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1 **Interaction between dietary selenium and methylmercury on growth performance,**
2 **deposition and health parameters in rainbow trout fed selenium-rich tuna-based diets or**
3 **selenium-poor plant-based diets**

4

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19 **Highlights**

- 20 • Se addition in plant diets prevented growth reduction induced by MeHg at 21 days
- 21 • SeMet in tuna diets hampered MeHg-induced pro-inflammatory response at 21 days
- 22 • Se(IV) in tuna diets reduced Hg body level in fish fed MeHg at 21 days
- 23 • MeHg addition in tuna diets limited growth reduction by Se(IV) at 168 days
- 24 • MeHg addition in plant and tuna diets increased body Se content at 168 days

25 **Abstract**

26 This study evaluated the effect of dietary mercury (Hg) and selenium (Se) sources and levels
27 on growth performance, Hg and Se accumulation, pro-inflammatory cytokine levels and global
28 health parameters in rainbow trout juveniles. A 6-month feeding trial was carried out with a
29 control plant-based diet (containing analyzed Se and Hg levels: 0.3 and 0 mg/kg diet,
30 respectively) or a control tuna-based diet (containing analyzed Se and Hg levels: 7.5 and 0.3
31 mg/kg diet, respectively) supplemented with 0 or 1.5 mg Se/kg diet supplied either as sodium
32 selenite (Se(IV)) or selenomethionine (SeMet) combined with 0, 1.6 or 2 mg Hg/kg diet
33 supplied as methylmercury (MeHg). Fish sampling was carried out at 2 times: after a short (21
34 days) and a long term dietary exposure (168 days). In the short term, a temporarily reduced
35 growth was noticed in fish fed MeHg-supplemented plant-based diet in absence of dietary Se
36 supplementation. MeHg supplementation increased pro-inflammatory cytokine TNF- α and IL-
37 1 β levels in plant and tuna-based diets. MeHg supplementation also affected short-term fish
38 global health parameters with an increase of glucose and albumin levels in tuna-based diets.
39 The addition of SeMet in MeHg-supplemented tuna-based diets protected against the increase
40 of TNF- α level in the long term whereas the addition of Se(IV) in MeHg-supplemented tuna-
41 based diets decreased whole-body Hg level and retention in the short term. In the long term, a
42 reduced growth, a higher feed conversion ratio and a lower protein efficiency ratio were
43 recorded in fish fed Se(IV)-supplemented tuna-based diets in absence of MeHg
44 supplementation. The addition of Se(IV) or SeMet in tuna-based diets increased plasma IL-6
45 level. The addition of MeHg in plant and tuna-based diets increased Se accumulation and
46 retention. This work underlines that different forms of Se supplementation, in two dietary
47 background context (low basal Se level in plant-based diets and high basal Se level in tuna-
48 based diets), have specific effects on metabolism and biological consequences of dietary MeHg.
49 Dietary inorganic Se (but not organic Se) affected MeHg metabolism by reducing Hg

50 accumulation in fish. However, dietary organic Se displayed better ability to afford protection
51 against MeHg pro-inflammatory effects.

52

53 **Keywords (between 4 and 6 words maximum):**

54 Methylmercury; sodium selenite; selenomethionine; tuna by-products; inflammation; rainbow
55 trout.

56 **1. Introduction**

57 Global concerns of public opinion rise on aquaculture production and its impact on the
58 environment, due to the use of fishmeal (FM) and fish oil (FO) produced from wild fish catch
59 (FAO, 2022). Plant and other alternative ingredients are increasingly used in aquafeed
60 formulation to replace FM and FO (FAO, 2022). Another strategy is to increase the part of fish
61 by-products: in 2020, 27% of the global production of FM and 48% of the total production of
62 FO came from by-products (IFFO, 2021). Tunas represent one of the most high-value fish group
63 with their high catch volume and important economic value. In 2020, catches of tuna and tuna-
64 like species represented 7.8 million tonnes (FAO, 2022). Tuna cannery industry generates high
65 amount of by-products made of viscera, head, bones, skin and fins, representing up to 70% of
66 processed fish (FAO, 2022). Reports are available concerning the use of tuna by-products as
67 aquafeed ingredient for FM replacement. A substitution up to 30% of FM by tuna by-products
68 during 7 weeks in olive flounder juveniles (Kim et al., 2014) and a substitution up to 75%
69 during 12 weeks in Korean rockfish juveniles (Kim et al., 2018) had no adverse effect on growth
70 compared to fish receiving a non FM-substituted commercial diet. On the other hand, a FM
71 replacement by 55% of tuna by-products decreased final body weight and increased feed
72 conversion ratio of rainbow trout, compared to fish fed a commercial diet with anchovy meal
73 as FM after 12 weeks of feeding (Tekinay et al., 2009). Tunas accumulate contaminants like
74 mercury (Hg), lead and arsenic (Ormaza-González et al., 2020) and Hg levels in tunas vary
75 widely depending on factors such as species and tissues (Ruelas-Inzunza et al., 2018).

76 Therefore, contrary to plant feedstuffs that present other nutritional limitations (Gatlin
77 et al., 2007), the presence of Hg in tuna by-products raises some concern with regards to fish
78 welfare and consumer safety as World Health Organization has classified Hg in the top ten
79 chemicals of major concern for public health. Hg toxicity depends, among others on chemical
80 Hg form (Jang et al., 2020). Methylmercury (MeHg) is the predominant chemical form found

81 in the environment and threatens human health to a higher extent than Hg inorganic forms
82 (Honda et al., 2006). In salmonids, toxicity threshold is also reported to be lower for MeHg
83 than for inorganic Hg (Berntssen et al., 2004) and a dietary level of 2 mg/kg MeHg has been
84 shown to induce a pro-inflammatory response in juvenile Nile tilapia (Abu Zeid et al., 2021).

85 In addition to Hg, tunas accumulate high amount of selenium (Se) (Yamashita et al.,
86 2011). Thus, tuna by-products are expected to contain high Se concentration, probably above
87 rainbow trout and salmonid Se requirement, defined between 0.15 and 0.65 mg/kg diet (NRC,
88 2011; Antony Jesu Prabhu et al., 2020). On the contrary, plant-based aquafeeds are known to
89 contain low Se level, below salmonid requirements (Antony Jesu Prabhu et al., 2020). This
90 essential element plays also a great role in the protection against Hg toxicity as demonstrated
91 in goldfish and zebrafish (Bjerregaard et al., 2011; Amlund et al., 2015). These studies
92 underlined also the importance of dietary Se concentration and chemical forms on Hg
93 accumulation and detoxification.

94 The aim of this study was to investigate the impact of dietary MeHg and various Se
95 chemical forms in alternative aquafeeds containing different basal Hg and Se concentrations.
96 The Hg and Se deposition linked with growth performance, pro-inflammatory and overall
97 health status after a short and long-term dietary exposure was assessed in rainbow trout
98 juveniles.

99

100 **2. Material and methods**

101 *2.1. Ethical statement*

102 The feeding trial was conducted in accordance with the European directive 2010/63/EU
103 and the French decree n° 2013-118 on the protection of animals used for scientific purposes.
104 The protocol was approved by the Ethical Committee C2EA-73 and the French Ministry of
105 Higher Education and Research (reference number APAFIS#27846-2020102812241350 v2).

106

107 2.2. Experimental diets

108 Diets were manufactured in the INRAE experimental facilities of Donzacq (Landes,
109 France, <https://doi.org/10.15454/GPYD-AM38>), using a twin-screw extruder (BC 45, Cleextral,
110 Firminy, France). Twelve feeds were formulated with two different basal ingredient
111 compositions (Table 1a). Plant-based diets were formulated with plant-derived proteins and
112 tuna-based diets with FM derived from tuna by-products (Marine Biotechnology Products,
113 Port-Louis, Mauritius). Contrary to tuna-based diets, plant-based diets were MeHg-free and
114 known to contain low basal Se level. Control plant (PC) and control tuna (TC) diets were
115 unsupplemented with MeHg and Se(IV) or SeMet either, containing thus only basal levels of
116 Hg and Se (Table 1b). Two diets were supplemented with methylmercury(II) chloride (Sigma-
117 Aldrich, Saint-Quentin-Fallavier, France): 2 mg Hg/kg diet for plant-based diet (PH) and 1.6
118 mg Hg/kg diet for tuna-based diet (TH). Four other diets were supplemented with 1.5 mg Se/kg
119 diet, using either inorganic Se source (sodium selenite (Se(IV))), Sigma-Aldrich, Saint Louis,
120 Missouri, USA) in diets PI and TI or organic Se source (L-selenomethionine (SeMet), Excential
121 Selenium 4000, Orffa, Breda, Netherlands) in diets PO and TO, respectively. Two diets were
122 supplemented with both Se(IV) and MeHg (PHI and THI diets) and two others with both SeMet
123 and MeHg (PHO and THO diets).

