Frogs, the Present of the Future Protein Source

Frogs, alongside the rest of amphibians, are facing extinction. A series of interacting agents like climate change, freshwater pollution, illegal trade, and emerging diseases are pushing species into the abyss. As they don't tolerate high temperatures global warming is having a great impact on them and even mountain amphians are being affected. Aditionally, fertilizers used on farming activities increase water nitrate concentrations making them toxic for aquatic species as frogs. Illegal trade has an important role too. Lots of amphibians are taken from the wild to become a terrarium pet or a tasty dish, or even a traditional medicine. The pet amphibian trade is responsible for the worldwide spread of at least two deadly amphibian pathogens: Batrachochytrium dendrobatidis, which infects frogs and toads and Batrachochytrium salamandrivorans, affecting newts and salamanders. Wild freshwater fishes which act as carriers are related to Ranavirus spread, another emergent disease of amphibians.

Frogs are really complex creatures. Their life cycle includes 46 larval development stages (Gosner stages) and they go trough gradual changes on anatomy and phisiology involving, among others, the respiratory and digestive system. This makes them difficult to care for and their farming a true adventure.

Frogs are invaluable environmental sentinels, due to the permeability of their skin, as they act as the "canary in the coalmine" being among the first species affected by contamination in a certain place.

An interdisciplinary approach is needed to develop captive breeding programmes to ensure species survival. Frog farming has a major role in replacing wild-caughts that damage natural populations and poses a risk for food safety. Compared to the farming of other species, frog farming is a young sector with less than a century of development. There is a need for a deep knowledge of frog`s biology to unlock the secrets of frog farming.

Frog farming, or raniculture, encompasses activities related to frog production (maintenance, reproduction, breeding, fattening...) and is part of the aquaculture industry. The objectives of raniculture can be commercial, such as human feeding (frog legs), animal feeding, by-products (skin...), substances for the pharmaceutical industry, individuals for research, or non-commercial, like repopulation with threatened species.

Nearly 99% of total frog legs consumed worldwide are from furtively fished animals, with frog farming representing less than 0.5% of total aquaculture. The American Bullfrog (*Lithobates catesbeianus*) is the "prince" of raniculture, by far the most cultured species in Asia and South America. It is big, voracious and highly adaptable, but those virtues for farming also make it fearsome. It is considered an invasive alien species in many countries and banned in the European Union. So there is a need to develop the farming of native species with lower environmental impact. There are many species suitable for frog farming, such as the genus *Pelophylax* in Europe and North Africa and *Leptodactylus latrans* in South America. According to FAO, there are some criteria that a species needs to meet to be suitable for aquaculture including high growth rate, climate tolerance, ability to reproduce in captivity and acceptance of artificial food.

The demand for frog legs is related to traditional cuisine with an estimated demand in Europe of over five thousand tons per year (mainly in France and to a lesser extent in countries like Belgium, Spain, and Italy). In the United States, the second-biggest consumer of these delicacies, the demand surpasses the two thousand tons per year, mostly in Southern states. There are mature markets based on traditional specialities (cuts and preparations) where consumption is no longer growing due to a shortage of supply. There is a new market in Asia, especially in China, which is rapidly increasing its consumption with huge commercial potential. Frogs are steadily jumping into the kitchens of the most important chefs around the world.

Indonesia and, on a smaller scale, Turkey and Vietnam, are the main exporters of frog legs. As previously stated, the vast majority are from the wild, which poses a threat to food safety and species survival. Efforts should be made to develop frog farming in these countries before depleting natural resources. While not considered lovely animals, their extinction will lead to plagues of insects like malaria-carrying mosquitos in tropical regions.

Even if they are an unfamiliar food source for the majority of the population, frog legs have a wide range of health and nutritional benefits. Among other benefits, frog legs are a great source of protein (around 16%) with all the essential amino acids and hypoallergenic properties, less than 1% fat (with omega-3 fatty acids) and high digestibility. Frog legs are also an important source of calcium, phosphorus, selenium, potassium and vitamins of groups A and B. It is also an ideal meat in the fight against hypertension due to its low sodium content. Ready-to-eat meals are a path to be explored in the journey to publicise this healthy product.

Facilities dedicated to the commercial production of frogs are known as frog farms. Depending on the number of animals per square metre and the degree of technification, we can distinguish the following production systems: extensive, semi-intensive and intensive. It is mainly semi-intensive farming with some geographical differences according to climate conditions. Raniculture is a challenge in terms of management due to the complexity of the biological cycle of frogs. This sector is scarcely technified, relying on hand labour (for tasks such as feeding, corpse removal, and frog catching) and based on ponds or outdoor pools such as the "ranario" system (Brazil, Asia) or indoors in greenhouses such as the "amphifarm" system (France, Turkey). There have even been a few attempts for intensification, with poor results on health management.

In this scenario of global population growth and climate change, the search for new protein sources is one of the biggest challenges for humanity. In contrast with other farmed species, frog farming demands little in terms of

water and housing space, and thus is a good alternative for rural areas and developing countries.

