OPEN ACCESS Freely available online

Fisheries and Aquaculture Journal

ISSN: 2150-3508

Mini Review

Potassium Homeostasis and Fish Welfare in Coupled Aquaponic Systems

Francisco Xose Presas-Basalo*

Department of Agricultural and Environmental Sciences, University of Rostock, Rostock, Germany

ABSTRACT

Potassium is an essential nutrient in aquaponics. This review starts elaborating on the different water potassium concentrations in Recirculating Aquaculture Systems (RAS), aquaponics, and hydroponic solutions to later illustrate the importance of potassium homeostasis and its role in fish organs and tissues. The discussion then is divided into potassium imbalances that lead to hyperkalaemia and hypokalaemia, along with its symptoms and consequences. Potential hyperkalaemia in African catfish reared at water potassium concentrations of 600 mg $K^{+}L^{-1}$ is also debated. This paper concludes with the recommended water potassium concentrations for African catfish in aquaponics.

Keywords: Aquaponics; Potassium homeostasis; Hyperkalaemia; Hypokalaemia; Toxicity; Safe levels; Fish behaviour; Aquaculture

INTRODUCTION

Potassium water concentrations in aquaculture/ aquaponic settings

Potassium is the mineral with the highest concentration in various hydroponics water nutrient formulations, followed by nitrogen, phosphorous, and calcium in Table 1 [1-5]. Potassium deficiency entails limited plant growth and absorption of other nutrients-such as nitrogen-in Aquaponic systems [6,7]. As the primary role of plants in Aquaponic systems is the removal of nitrate from the system which is toxic to fish [8,9], managing properly potassium and other nutrients in Aquaponic systems leads to better water quality, fish welfare, less water exchange, and a higher resource use efficiency [10]. Achieving optimal potassium nutrient management in Aquaponic entails an active addition of potassium as the concentration of potassium in an aquaculture system is significantly lower than those in hydroponic systems-up to 45 times less in an aquaculture system than in a hydroponics solution [11].

The toxicity of nitrogen compounds in African catfish (*Clarias gariepinus*) were well known and described in literature for a long time [12,13], while the effects of potassium water concentrations on fish health were not studied previously. It is now known that potassium can be added to aquaculture systems up to a concentration of 400 mg $K^{+}L^{-1}$, without negative effects on the health of African catfish (*Clarias gariepinus*). This water potassium concentration could be increased up to 600 mg $K^{+}L^{-1}$

Nutrient	RAS nutrient concentration [in mg L^{-1}]	Hydroponics nutrient formulations [in mg L^{-1}]		
		Hoagland and Arnon (1938)	Cooper (1979)	Steiner (1984)
N(NO^{3}-N)	0-400	210	236	168
	20-137			
	100			
P(PO_4^{3-}-P)	0.01-3	31	60	31
	8-17			
K	<5	234	300	273
	27-106			
Ca	4-160	160	185	180
Mg	<15	34	50	48
S	<50	64	68	336
Fe	0.2-2.5	2.5	12	02-08
Cu	0.03-0.05	0.02	0.1	0.02
Zn	0.34-0.44	0.05	0.1	0.11
Mn	0.6-0.8	0.5	2	0.62
B	0.9-0.19	0.5	0.3	0.44
Mo	0.01	0.01	0.2	4

Table 1: Recirculating Aquaculture System (RAS) nutrient concentrations and plant nutrient requirements.

Correspondence to: Dr Francisco Xose Presas-Basalo, Department of Agricultural and Environmental Sciences, University of Rostock, Rostock, Germany, E-mail: presasbasalo@gmail.com

Received: 15-Feb-2022, Manuscript No. FAJ-22-15951; **Editor assigned:** 18-Feb-2022, PreQC No. FAJ-22-15951 (PQ); **Reviewed:** 04-Mar-2022, QC No. FAJ-22-15951; **Revised:** 08-Mar-2022, Manuscript No. FAJ-22-15951 (R); **Published:** 15-Mar-2022; DOI: 10.35248/ 2150-3508.22.13.290.

Citation: Presas-Basalo FX (2022) Potassium Homeostasis and Fish Welfare in Coupled Aquaponic Systems. Fish Aqua J.13:290.

without significantly affecting African catfish growth, though behavior at such high water potassium concentrations is affected. Concentrations of 600 mg $K^{+}L^{-1}$ increase African catfish feeding time, aggressiveness, and sedentary behavior without compromising fish growth. Knowing safe potassium concentrations in African catfish aquaculture allows the safe and ethical use of KOH and other potassium-containing alkalinity agents to control water pH in coupled Aquaponic systems [14,15].