124

125 2.3. Experimental design

126 A 6-month feeding trial was carried out in the INRAE experimental fish farm at
127 Donzacq. All-female diploid rainbow trout (*Oncorhynchus mykiss*) from the same parental
128 stock ($n = 1800$) with an initial body weight of 26 ± 1 g were randomly allocated to 50-L
129 fiberglass tanks with 50 fish per tank for the first two months, then to 150-L fiberglass tanks
130 with 26 fish per tank for the last four months of the trial. Water flow was set to ensure an oxygen

131 concentration above 90% saturation. Tanks were supplied with flow-through (0.1 L/s, renewal
132 4.5 times/h at the beginning, then 0.25 L/s, renewal 7 times/h) spring water at 17 ± 1 °C. Fish
133 were hand-fed twice a day to visual satiation under natural light regimen. Each diet was
134 distributed to three replicate groups of fish over a 6-month growth trial. Mortality was recorded
135 daily. Fish from each tank were bulk weighed every three weeks.

136

137 *2.4. Sampling and data collection*

138 Before every weighing and sampling (after 21 and 168 days), fish were overnight
139 starved during 16 h. At the start, 21 fish in common, then 8 fish from each replicate tank ($n =$
140 24 fish per diet) at day 21 and day 168 were anaesthetized with benzocaine (30 mg/L) then
141 killed with an overdose of benzocaine (60 mg/L). Fish were weighed and blood samples were
142 collected from the caudal vein. Plasma was recovered from half of the centrifuged ($5500 \times g$
143 for 10 min) blood samples, immediately frozen and stored at -80 °C prior to analysis ($n = 12$
144 per diet). Three fish collected at the start and two fish per tank at day 21 and day 168 ($n = 6$ per
145 diet) were frozen and stored at -20 °C prior to proximate analysis. The liver of other collected
146 fish ($n = 18$ at the start and $n = 18$ per diet at day 21 and day 168) were weighed for calculating
147 hepatosomatic index (HSI). At the end of the feeding trial, remaining fish (from 3 to 10 per
148 tank) were fed for another week, anaesthetized and killed 16 h after the last meal for faeces
149 collection in distal gut for the determination of apparent digestibility coefficient (ADC) of Se
150 and Hg. The samples of faeces were collected over ice, pooled per tank, frozen immediately
151 and stored at -20 °C prior to Hg and Se analysis.

152

153 *2.5. Proximate and mineral analyses in diets, whole fish and faeces*

154 Dry matter content was determined by drying directly faeces samples or after grinding
155 fish and diet samples at 105 °C for 24 h. Whole fish and faeces samples were freeze-dried

156 before further analyses. Proximate composition of diets and freeze-dried fish was determined
157 according to following procedures: ash by incineration at 550 °C for 10 h, protein ($N \times 6.25$)
158 by the Kjeldahl method after acid digestion, total lipid according to Folch et al. (1957) using
159 dichloromethane instead of chloroform and gross energy in an adiabatic bomb calorimeter.
160 Total Se and Hg concentrations in diet, freeze-dried fish and faeces samples were measured by
161 inductively coupled plasma mass spectrometry (ICP-MS) according to Silva et al. (2019).

162

163 *2.6. Determination of apparent digestibility coefficient (ADC) of minerals*

164 The apparent digestibility coefficient (ADC) of Se and Hg was measured using
165 vanadium (V) as an internal marker in faeces and diets according to Witkowski et al. (2019).

166

167 *2.7. Determination of plasma and blood metabolites*

168 Plasma metabolites were determined in plasma of fish, $n = 3$ pooled samples per dietary
169 treatment representing 4 fish each. Fish pro-inflammatory cytokines: tumor necrosis factor α
170 (TNF- α), interleukine 1 β (IL-1 β) and interleukine 6 (IL-6) were determined with ELISA kit
171 tests (Cusabio Biotech Co., Wuhan, Hubei, China) according to manufacturer's instructions
172 using zebrafish TNF- α (cat. No. CSB-E13254Fh), zebrafish IL-1 β (cat. No. CSB-E13254Fh)
173 and Atlantic salmon (*Salmo salar*) IL-6 (cat. No. CSB-E13258Fh). TNF- α and IL-6 ELISA kits
174 used a competitive inhibition enzyme immunoassay technique whereas IL-1 β ELISA kit used
175 a quantitative sandwich enzyme immunoassay technique. Kits provided cytokines biotin-
176 conjugated, avidin conjugated horseradish peroxidase and a substrate solution. Horseradish
177 peroxidase transformed the substrate into a coloured product. In TNF- α and IL-6 ELISA kits,
178 colour developed in opposite to the amount of pro-inflammatory cytokines in samples. In IL-
179 1 β ELISA kit, the colour developed in proportion to the amount of IL-1 β in samples. The
180 absorbance was measured at 450 nm with a microplate reader and converted into concentrations

181 using the standard curve formula. Plasma lysozyme activity was determined according to Ellis
182 et al. (1990) using a turbidimetric assay with lyophilized particles of *Micrococcus lysodeikticus*
183 (Merck, Saint-Quentin-Fallavier, France). Alanine amino transferase (ALAT) and aspartate
184 amino transferase (ASAT) activities were assessed in plasma by an end-point colorimetric test
185 (AST GOT-ALT GPT Biolabo, France) at 505 nm with 2-oxoglutarate and 2,4-
186 dinitrophenylhydrazine according to the manufacturer's instructions using 40 μ L of fish
187 plasma. Total protein content in plasma was determined through the colorimetric Biuret method
188 using bicinchoninic acid (BCA) solution and copper(II) sulfate solution (Interchim uptima,
189 France), using 10 μ L of plasma sample diluted in distilled water (1:100) mixed with 200 μ L of
190 working reagent (50 volumes of BCA with 1 volume of copper(II) sulfate solution). Absorbance
191 was measured at 562 nm. Total immunoglobulin level in plasma was determined using 10 μ L
192 of plasma samples diluted in distilled water (1:100), mixed with an equal volume of
193 polyethylene glycol 70 % and centrifuged at 10 000 g, for 30 min at 15 °C for immunoglobulin
194 precipitation. Precipitated samples (10 μ L) were mixed with 200 μ L of a solution containing
195 BCA and copper(II) sulfate (1:50) into a microplate and then incubated for 30 min at 37 °C.
196 The absorbance was measured at 562 nm and converted into concentration using a standard
197 curve as for total protein determination. Albumin level in plasma samples was assessed by end-
198 point colorimetric test using bromocresol green method. A volume of 10 μ L of plasma was used
199 and absorbance was measured at 630 nm. Glycaemia was assessed at 504 nm using 5 μ L of fish
200 plasma and colorimetric method with glucose oxidase, following manufacturer's instructions
201 (Glucose GOD-POD, Sobioda S.A.S, Montbonnot St Martin, France). Haemoglobin was
202 measured in blood samples ($n = 3$ per dietary treatment) using a colorimetric method (Hb-
203 Randox kit, Ref HG1539, United Kingdom) following the manufacturer's instructions with 20
204 μ L of blood.

205

206 2.8. *Statistical analyses*

207 Data are expressed as mean \pm standard error (SEM). Differences between dietary groups
208 were analysed using a two-way ANOVA to test the effect of dietary Hg supplementation and
209 dietary Se supplementation and their interaction. Prior to the two-way ANOVA, normality and
210 homogeneity of variance of data were checked with a Shapiro-Wilk and a Levene test,
211 respectively. When appropriate, analysis was followed with a Tukey *post hoc* test. Statistical
212 analyses were performed using R software (version 3.6.1, R development Core Team, 2008).
213 Differences were considered significant when *p-value* was < 0.05 .

