Nanomaterial safety for microbially-colonized hosts: Microbiota-mediated physisorption interactions and particle-specific toxicity

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Curriculum vitae

Bregje was born in 1993 in Haarlem, where she followed pre-university education (VWO) at Lyceum Sancta Maria (2006-2011). In September 2011, she started her academic training at Leiden University by following the BSc program in Biology. Here, she developed a particular interest in research investigating biological phenomena at different, interconnected scales in time and space. In February 2014, Bregje concluded her BSc degree at Naturalis Biodiversity Center with a research project 'looking for cryptic species in Pontoniine shrimps', under the supervision of dr. Charles H.J.M. Fransen. After graduating (*summa cum laude*) Bregje was awarded the 'Professor Kees Bakker prijs 2014' for her BSc degree, which, in combination with the ISME16 travel grant, supported her visit to the 16th International Symposium on Microbial Ecology in Montreal (Canada).

In September 2014, Bregje continued her academic training by following the MSc degree in Limnology & Oceanography (Biological Sciences) at the University of Amsterdam. In two research projects, she developed a growing interest in the effects of microbial activity on water quality and ecosystem functioning. In a first project, supervised by dr. J. Merijn Schuurmans and dr. Hans C.P. Matthijs, she studied the role of cyanotoxin microcystin in the sensitivity of cyanobacteria to strong oxidative stress. In a second project, supervised by dr. J. Arie Vonk and dr. Harm G. van der Geest, she studied algal survival in limnetic aggregates from the turbid water column of large and shallow delta lake Markermeer (the Netherlands). By way of a literature study, supervised by dr. Eva S. Deutekom, she also investigated the role of host-microbiota interactions in the adaptive potential of the coral holobiont to the negative impacts of ocean acidification on coral calcification. Bregje graduated (*cum laude*) for her MSc degree in November 2016.

In October 2017, Bregje returned to Leiden University as PhD candidate at the Institute of Environmental Sciences (CML). Here, she joined the Ecotox team led by prof. dr. Martina G. Vijver and prof. dr. Willie J.G.M. Peijnenburg, to study the effects of host-associated microbiota on particle-specific nanomaterial toxicity. Her research contributed to the Horizon 2020 project PATROLS (www.patrols-h2020.eu), awarded to Martina Vijver and fellow researchers. Bregje presented her work at the PATROLS General Assembly in Fribourg (Switzerland, 2019), at the PATROLS Early Career Researcher Webinar (online, 2020), at the Society of Environmental Toxicology and Chemistry Europe 30th Annual Meeting (SETAC SciCon, online, 2020), and at the 10th International Conference on Nanotoxicology (NanoTox, online, 2021). The results of her PhD research are presented in this thesis.

List of publications

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Bregje

September 2022

APPENDIX

Supplementary tables for **Chapter 1** and **Chapter 6**.

Table S1: Experimental investigations on the effects of nanoparticles on host-associated microbiota.[a] Experiments are sorted by the experimental context ('environmental health', or 'human and animal health'), the presence or absence ('N.D.') of identified effects on microbiota composition, nanoparticle core material, and host species. Literature that has been published before or in March 2022 is presented.

ENVIRONMENTAL HEALTH: AQUEOUS EXPOSURE									
Effect on microbiota	*Nanoparticle*				*Host*	*Microbiota*	*Concentration*	*Exposure time (d)*	*Reference (DOI)*
	Core[b]	*Coating*[c]	*Shape*[d]	*Size*[e]			*($\mu g \cdot L^{-1}$)*		
Yes	Ag	none	S	51	*Danio rerio*	Gut	10 - 100	45	Ma et al. 2018 (10.1039/c7en00740j)
Yes	Ag	none	S	15	*Danio rerio*	Body	250	2	Brinkmann et al. 2020 (10.1080/17435390.2020.1755469)
Yes	Ag	none	S	60	*Danio rerio*	Gut	100	15 -75	Chen et al. 2021 (10.1128/mSystems.00630-21)
Yes	Ag	citrate	S	20	*Daphnia magna*	Gut	0.43 - 4.3	1 - 21	Li et al. 2019 (10.1039/c9en00587k)
Yes	Ag	none	S	20	*Daphnia magna*	Gut	0.43	21 - 84	Li et al. 2022 (10.1039/d1en00765c)
Yes	Ag	none	A	20	*Drosophila melanogaster*	Gut	$450 \cdot 10^3$	1.68	Han et al. 2014 (10.1016/j.scitotenv.2013.12.129)

