

Modelos *in vitro* para el desarrollo de una acuicultura sustentable

P. Olivares-Ferretti¹, V. Chavez¹, H. Herrera³, C. Lara² y J. Parodi^{1,2*}

¹ Laboratorio de Investigación y Educación Biosocial Tonalli Ltda., Temuco, Chile

² Aton investigación aplicada, San, Jose, Costa Rica

³ Mares Limpios SpA., Puerto Montt, Chile

*jparodi@tonalli-ltda.com

- Abenavoli, L., Capasso, R., Milic, N. & Capasso, F. 2010. Milk thistle in liver diseases: past, present, future. *Phytother. Res.*, 24: 1423-1432.
- Akhtar, A. 2012. The costs of animal experiments. In: *Animals and public Health*. London, UK: Macmillan. p 132-167.
- Badiola, M., Mendiola, D. & Bostock, J. 2012. Recirculating aquaculture systems (RAS) analysis: main issues on management and future challenges. *Aquacult. Eng.*, 51: 26-35.
- Bairoch, A. 2018. The cellosaurus, a cell-line knowledge resource. *J. Biomol. Tech.*, 29: 25-38.
- Balmer, B., Getchell, R., Powers, R., Lee, J., Zhang, T., Jung, M., Purcell, M., y col. 2018. Broad-spectrum antiviral JL122 blocks infection and inhibits transmission of aquatic rhabdoviruses. *Virology*, 525: 143-149.
- Blagodatski, A. & Katanaev, V. 2011. Technologies of directed protein evolution in vivo. *Cell Mol. Life Sci.*, 68: 1207-1214.
- Bols, N. 1991. Biotechnology and aquaculture: The role of cell cultures. *Biotechnol. Adv.*, 9: 31-49.
- Brasse-Lagnel, C., Lavoinne, A. & Husson, A. 2010. Amino acid regulation of mammalian gene expression in the intestine. *Biochimie.*, 92: 729-735.
- Cano, I., Taylor, N., Bayley, A., Gunning, S., McCullough, R., Bateman, K., Nowak, B. & Paley, R. 2019. In vitro gill cell monolayer successfully reproduces in vivo Atlantic salmon host responses to *Neoparamoeba perurans* infection. *Fish Shellfish Immun.*, 86: 287-300.
- Cathers, H., Mane, S., Tawari, N., Balakuntla, J., Plata, G., Krishnamurthy, M., MacDonald, A., y col. 2022. In silico, in vitro and in vivo characterization of host-associated *Lactobacillus curvatus* strains for potential probiotic applications in farmed Atlantic salmon (*Salmo salar*). *Sci. Rep.*, 12: 18417.
- Cleveland, B. 2014. In vitro and in vivo effects of phytoestrogens on protein turnover in rainbow trout (*Oncorhynchus mykiss*) white muscle. *Comp. Biochem. Phys. C*, 165: 9-16.
- Cuanalo-Contreras, K. & Benkmann, D. 2022. Towards more human and humane testing: the role of the device supplier industry. *Altern Lab Anim.*, 50: 62-70.
- Dannevig, B., Brudeseth, B., GjØen, T., Rode, M., Wergeland, H., Ovnsen, Ø. & Press, C. 1997. Characterisation of a long-term cell line (SHK-1) developed from the head kidney of Atlantic salmon (*Salmo salar* L.). *Fish Shellfish Immun.*, 7: 213-226.
- Dannevig, B., Falk, K. & Namork, E. 1995. Isolation of the causal virus of infectious salmon anaemia (ISA) in a long-term cell line from Atlantic salmon head kidney. *J. Gen Virol.*, 76: 1353-1359.
- Dehler, C., Boudinot, P., Martin, S. & Collet, B. 2016. Development of an efficient genome editing method by CRISPR/Cas9 in a fish cell line. *Mar. Biotechnol.*, 18: 449-452.