Potassium in fish physiology and its homeostasis

Potassium has an important role in the maintenance of the osmotic equilibrium between the cells and the extracellular medium [16,17], the maintenance of the acid-base equilibrium of fish [18], the transmission of the neural impulse in the brain, and muscular contraction -being especially important in the cardiac muscle. Alterations of potassium homeostasis have the potential to affect the nervous system and trigger cardiac disturbances [19]. Whether water potassium concentrations affect potassium homeostasis or not depends on the proper functioning of the sodium-potassium pump [20].

The maintenance of potassium within the physiological levels 3.5 mmol L^{-1} to 4.4 mmol L^{-1} in plasma [21], is a complex process that depends on the balance between dietary and supplemental intake, and body excretion [19]. The main source of potassium in fish species is through dietary potassium uptake, though fish can also uptake potassium from the rearing water through the gills [22]. A diet rich in potassium, or an increase of the uptake of potassium through the gills, leads to high accumulation of potassium in the body if the excretory system does not function properly. The excretion of this excess of potassium takes place mainly through the kidney though it can also take place through the gut and the gills when the kidneys cannot maintain potassium homeostasis due to failure or high body potassium concentrations [19,23].

African catfish is a very resilient species able to survive in waters with high nutrient concentrations where other fish species would perish. Adapting water potassium concentrations when choosing other fish species in an Aquaponic system is essential. Research has been done on the physiological disturbances and symptoms of hyperkalaemia in fish, enabling an assessment of symptoms that might appear when reaching water potassium toxic levels.

Hyperkalaemia

Hyperkalaemia affects primarily tissues and organs where the sodium-potassium cellular grading is most important. A misbalance of potassium will be first shown in disturbances in the muscular and neural systems due to the importance of potassium in its functioning. The maintenance of potassium within normal metabolic levels in the different tissues-2650 mEq in muscle and 4 mEq L^{-1}-5 mEq L^{-1} in plasma is crucial for the proper functioning of the cardiac tissue. High concentrations of extracellular potassium (10 K^{+}mmol L^{-1}-12.5 K^{+}mmol L^{-1}) affect heart performance particularly [24]. These potassium concentrations lead to a reduction of the contractive force of isolated heart strips by a 50% to 100%. It also has proven to reduce the resting membrane potential of myocardial cells while decreasing the duration and the strength of myocardial contractions [25]. These effects of hyperkalaemia have been proven true in rainbow trout *(Oncorhynchus mykiss)* and freshwater turtle *(Trachemis scripta elegans)* [26]. Besides, the high concentrations of potassium in blood led to a noticeable arrhythmia -alteration in cardiac rhythms, as it was documented previously in other vertebrates [24,27]. Alterations of the heartbeat lead to irregular nutrient and oxygen supply to the various fish organs, altering its proper performance. At the same time, an excess of potassium in the blood leads to its elimination through the gills, kidney, and intestine; increasing the maintenance energy requirements as the process is ATP dependent [19,22,27].

Previous studies in turbot [28], shark [29], or big game fish [30], have concluded that a high concentration of potassium in plasma is an indicator of fish stress. The presence of potassium in the extracellular medium might lead to the activation of different stress response pathways [31].

Measuring muscle performance to establish potential potassium intoxications might be restricted to research facilities due to its complexity. Aquaculture farms can suspect potential hyperkalaemia through fish behavior observations. The nervous system is severely affected by potassium misbalances, leading to anomalous behavior patterns resulting from neural physiological disturbances that are easier to be assessed in a production facility.

Spreading depression is a transient wave of neural and glial depolarization that entails massive trans membrane and water shifts. Increases above the threshold of 12 mM $K^{+}L^{-1}$ trigger spreading depression in many vertebrates, including catfish species [32]. The ability of some fish-skates to maintain potassium levels in the cerebrospinal fluid below this threshold is limited when compared with other vertebrates [33,34]. An increase in the extracellular potassium concentration above the threshold in a cortex area of less than one mm^3 in rodents triggers the depolarization of the neural tissue. The extracellular potassium concentration rises from the resting state of 3 mM at the resting state to 30 mM-50 mM sometimes reaching 80 Mm in most species. The extracellular space shrinks by more than 50% increasing the extracellular ion concentration. Water, Ca^{2+}, and Na^{+} enter the intracellular matrix, leading to the release of many; if not all-neurotransmitters and neuromodulators within the depolarized tissue. The mechanisms of recovering after depolarization act within a minute and entail an increased activity of the Na^{+}/K^{+}-ATPase, intracellular buffering of $[Ca^{2+}]$, spatial buffering by the astrocytes network, and vascular clearance. These processes are energy dependent and consume a significant amount of oxygen and glucose [35]. Therefore, water potassium concentrations at high levels maintained over an extended period, possibly well above 670 mg K^+L^{-1} in African catfish aquaculture, lead to decreased growth due to an increase of the energy expenditure allocated to ion homeostasis and an alteration in the feeding behavior, aggressiveness, or swimming patterns [14,15].