Yes	Ag	carbon	A	25	*Populus nigra*	Phyllo-sphere	$1 \cdot 10^3$	70	Vitali et al. 2019 (10.1007/s00253-019-10071-2)
Yes	Ag	none	S	35	*Schmidtea mediterranea*	Body	$10 \cdot 10^3$	7	Bijnens et al. 2021 (10.1016/j.aquatox.2020.105672)
Yes	Ag	PVP	S	33	*Schmidtea mediterranea*	Body	$10 \cdot 10^3$	7	Bijnens et al. 2021 (10.1016/j.aquatox.2020.105672)
Yes	CeO_2	none	I	15	*Fragaria ananassa*	Rhizo-sphere	$0.3 \cdot 10^6$-$2 \cdot 10^6$	45	Dai et al. 2020 (10.1021/acssuschemeng.9b07422)
Yes	Mo	none	NA	60	*Cicer arientinum*	Rhizo-sphere	$10 \cdot 10^3$	40	Shcherbakova et al. 2017 (10.1007/s13199-016-0472-1)
Yes	Se	none	A	40	*Danio rerio*	Gut	100	90	Chen et al. 2022 (10.1016/j.scitotenv.2021.150963)
Yes	TiO_2	none	A	8	*Danio rerio*	Gut	100	90	Chen et al. 2022 (10.1016/j.scitotenv.2021.150963)
Yes	TiO_2	none	I	21	*Mytilus gallo-provincialis*	Hemo-lymph	100	4	Auguste et al. 2019 (10.1016/j.scitotenv.2019.03.133)
Yes	ZnO	none	A	30	*Danio rerio*	Gut	100	90	Chen et al. 2022 (10.1016/j.scitotenv.2021.150963)

ENVIRONMENTAL HEALTH: FOOD EXPOSURE

Effect on microbiota	*Nanoparticle*				*Host*	*Microbiota*	*Concentration*	*Exposure time (d)*	*Reference (DOI)*
	Core[b)]	*Coating* [c)]	*Shape*[d)]	*Size* [e)]			*($mg \cdot kg^{-1}$)*[f)]		
N.D.	TiO_2	none	A	31	*Oreochromis niloticus*	Gut	1 $mg \cdot kg\ bw^{-1} \cdot d^{-1}$	28	Sherif et al. 2021 (10.1111/are.15539)
N.D.	TiO_2	none	A	53	*Oreochromis niloticus*	Gut	1 $mg \cdot kg\ bw^{-1} \cdot d^{-1}$	28	Sherif et al. 2021 (10.1111/are.15539)
N.D.	ZnO	none	S	28	*Cyprinus carpio*	Gut	500	42	Chupani et al. 2019 (10.1007/s11356-019-05616-x)
Yes	Ag	none	S	20	*Cyprinus carpio*	Gut	50 to 150	60	Khorshidi et al. 2018 (10.1007/s40995-016-0130-8)
Yes	Ag	none	S	50	*Folsomia candida*	Gut	200	28	Zhu et al. 2018 (10.1021/acs.est.8b02825)
Yes	Ag	none	A	28	*Spodoptera litura*	Gut	6.4	1	Bharani and Namasivayam 2017 (10.1016/j.jece.2016.12.023)
Yes	CuO	none	S	40	*Bombyx mori*	Gut	10	5	Muhammad et al. 2022 (10.1016/j.scitotenv.2021.152608)

Yes	MoO_3	none	S	92	*Danio rerio*	Gut	0.2 to 0.4 (lyosol mass·kg water^{-1})	7	Aleshina et al. 2020 (10.1007/s13762-019-02509-x)
Yes	MoO_3	none	S	92	*Danio rerio*	Gill	0.2 to 0.4 (lyosol mass·kg water^{-1})	7	Aleshina et al. 2020 (10.1007/s13762-019-02509-x)
Yes	TiO_2	none	A	8	*Bombyx mori*	Gut	Leaves soaked in 5 mg·L^{-1}	4	Li et al. 2020 (10.1016/j.scitotenv.2019.135273)
Yes	TiO_2	none	A	13	*Oreochromis niloticus*	Gut	1 mg·kg bw^{-1}·d^{-1}	28	Sherif et al. 2021 (10.1111/are.15539)
Yes	ZnO	none	A	50	*Bombyx mori*	Gut	10	5	Muhammad et al. 2022 (10.1016/j.scitotenv.2021.152608)