214

215 **3. Results**

216 *3.1. Dietary MeHg impact on growth performance, proximate body composition of rainbow*
217 *trout juveniles and interactive effects of dietary Se*

218 After 21 days of feeding, fish fed MeHg-supplemented plant-based diet PH displayed
219 decreased body weight compared to fish fed control plant-based diet PC (Fig. 1A). Such effect
220 of MeHg was not noticed in the presence of Se in diets PHI and PHO compared to control diets
221 PI and PO (Fig. 1A). No significant effect of dietary MeHg supplementation was noticed on
222 feed intake (FI) whereas a significant interaction was detected between MeHg and dietary Se
223 forms on feed conversion ratio (FCR) and protein efficiency ratio (PER), but Tuckey's *post hoc*
224 test did not allow to discriminate between plant-based dietary groups (Table 2). The highest
225 FCR and the lowest PER were displayed in PH group and the lowest FCR and highest PER
226 were noticed in PC group (Table 2). After 168 days of feeding, fish fed PH diet displayed
227 decreased body ash retention compared to fish fed PC diet (Table 2). No other significant effect
228 of MeHg supplementation in plant-based diets was observed on body weight (Fig. 1B), FI, FCR,
229 PER, survival or proximate body composition (Table 2).

230 After 21 days of feeding, fish fed MeHg-supplemented tuna-based diets TH, THI and
231 THO exhibited decreased body gross energy content compared to fish fed control diets TC, TI
232 and TO (Table 3) without significant effect on growth (Fig. 1A). After 168 days of feeding, fish
233 fed MeHg-supplemented diets TH, THI and THO displayed higher FI and reduced
234 hepatosomatic index compared to fish fed TC, TI and TO (Table 3). A higher body weight was
235 recorded in fish fed the MeHg and Se(IV)-supplemented diet THI compared to the control group
236 TI (Fig. 1B) without significant difference on FCR and PER (Table 3). No significant effect of
237 dietary MeHg was recorded on survival rate of fish fed tuna-based diets (Table 3).

238

239 *3.2. Dietary Se impact on growth performance, proximate body composition of rainbow trout* 240 *juveniles and interactive effect of dietary MeHg*

241 After 21 days of feeding, fish fed Se-supplemented plant-based diets PI, PHI, PO and
242 PHO displayed no significant differences in growth performance (Fig. 1A and Table 2) or
243 proximate body composition compared to fish fed control diets PC and PH (Table 2). After 168
244 days of feeding, higher body dry matter, total lipid, gross energy content and lipid retention
245 were noticed in fish fed Se-supplemented diets PI and PO compared to the control group PC
246 (Table 2), but no significant effect of dietary Se supplementation was noticed on fish body
247 weight (Fig. 1B) or other growth and survival parameters (Table 2).

248 After 21 days of feeding, fish fed Se-supplemented tuna-based diets TI, THI, TO and
249 THO displayed decreased body weight compared to fish fed diets TC and TH (Fig 1A). After
250 168 days of feeding, reduced body weight was recorded in fish fed Se(IV)-supplemented diet
251 TI compared to fish fed diets TC and TO (Fig. 1B). Fish fed SeMet-supplemented diets TO and
252 THO displayed higher PER, protein retention and decreased FCR compared to Se(IV)-
253 supplemented diets TI and THI (Table 3). Fish fed Se-supplemented diets TI, THI, TO and
254 THO exhibited reduced ash retention compared to fish fed control diets TC and TH (Table 3).

255 No significant effect of dietary Se was recorded on survival rate of fish fed tuna-based diets
256 (Table 3).

257

258 *3.3. Dietary MeHg impact on Hg and Se body composition, retention and digestibility in*
259 *rainbow trout juveniles and interactive effect of dietary Se*

260 MeHg supplementation in plant-based diets PH, PHI and PHO increased both short-
261 term and long-term body Hg content compared to fish fed control diets PC, PI and PO (Fig. 2A
262 and Fig. 2B). After 168 days of feeding, fish fed diets PH, PHI and PHO displayed higher faecal
263 Hg content compared to fish fed diets PC, PI and PO (Table 4). Fish exposed to diet PHO
264 exhibited higher body Se content compared to fish receiving diet PO (Fig. 2D). Fish fed diets
265 PHI and PHO presented reduced faecal Se content, increased Se digestibility and retention
266 compared to fish fed diets PI and PO (Table 4).

267 In both the short and long term, higher body Hg content and lower Hg retention were
268 recorded in fish fed MeHg-supplemented tuna-based diets TH, THI and THO compared to diets
269 TC, TI and TO (Fig. 2A, Fig. 2B and Table 5). After 168 days of feeding, diets TH, THI and
270 THO increased faecal Hg content and Hg apparent digestibility coefficient compared to diets
271 TC, TI and TO (Table 5). After 21 days of feeding, fish fed THI diet exhibited reduced Hg
272 retention compared to fish fed TI diet (Table 5). Fish fed diets TH, THI and THO displayed
273 decreased Se retention (Table 5) without significant impact on body Se content (Fig. 2C)
274 compared to fish fed control diets TC, TI and TO. However, in the long term, increased Se
275 retention (Table 5) and body Se content (Fig. 2D) were recorded in fish exposed to diets TH,
276 THI and THO compared to fish receiving diets TC, TI and TO.

277

278 *3.4. Dietary Se impact on Hg and Se body composition, retention and digestibility in rainbow*
279 *trout juveniles and interactive effect of dietary MeHg*

280 In both the short and long term, fish exposed to Se-supplemented plant-based diets PI,
281 PHI, PO and PHO displayed higher body Se content compared to fish fed control diets PC and
282 PH (Fig. 2C and Fig. 2D). The highest body Se content was observed in fish fed SeMet-
283 supplemented diets PO and PHO (Fig. 2C and Fig. 2D). These fish also exhibited higher Se
284 digestibility compared to fish fed Se(IV)-supplemented diets PI and PHI and non Se-
285 supplemented diets PC and PH with a higher Se retention and a reduced faecal Se content
286 compared to fish fed PI and PHI (Table 4). Fish fed Se(IV)-supplemented diets PI and PHI
287 displayed a higher short-term Se retention compared to fish fed PC and PH but a reduced long-
288 term Se retention (Table 4). Se(IV) supplementation in MeHg-supplemented diet PHI increased
289 faecal Hg content compared to diets PH and PHO (Table 4) without significant effect on Hg
290 digestibility, retention (Table 4) or body Hg content (Fig. 2B).

291 Se supplementation in tuna-based diets TI, THI, TO and THO increased fish body Se
292 content (Fig. 2C and Fig. 2D) and retention (Table 5) as early as 21 days of feeding with a
293 superiority for SeMet, similarly to plant-based diets. No significant differences were observed
294 on Se digestibility coefficient and faecal Se content between fish fed the Se(IV)-supplemented
295 diets TI and THI and fish fed SeMet-supplemented diets TO and THO (Table 5). After 21 days
296 of feeding, fish fed Se(IV)-supplemented diet THI displayed a reduced whole-body Hg content
297 compared to fish fed diets TH and THO (Fig. 2A) with a significantly reduced Hg retention
298 compared to fish fed diet THO (Table 5).

299

300 *3.5. Dietary MeHg impact on plasma pro-inflammatory cytokines and global health parameters* 301 *in rainbow trout juveniles and interactive effect of dietary Se*

302 Short-term feeding with MeHg-supplemented plant-based diets PH, PHI and PHO
303 induced higher plasma TNF- α and IL-1 β levels compared to control diets PC, PI and PO (Fig.
304 3A and Fig. 3C). Long-term feeding with MeHg-supplemented plant-based diets also resulted

305 in higher plasma TNF- α levels, however only fish fed the diet PHO supplemented with both
306 MeHg and SeMet, exhibited significantly higher TNF- α levels than those fed the control diet
307 PO (Fig. 3B). A long-term dietary supplementation with MeHg increased plasma total protein
308 content and decreased immunoglobulin proportion when fed with Se(IV) (Table 6).