Hypokalaemia

Hypokalaemia-lower potassium in blood than normal is also leads to physiological disturbances in the same systems and organs as hyperkalaemia. It is therefore important to discuss the effects of hypokalaemia in fish physiology to assess symptoms and then discern between hyperkalaemia or hypokalaemia in aquaculture systems with analyses on feed formulation and potassium water concentrations.

Marine teleosts are more sensitive than freshwater fish to low water potassium concentrations due to differences in adaptation to water salinity [36]. A low water potassium concentration leads to acute morbidity and mortality in marine teleost's *(Hippocampus sp.; Gobiodon sp.; Cymatogaster sp.; Clepticus sp.)* and marine invertebrates. The low potassium concentration leads to disturbances in the sodium-potassium ratio affecting the activity of the Na+/K+-ATPase pump. The animals reared in water with a low potassium concentration showed in appetence and activity changes. Periods of lethargy with events of hyperactivity as well disturbances in the breathing ratetachypnoea and dyspnoea-were recorded in most of the affected teleosts. Besides behaviour change, the affected teleosts also showed decreased growth or weight loss, paralysis, and loss of equilibrium [37].

In conditions of hypokalaemia, or low potassium diets, channel catfish can uptake potassium present in the water through the gills [38]. This potassium uptake is dependent on the availability of potassium in water. Low water potassium concentrations lead to reduced growth in marine organisms such as the pacific white shrimp *(Litopenaeus vannamei)*. The reduced growth due to this unfavourable environmental condition can be corrected either by direct uptake in the gills or through feed supplementation [39].

DISCUSSION

Effects of various water potassium concentrations in African catfish

Water potassium concentration up to 600 mg K^+L^{-1} did not affect African catfish growth indicating that this fish species was capable of maintaining potassium homeostasis without a significant increase of energy expenditure during the 43 days of the timeframe of the experiment [14,35]. Growth results indicate that hyperkalaemia is unlikely to happen at aquaponic water potassium concentration.

However, the feeding time of the cohort reared at 600 mg K^+L^{-1} was affected, being ≥ 3.7-fold higher than in the other groups and leaving feed uneaten on several days [14,15]. This increased feeding time did not affect growth during the experiment, but it is plausible that this behaviour alteration hinders growth in the long term, especially as the individuals studied were juveniles and the compounding effect would have an impact on the adult weight if this behaviour was maintained over time.

The increased feeding time along with the sedentary behaviour and higher eventual aggressiveness of the K-600 group are indications that events of spreading depression could have happened during the research period, suggesting potential hyperkalaemia and loss of potassium balance in neural tissues that affect behaviour. Nevertheless, whole fish sample analyses did not indicate a higher potassium concentration, contradicting the hyperkalaemia origin of this behaviour alteration and supporting the argument of the maintenance of potassium homeostasis at high water potassium concentrations [14,15].

Knowing safe potassium concentrations in African catfish aquaculture allows the safe and ethical use of KOH and other potassium-containing alkalinity agents to control water pH in coupled aquaponic systems. Potassium concentrations reached 670 mg K^+L^{-1} in K-600 group due to potassium accumulation at the end of the experiment, not being lethal to *Clarias gariepinus*, nor affecting its growth [14]. However African catfish is a very resilient species able to survive in waters with high nutrient concentrations where other fish species would perish. Adapting water potassium concentrations when choosing other fish species in an aquaponic system is essential (Table 2).

Treatment (mg K^+ L^{-1})				
Parameters	Growth	Feeding time	Feed uneaten	Biting wounds
Units	[g $fish^{-1}$]	[mins]	[g $fish^{-1}$]	[n $fish^{-1}$]
K-0 (Control)	106.58 ± 7.28	2.83^a ± 0.25	0^a	3.04^a ± 1.68
K-200	110.38 ± 2.35	4.13^{ab} ± 1.46	0^a	3.04^{ab} ± 2.59
K-400	116.01 ± 5.19	3.73^b ± 0.29	0^a	3.75^{ab} ± 2.80
K-600	110.30 ± 14.85	15.03^{ab} ± 11.26	2.58^b ± 3.77	5.21^b ± 3.01
p-value	0.494	0.045	0.013	0.025

Means sharing the same superscript are not significantly different from each other.