ENVIRONMENTAL HEALTH: SOIL EXPOSURE

Effect on microbiota	*Nanoparticle*				*Host*	*Microbiota*	*Concentration (mg·kg^{-1})*[f)]	*Exposure time (d)*	*Reference (DOI)*
	Core[b)]	*Coating*[c)]	*Shape*[d)]	*Size*[e)]					
Yes	Ag	none	S	50	*Eisenia fetida*	Gut	10 - 400	28	Swart et al. 2020 (10.1016/j.envpol.2020.115633)
Yes	Ag	none	S	15	*Lactuca sativa*	Rhizo-sphere	1 - 50	63	Wu et al. 2021 (10.1021/acssuschemeng.1c04987)
Yes	Ag	none	NA	16	*Linum usitatissimum*	Rhizo-sphere	0.125 (+ sprayed with 100 µg·L^{-1} after 7 d)	21	Gorczyca et al. 2018 (10.1007/s11356-018-3346-7)
Yes	Ag	carbon	A	25	*Populus nigra*	Rhizo-sphere	1 mg·L^{-1} pot water	70	Vitali et al. 2019 (10.1007/s00253-019-10071-2)
Yes	Ag	none	NA	16	*Triticum aestivum*	Rhizo-sphere	0.125 (+ sprayed with 100 µg·L^{-1} after 7 d)	21	Gorczyca et al. 2018 (10.1007/s11356-018-3346-7)
Yes	Ag	citrate	S	11	*Triticum aestivum*	Rhizo-sphere	3	14	Feng et al. 2021 (10.1016/j.scitotenv.2021.149200)
Yes	Ag	none	I	20	*Zea mays*	Rhizo-sphere	100	117	Sillen et al. 2020 (10.1186/s40168-020-00904-y)
Yes	Ag_2S	none	S	95	*Eisenia fetida*	Gut	114 - 34·10^{3}	60	Wu et al. 2020 (10.1021/acs.est.0c01241)
Yes	Ag_2S	none	S	95	Pontocolex corethrurus	Gut	114 - 34·103	60	Wu et al. 2020 (10.1021/acs.est.0c01241)
Yes	CuO	none	S	9	*Carya illinoinensis*	Rhizo-sphere	10 - 1·10^{3}	45	Salas-Leiva et al. 2021 (10.1016/j.apsoil.2020.103772)

Yes	CuO	none	CB	20	*Eisenia fetida*	Gut	160	28	Swart et al. 2020 (10.3390/nano10071337)
Yes	CuO	none	CB	20	*Eisenia fetida*	Gut	10 - 400	28	Swart et al. 2020 (10.1016/j.envpol.2020.115633)
Yes	CuO	none	I	23	*Enchytraeus crypticus*	Gut	100	21	Ma et al. 2020 (10.1016/j.envpol.2019.113463)
Yes	CuO	none	A	50	*Folsomia candida*	Gut	100	28	Ding et al. 2020 (10.1016/j.chemosphere.2020.127347)
Yes	CuO	none	NA	28	*Triticum aestivum*	Rhizo-sphere	50	28	Guan et al. 2020 (10.1021/acs.est.0c00036)
Yes	Se	none	S	62	*Brassica chinensis*	Rhizo-sphere	0.5	60	Wang et al. 2022 (10.1039/d1en00740h)
Yes	TiO_2	none	NA	68	*Linum usitatissimum*	Rhizo-sphere	0.125 (+ sprayed with 100 $\mu g \cdot L^{-1}$ after 7 d)	21	Gorczyca et al. 2018 (10.1007/s11356-018-3346-7)
Yes	TiO_2	none	NA	68	*Triticum aestivum*	Rhizo-sphere	0.125 (+ sprayed with 100 $\mu g \cdot L^{-1}$ after 7 d)	21	Gorczyca et al. 2018 (10.1007/s11356-018-3346-7)

HUMAN AND ANIMAL HEALTH: AIR EXPOSURE

	Nanoparticle								
Effect	*Core*[b)]	*Coating*[c)]	*Shape*[d)]	*Size*[e)]	*Host*	*Microbiota*	*Concentration (mg·kg bw⁻¹·d⁻¹)*[f)]	*Exposure time (d)*	*Reference (DOI)*
Yes	La_2O_3	none	S	23	Mus musculus	Lung	2	1	Zheng et al. 2021 (10.1186/s12989-021-00410-5)
Yes	NiO	none	NA	5	Rattus norvegicus	Lung	0.05-0.16 mg (one dose)	1-28	Jeong et al. 2022 (10.3390/ijerph19010522)
Yes	SiO_2	none	S	49	Mus musculus	Gut	2.5	45	Ju et al. 2020 (10.1039/d0en01021a)

HUMAN AND ANIMAL HEALTH: AQUEOUS EXPOSURE

	Nanoparticle								
Effect on microbiota	*Core*[b)]	*Coating*[c)]	*Shape*[d)]	*Size*[e)]	*Host*	*Microbiota*	*Concentration ($\mu g \cdot L^{-1}$)*[f)]	*Exposure time (d)*	*Reference (DOI)*
N.D.	Ag	glutha-thione	S	20	*Homo sapiens*	Gut	$7.6 \cdot 10^3$	2	Cueva et al. 2019 (10.1016/j.fct.2019.110657)