309 Short-term feeding with MeHg-supplemented tuna-based diets TH, THI and THO
310 induced higher plasma IL-1 β (Fig. 3C), glucose and albumin levels (Table 7) compared to fish
311 fed diets TC, TI and TO. Plasma TNF- α level was also increased in MeHg-supplemented, non
312 Se-supplemented diet TH compared to control diet TC (Fig. 3A). When MeHg was added
313 concomitantly with both Se compounds (Se(IV) and SeMet) in diets THI and THO, no more
314 significant increase of TNF- α level was observed compared to non MeHg-supplemented diets
315 TI and TO (Fig. 3A). On the contrary, MeHg intake increased lysozyme levels only when fed
316 with SeMet in diet THO compared to control diet TO (Table 7). In the long term, no more
317 significant effect of MeHg supplementation in tuna-based diets was noticed (Fig. 3B, Fig. 3D,
318 Fig. 3F and Table 7).

319

320 *3.6. Dietary Se impact on plasma pro-inflammatory cytokines and global health parameters in* 321 *rainbow trout juveniles and interactive effect of dietary MeHg*

322 Short-term feeding with Se(IV)-supplemented diets PI and PHI resulted in decreased
323 plasma IL-1 β levels compared to other plant-based diets PC, PH, PO and PHO (Fig. 3C). In
324 fish fed non MeHg-supplemented diets for 168 days, SeMet increased blood haemoglobin
325 levels (Table 6) compared to control diet PC but when added concomitantly with MeHg in diet
326 PHO, SeMet increased plasma TNF- α levels compared to diet PHI (Fig. 3B). Long-term Se(IV)
327 intake in plant-based diets PI and PHI increased blood haemoglobin levels compared to non-Se
328 supplemented diets PC and PH (Table 6).

329 Short-term feeding with SeMet-supplemented diets TO and THO reduced plasma TNF-
330 α and IL-1 β levels compared to other tuna-based diets TC, TH, TI and THI (Fig. 3A and Fig.
331 3C). In absence of dietary MeHg supplementation, Se(IV)-supplemented diet TI led to higher
332 TNF- α levels compared to control diet TC (Fig. 3A) and higher lysozyme levels compared to
333 SeMet-supplemented diet TO (Table 7). Long-term SeMet supplementation decreased TNF- α
334 level only when supplemented with MeHg in diet THO compared to diets TH and THI (Fig.
335 3B) whereas both Se(IV) and SeMet supplementation in diets TI, THI, TO and THO increased
336 IL-6 levels compared to non Se-supplemented diets TC and TH (Fig. 3F).

337

338 **4. Discussion**

339 *4.1. Short-term effect of dietary MeHg on growth, pro-inflammatory cytokines, overall health*
340 *status and Hg deposition in rainbow trout juveniles and interactive effect of dietary Se*

341 In MeHg-supplemented plant-based diet PH, containing low basal Se level (1.8 mg
342 Hg/kg diet and 0.3 mg Se/kg diet), MeHg caused a transient growth reduction with higher FCR
343 and plasma pro-inflammatory cytokine content observed only after 21 days of feeding without
344 effect on survival. Such transient effect, after a 21-day exposition to dietary MeHg, is to our
345 knowledge, not reported in the literature. Nile tilapia exposed to MeHg-supplemented FM-
346 based diet (2 mg Hg/kg, 30 days of feeding) displayed higher pro-inflammatory cytokine
347 transcript levels (TNF- α , IL-1 β and IL-8) in the spleen (Abu Zeid et al., 2021). Our study
348 confirm those observations but at a plasma metabolite level. Recently, a meta-analysis in
349 Atlantic salmon underlined that fish growth performance decreased with increased severity of
350 enteritis, a pathological state associated with important induction of pro-inflammatory
351 parameters in intestines (Agboola et al., 2022). Thus, the inflammation noticed in our study
352 could explain the observed growth reduction. However, fish fed MeHg-supplemented tuna-
353 based diets displayed also higher pro-inflammatory cytokine levels and despite a decreased

354 gross energy content, those fish displayed no growth alteration. So the transient growth
355 reduction observed in fish fed MeHg in low Se plant-based diets might not only be related to
356 the induction of inflammatory response but also to a toxic effect of Hg that would be
357 emphasized in absence of Se such as the induction of oxidative stress (Baldissera et al., 2020).
358 Indeed we noticed increased transcript levels of antioxidant enzymes such as glutathione-S-
359 transferase π and methionine sulfoxide reductase B3 in liver of trout fed the MeHg-
360 supplemented plant-based diet PH for 21 days compared to the control diet PC (Bidon et al.,
361 2021). An increased transcript level of the selenoprotein P and glutathione peroxidase 1 in Se-
362 supplemented diets PI, PHI, PO and PHO was also noticed, suggesting a better antioxidant
363 protection with dietary Se supplementation that deserves further investigation for a better
364 characterization and understanding.

365 The effects observed after 21 days of feeding on growth and inflammatory status by
366 dietary MeHg in low Se plant-based diets was not supported by plasma parameters. Short-term
367 effects of dietary MeHg were recorded but only in fish fed tuna-based diets with an increase of
368 glucose and albumin levels. A 3-month feeding trial on Atlantic salmon established at 5 mg
369 MeHg/kg the threshold at which the lowest toxic effect of dietary MeHg could be observed
370 with a reduction of haematocrit and an increase of plasma protein (Berntssen et al., 2004). This
371 concentration is above our dietary MeHg levels and could explain our results in rainbow trout.

372 The addition of MeHg in plant and tuna-based diets increased significantly the whole-
373 body Hg level after short and long-term feeding. Despite the same level of dietary MeHg in
374 plant and tuna-based diets, higher body Hg content were noticed in fish fed plant-based diets,
375 after short (1.8 fold increase in PH diet compared to TH) and long-term exposure (1.3 fold
376 increase in PH diet compared to TH). A negative linear correlation have been underlined
377 between dietary molar ratio of Se/Hg and total Hg levels in Sacramento splittail larvae (Deng
378 et al., 2008). Molar ratio of Se/Hg in MeHg-supplemented tuna-based diets was higher than in

379 MeHg-supplemented plant-based diets (11.6 vs. 2.0, respectively) and might explain why fish
380 fed MeHg-supplemented tuna-based diets displayed lower whole-body Hg level than fish fed
381 MeHg-supplemented plant-based diets. However, despite the fact that dietary Se/Hg molar ratio
382 was negatively correlated to whole-body Hg level in fish, it must be addressed that this
383 parameter did not take into consideration chemical form of Se, another parameter that can
384 influence Hg deposition. Indeed, despite a similar or even higher dietary Se/Hg molar ratio in
385 THO diet compared to THI diet (13.0 vs. 11.9, respectively), fish fed THO displayed higher
386 whole-body Hg level than fish fed THI in the short term (0.28 vs. 0.22 mg Hg/kg wet weight,
387 respectively). However, this effect was no more significant after 168 days of feeding (0.78 vs.
388 0.91 mg Hg/kg wet weight). The reduced Hg digestibility (57% vs. 87% for MeHg-
389 supplemented tuna and plant-based diets) associated with the reduced Hg retention after short
390 (52% vs. 75% for MeHg-supplemented tuna and plant-based diets, respectively) and long term
391 (54% vs. 64% for MeHg-supplemented tuna and plant-based diets, respectively) supports the
392 reduced body Hg content for fish fed high Se tuna-based diets. It is noteworthy that, in fish fed
393 MeHg-supplemented plant-based diets, Hg retention was higher after a short-term than a long-
394 term exposure (75% after 21 days vs. 64% after 168 days of feeding). Similar trends were
395 observed in muscle of zebrafish fed 5 and 10 mg MeHg/kg diet after 2 weeks by Amlund et al.
396 (2015) and attributed to a variation in the uptake or in the elimination kinetic. It would have
397 been interesting to also determine Hg digestibility after a short term exposure to know if there
398 is variation in Hg uptake through time and describe better the Hg kinetic deposition in rainbow
399 trout.