- Espe, M. & Holen, E. 2013. Taurine attenuates apoptosis in primary liver cells isolated from Atlantic salmon (*Salmo salar*). *Brit J. Nutr.*, 110: 20-28.
- Fent, K. 2001. Fish cell lines as versatile tools in ecotoxicology: assessment of cytotoxicity, cytochrome P4501A induction potential and estrogenic activity of chemicals and environmental samples. *Toxicol in Vitro*, 15: 477-488.
- Flores, C., Rojas, S., Aguayo, C., Parodi, J., Mann, G., Pearson, J., Casanella, P. & Sobrevia, L. 2003. Rapid stimulation of L-arginine transport by D-glucose involves p42/44(mapk) and nitric oxide in human umbilical vein endothelium. *Circ. Res.*, 92: 64-72.
- Gil A. 2002. Modulation of the immune response mediated by dietary nucleotides. *Eur. J. Clin. Nutr.*, 56: S1-S4.
- Gordon, J. & Sargent, J. 1992. The incorporation and metabolism of polyunsaturated fatty acids in phospholipids of cultured cells from chum salmon (*Oncorhynchus keta*). *Fish Physiol. and Biochem.*, 10: 99-109.
- Goswami, M., Belathur, Y. & Sathiyarayanan, A., Pinto, N., Duscher, A., Ovissipour, R., Lakra, W., y col. 2022. Cellular aquaculture: prospects and challenges. *Micromachines*, 13: 828.
- Goswami, M., Yashwanth, B., Trudeau, V. & Lakra, W. 2022. Role and relevance of fish cell lines in advanced in vitro research. *Mol. Biol. Rep.*, 49: 2393-2411.
- Hernández-Moreno, D., Blázquez, M., Navas, J. & Fernández-Cruz, M. 2022. Fish cell lines as screening tools to predict acute toxicity to fish of biocidal active substances and their relevant environmental metabolites. *Aquat. Toxicol.*, 242: 106020.
- Isoherranen, N. & Foti, R. 2020. In vitro characterization and in vitro to in vivo predictions of drug-drug interactions. In: *Identification and quantification of drugs, metabolites, drug metabolizing enzymes, and transporters Elsevier*. p 273-309.
- Jayesh, P., Seena, J. & Singh, I. 2012. Establishment of shrimp cell lines: perception and orientation. *Indian J. Virol.*, 23: 244-251.
- Kántás, B., Szöke, É., Börzsei, R., Bánhegyi, P., Asghar, J., Hudhud, L., Steib, A., y col. 2021. In silico, in vitro and in vivo pharmacodynamic characterization of novel analgesic drug candidate somatostatin SST4 receptor agonists. *Front. Pharmacol.*, 11: 601887.
- Kawano, A., Haiduk, C., Schirmer, K., Hanner, R., Lee, L., Dixon, B. & Bols, N. 2011. Development of a rainbow trout intestinal epithelial cell line and its response to lipopolysaccharide. *Aquacult. Nutr.*, 17: e241-e252.
- Krampe, B. & Al-Rubeai, M. 2010. Cell death in mammalian cell culture: molecular mechanisms and cell line engineering strategies. *Cytotechnology*, 62: 175-188.
- Lakra, W., Swaminathan, T. & Joy, K. 2011. Development, characterization, conservation and storage of fish cell lines: a review. *Fish Physiol. Biochem.*, 37: 1-20.
- Laursen, J. & Yoshino, T. 1999. *Biomphalaria glabrata* embryonic (Bge) cell line supports in vitro miracidial transformation and early larval development of the deer liver fluke, *Fascioloides magna*. *Parasitology*, 118: 187-194.
- Lee, O., Green, J. & Tyler, C. 2015. Transgenic fish systems and their application in ecotoxicology. *Crit. Rev. Toxicol.*, 45: 124-141.