N.D.	Ag	PEG	S	4	*Homo sapiens*	Gut	$11 \cdot 10^3$	2	Cueva et al. 2019 (10.1016/j.fct.2019.110657)
N.D.	IO	carboxymethyl-dextran	A	7	*Rattus norvegicus*	Mouth	$1 \cdot 10^6$	21	Liu et al. 2018 (10.1038/s41467-018-05342-x)
N.D.	IO	dextran	S	35	*Rattus norvegicus*	Mouth	$1 \cdot 10^6$	21	Naha et al. 2019 (10.1021/acsnano.8b08702)
Yes	Ag	citrate	NA	14	*Homo sapiens*	Gut	$1 \cdot 10^3$	1	Catto et al. 2019 (10.1016/j.envpol.2018.11.019)
Yes	Ag	none	S	10	*Homo sapiens*	Mouth	$5.2 \cdot 10^3$	2	Espinosa-Cristoba et al. 2019 (10.1155/2019/3205971)
Yes	Ag	none	S	29	*Homo sapiens*	Mouth	$5.2 \cdot 10^3$	2	Espinosa-Cristoba et al. 2019 (10.1155/2019/3205971)
Yes	Ag	citrate	S	14	*Homo sapiens*	Gut	1-30	42	Li et al. 2021 (10.1016/j.scitotenv.2020.143983)
Yes	CHX PR_4^+	PS_{64}-*b*-$PDMA_{53}$	S	26	*Rattus norvegicus*	Mouth	$5 \cdot 10^5$ - $8 \cdot 10^5$	13	Ostadhossein et al. 2021 (10.1038/s42003-021-02372-y)
Yes	CeO_2	none	R	8	*Homo sapiens*	Gut	0.01	5	Taylor et al. 2015 (10.1089/ees.2014.0518)
Yes	CuO	none	A	40	*Homo sapiens*	Mouth	$10 \cdot 10^3$-$100 \cdot 10^3$	0.67	Kahn et al. 2013 (10.1016/j.matlet.2013.01.085)
Yes	Se	Polystyrene-4-sulfonate	S	46	*Gallus domesticus*	Gut	$9 \cdot 10^2$	2	Gangadoo et al. 2019 (10.1016/j.aninu.2019.06.004)
Yes	TiO_2	none	S	27	*Homo sapiens*	Gut	$3 \cdot 10^3$	5	Taylor et al. 2015 (10.1089/ees.2014.0518)
Yes	TiO_2	none	A	25	*Homo sapiens*	Gut	$0.1\ \mu g \cdot d^{-1}$	7	Agans et al. 2019 (10.1093/toxsci/kfz183)
Yes	ZnO	none	A	35	*Homo sapiens*	Mouth	$10 \cdot 10^3$-$100 \cdot 10^3$	0.67	Kahn et al. 2013 (10.1016/j.matlet.2013.01.085)
Yes	ZnO	none	S	24	*Homo sapiens*	Gut	0.01	5	Taylor et al. 2015 (10.1089/ees.2014.0518)
Yes	ZnO	alcohol/ alkene	S	32	*Homo sapiens*	Gut	20	NA	Zhou et al. 2021 (10.3389/fmicb.2021.700707)

HUMAN AND ANIMAL HEALTH: FOOD EXPOSURE

	Nanoparticle	

Effect on microbiota	*Core[b)]*	*Coating[c)]*	*Shape[d)]*	*Size[e)]*	*Host*	*Microbiota*	*Concentration ($mg \cdot kg^{-1}$)[f)]*	*Exposure time (d)*	*Reference (DOI)*
N.D.	Ag	none	C	4	*Gallus domesticus*	Gut	50 (drinking water)*	30	Vadalasetty et al. 2018 (10.1186/s12917-017-1323-x)
N.D.	CeO_2	none	S	35	*Mus musculus*	Gut	$10 \cdot 10^3$	21	Bredeck et al. 2021 (10.1080/17435390.2021.1940339)
Yes	Ag	none	A	58	*Danio rerio*	Gut	500	14	Merrifield et al. 2013 (10.1016/j.envpol.2012.11.017)
Yes	Ag	PVP	A	55	*Mus musculus*	Gut	0.046-4.6	28	Van den Brule et al. 2016 (10.1186/s12989-016-0149-1)
Yes	Ag	PVP	S	40	*Mus musculus*	Gut	$2 \cdot 10^3$	28	Bredeck et al. 2021 (10.1080/17435390.2021.1940339)
Yes	Ag	PVP	A	55	*Mus musculus*	Gut	0.004-0.4	168	Perez et al. 2021 (10.1016/j.fct.2021.112352)
Yes	Au	*C. verum* bio-actives	S	15	*Mus musculus*	Gut	10 (drinking water) *	56	Sharma et al. 2022 (10.1016/j.mtbio.2022.100204)
Yes	Chitosan	none	A	50	*Sus domesticus*	Gut	100-400	28	Xu et al. 2020 (10.1111/jpn.13283)
Yes	Cu	none	A	87	*Danio rerio*	Gut	500	14	Merrifield et al. 2013 (10.1016/j.envpol.2012.11.017)
Yes	Cu	chitosan	NA	95	*Gallus domesticus*	Gut	50-150	42	Wang et al. 2011 (10.3382/ps.2011-01511)
Yes	Cu	none	NA	55	*Gallus domesticus*	Gut	1.7	28	Yausheva et al. 2018 (10.1007/s11356-018-1991-5)
Yes	Cu	none	S	50	*Rattus norvegicus*	Gut	3.25-6.5	28	Cholewinska et al. 2018 (10.1371/journal.pone.0197083)
Yes	CuZn	none	NA	65	*Gallus domesticus*	Gut	2.84	28	Yausheva et al. 2018 (10.1007/s11356-018-1991-5)
Yes	Fe	none	NA	50	*Gallus domesticus*	Gut	8	28	Yausheva et al. 2018 (10.1007/s11356-018-1991-5)
Yes	Pectin	none	NA	64	*Mus musculus*	Gut	$7.5 \cdot 10^3$ (drinking water)*	28	Chandrarathna et al. 2020 (10.3390/md18030175)
Yes	Spore coat	none	S	100	*Mus musculus*	Gut	$10 \cdot 10^6$ CFUs (drinking water)*	42	Song et al. 2021 (10.1002/adfm.202104994)
Yes	SiO_2	none	A	13	*Mus musculus*	Gut	$10 \cdot 10^3$	21	Bredeck et al. 2021 (10.1080/17435390.2021.1940339)
Yes	SiO_2	none	A	15.5	*Mus musculus*	Gut	0.8-80	168	Perez et al. 2021 (10.1016/j.fct.2021.112352)

