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Review

Fish Skin Mucus Extracts: An Underexplored Source of Antimicrobial Agents

Rocío Díaz-Puertas [1], Mikolaj Adamek [2], Ricardo Mallavia [1] and Alberto Falco [1,*]

[1] Institute of Research, Development and Innovation in Healthcare Biotechnology in Elche (IDiBE), Miguel Hernández University, 03202 Elche, Spain; r.diaz@umh.es (R.D.-P.); r.mallavia@umh.es (R.M.)
[2] Fish Disease Research Unit, Institute for Parasitology, University of Veterinary Medicine, 30559 Hannover, Germany; mikolaj.adamek@tiho-hannover.de
* Correspondence: alber.falco@umh.es

Supplementary Materials

Summary:

Table S1: List of antibacterial studies using aqueous skin mucus extracts from different fish species.

Table S2: List of antibacterial studies using organic skin mucus extracts from different fish species.

Table S3: List of antibacterial studies using acidic skin mucus extracts from different fish species.

Table S4: List of antibacterial studies using crude skin mucus from different fish species.

Table S1. List of antibacterial studies using aqueous skin mucus extracts from different fish species.

Fish species	Extraction [1]	Bacteria [2]		Antimicrobial assay [3]	Ref.
		Sensitive	Resistant		
Amphiprion clarkii	W	G-: *Aeromonas hydrophila, Pseudomonas fluorescens, Vibrio alginolyticus, Vibrio harveyi, Vibrio parahaemolyticus*	G+: *Micrococcus lysodeikticus, Staphylococcus aureus*	BD	[1]
Anabas testudineus	AB		G+*: Bacillus subtilis, S. aureus* G-*: A. hydrophila, Escherichia coli, Pseudomonas aeruginosa, Salmonella spp., Salmonella choleraesuis, Serratia marcescens*	AWD	[2]
Anguilla anguilla	PS	G+: *S. aureus,* G-: *V. alginolyticus, Vibrio fluvialis, V. parahaemolyticus*	G+: *Enterococcus faecium, Staphylococcus epidermidis* G-: *A. hydrophila, E. coli, Klebsiella pneumoniae, Photobacterium damselae* subsp. *piscicida, P. aeruginosa, Salmonella typhi, Vibrio anguillarum*	DD	[3]
Arius maculatus	PS	G-: *E. coli, P. aeruginosa, Salmonella spp., Shigella spp., Vibrio cholerae*		DD	[4]
Barbonymus schwanenfeldii	W		G+: *Bacillus cereus, S. aureus* G-: *Shigella boydii, E. coli*	DD	[5]
Catla catla	PS	G-: *A. hydrophila, Aeromonas sobria, P. fluorescens, V. anguillarum.*		DD	[6]
	PS	G-: *E. coli, K. pneumoniae, P. aeruginosa, S. typhi, V. cholerae*		DD	[7]
Channa gachua	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, Vibrio fischeri*		DD	[8]
Channa marulius	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, V. fischeri*		DD	[8]
Channa micropeltes	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, V. fischeri*		DD	[8]
Channa punctatus	PS	G+: *Lactobacillus bulgaricus, S. aureus* G-: *E. coli, Klebsiella oxytoca, K. pneumoniae, P. aeruginosa,*		DD	[9]

