closed fish farming systems, 2010. Eurofish, Copenhagen, Denmark.
[40] Anonymous, 2014. Food and Agriculture Organization of the United Nations (FAO). Small-Scale Aquaponic Food Production. FAO Fisherıes and Aquaculture Technical Paper, ISSN 2070-7010, 262s.
[41] Anonymous. The Aquaponic Source. What is Aquaponics. Erişim Tarihi: 03.02.2017. https://www.theaquaponicsource.com/what-is-aquaponics/
[42] Pattillo, DA. Aquaponic System Design and Management. Erişim Tarihi: 03.02.2017.https://www.extension.iastate.edu/forestry/tri_state/tristate_2014/talks/PDFs/Aquaponic _System_Design_and_Management.pdf
[43] Kızak, V. Aquaponic in Aquaculture. Erişim Tarihi: 04.02.2017. http://docplayer.biz.tr/ 28905952-Su-urunleri-yetistiriciliginde-akuaponik-yetistiricilik.html
[44] The University of Maine Center for Cooperative Aquaculture Research. Integrated Multi-Trophic Aquaculture. Access Date: 12.03.2017. https://umaine.edu/cooperativeaquaculture /integrated-multi-trophic-aquaculture/.
[45] Barrington, K, Ridler N, Chopin T, Robinson S, Robinson B. Social aspects of the sustainability of integrated multi-trophic aquaculture. Aquacult Int, 2010; 18:201–211.
[46] Ferreira J, G Saurel and Ferreira JM. Cultivation of gilthead bream in monoculture and integrated multi-trophic aquaculture. Analysis of production and environmental effects by means of the farm model. Aquaculture 358–359, 2012; 23–34.
[47] Muir, W.M. Incorporation of competitive effects in forest tree or animal breeding programs Genetics, 2005; 170, pp. 1247-1259.
[48] Bijma, P. Muir, W.M., van Arendonk, J.A.M. Multilevel selection 1: quantitative genetics of inheritance and response to selection, Genetics, 2007; 175 , pp. 277-288.
[49] Gjedrem T, Robinson N, Rye M. The importance of selective breeding in aquaculture to meet future demands for animal protein: a review. Aquaculture, 2012; 350:117-29.
[50] Besson M, Komen H, Aubin J, De Boer I.J, Poelman M, Quillet E, Vancoillie C, Vandeputte M, Van Arendonk J.A. Economic values of growth and feed efficiency for fish farming in recirculating aquaculture system with density and nitrogen output limitations: a case study with African catfish (). Journal of animal science, 2014; 92(12):5394-405.
[51] Bell M.J, Wall E, Russell G, Simm G, Stott A.W. The effect of improving cow productivity, fertility, and longevity on the global warming potential of dairy systems. Journal of Dairy Science, 2011; 94(7):3662-78.