Yes	Thyme	chitosan	S	90	*Gallus domesticus*	Gut	60	42	Hosseini et al. 2018 (10.1080/00071668.2018.1521511)
Yes	TiO_2	none	NA	10	*Mus musculus*	Gut	$1\cdot10^{3}$	91	Mu et al. 2019 (10.1021/acs.jafc.9b02391)
Yes	TiO_2	none	NA	50	*Mus musculus*	Gut	$1\cdot10^{3}$	91	Mu et al. 2019 (10.1021/acs.jafc.9b02391)
Yes	TiO_2	none	NA	100	*Mus musculus*	Gut	$1\cdot10^{3}$	91	Mu et al. 2019 (10.1021/acs.jafc.9b02391)
Yes	TiO_2	none	A	33	*Mus musculus*	Gut	1	56	Cao et al. 2020 (10.1002/smll.202001858)
Yes	TiO_2	none	A	26	*Mus musculus*	Gut	$10\cdot10^{3}$	28	Bredeck et al. 2021 (10.1080/17435390.2021.1940339)
Yes	TiO_2	none	S	25	*Mus musculus*	Gut	20	56	Zhao et al. 2021 (10.1021/acs.jafc.1c03301)
Yes	ZnO	none	NA	30	*Gallus domesticus*	Gut	25-100	63	Feng et al. 2017 (10.3389/fmicb.2017.00992)
Yes	ZnO	none	NA	90	*Gallus domesticus*	Gut	5	28	Yausheva et al. 2018 (10.1007/s11356-018-1991-5)
Yes	ZnO	none	NA	23	*Sus domesticus*	Gut	$600\text{-}2\cdot10^{3}$	14	Xia et al. 2017 (10.18632/oncotarget.17612)

HUMAN AND ANIMAL HEALTH: GAVAGE EXPOSURE

Effect on microbiota	*Nanoparticle*				*Host*	*Microbiota*	*Concentration*	*Exposure time (d)*	*Reference (DOI)*
	Core[b)]	*Coating*[c)]	*Shape*[d)]	*Size*[e)]			*($mg\cdot kg\ bw^{-1}\cdot d^{-1}$)*[f)]		
N.D.	Ag	PVP	20	A	*Mus musculus*	Gut	10	28	Wilding et al. 2016 (10.3109/17435390.2015.1078854)
N.D.	IO	dextran	50	NA	*Sus domesticus*	Gut	1.5**	23	Mazgaj et al. 2021 (10.3390/ijms22189930)
N.D.	IO	phospho-lipid	100	NA	*Sus domesticus*	Gut	1.5**	23	Mazgaj et al. 2021 (10.3390/ijms22189930)
N.D.	ZnO	none	40	A	*Mus musculus*	Gut	250	49	Wang et al. 2017 (10.1007/s12011-017-0934-1)
Yes	Ag	none	20	NA	*Mus musculus*	Gut	$2\cdot10^{-3}$	45	Wu et al. 2020 (10.1039/c9en01387c)