400 Interestingly, the short-term effect of dietary MeHg in diet PH containing low basal
401 Se level on fish growth, was not observed in Se-supplemented diets PHI and PHO or in Se-rich
402 tuna diets. Similar protective effect of high dietary Se on MeHg-induced growth reduction was

403 reported in zebrafish exposed during 153 days to 10 mg/kg diet of SeMet and 12 mg/kg diet of
404 MeHg (Penglase et al., 2014).

405

406 *4.2. Effect of dietary MeHg on Se deposition in rainbow trout juveniles*

407 No short-term effect of dietary MeHg was found on Se whole-body level. However,
408 higher Se retention and digestibility were noticed after long-term exposure to MeHg-
409 supplemented plant-based diets. Similarly, fish fed MeHg-supplemented tuna-based diets
410 displayed higher Se retention, highlighting the effects of dietary MeHg on whole-body Se
411 deposition in both dietary groups. The increase of Se digestibility observed in fish fed MeHg-
412 supplemented diets contradicts the decreased SeMet digestibility described in juvenile white
413 sturgeon by Huang et al. (2013). The differences observed in both studies could be attributed
414 to the dissimilar Hg and Se exposures. In the study of Huang et al. (2013), MeHg and SeMet
415 were administered by intragastric gavage at lower concentration than in our study (0.85 mg
416 Hg/kg body weight and 0.5 mg Se/kg body weight). On the other hand, the increase of whole-
417 body Se level measured in fish fed MeHg-supplemented diets was reported in Sacramento
418 spittail larvae exposed to dietary SeMet (0.64-35.0 mg/kg diet) and MeHg (0.01-11.7 mg/kg
419 diet) with higher whole-body Se level when concomitantly exposed to SeMet and MeHg (Deng
420 et al., 2008). The increase of body Se level in fish exposed simultaneously to MeHg and Se in
421 comparison to the one only exposed to Se could be attributed to the formation of Se-Hg
422 complexes such as mercury selenide recently identified in freshwater fish as Hg detoxification
423 pathway (Manceau et al., 2021).

424

425 *4.3. Effect of dietary Se on Hg deposition, pro-inflammatory cytokines, growth in rainbow trout* 426 *juveniles and interactive effect of dietary MeHg*

427 A short-term effect of Se(IV) was observed on Hg deposition with lower whole-body
428 Hg level and retention measured in fish fed THI diet. This result highlights the superiority of
429 Se(IV) over SeMet to reduce Hg level in agreement with data reported in rainbow trout and
430 goldfish by Bjerregaard et al. (1999, 2011). The lack of dietary SeMet effect on Hg deposition
431 has also been reported in muscle of rainbow trout fed concomitantly MeHg and SeMet by
432 Ribeiro et al. (2022), stressing the importance of Se chemical form on Hg detoxification. The
433 lowering effect of Se(IV) supplementation in Se-rich tuna-based diets on body Hg accumulation
434 was not noticed in Se-low plant-based diets, supporting the idea of a minimal Se threshold
435 concentration to detect effects on Hg accumulation, as reported in an earlier study (Bjerregaard
436 et al., 2011).

437 A protective effect of dietary Se on the short-term pro-inflammatory effect of dietary
438 MeHg was recorded in our study. Both Se(IV) and SeMet addition in tuna-based diets helped
439 to alleviate the increase of TNF- α level by dietary MeHg addition after a short-term exposure
440 whereas only SeMet reduced TNF- α level after a long-term exposure. This result highlights the
441 superiority of SeMet to afford protection against MeHg pro-inflammatory effects in the long
442 term in presence of high dietary basal Se level in tuna-based diets, as the lowering effect of
443 SeMet on cytokine levels was not observed with plant-based diets. The greater capacity of
444 SeMet over Se(IV) to reduce inflammatory response was also reported in head kidney
445 leucocytes isolated from Atlantic salmon post-smolts after a 9-week feeding trial (Antony Jesu
446 Prabhu et al., 2020). As described earlier, inflammation could be responsible for a reduction of
447 fish growth (Agboola et al., 2022). In fish fed plant-based diets, Se supplementation had no
448 influence on the inflammatory state of fish, despite an improvement of growth in fish fed the
449 Se-supplemented diets PHI and PHO compared to fish fed the MeHg-supplemented diet PH.
450 Thus, as mentioned before, inflammation alone cannot explain effects on fish growth.

451 On the other hand, despite the anti-inflammatory effect of Se discussed above, too high
452 dietary Se level could also be detrimental. After a short-term feeding with the Se(IV)-
453 supplemented tuna-based diet TI, plasma TNF- α content was increased. Evidences of pro-
454 inflammatory effects in presence of high dietary Se levels are scarce in fish. To our knowledge,
455 only the study of Pérez-Valenzuela et al. (2021) reported mononuclear cell infiltration in
456 rainbow trout liver, a sign of early inflammation after an 8-week feeding trial using 10 mg Se/kg
457 diet supplied as Se-yeast, an organic chemical form of Se. IL-6 levels were increased after a
458 long-term exposure with Se-supplemented tuna-based diets compared to fish fed non Se-
459 supplemented tuna-based diets, strengthening the possibility of pro-inflammatory response
460 occurring after a Se supplementation in presence of high dietary Se level.

461 The growth reduction noticed with TI after 6 months of feeding suggests the
462 supplementation with Se(IV) in tuna-based diet containing high basal Se level might be toxic
463 for rainbow trout but not when supplemented as SeMet. Se toxicity threshold in fish depends
464 on chemical form of Se (Berntssen et al., 2018) and Se(IV) is considered more toxic than SeMet
465 (Berntssen et al., 2017) with a lower toxicity threshold (Berntssen et al., 2018). These results
466 are in accordance with our study as we did not observe adverse effects on growth with SeMet,
467 despite the similar dietary Se level assessed in our tuna-based diets (9 mg Se/kg diet). However,
468 it is important to note that, in tuna-based diets, basal Se level represents about 80% of the total
469 Se concentration found in Se-supplemented tuna-based diets. The suspected principal chemical
470 form of Se found in tuna is selenoneine, an organic chemical form of Se (Yamashita and
471 Yamashita, 2010). Thus our results might rely on the chemical form added in the diet but also
472 on the high basal Se level naturally present in tuna-based diets. It might be of great interest to
473 perform a speciation analysis on tuna by-products and fish fed with these tuna-based diets to
474 precisely characterize chemical form of Se.

475 When MeHg was added to TI diet, detrimental effects on fish growth performance were
476 alleviated, underlying an antagonist effect of MeHg, maybe through the formation of Hg-Se
477 compounds that are potentially associated with a reduction of Se bioavailability (Raymond and
478 Ralston, 2020).

479

480 *4.4. Tuna by-products an interesting source of selenium for aquafeeds?*

481 Tuna-based diets used in the present study displayed high Se levels, far above salmonid
482 requirement (Antony Jesu Prabhu et al., 2020). Despite Se concentration in the TC diet equal
483 to 7.5 mg Se/kg diet and thus below levels reported to reduce fish growth performance: 13 mg
484 Se/kg diet supplied as Se(IV) for rainbow trout (Hilton et al., 1982) and 11 mg Se/kg diet for
485 Atlantic salmon (Berntssen et al., 2018), it might be safer to reduce dietary Se level. Tuna, like
486 other fish, accumulate Se mainly in liver and kidney (Ruelas-Inzunza et al., 2018; Belmonte et
487 al., 2021). These organs are parts of tuna by-products, thus adjusting their level in by-products
488 might be interesting to control Se level. Another possibility to reduce dietary Se level is to
489 decrease the level of tuna by-products inclusion, in our study, we used an inclusion level of
490 60%, lower level might be suitable.

491 However, the main concern of FM prepared from tuna by-products used in aquaculture
492 comes from the presence of contaminants, especially MeHg (Kim et al., 2019). In Europe, the
493 limit for Hg concentration in rainbow trout muscle must not exceed 0.3 mg/kg for human
494 consumption (European Union, 2022). This threshold was not exceeded at whole-body level in
495 fish fed the control tuna-based diet, even after 6 months of feeding, with whole-body Hg level
496 concentration of 0.13 mg Hg/kg that might comply with the existing EU regulation, highlighting
497 the potential of this ingredient for aquafeeds. However, Hg is known to accumulate in muscle
498 (Giblin and Massaro, 1973) and so the Hg level in muscle is requested to conclude about the
499 potential use of tuna by-products as aquafeed ingredient for rainbow trout aquaculture.