Lim, J. & Gong, S. 2013. Somatic cell transformation into stem cell-like cells induced by different microenvironments. *Organogenesis*, 9: 245-248.

López, L., Flores-Ibarra, M., Bañuelos-Vargas, I., Galaviz, M. & True, C. 2015. Effect of fishmeal replacement by soy protein concentrate with taurine supplementation on growth performance, hematological and biochemical status, and liver histology of totoaba juveniles (*Totoaba macdonaldi*). *Fish Physiol. Biochem.*, 41: 921-936.

Lorenzen, E., Carstensen, B. & Olesen, N. 1999. Inter-laboratory comparison of cell lines for susceptibility to three viruses: VHSV, IHNV and IPNV. *Dis. Aquat. Organ.*, 37: 81-88.

Lorian, V. 1988. Differences between in vitro and in vivo studies. *Antimicrob. Agents Ch.*, 32: 1600-1601.

Lulijwa, R., Alfaro, A., Merien, F., Meyer, J. & Young, T. 2019. Advances in salmonid fish immunology: a review of methods and techniques for lymphoid tissue and peripheral blood leucocyte isolation and application. *Fish Shellfish Immun.*, 95: 44-80.

Mondal, H. & Thomas, J. 2022. A review on the recent advances and application of vaccines against fish pathogens in aquaculture. *Aquacult. Int.*, 30: 1971-2000.

Montecino, V., Molina, X., Bothwell, M., Muñoz, P., Carrevedo, M., Salinas, F., Kumar, S. y col. 2016. Spatio temporal population dynamics of the invasive diatom *Didymosphenia geminata* in central-southern Chilean rivers. *Sci. Total Environ.*, 568: 1135-1145.

Morin, G., Pinel, K., Dias, K., Seiliez, I. & Beaumatin, F. 2020. RTH-149 cell line, a useful tool to decipher molecular mechanisms related to fish nutrition. *Cells*, 9: 1754.

Neukirch, M., Bottcher, K. & Bunnarjirakul, S. 1999. Isolation of a virus from koi with altered gills. *Bull. Eur. Assn. Fish.*, P 19: 221-224.

Olivares-Ferretti, P., Chavez, V., Maguregui, E., Jiménez, S., Colom, O. & Parodi, J. 2024. Exploring the metabolic and antioxidant potential of solerger: implications for enhanced animal production. *Biotechnol. Rep.*, 41: e00821.

Olivares-Ferretti, P., Hernandez, K., Peredo-Parada, M., Chavez, V., Carmona, E., Astuya, A. & Parodi, J. 2019. Polyphenols obtained from *Didymosphenia geminata* (Lyngbye) Schmith altered the viability and proliferation of salmonids cells lines SHK-1 and CHSE-214. *Aquat. Toxicol.*, 211: 141-147.

Olivares-Ferretti, P., Sánchez, R., Ochoa, de la Paz L. & Parodi, J. 2020. A synergy of the nutritional additives taurine and silymarin in salmon farming: evaluation with the CHSE-214 cellular model. *Fish Physiol. Biochem.*, 46: 945-952.

Olivares, P., Sanchez, R., Carmona, E., Astuya, A., Herrera, H. & Parodi, J. 2016. Nucleotides and effect over starving condition on fish SHK-1 cells model. *J. Aquac. Res. Dev.*, 7: 9.

Ormeño, D., Romero, F., López-Fenner, J., Ávila, Á., Martínez-Torres, A. & Parodi, J. 2013. Ethanol reduces amyloid aggregation in vitro and prevents toxicity in cell lines. *Arch. Med. Res.*, 44: 1-7.

Ou-Yang, Z., Huang, X., Huang, E., Huang, Y., Gong, J., Sun, J. & Qin, Q. 2010. Establishment and characterization of a new marine fish cell line derived from red-spotted grouper *Epinephelus akaara*. *J. Fish Biol.*, 77: 1083-1095.

Parameswaran, V., Shukla, R., Bhonde, R. & Hameed, A. 2006. Establishment of embryonic cell line from sea bass (*Lates calcarifer*) for virus isolation. *J. Virol. Methods*, 137: 309-316.

Parodi, J., Flores, C., Aguayo, C., Rudolph, M., Casanello, P. & Sobrevia, L. 2002. Inhibition of nitrobenzylthioinosine-sensitive adenosine transport by elevated D-glucose involves activation of P2Y2 purinoceptors in human umbilical vein endothelial cells. *Circ. Res.*, 90: 570-577.