Yes	Ag	citrate	18	S	*Mus musculus*	Gut	3	7	Lyu et al. 2021 (10.1038/s41598-021-85919-7)
Yes	Ag	PVP	10	NA	*Mus musculus*	Gut	1-5	36	Meier et al. 2021 (10.1016/j.impact.2021.100343)
Yes	Ag	citrate	10	NA	*Rattus norvegicus*	Gut	9-36	91	Williams et al. 2014 (10.3109/17435390.2014.921346)
Yes	Ag	citrate	75	NA	*Rattus norvegicus*	Gut	9-36	91	Williams et al. 2014 (10.3109/17435390.2014.921346)
Yes	Ag	PVP	84	CB	*Rattus norvegicus*	Gut	3.6	14	Javurek et al. 2017 (10.1038/s41598-017-02880-0)
Yes	Ag	PVP	93	S	*Rattus norvegicus*	Gut	3.6	14	Javurek et al. 2017 (10.1038/s41598-017-02880-0)
Yes	Au	Tannic acid	5	S	*Mus musculus*	Gut	0.025	8	Zhu et al. 2018 (10.1186/s12951-018-0415-5)
Yes	Fullerenol	none	95	S	*Mus musculus*	Gut	20	28	Li et al. 2018 (10.1186/s12989-018-0241-9)
Yes	HAHp/ZnO	HAHp	50	H	*Mus musculus*	Gut	$1 \cdot 10^3$	14	Song et al. 2018 (10.3390/md16010023)
Yes	Hydro-phobic segment (hydro-carbon)	PEG-catechol	100	S	*Rattus norvegicus*	Gut	$4 \cdot 10^3$	5	Zhao et al. 2021 (10.1038/s41467-021-27463-6)
Yes	IO	Ginseno-side-R3	8	I	*Mus musculus*	Gut	70	84	Ren et al. 2020 (10.1002/smll.201905233)
Yes	Polystyrene	none	47	S	*Mus musculus*	Gut	0.2-10	30	Xiao et al. 2022 (10.1016/j.envpol.2021.118184)
Yes	Pt	citrate	5	S	*Mus musculus*	Gut	0.025	8	Zhu et al. (201910.2147/IJN.S210655)
Yes	Se	none	40	S	*Mus musculus*	Gut	0.1	10	Deng et al. 2021 (10.1039/d0nr07981b)
Yes	Se	Albumin	96	S	*Mus musculus*	Gut	0.1	10	Deng et al. 2021 (10.1039/d0nr07981b)
Yes	Se	none	39	S	*Rattus norvegicus*	Gut	$3 \cdot 10^{-3}$	1	Lin et al. (202110.1016/j.nantod.2020.101010)
Yes	SiO_2	none	27	A	*Mus musculus*	Gut	$3 \cdot 10^3$	28	Diao et al. 2021 (10.1186/s12951-021-00916-2)
Yes	TiO_2	none	29	A	*Mus musculus*	Gut	100	28	Li et al. 2018 (10.1039/c8nr00386f)

Yes	TiO_2	none	25	A	*Mus musculus*	Gut	1	7	Li et al. 2019 (10.1016/j.impact.2019.100164)
Yes	TiO_2	none	85	I	*Mus musculus*	Gut	$1\cdot10^{3}$	1-14	Kurtz et al. 2020 (10.1002/jat.3991)
Yes	TiO_2	none	21	A	*Mus musculus*	Gut	150	30	Zhang et al. 2020 (10.1007/s00204-020-02698-2)
Yes	TiO_2	none	38	S	*Mus musculus*	Gut	100	10	Gao et al. 2021 (10.1039/d0nr08106j)
Yes	TiO_2	none	30	I	*Mus musculus*	Gut	40	56	Zhu et al. 2021 (10.1007/s12274-020-3210-1)
Yes	TiO_2	none	29	A	*Rattus norvegicus*	Gut	2-50	30	Chen et al. 2019 (10.1039/c9nr07580a)
Yes	TiO_2	none	29	A	*Rattus norvegicus*	Gut	2-50	90	Chen et al. 2019 (10.1186/s12989-019-0332-2)
Yes	TiO_2	none	21	A	*Rattus norvegicus*	Gut	5	13	Mao et al. 2019 (10.1186/s11671-018-2834-5)
Yes	TiO_2	none	25	A	*Rattus norvegicus*	Gut	1-100	14	Zhao et al. 2020 (10.1016/j.ecoenv.2020.111393)
Yes	WO_3	none	48	S	*Mus musculus*	Gut	0.3 $mmol\cdot kg\ bw^{-1}$	7	Qin et al. (202110.1016/j.nantod.2021.101234)
Yes	ZnO	none	50	S	*Mus musculus*	Gut	26	30	Chen et al. 2020 (10.1039/d0nr04563b)

HUMAN AND ANIMAL HEALTH: OTHER EXPOSURES

Effect on microbiota	*Nanoparticle*				*Host*	*Microbiota*	*Concentration*	*Exposure time (d)*	*Reference (DOI)*
	Core [b]	*Coating* [c]	*Shape* [d]	*Size* [e]					
Yes	Ag	protein	sphere	49	*Homo sapiens*	Gut	396 mg (capsule)	8.5	Vamanu et al. 2018 (10.3390/nu10050607)
Yes	$AgVO_3$	Ag nano-particle	wire	10	*Homo sapiens*	Mouth	10-50 $mg\cdot L\ resin^{-1}$	7	De Castro et al. 2021 (10.1007/s10266-020-00582-0)

[a] Literature was retrieved from the Web of Science Core Collection database, accessed on 27 March 2022 through Leiden University's library, using the search string '(nanomaterial* OR nanoparticle*)' for the title, and the search string '(microbiome OR microbiota)' for the abstract of articles.