		Proteus mirabilis, S. paratyphi, S. typhi, V. cholerae			
	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, V. fischeri*		DD	[8]
	W	G+: *S. aureus, Micrococcus luteus*	G -: *E. coli, P. aeruginosa, S. typhi*	DD	[10]
Channa striatus	W	G-: *A. hydrophila*	G+: *B. subtilis* *G-: K. pneumoniae, P. aeruginosa, Proteus vulgaris, Salmonella enteritidis*	DD, BD	[11]
	W	G+: *L. bulgaricus, S. aureus* G-: *E. coli, K. oxytoca, P. aeruginosa, K. pneumoniae, S. paratyphi, S. typhi, P. mirabilis, V. cholerae*		AWD	[12]
	PS	G+: *B. subtilis, M. luteus, S. aureus, Steptococcus pyogenes* G-: *E. coli, P. vulgaris, P. aeruginosa, Salmonella typhimurium, V. cholera, Mycobacterium smegmatis*		AWD	[13]
	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, V. fischeri*		DD	[8]
Cirrhinus mrigala	PS	G+: *L. bulgaricus S. aureus* G-: *E. coli, K. oxytoca, K. pneumoniae, P. aeruginosa, P. mirabilis, S. paratyphi, S. typhi, V. cholerae*		DD	[9]
	W	G-: *P. aeruginosa, S. paratyphi, S. typhi, V. cholerae*	G+: *S. aureus,*	DD	[14]
Clarias batrachus	AB	G+: *S. aureus* G-: *A. hydrophila, E. coli, K. pneumonia, P. aeruginosa, P. vulgaris*	G+: *Bacillus coagulans*	DD	[15]
	PS	G-: *A. hydrophila, E. coli, P. aeruginosa, V. anguillarum, V. fischeri*		DD	[16]
Ctenopharyngodon idella	PS	G+: *B. cereus, S. aureus, S. epi-dermidis* G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[17]

	PS	G-: *A. hydrophila, A. sobria, P. fluorescens, V. anguillarum.*		DD	[6]
	PS	G-: *E. coli, K. pneumoniae, P. aeruginosa, S. typhi, V. cholerae*		DD	[7]
Cyprinus carpio	AB		G+: *S. epidermis* G-: *Aeromonas salmonicida, E. coli, Listonella anguillarum, P. aeruginosa, Salmonella enterica, Yersinia ruckeri*	BD	[18]
	PS	G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*		AWD	[17]
Dentex dentex	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae, Shewanella putrefaciens, V. harveyi, V. angillarum*		OD	[19]
Dicentrarchus labrax	PS	G+: *S. aureus*	G-: *P. damselae* subsp. *piscicida, Tenacibaculum maritimum, V. anguillarum, V. damsela*	DD	[20]
	PS	G+: *S. aureus* G-: *V. alginolyticus, V. fluvialis, V. parahaemolyticus*	G+: *E. faecium, S. epidermidis* G-: *A. hydrophila, E. coli, K. pneumoniae, P. damselae* subsp. *piscicida, P. aeruginosa, S. typhi, V. anguillarum,*	DD	[3]
	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae, S. putrefaciens, V. harveyi, V. angillarum*		OD	[19]
Epinephelus marginatus	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae, S. putrefaciens, V. harveyi, V. angillarum*		OD	[19]
Epinephelus tauvina	AB		G-: *A. hydrophila, E. coli, S. typhi, K. pneumonia, P. mirabilis, P. fluorescens, V. alginolyticus, V. harveyi, V. parahemolyticus*	AWD	[21]
Heteropneustes fossilis	PS	G+: *B. subtilis, M. luteus, S. aureus, S. pyogenes* G-: *E. coli, P. vulgaris, P. aeruginosa, S. typhimurium, V. cholera, M. smegmatis*		AWD	[13]
Hypophthalmichthys nobilis	PS	G+: *B. cereus, S. aureus, S. epidermidis*		AWD	[17]