500

501 **5. Conclusion**

502 In conclusion, the present work highlights the importance of dietary chemical forms and
503 concentration of Se on the understanding of MeHg and Se effects. MeHg accumulation was
504 reduced by Se(IV) in high Se tuna-based diets after a short-term exposure and MeHg-induced
505 pro-inflammatory response was hampered by SeMet in high Se tuna-based diets. On the other
506 hand, growth performance and inflammatory status were impaired by Se(IV) in Se-rich tuna-
507 based diets, and paradoxically, antagonist effect by MeHg supplementation was displayed. Se
508 digestibility, body content and retention were also higher in fish exposed to dietary MeHg, that
509 deserves further investigation.

510

511 **Abbreviations**

512 ALAT, alanine amino transferase; ASAT, aspartate amino transferase; Hg, mercury; IL-1 β ,
513 interleukine 1 β ; IL-6, interleukine 6; MeHg, methylmercury; PC, control plant-based diet; PH,
514 methylmercury-supplemented plant-based diet; PHI, methylmercury and selenite-
515 supplemented plant-based diet; PHO, methylmercury and selenomethionine supplemented
516 plant-based diet; PI, selenite-supplemented plant-based diet; PO, selenomethionine-
517 supplemented plant-based diet; Se, selenium; Se(IV), selenite; SeMet, selenomethionine; TNF-
518 α , tumor necrosis factor α ; TC, control tuna-based diet; TH, methylmercury-supplemented tuna-
519 based diet; THI, methylmercury and selenite-supplemented tuna-based diet; THO,
520 methylmercury and selenomethionine-supplemented tuna-based diet; TI, selenite-
521 supplemented tuna-based diet; TO, selenomethionine-supplemented tuna-based diet.

522

523 **Author's contributions**

524 **MB:** Conceptualization, Formal analysis, Investigation, Data curation, Writing – original draft,
525 review & editing, Visualization; **AJPP:** Conceptualization, Formal analysis, Investigation,
526 Writing – review & editing, Funding acquisition; **AB:** Formal analysis, Data curation; **AH:**
527 Formal analysis, Data curation; **JR:** Writing – review & editing, Supervision; **ZPZ:**
528 Conceptualization, Writing – review & editing, Funding acquisition; **SFD:** Conceptualization,
529 Formal analysis, Investigation, Data curation, Writing –review & editing, Supervision.

530

531 **Declaration of Competing Interest**

532 The authors declare that they have no known competing financial interests or personal
533 relationships that could have appeared to influence the work reported in this paper.

534

535 **Data availability**

536 Data will be made available on request

537

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552

553 **References**

554

555 Abu Zeid, E.H., Khalifa, B.A., Said, E.N., Arisha, A.H., Reda, R.M., 2021. Neurobehavioral
556 and immune-toxic impairments induced by organic methyl mercury dietary exposure in Nile
557 tilapia *Oreochromis niloticus*. *Aquat. Toxicol.* 230, 105702.
558 <https://doi.org/10.1016/j.aquatox.2020.105702>

559

560 Agboola, J.O., Chikwati, E.M., Hansen, J.Ø., Kortner, T.M., Mydland, L.T., Krogdahl, Å.,
561 Djordjevic, B., Schrama, J.W., Øverland, M., 2022. A meta-analysis to determine factors
562 associated with the severity of enteritis in Atlantic salmon (*Salmo salar*) fed soybean meal-
563 based diets. *Aquaculture* 555, 738214. <https://doi.org/10.1016/j.aquaculture.2022.738214>

564

565 Amlund, H., Lundebye, A.-K., Boyle, D., Ellingsen, S., 2015. Dietary selenomethionine
566 influences the accumulation and depuration of dietary methylmercury in zebrafish (*Danio*
567 *rerio*). *Aquat. Toxicol.* 158, 211–217. <https://doi.org/10.1016/j.aquatox.2014.11.010>

568

569 Antony Jesu Prabhu, P., Holen, E., Espe, M., Silva, M.S., Holme, M.-H., Hamre, K., Lock, E.-
570 J., Waagbø, R., 2020. Dietary selenium required to achieve body homeostasis and attenuate
571 pro-inflammatory responses in Atlantic salmon post-smolt exceeds the present EU legal limit.
572 *Aquaculture* 526, 735413. <https://doi.org/10.1016/j.aquaculture.2020.735413>

573

574 Baldissera, M.D., Souza, C.F., da Silva, A.S., Henn, A.S., Flores, E.M.M., Baldisserotto, B.,
575 2020. Diphenyl diselenide dietary supplementation alleviates behavior impairment and brain
576 damage in grass carp (*Ctenopharyngodon idella*) exposed to methylmercury chloride. *Comp.*
577 *Biochem. Physiol. C-Toxicol. Pharmacol.* 229. <https://doi.org/10.1016/j.cbpc.2019.108674>

578

579 Belmonte, A., Muñoz, P., Santos-Echeandía, J., Romero, D., 2021. Tissue distribution of
580 mercury and its relationship with selenium in Atlantic bluefin tuna (*Thunnus thynnus* L.). Int.
581 J. Environ. Res. Public Health 18, 13376. <https://doi.org/10.3390/ijerph182413376>

582

583 Berntssen, M.H.G., Hylland, K., Julshamn, K., Lundebye, A.-K., Waagbo, R., 2004. Maximum
584 limits of organic and inorganic mercury in fish feed. Aquac. Nutr. 10, 83–97.
585 <https://doi.org/10.1046/j.1365-2095.2003.00282.x>

586

587 Berntssen, M.H.G., Sundal, T.K., Olsvik, P.A., Amlund, H., Rasinger, J.D., Sele, V., Hamre,
588 K., Hillestad, M., Buttle, L., Ørnsrud, R., 2017. Sensitivity and toxic mode of action of dietary
589 organic and inorganic selenium in Atlantic salmon (*Salmo salar*). Aquat. Toxicol.
590 <https://doi.org/doi.org/10.1016/j.aquatox.2017.09.014>

591

592 Berntssen, M.H.G., Betancor, M., Caballero, M.J., Hillestad, M., Rasinger, J., Hamre, K., Sele,
593 V., Amlund, H., Ørnsrud, R., 2018. Safe limits of selenomethionine and selenite
594 supplementation to plant-based Atlantic salmon feeds. Aquaculture 495, 617–630.
595 <https://doi.org/10.1016/j.aquaculture.2018.06.041>

596

597 Bidon, M., Marchan Moreno, C., El Hanafi, K., Queipo Abad, S., Roy, J., Amouroux, D.,
598 Bueno, M., Pedrero-Zayas, Z., Fontagné-Dicharry, S., 2021. Dietary methylmercury and
599 selenium interactions in rainbow trout juveniles (*Oncorhynchus mykiss*). Aquaculture Europe
600 21. Oceans of opportunity, European Aquaculture Society (EAS), Oct 2021, Madeira, Portugal,
601 pp. 150-151. <https://aquaeas.org/Program/PaperDetail/38846>

602

603 Bjerregaard, P., Andersen, B.W., Rankin, J.C., 1999. Retention of methyl mercury and
604 inorganic mercury in rainbow trout *Oncorhynchus mykiss* (W): effect of dietary selenium.
605 *Aquat. Toxicol.* 45, 171–180. [https://doi.org/10.1016/S0166-445X\(98\)00099-X](https://doi.org/10.1016/S0166-445X(98)00099-X)
606

607 Bjerregaard, P., Fjordside, S., Hansen, M.G., Petrova, M.B., 2011. Dietary selenium reduces
608 retention of methyl mercury in freshwater fish. *Environ. Sci. Technol.* 45, 9793–9798.
609 <https://doi.org/10.1021/es202565g>
610

611 Deng, D., Teh, F., Teh, S., 2008. Effect of dietary methylmercury and seleno-methionine on
612 Sacramento splittail larvae. *Sci. Total Environ.* 407, 197–203.
613 <https://doi.org/10.1016/j.scitotenv.2008.08.028>
614