Parodi, J., Montecinos-Oliva, C., Varas, R., Alfaro, I., Serrano, F., Varas-Godoy, M., Muñoz, F., y col. 2015. Wnt5a inhibits K(+) currents in hippocampal synapses through nitric oxide production. *Mol. Cell Neurosci.*, 68: 314-322.

Pasquariello, R., Verdile, N., Pavlovic, R., Panseri, S., Schirmer, K., Brevini, T. & Gandolfi, F. 2021. New stable cell lines derived from the proximal and distal intestine of rainbow trout (*Oncorhynchus mykiss*) retain several properties observed in vivo. *Cells*, 10: 1555.

Ringø, E., Zhou, Z., Vecino, J., Wadsworth, S., Romero, J., Kroghdahl, A., Olsen, R., y col. 2016. Effect of dietary components on the gut microbiota of aquatic animals. A never-ending story? *Aquacult. Nutr.*, 22: 219-282.

Rolland, J., Bouchard, D., Coll, J. & Winton, J. 2005. Combined use of the ASK and SHK-1 cell lines to enhance the detection of infectious salmon anemia virus. *J. Vet. Diagn. Invest.*, 17: 151-157.

Saito, T., Goto-Kazeto, R., Arai, K. & Yamaha, E. 2008. Xenogenesis in teleost fish through generation of germ-line chimeras by single primordial germ cell transplantation. *Biol. Reprod.*, 78: 159-166.

Sanchez, R., Olivares, P., Carmona, E., Astuya, A., Herrera, H. & Parodi, J. 2016. Fish nutrition additives in SHK-1 cells: protective effects of silymarin. *Adv. Biosci. Biotechnol.*, 7: 55-62.

Scott, J., Belden, J. & Minghetti, M. 2021. Applications of the RTgill-W1 cell line for acute whole-effluent toxicity testing: in vitro–in vivo correlation and optimization of exposure conditions. *Environ. Toxicol. Chem.*, 40: 1050-1061.

Segner, H. 1998. Fish cell lines as a tool in aquatic toxicology. In: *Fish ecotoxicology*. Basel: Birkhäuser Basel. p 1-38.

Segner, H., Blair, J., Wirtz, G. & Miller, M. 1994. Cultured trout liver cells: utilization of substrates and response to hormones. *In Vitro Cell Dev. Biol. Anim.*, 30: 306-311.

Shearer. 2000. Experimental design, statistical analysis and modelling of dietary nutrient requirement studies for fish: a critical review. *Aquaculture Nutrition*, 6: 91-102.

Subbiahanadar, K., Selvan Christyraj, J., Rajagopalan, K., Yesudhasan, B., Venkatachalam, S., Mohan, M., Chellathurai Vasantha, N. & Selvan Christyraj, J. 2021. Alternative to FBS in animal cell culture - An overview and future perspective. *Heliyon*, 7: e07686.

Torreillas, S., Montero, D. & Izquierdo, M. 2014. Improved health and growth of fish fed mannan oligosaccharides: potential mode of action. *Fish Shellfish Immunol.*, 36: 525-544.

Wolf, K., Gravell, M. & Malsberger, R. 1966. Lymphocystis virus: isolation and propagation in centrarchid fish cell lines. *Science*, 151: 1004-1005.

Wolf, K. & Quimby, M. 1962. Established eurythermic line of fish cells in vitro. *Science*, 135: 1065-1066.

Wuest, D., Harcum, S. & Lee, K. 2012. Genomics in mammalian cell culture bioprocessing. *Biotechnol. Adv.*, 30: 629-638.

Yadav, M., Rastogi, A., Criollo Joaquin, M., Verma, D., Rathore, G., Swaminathan, T., Paria, A., y col. 2021. Establishment and characterization of a continuous cell line from heart of Nile tilapia *Oreochromis niloticus* and its susceptibility to tilapia lake virus. *J. Virol. Methods*, 287: 113989.

Yevenes, G., Peoples, R., Tapia, J., Parodi, J., Soto, X., Olate, J. & Aguayo, L. 2023. Modulation of glycine-activated ion channel function by G-protein betagamma subunits. *Nat. Neurosci.*, 6: 819-824.