		G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*			
	PS	G-: *A. hydrophila, A. sobria, P. fluorescens, V. anguillarum.*		DD	[6]
	PS	G-: *E. coli, K. pneumoniae, P. aeruginosa, S. typhi, V. cholerae*		DD	[7]
	PS	G+: *B. cereus, S. aureus, S. epidermidis* G-: *A. hydrophilla, E. coli, K. pneumonia, P. aeruginosa,*		AWD, APD	[22]
Labeo rohita	PS	G-: *A. hydrophila, A. sobria, P. fluorescens, V. anguillarum.*		DD	[6]
	PS	G-: *E. coli, K. pneumoniae, P. aeruginosa, S. typhi, V. cholerae*		DD	[7]
Labrus bergylta	W		G+: *B. cereus, B. subtilis, Bacillus megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*	AWD, BD	[23]
	W		G+: *B. subtilis, Lactobacillus plantarum* G-: *A. sobria, Citrobacter sp., Edwardsiella tarda, E. coli, Enterobacter sp., L. anguillarum, Shewanella baltica, Y. ruckeri*	DD	[24]
Melanogrammus aeglefinus	AB		G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*	BD	[18]
Morone saxatilis	AB		G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*	BD	[18]
Myxine glutinosa	AB		G-: *S. enterica*	BD	[18]
Oreochromis niloticus	W		G-: *V. harveyi, V. parahaemolyticus*	BD, OD	[25]
Oreochromis mossambicus	AB	G+: *S. aureus* G-: *A. hydrophila, E. coli, K. pneumonia, P. aeruginosa, P. vulgaris*	G+: *B. coagulans*	DD	[15]
Pagellus bogaraveo	PS	G-: *V. parahaemolyticus*	G+: *E. faecium, S. aureus, S. epidermidis* G-: *A. hydrophila, E. coli, K. pneumoniae, P. damselae* subsp.	DD	[3]

			iscicida, P. aeruginosa, S. typhi, V. alginolyticus, V. anguillarum, V. fluvialis		
Periophthalmodon schlosseri	PS	G+: *Bacillus anthracis, S. aureus* G-: *E. coli, P. mirabilis, P. aeruginosa, S. typhi, V. cholerae, K. pneumoniae*		DD, BD	[26]
Platichthys flesus	W	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Pollachius virens	W	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Rita rita	W	G+: *S. aureus, M. luteus* G -: *S. typhi*	G -: *E. coli, P. aeruginosa*	DD	[10]
Salvelinus alpinus	AB		G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*	BD	[18]
Salvelinus fontinalis	AB		G+*: S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*	BD	[18]
Scaphtalamus rhombus	W	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Scophthalamus maximus	PS	G+*: S. aureus* G-: *P. damselae* subsp. *piscicida, V. anguillarum*	G-: *T. maritimum, V. damsela*	DD	[20]
Solea senegalensis	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae subsp. piscicida, S. putrefaciens, V. anguillarum, V. harveyi*		OD	[27]

Solea solea	W	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Sparus aurata	PS	G+: *S. aureus*	G-: *P. damselae* subsp. *piscicida, T. maritimum, V. anguillarum, V. damsela*	DD	[20]
	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae, S. putrefaciens, V. harveyi, V. angillarum*		OD	[19]
Umbrina cirrosa	TBS	G+: *B. subtilis* G-: *E. coli, P. damselae, S. putrefaciens, V. harveyi, V. angillarum*		OD	[19]

[1] AB: ammonium bicarbonate; PS: physiological saline; W: water; TBS: tris buffered saline

[2] G+: gram-positive; G-: gram-negative

[3] APD: agar plate dilution; AWD: agar well diffusion; BD: broth dilution; DD: disc diffusion; OD: optical density

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Table S2. List of antibacterial studies using organic skin mucus extracts from different fish species.