615 Ellis, A.E., Stolen, J.S., Fletcher, T.C., Anderson, D.P., Roberson, B.S., Van Muiswinkel,
616 W.B., 1990. Lysozyme assays. In: Stolen, J.S., Fletcher, T.C., Anderson, D.P., Roberson,
617 B.S., Van Muiswinkel, W.B. (Eds.), *Techniques in Fish Immunology*. SOS Publications, Fair
618 Haven, New Jersey, pp. 101-103.
619

620 European Union, 2022. Commission regulation (EU) 2022/617 of 12 April 2022 amending
621 Regulation (EC) no 1881/2006 as regards maximum levels of mercury in fish and salt. *Off. J.*
622 *Eur. Union L115*, 65, 60-63. <https://eur-lex.europa.eu/eli/reg/2022/617/oj>
623

624 FAO, 2022. *The State of World Fisheries and Aquaculture 2022. Towards Blue*
625 *Transformation*. Rome. <https://doi.org/10.4060/cb9264en>
626

627 Folch, J., Lees, M., Sloane Stanley, G.H., 1957. A simple method for the isolation and
628 purification of total lipids from animal tissues. *J. Biol. Chem.* 226, 497– 509.
629

630 Gatlin, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman,
631 E., Hu, G., Krogdahl, Å., Nelson, R., Overturf, K., Rust, M., Sealey, W., Skonberg, D., J
632 Souza, E., Stone, D., Wilson, R., Wurtele, E., 2007. Expanding the utilization of sustainable
633 plant products in aquafeeds: a review. *Aquac. Res.* 38, 551-579.
634 <http://dx.doi.org/10.1111/j.1365-2109.2007.01704.x>
635

636 Giblin, F.J., Massaro, E., 1973. Pharmacodynamics of methylmercury in the rainbow trout
637 (*Salmo gairdneri*): tissue uptake, distribution and excretion. *Toxicol. Appl. Pharmacol.* 24, 81–
638 91.
639

640 Hilton, J.W., Hodson, P.V., Slinger, S.J., 1982. Absorption, distribution, half-life and possible
641 routes of elimination of dietary selenium in juvenile rainbow trout (*Salmo gairdneri*). *Comp.*
642 *Biochem. Physiol.* 71C, 49–55. [https://doi.org/10.1016/0306-4492\(82\)90009-0](https://doi.org/10.1016/0306-4492(82)90009-0)
643

644 Honda, S., Hylander, L., Sakamoto, M., 2006. Recent advances in evaluation of health effects
645 on mercury with special reference to methylmercury – a minireview. *Environ. Health Prev.*
646 *Med.* 11, 171–176. [https://doi.org/10.1007%2F1447-0570\(2006\)11%3E171%3E1.0.TX](https://doi.org/10.1007%2F1447-0570(2006)11%3E171%3E1.0.TX)
647

648 Huang, S.S.-Y., Strathe, A.B., Fadel, J.G., Johnson, M.L., Lin, P., Liu, T.-Y., Hung, S.S.O.,
649 2013. The interactive effects of selenomethionine and methylmercury on their absorption,
650 disposition, and elimination in juvenile white sturgeon. *Aquat. Toxicol.* 126, 274–282.
651 <https://doi.org/10.1016/j.aquatox.2012.09.018>

652

653 IFFO (The Marine Ingredients Organisation), 2021. By-product. In: IFFO.

654 www.iffocom.com/product

655

656 Jang, J.-W., Lee, S., Lee, B.-J., Hur, S.-W., Son, M.-H., Kim, K.-W., Kim, K.-D., Han, H.-S.,

657 2020. A comparative study of effects of dietary mercuric chloride and methylmercury chloride

658 on growth performance, tissue accumulation, stress and immune responses, and plasma

659 measurements in Korean rockfish, *Sebastes schlegeli*. Chemosphere 260, 127611.

660 <https://doi.org/10.1016/j.chemosphere.2020.127611>

661

662 Kim, H.S., Jung, W.-G., Myung, S.H., Cho, S.H., Kim, D.S., 2014. Substitution effects of

663 fishmeal with tuna byproduct meal in the diet on growth, body composition, plasma chemistry

664 and amino acid profiles of juvenile olive flounder (*Paralichthys olivaceus*). Aquaculture 431,

665 92–98. <https://doi.org/10.1016/j.aquaculture.2014.03.025>

666

667 Kim, K.-D., Jang, J.W., Kim, K.-W., Lee, B.-J., Hur, S.W., Han, H.-S., 2018. Tuna by-product

668 meal as a dietary protein source replacing fishmeal in juvenile Korean rockfish *Sebastes*

669 *schlegeli*. Fish. Aquat. Sci. 21, 29. <https://doi.org/10.1186/s41240-018-0107-y>

670

671 Kim, K., Park, Y., Je, H.-W., Seong, M., Damusaru, J.H., Kim, S., Jung, J.-Y., Bai, S.C., 2019.

672 Tuna byproducts as a fish-meal in tilapia aquaculture. Ecotoxicol. Environ. Saf. 172, 364–372.

673 <https://doi.org/10.1016/j.ecoenv.2019.01.107>

674

675 Manceau, A., Bourdineaud, J.-P., Oliveira, R.B., Sarrazin, S.L.F., Krabbenhoft, D.P., Eagles-

676 Smith, C.A., Ackerman, J.T., Stewart, A.R., Ward-Deitrich, C., del Castillo Busto, M.E.,

677 Goenaga-Infante, H., Wack, A., Retegan, M., Detlefs, B., Glatzel, P., Bustamante, P., Nagy,
678 K.L., Poulin, B.A., 2021. Demethylation of methylmercury in bird, fish, and earthworm.
679 Environ. Sci. Technol. 55, 1527–1534. <https://doi.org/10.1021/acs.est.0c04948>
680

681 NRC, National Research Council, 2011. Nutrient Requirements of Fish and Shrimp. The
682 National Academies Press, Washington DC.
683

684 Ormaza-González, F.I., Ponce-Villao, G.E., Pin-Hidalgo, G.M., 2020. Low mercury, cadmium
685 and lead concentrations in tuna products from the eastern Pacific. Heliyon 6, e04576.
686 <https://doi.org/10.1016/j.heliyon.2020.e04576>
687

688 Penglase, S., Hamre, K., Ellingsen, S., 2014. Selenium and mercury have a synergistic negative
689 effect on fish reproduction. Aquat. Toxicol. 149, 16–24.
690 <https://doi.org/10.1016/j.aquatox.2014.01.020>
691

692 Pérez-Valenzuela, J., Mejias, M., Ortiz, D., Salgado, P., Montt, L., Chavez-Baez, I., Vera-
693 Tamargo, F., Mandakovic, D., Wacyk, J., Pulgar, R., 2021. Increased dietary availability of
694 selenium in rainbow trout (*Oncorhynchus mykiss*) improves its plasma antioxidant capacity and
695 resistance to infection with *Piscirickettsia salmonis*. Vet. Res. 52, 64.
696 <https://doi.org/10.1186/s13567-021-00930-0>
697

698 R development Core Team, 2008. R: a language and environment for statistical computing. R
699 Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org>
700

701 Raymond, L.J., Ralston, N.V.C., 2020. Mercury: selenium interactions and health implications.
702 Neurotoxicology 81, 294–299. <https://doi.org/10.1016/j.neuro.2020.09.020>
703

704 Ribeiro, M., Zephyr, N., Silva, J.A.L., Danion, M., Guérin, T., Castanheira, I., Leufroy, A.,
705 Jitaru, P., 2022. Assessment of the mercury-selenium antagonism in rainbow trout fish.
706 Chemosphere 286, 131749. <https://doi.org/10.1016/j.chemosphere.2021.131749>
707

708 Ruelas-Inzunza, J., Šlejkovec, Z., Mazej, D., Fajon, V., Horvat, M., Ramos-Osuna, M., 2018.
709 Bioaccumulation of As, Hg, and Se in tunas *Thunnus albacares* and *Katsuwonus pelamis* from
710 the eastern Pacific: tissue distribution and As speciation. Environ. Sci. Pollut. Res. 25, 19499–
711 19509. <https://doi.org/10.1007/s11356-018-2166-0>
712