[b] Nanoparticle core abbreviations: Ag, silver; Ag_2S, silver sulfide; Au, gold; $AgVO_3$, silver vanadate; CeO_2, cerium dioxide; CHX PR_4^+, cationic phenyl-bis biguanide chlorhexidine tributylhexadecylphosphonium bromide; Cu, copper; CuO, copper oxide; Fe, iron; HAHp, half-fin anchovy hydrolysates; La_2O_3, lanthanum oxide; Mo, molybdenum; MoO_3, molybdenum trioxide; NiO, nickel oxide; IO, iron oxide;; Pt, platinum; Se, selenium; SiO_2, silicium dioxide; TiO_2, titanium dioxide; WO_3, tungsten trioxide ;ZnO, zinc oxide.

[c] Nanoparticle coating abbreviations: HAHp, half-fin anchovy hydrolysates; PEG, polyethylene glycol; PS-PDMA, polystyrene-poly(*N*,*N*-dimethylacrylamide); PVP, polyvinylpyrrolidone.

[d] Nanoparticle shape abbreviations: A, amorphous; C, crystal; CB, cuboid; H, hexagonal; I, irregular; R, rods; S, (semi)-spherical.

[e] For cuboids and wires, the smallest external dimension is presented.

[f] In case different concentration units were reported, this is specified at the concerning rows.

* For drinking water exposures, 1 L water is expressed as 1 kg 'food'.

** The concentration was based on the average weight of exposed piglets over the exposure time.

Supplementary table S2 starts at the next page.

Table S2: Relative abundances of bacterial taxa in zebrafish larvae microbiota as determined based on 16S rRNA sequencing. Replicates 1, 2 and 3 correspond to the pooled DNA of 30 larvae at 3 days post-fertilization. Mean and standard error of the mean (SEM) are given in the final column. Sequence data can be retrieved from the Sequence Read Archive under BioProject PRJNA860062 (BioSamples SAMN29820940, SAMN29820941 and SAMN29820942). Genus and species level identification was based on the SILVA 138 small subunit (16S/18S) rRNA database Ref NR 99, and family to phylum level classifications were retrieved from NCBI Taxonomy Browser. The total number of amplicon sequence variants upon filtering of sequences from a negative control (BioSample SAMN29820946), chloroplasts and mitochondria for replicate 1, 2 and 3 were 2950, 1948, and 3874, respectively. The corresponding QIIME2 pipeline is available via Zenodo (DOI: 10.5281/zenodo.6891712).

					Relative abundance (%)			
Phylum	*Class*	*Order*	*Family*	*Species*	*1*	*2*	*3*	*Mean ± SEM*
Actinobacteriota	Actinobacteria	Bifidobacteriales	Bifidobacteriaceae	*Bifidobacterium* sp.	1.9	0	0	0.6 ± 0.6
		Propionibacteriales	Propionibacteriaceae	*Cutibacterium* sp.	0	0.6	0	0.2 ± 0.2
	Coriobacteriia	Coriobacteriales	Coriobacteriaceae	*Collinsella* sp.	0.6	0	0	0.2 ± 0.2
Bacteroidota	Bacteroidia	Bacteroidales	Barnesiellaceae	*Barnesiella* sp.	0.2	0	0	0.1 ± 0.1
		Cytophagales	Prevotellaceae	*Prevotella* sp.	0.6	0	0	0.2 ± 0.2
				Prevotella nigrescens	0.3	0	0	0.1 ± 0.1
				Flectobacillus sp.	0	0	3.1	1.0 ± 1.0
		Flavobacteriales	Weeksellaceae	*Chryseobacterium* sp.	0.2	0	0	0.1 ± 0.1
				Candidatus *Chryseobacterium* sp.	0	1.4	0	0.5 ± 0.5
Firmicutes	Bacilli	RF39	RF39	RF39 bacterium	0.1	0	0	0.1 ± 0.03
	Clostridia	Eubacteriales	Eubacteriaceae	*Eubacterium coprostanoligenes*	0.8	0	0	0.3 ± 0.3
			Lachnospiraceae	*Agathobacter rectale*	0.7	0	0	0.2 ± 0.2
				Blautia sp.	0.6	0	0	0.2 ± 0.2
				Coprococcus sp.	0.9	0	0	0.3 ± 0.3
				Dorea sp.	0.4	0	0	0.2 ± 0.1
				Fusicatenibacter sp.	0.9	0	0	0.3 ± 0.3
			Oscillospiraceae	*Ruminococcus* sp.	0.6	0	0	0.2 ± 0.2
				Subdoligranulum sp.	0.6	0	0	0.2 ± 0.2
				UCG-002 bacterium	1.1	0	0	0.4 ± 0.4
				UCG-005 bacterium	0.2	0	0	0.1 ± 0.1
			Peptostreptococcaceae	*Romboutsia* sp.	0.8	0	0	0.3 ± 0.3