Fish species	Extraction [1]	Bacteria [2]		Antimicrobial assay [3]	Ref.
		Sensitive	Resistant		
Barbonymus Schwanenfeldii	ET, DCM	G+: *Bacillus cereus, Staphylococcus aureus* G-: *Shigella boydii, Escherichia coli*		DD	[5]
Cyprinus carpio	DCM	G-: *Salmonella enterica*		BD	[18]
Epinephelus tauvina	ET		G-: *Aeromonas hydrophila, E. coli, Salmonella typhi, Klebsiella pneumonia, Proteus mirabilis, Pseudomonas fluorescens, Vibrio alginolyticus, Vibrio harveyi, Vibrio parahemolyticus*	AWD	[21]
Gadus morhua	ACN + 1% TFA	G+: *Bacillus megaterium* G-: *E. coli*		AWD, BD	[28]
Labrus bergylta	DCM	G-: *E. coli, K. pneumoniae, Proteus vulgaris, Pseudomonas aeruginosa, Serratia marcescens*	G+: *B. cereus, Bacillus subtilis, B. megaterium, S. aureus, Streptococcus sp.*	AWD, BD	[23]
	DCM		G+: *B. subtilis, Lactobacillus plantarum* G-: *Aeromonas sobria, Citrobacter sp., Edwardsiella tarda, E. coli, Enterobacter sp., Listonella anguillarum, Shewanella baltica, Yersinia ruckeri*	DD	[24]
Melanogrammus aeglefinus	DCM		G-: *S. enterica*	BD	[18]
Morone saxatilis	DCM	G-: *S. enterica*		BD	[18]
Myxine glutinosa	DCM		G-: *S. enterica*	BD	[18]
Oreochromis niloticus	DCM	G-: *V. harveyi*	G-: *V. parahaemolyticus*	BD, OD	[25]
	ET	G-: *V. harveyi*		DD, BD	[29]
Periophthalmodon schlosseri	ET	G+: *Bacillus anthracis, S. aureus* G-: *E. coli, P. mirabilis, P. aeruginosa, S. typhi, Vibrio cholerae, K. pneumoniae*		DD, BD	[26]
Platichthys flesus	DCM	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris,*		AWD, BD	[23]

		P. aeruginosa, S. marcescens			
Pollachius virens	DCM	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Salvelinus alpinus	DCM		G-: *S. enterica*	BD	[18]
Salvelinus fontinalis	DCM	G-: *S. enterica*		BD	[18]
Scaphtalamus rhombus	DCM	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]
Solea solea	DCM	G+: *B. cereus, B. subtilis, B. megaterium, S. aureus, Streptococcus sp.* G-: *E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. marcescens*		AWD, BD	[23]

[1] ACN: acetonitrile; DCM: dichloromethane; ET: ethanol; TFA: trifluoroacetic acid.

[2] G+: gram-positive; G-: gram-negative

[3] AWD: agar well diffusion; BD: broth dilution; DD: disc diffusion; OD: optical density

Table S3. List of antibacterial studies using acidic skin mucus extracts from different fish species.

Fish species	Extraction [1]	Bacteria [2]		Antimicrobial assay [3]	Ref.
		Sensitive	Resistant		
Anabas testudineus	AA	G+: *Bacillus subtilis, Staphylococcus aureus* G-: *Aeromonas hydrophila, Escherichia coli, Pseudomonas aeruginosa, Salmonella spp., Salmonella choleraesuis, Serratia marcescens*		AWD	[2]
Channa punctatus	AA, TFA	G+: *S. aureus, Micrococcus luteus*	G -: *E. coli, P. aeruginosa, Salmonella typhi*	DD	[10]
Channa striatus	AA	G+: *B. subtilis* G-: *A. hydrophila, Klebsiella pneumoniae, P. aeruginosa, Proteus vulgaris, Salmonella enteritidis*		DD, BD	[11]
	AA	G+: *Enterococcus faecalis, M. luteus, S. aureus,* G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[30]
Cirrhinus mrigala	AA	G+: *S. aureus,* G-: *P. aeruginosa, S. paratyphi, S. typhi, V. cholerae*		DD	[14]
	TFA	G-: *S. paratyphi, V. cholerae*	G+: *S. aureus,* G-: *P. aeruginosa, S. typhi*	DD	[14]
Clarias batrachus	AA	G+: *E. faecalis, M. luteus, S. aureus* G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[30]
Cyprinus carpio	AA		G+: *Staphylococcus epidermis* G-: *Aeromonas salmonicida, E. coli, Listonella anguillarum, P. aeruginosa, Salmonella enterica, Yersinia ruckeri*	BD	[18]
Epinephelus tauvina	AA	G-: *A. hydrophila, E. coli, S. typhi, K. pneumonia, Proteus mirabilis, Pseudomonas fluorescens, Vibrio alginolyticus, Vibrio harveyi, Vibrio parahemolyticus*		AWD	[21]
Melanogrammus aeglefinus	AA	G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*		BD	[18]
Morone saxatilis	AA		G-: *S. enterica*	BD	[18]