The main challenge for frog farmers is the fact that frogs only eat food that is moving. Artificial feeding techniques involve selecting the appropriate pellet size based on the smallest organism in the population, and administering food to the pond so that all frogs can eat and have access at the same time. They generally refuse to eat dead or at least non-moving food. This implies insect farming or training frogs to eat feed pellets by inducing their movement or mixing with live insect larvae.

Small-scale fly farms are present in nearly all frog farms for adult frog feeding, while tadpoles feed readily on common aquaculture fry feeds or vegetable by-products. It must be stated that frogs, like amphibians, have two different lives: one as a "fishlike" herbivorous tadpole and the other as a ground-dwelling insectivorous adult. Frogs go through two stages of fasting, the first one while the newly-hatched tadpole is reabsorbing the vitelium and the other one when the metamorphosised froglet reabsorbs the tail. There is a need to investigate a frog`s nutritional demands throughout its different stages to improve zootechnical indexes and thereupon business profitability. As insectivore frogs' diets will naturally be 30% to 60% protein and between 10% to 30% fats on a fresh weight basis, future specialised feeds must be based on agro-industrial by-products and industrial-scale farmed insects to achieve so-called environmental sustainability.

The lack of skilled labour is another deterrence for the development of this sector. While there are a lot of courses worldwide about aquaculture, frog culture has little or no

impact on their programmes. Furthermore, there is a huge need for labour for daily operations of frog farms such as feeding, size classification (to avoid cannibalism), pond cleaning and corpse removal. The identification of death individuals is a time-consuming task on heavily-stocked raniculture ponds, with individuals tending to stay close to each other.

Zootecnic indexes on bullfrog farming show up a mortality rate of 30–40% for the whole production and an estimated feed conversion ratio between 2:1 and 2.5:1. These values must be improved through investigation on topics such as health and feeding.

The main costs of operation are represented by labour and feed. The economic viability is based on getting cheaper food sources and performing more efficient task management to increase production with the same workforce. Before achieving the intensification of frog farming, labour cost and other management problems must be resolved.

The recent ban on bullfrog farming in Argentina due to the risk of ranavirus spread to wild populations illustrates the hazard of emerging diseases. Frog farm veterinarians have to deal with both the great variety of pathogens and the fact that little is known about amphibian pathology. Additionally, specific drugs are also out of the picture. Correct quarantine measures are the best available tool against amphibian diseases. Some of the most important diseases are the following:

- **Chytridiomycosis**: the so-called amphibian deadly fungus (*Batrachochytrium dendrobatidis*) has been involved in mass extinctions of frogs since the 1990s. Tadpoles act as carriers as they only have keratin (the targeted tissue) in their mouthparts. It mainly affects newly metamorphosed frogs disturbing skin respiration and water uptake with a fatal outcome. New frogs must be sampled for the disease and quarantine measures must be taken to protect the whole farm. Itraconazole has proven effective on chytrid fungus treatment but more trials should be done. Due to its intolerance to hot temperatures, frog farms sited in the tropics are less likely to suffer this disease.
- **Ranavirus**: this emerging disease of amphibians affects anurans in any stage of their life cycle. There are no external pathognomonic signs to state that ranavirus is present and therefore necropsy is advised. Quarantine and disease testing are the only effective measures against this virus. Massive deaths in the wild amphibians group are a clue to determine the presence of this virus in the area.
- **Red-leg disease**: it appears as hyperemia of the ventral skin of legs and abdomen caused by a systemic infection of gram-negative bacterias. It can be treated through antibiotic baths but to avoid antibiotic resistance, previous antibiogram and sensitivity tests are advised.
- **Lung nematodes**: they are one of the most common pathogens affecting captive frogs. *Rhabdias bufonis* causes loss of appetite and decreased growth rates triggering death if not treated. Captivity stress could lead to nematode infestations that must be prevented through antihelmintic treatments.
- **Saprolegniasis**: this is a pathogenic water mould of amphibian eggs. It appears as a superficial cotton-like growth that can affect already weakened egg clutches.

A quarantine area and a small lab are necessary to isolate diseased frogs and newcomers and perform routine procedures such as necropsies, treatment preparations and water checks.

Frogs, like other aquatic animals, depend entirely on water. In the tadpole stage, water parameters like pH, ammonia, temperature and oxygen concentration must be monitored frequently because incorrect values could be lethal. When adults, frogs must have access to water and high relative humidity with at least a daily water change to remove faeces and food debris. Common aquarium water tests should be enough to measure basic water quality parameters, but a spectrophotometer would be advisable when working with a high number of water samples.

Beyond human feeding, there are other reasons to farm frogs such as biotechnology or conservation. The so-called dart frogs (family Dendrobatidae) are a group of new world frogs characterised by producing deadly toxins. These toxins are also raw materials for promising drugs against cancer and other human diseases.

Other amphibians like toads and salamanders have their own toxins with a similar pharmaceutical interest.

For reintroduction purposes, extreme precautions must be taken to avoid the introduction of diseased individuals. Poorly managed conservation efforts could have a terrible outcome. Pet food is another sector where frog meat could occupy a relevant place due to its nutritional value.

Frog farming is still an incipient and underdeveloped branch of aquaculture. The future development relies on the technification of farms, labour training and a deeper knowledge of amphibian diseases. There is a long walk ahead of professionals involved in frog farming.

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