		Tissierellales	Peptoniphilaceae	*Anaerococcus* sp.	0.2	0	0	0.1 ± 0.1
				Parvimonas sp.	0	0	0.7	0.2 ± 0.2
	Negativicutes	Veillonellales	Veillonellaceae	*Dialister invisus*	1.3	0	0	0.4 ± 0.4
Proteobacteria	Alpha-proteobacteria	Caulobacterales	Caulobacteraceae	*Caulobacter* sp.	0	2.3	0	0.8 ± 0.8
				Unassigned	1.3	0	0	0.4 ± 0.4
		Hyphomicrobiales	Boseaceae	*Bosea* sp.	0	0	1.1	0.4 ± 0.4
			Bradyrhizobiaceae	*Bradyrhizobium* sp.	1.4	0	0	0.5 ± 0.5
			Methylobacteriaceae	*Methylobacterium jeotgali*	0	1.3	0	0.4 ± 0.4
			Pleomorphomonadaceae	Unassigned	0.9	0	0	0.3 ± 0.3
			Rhizobiaceae Bradyrhizobiaceae	*Allorhizobium-Neorhizobium-Pararhizobium-Rhizobium* sp.	2.3	6.0	0.9	3.1 ± 1.5
		Rhodospirillales	Rhodospirallaceae	*Taonella* sp.	0.2	3.0	0	1.1 ± 1.0
		Sphingomonadales	Sphingomonadaceae	*Sphingomonas* sp.	0.5	4.2	0	1.6 ± 1.3
	Beta-proteobacteria	Burkholderiales	Burkholderiaceae	*Limnobacter humi*	0	0.3	0	0.1 ± 0.1
				Ralstonia sp.	5.0	5.4	0	3.5 ± 1.7
				Unassigned	0.2	2.0	3.2	1.8 ± 0.9
			Chromatiaceae	*Rheinheimera* sp.	0.5	0	0	0.2 ± 0.2
			Comamonadaceae	*Delftia* sp.	0	1.5	1.4	1.0 ± 0.5
				Pelomonas sp.	1.8	6	0.4	2.7 ± 1.7
				Pelomonas puraquae	0.6	0	0	0.2 ± 0.2
			Oxalobacteraceae	*Massilia* sp.	0	0.8	0	0.3 ± 0.3
				Pseudoduganella sp.	0	1.4	0	0.5 ± 0.5
				Unassigned	0.7	2.6	4.4	2.5 ± 1.1
				Undibacterium sp.	0.4	0	0	0.1 ± 0.1
		Neisseriales	Chromobacteriaceae	*Vogesella* sp.	58.4	53.6	69.9	60.6 ± 4.8
		Rhodocyclales	Azonexaceae	*Dechloromonas* sp.	1.8	0.9	0	0.9 ± 0.5
	Gamma-proteobacteria	Aeromonadales	Aeromonadaceae	*Aeromonas* sp.	0.4	0	0.7	0.4 ± 0.2
			Unassigned	Unassigned	0.4	0	0	0.1 ± 0.1
		Cardiobacteriales	Cardiobacteriaceae	*Cardiobacterium hominis*	0.5	0	0	0.2 ± 0.2
		Enterobacteriales	Enterobacteriaceae	*Escherichia/Shigella* sp.	0	0	0.6	0.2 ± 0.2
		Nevskiales	Solimonadaceae	Unassigned	1.1	0	0	0.4 ± 0.4
		Pseudomodales	Pseudomonadaceae	*Pseudomonas* sp.	0.6	0	4.5	1.7 ± 1.4

				Pseudomonas luteola	0	0	0.9	0.3 ± 0.3
		Xanthomonadales	Xanthomonadaceae	*Stenotrophomonas* sp.	4.3	0	3.1	2.5 ± 1.3
Verrucomicrobiota	Verrucomicrobiae	Puniceicoccales	Puniceicoccaceae	Unassigned	0.4	0	0	0.1 ± 0.1
Unassigned bacteria	Unassigned	Unassigned	Unassigned	Unassigned	2.1	3.6	2.3	2.7 ± 0.5
Unassigned	Unassigned	Unassigned	Unassigned	Unassigned	0.9	3.2	2.8	2.3 ± 0.7