Myxine glutinosa	AA	G+: *S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, S. enterica, Y. ruckeri*		BD	[18]
Oreochromis niloticus	AA	G-: *V. harveyi*	G-: *V. parahaemolyticus*	BD, OD	[25]
	AA	G+: *E. faecalis, M. luteus, S. aureus,* *G-: A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[30]
Puntius sophore	AA	G+*: B. subtilis, S. aureus* G-: *E. coli, P. aeruginosa*		AWD	[31]
Rita rita	AA, TFA	G+: *S. aureus and M. luteus* G -: *S. typhi*	G -: *E. coli, P. aeruginosa*	DD	[10]
Salvelinus alpinus	AA		G-: *S. enterica*	BD	[18]
Salvelinus fontinalis	AA	G+*: S. epidermis* G-: *A. salmonicida, E. coli, L. anguillarum, P. aeruginosa, Salmonella enterica, Y. ruckeri*		BD	[18]

[1] AA: acetic acid TFA: trifluoroacetic acid.

[2] G+: gram-positive; G-: gram-negative

[3] AWD: agar well diffusion; BD: broth dilution; DD: disc diffusion; OD: optical density

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Table S4. List of antibacterial studies using crude skin mucus from different fish species.

Fish species	Bacteria [1]		Antimicrobial assay [2]	Ref.
	Sensitive	Resistant		
Argyrosomus regius	G-: *Escherichia coli, Pseudomonas anguilliseptica, Vibrio anguillarum*		OD	[32]
Channa argus	G-: *E. coli*		OD	
Channa striatus	G-: *A. hydrophila*	G+: *Bacillus subtilis* G-: *Klebsiella pneumoniae, Pseudomonas aeruginosa, Proteus vulgaris, Salmonella enteritidis*	DD, BD	[11]
Clarias batrachus	G+: *B. subtilis, Staphylococcus aureus* G-: *K. pneumoniae, P. vulgaris, P. aeruginosa, S. paratyphi*		DD	[33]
Ctenopharyngodon idella	G+: *Bacillus cereus, S. aureus, Staphylococcus epidermidis* G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[17]
Cyprinus carpio	G+: *B. cereus, S. aureus, S. epidermidis* G-: *A. hydrophila, E. coli, K. pneumoniae, P. aeruginosa*		AWD	[17]
Dasyatis pastinaca	G-: *E. coli, K. pneumoniae, P. aeruginosa*	G+: *E. faecalis, S. aureus, Streptococcus agalactiae*	CC	[34]
Dicentrarchus labrax	G-: *E. coli, V. anguillarum*	G-: *Pseudomonas anguilliseptica*	OD	[32]
Oncorhynchus mykiss		G+: *B. cereus, S. aureus, S. pneumoniae* G-: *Citrobacter freundii, Enterobacter aerogenes, E. coli, Klebsiella oxyttoca, K. pneumoniae, Neisseria lactamica, Proteus mirabilis, Pseudomonas fluorescens, P. vulgaris, P. aeruginosa*	DD	[35]
Sparus aurata	G-: *E. coli, Pseudomonas anguilliseptica, V. anguillarum,*		OD	[32]

[1] G+: Gram-positive; G-: Gram-negative

[2] AWD: agar well diffusion; BD: broth dilution; CC: cell counting; DD: disc diffusion; OD: optical density

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