Table 2: African catfish parameters under various water potassium concentrations.

CONCLUSION

Potassium concentrations between 200 mg $K^{+}L^{-1}$ and 400 mg $K^{+}L^{-1}$ are essential for plant growth in Aquaponic while high potassium water concentrations might trigger potassium homeostatic imbalances in some fish species. Hyperkalaemia and hypokalaemia are severe potassium homeostatic disturbances that affect fish welfare. Aquaponic water concentrations up to 400 do not lead to hyperkalaemia in African catfish *(Clarias gariepinus)*, as the species is able to maintain homeostasis in these potassium water concentrations. It also seems that water potassium concentration higher than 200 mg $K^{+}L^{-1}$ are more suitable for African catfish aquaculture than potassium concentrations closer to zero. Therefore, it is recommended to maintain a water potassium concentration between 200 mg $K^{+}L^{-1}$ and 400 mg K+L-1 for best African catfish welfare and growth.

REFERENCES

1. Asao, T. Hydroponics: A standard methodology for plant biological researches. Intechopen. 2012:258.
2. Cooper A. The ABC of NFT (Nutrient Film Technique); The world's first method of crop production without a solid rooting medium. Grower Books, 1979.
3. Hoagland DR, Arnon DI. The water-culture method for growing plants without soil. Circ-Calif Agric Exp Tn. 1 950;347.
4. Steiner AA. The universal nutrient solution. International Congress on Soilless Culture, Lunteren (Netherlands), 1984.
5. Zainorin AN. The response of pinus caribaea mor. var. hondurensis seedlings to nitrogen, phosphorous and potassium fertilizers [pines]. UPM Agricultural University, Malaysia, 2012.
6. Wongkiew S, Hu Z, Chandran K, Lee JW, Khanal SK. Nitrogen transformations in aquaponic systems: A review. Aquac Engrg. 2017;76:9-19.
7. Ågren GI, Wetterstedt JM, Billberger MF. Nutrient limitation on terrestrial plant growth–modeling the interaction between nitrogen and phosphorus. New Phytol. 2012;194(4):953-60.
8. Schram E, Roques JA, Abbink W, Yokohama Y, Spanings T, de Vries P, et al. The impact of elevated water nitrate concentration on physiology, growth and feed intake of African catfish (*Clarias gariepinus)* (Burchell 1822). Aquac Res. 2014;45(9):1499-511.
9. Zou Y, Hu Z, Zhang J, Xie H, Guimbaud C, Fang Y. Effects of pH on nitrogen transformations in media-based aquaponics. Bioresour Technol. 2016;210:81-7.
10. Somerville C, Cohen M, Pantanella E, Stankus A, Lovatelli A. Small-scale aquaponic food production: integrated fish and plant farming. FAO Fish Tech Pap. 2014(589):I.
11. Graber A, Junge R. Aquaponic systems: Nutrient recycling from fish wastewater by vegetable production. Desalination. 2009;246(1-3): 147-56.
12. Roques JA, Schram E, Spanings T, van Schaik T, Abbink W, Boerrigter J, et al. The impact of elevated water nitrite concentration on physiology, growth and feed intake of African catfish (*Clarias gariepinus)* (Burchell 1822). Aquac Res. 2015;46(6):1384-95.
13. Schram E, Roques JA, Abbink W, Spanings T, De Vries P, Bierman S, et al. The impact of elevated water ammonia concentration on physiology, growth and feed intake of African catfish (*Clarias gariepinus)* . Aquac. 2010;306(1-4):108-15.
14. Presas-Basalo, F. X. Does water potassium concentration in aquaponics affect the performance of African catfish (Clarias gariepinus) (Burchell, 1822) (2017) MSc Thesis. Aquaculture and Fisheries Group (AFI), Wageningen University and Research (WUR). 2017.
15. Wenzel LC, Strauch SM, Eding E, Presas-Basalo FX, Wasenitz B, Palm HW. Effects of dissolved potassium on growth performance, body composition, and welfare of juvenile African catfish (*Clarias gariepinus)* . Fishes. 2021;6(2):11.
16. Adler S, Fraley DS. Potassium and intracellular pH. Kidney Int. 1977;11(6):433-42.
17. Knochel JP. Role of glucoregulatory hormones in potassium homeostasis. Kidney Int. 1977;11(6):443-52.
18. Adrogué HJ, Madias NE. Changes in plasma potassium concentration during acute acid-base disturbances. Am J Med. 1981;71(3):456-67.
19. Palmer BF. Regulation of potassium homeostasis. Clin J Am Soc
20. Tkatcheva V, Holopainen IJ, Hyvärinen H, Kukkonen JV. The responses of rainbow trout gills to high lithium and potassium concentrations in water. Ecotox Environ Safe. 2007;68(3):419-25.
21. Rustad P, Felding P, Franzson L, Kairisto V, Lahti A, Mårtensson A, et al. The nordic reference interval project 2000: Recommended reference intervals for 25 common biochemical properties. Scand J Clin Lab. 2004;64(4):271-84.
22. Department of Water Affairs and Forestry. South African water quality guidelines. In agricultural water use:Aquaculture. 1996.
23. Bentley PJ. Endocrines and osmoregulation: A comparative account of the regulation of water and salt in vertebrates. Ann Intern Med. 1973;46(4):325.
24. Fuller W, Tulloch LB, Shattock MJ, Calaghan SC, Howie J, Wypijewski K. Regulation of the cardiac sodium pump. Cell Mol Life Sci. 2013;70(8):1357-80.
25. Hanson LM, Obradovich S, Mouniargi J, Farrell AP. The role of adrenergic stimulation in maintaining maximum cardiac performance in rainbow trout *(Oncorhynchus mykiss)* during hypoxia, hyperkalaemia and acidosis at 10°C. J Exp Biol. 2006;209(13): 2442-51.
26. Kalinin A, Gesser H. Oxygen consumption and force development in turtle and trout cardiac muscle during acidosis and high extracellular potassium. J Comp Physiol B. 2002;1 72(2):145-5 1 .
27. Evans KJ, Greenberg A. Hyperkalaemia: A review. J Intensive Care Med. 2005;20(5):272-90.
28. Van Ham EH, Van Anholt RD, Kruitwagen G, Imsland AK, Foss A, Sveinsbø BO, et al. Environment affects stress in exercised turbot. Comp Biochem Phys A. 2003;136(3):525-38.
29. Pillans RD, Anderson WG, Good JP, Hyodo S, Takei Y, Hazon N, et al. Plasma and erythrocyte solute properties of juvenile bull sharks,

Carcharhinus leucas, acutely exposed to increasing environmental salinity. J Exp Mar Biol Ecol. 2006;33 1(2):145-5 7 .

30. Wells RM, McIntyre RH, Morgan AK, Davie PS. Physiological stress responses in big gamefish after capture: Observations on plasma chemistry and blood factors. Comp Biochem Phys A. 1986;84(3): 565-71.

31. Koeypudsa W, Jongjareanjai M. Impact of water temperature and sodium chloride (NaCl) on stress indicators of hybrid catfish (*Clarias gariepinus Burchell* x *C. macrocephalus Gunther*). Songklanakarin J Sci Technol. 2011;33(4).

32. Nicholson C, Kraig RP. Chloride and potassium changes measured during spreading depression in catfish cerebellum. Brain Res. 1975;96(2):384-9.

33. Bundgaard M, Cserr H. A glial blood-brain barrier in elasmobranchs. Brain Res. 1981;226(1-2):61-73.

34. Rice ME, Nicholson C. Behavior of extracellular K^+ and pH in skate (Raja erinacea) cerebellum. Brain Res. 1988;461(2):328-34.

35. Ayata C, Lauritzen M. Spreading depression, spreading depolarizations, and the cerebral vasculature. Physiol Rev. 2015;95(3):953-93.

36. Turekian KK, Turekian KK. Foundations of earth science series. In oceans. New Jersey: Prentice Hall, 1968. 120.

37. Hadfield CA, Clayton LA, Cohrs DK, Murphy DS. Acute morbidity and mortality in invertebrates and fish following exposure to potassium-deficient saltwater. J Fish Dis. 2012;35(7):549-53.

38. Wilson RP, El Naggar G. Potassium requirement of fingerling channel catfish, Ictalurus puntatus. Aquac. 1992;108(1-2):169-75.

39. Roy LA, Davis DA, Saoud IP, Henry RP. Supplementation of potassium, magnesium and sodium chloride in practical diets for the Pacific white shrimp, Litopenaeus vannamei, reared in low salinity waters. Aquac Nutr. 2007;13(2):104-13.