713 Silva, M.S., Kröckel, S., Jesu Prabhu, P.A., Koppe, W., Ørnstrud, R., Waagbø, R., Araujo, P.,
714 Amlund, H., 2019. Apparent availability of zinc, selenium and manganese as inorganic metal
715 salts or organic forms in plant-based diets for Atlantic salmon (*Salmo salar*). Aquaculture 503,
716 562–570. <https://doi.org/10.1016/j.aquaculture.2019.01.005>
717

718 Tekinay, A.A., Deveciler, E., Güroy, D., 2009. Effects of dietary tuna by-products on feed
719 intake and utilization of rainbow trout *Oncorhynchus mykiss*. J. Fish. Int., 4, 8–12.
720

721 Witkowski, S.J., Carter, C.G., Grünenwald, M., Hadley, S., MacLeod, C.K.A., Townsend, A.T.,
722 Adams, L.R., 2019. Development and assessment of novel endogenous markers in commercial
723 aquafeeds to measure apparent digestibility in large Atlantic salmon (*Salmo salar*) on salmon
724 farms. Aquaculture 508, 192–198. <https://doi.org/10.1016/j.aquaculture.2019.05.005>
725

726 Yamashita, Y., Yamashita, M., 2010. Identification of a novel selenium-containing compound,
727 selenoneine, as the predominant chemical form of organic selenium in the blood of bluefin tuna.
728 J. Biol. Chem. 285, 18134–18138. <https://doi.org/10.1074/jbc.C110.106377>
729
730 Yamashita, Y., Amlund, H., Suzuki, T., Hara, T., Hossain, M.A., Yabu, T., Touhata, K.,
731 Yamashita, M., 2011. Selenoneine, total selenium, and total mercury content in the muscle of
732 fishes. Fish. Sci. 77, 679–686. <https://doi.org/10.1007/s12562-011-0360-9>
733

734 **Table 1a**

735 Experimental diet formulation and composition.

Diet	Plant-based diets	Tuna-based diets
<i>Ingredients (%)</i>		
Plant-derived proteins ^a	73.8	25.8
Tuna by-products ^b	-	60
Crystalline amino acid premix ^c	3.2	-
Rapeseed lecithin ^d	2	-
Vegetable oils ^e	8	8
Fish oil ^f	8	4
Vitamin and mineral premixes ^g	5	2.2
Sodium selenite (mg Se/kg diet)	-	-
L-selenomethionine (mg Se/kg diet)	-	-
Methylmercury chloride (mg Hg/kg diet)	-	-
<i>Analytical composition</i>		
Dry matter (DM, %)	97.4	97.7
Crude protein (% DM)	49.3	51.2
Total lipid (% DM)	22.0	19.1
Gross energy (kJ/g DM)	24.8	24.1
Starch (% DM)	8.2	11.6
Ash (% DM)	6.7	7.8

736 ^a Plant-derived proteins (% diet in plant-based or tuna meal-based diets respectively): wheat
737 gluten, 18 or 0 (Roquette, France); corn gluten, 17 or 0 (Inzo, France); soybean protein
738 concentrate, 15 or 0 (Estril®75 Sopropêche, France); soybean meal, 5 or 0 (Sud-Ouest Aliment,
739 France); white lupin meal, 5 or 0 (Farilup500 Terrena, France); rapeseed meal, 5 or 0 (Primor
740 00 Sud-Ouest Aliment, France); dehulled pea mea, 3.8 or 10.8 (Primatex Sotexpro, France),
741 whole wheat, 5 or 15 (Sud-Ouest Aliment, France).

742 ^b Tuna meal HighPro68 (Port-Louis, Mauritius).

743 ^c Crystalline amino acid premix (% diet): L-lysine, 1.4; DL-methionine, 0.3; glucosamine, 0.5;
744 taurine, 0.3; betaine, 0.3; glycine, 0.2; alanine, 0.2.

745 ^d Adivec (France).

746 ^e Vegetable oils (% diet): rapeseed oil, 4; linseed oil, 2.4; palm oil 1.6.

747 ^f Sopropêche (France).

748 ^g Vitamin and mineral premixes Se-free (per kg diet): retinyl acetate, 5000 IU; cholecalciferol,
749 2500 IU; DL- α -tocopheryl acetate, 50 IU; sodium menadione bisulfate, 10 mg, thiamin-HCl, 1

750 mg; riboflavin, 4 mg; niacin, 10 mg; D-calcium pantothenate, 20 mg; pyridoxine-HCl, 3 mg;
751 myo-inositol, 0.3 g; D-biotin, 0.2 mg; folic acid, 1 mg; cyanocobalamin, 0.01 mg; L-ascorbyl-
752 2-polyphosphate, 50 mg; choline-HCl, 1 g; CaHPO₄·2H₂O (18% P; 22% Ca), 33 or 5 g in plant-
753 based or tuna meal-based diets respectively; CaCO₃ (40% Ca), 2.15 g; MgOH₂ (42% Mg), 1.24
754 g; KCl (52% K), 0.9 g; NaCl (39% Na), 0.4 g; FeSO₄·H₂O (33% Fe), 20 mg; ZnSO₄·H₂O (36%
755 Zn), 35 mg; MnO (77%); 10 mg; CuSO₄·5H₂O (25% Cu), 5 mg; NaF (45% F), 10 mg; CaI₂
756 (86% I), 3 mg; CoCO₃ (50% Co), 0.05 mg; BHA, 0.75 mg; BHT, 0.75 mg; propyl gallate, 0.15
757 mg; sepiolite, 200 mg. All ingredients were diluted with α-cellulose.
758

759 **Table 1b**

760 Supplementation level for sodium selenite, L-selenomethionine and methylmercury chloride

761 and elemental composition of tuna and plant-based diets.

Diet	Plant-based diets						Tuna-based diets					
	PC	PH	PI	PHI	PO	PHO	TC	TH	TI	THI	TO	THO
<i>Ingredients</i>												
Sodium selenite (mg Se/kg diet)	-	-	1.5	1.5	-	-	-	-	1.5	1.5	-	-
L-selenomethionine (mg Se/kg diet)	-	-	-	-	1.5	1.5	-	-	-	-	1.5	1.5
Methylmercury chloride (mg Hg/kg diet)	-	2	-	2	-	2	-	1.6	-	1.6	-	1.6
<i>Elemental composition (mg/kg diet)</i>												
Mercury	-	1.8	-	1.9	-	1.9	0.3	1.9	0.3	2.1	0.3	1.8
Selenium	0.3	0.3	3.2	2.3	2.3	2.0	7.5	7.2	9.0	9.8	9.0	9.0
Molar ratio of Se/Hg	-	0.4	-	3.1	-	2.6	62.7	9.9	84.7	11.9	83.2	13.0

762

763 **Table 2**

764 Growth performance, proximate body composition and retention of rainbow trout juveniles fed
 765 plant-based diets for 21 (D21) or 168 days (D168).

Plant based-diets	PC	PH	PI	PHI	PO	PHO	<i>p</i> _{Hg}	<i>p</i> _{Se}	<i>p</i> _{Hg×Se}
<i>Growth performance</i>									
FI ¹ D21	0.8 ± 0.0	0.7 ± 0.0	0.8 ± 0.0	0.8 ± 0.0	0.7 ± 0.0	0.8 ± 0.0	0.434	0.441	0.131
FI ¹ D168	2.9 ± 0.1	2.7 ± 0.0	3.0 ± 0.1	2.9 ± 0.1	2.7 ± 0.1	2.9 ± 0.0	0.590	0.587	0.391
FCR ² D21	0.79 ± 0.01 ^a	0.88 ± 0.02 ^a	0.85 ± 0.03 ^a	0.79 ± 0.01 ^a	0.81 ± 0.03 ^a	0.82 ± 0.01 ^a	0.400	0.630	0.023
FCR ² D168	0.89 ± 0.01	0.92 ± 0.04	0.94 ± 0.01	0.94 ± 0.01	0.90 ± 0.02	0.93 ± 0.03	0.306	0.318	0.791
PER ³ D21	2.6 ± 0.0 ^a	2.3 ± 0.1 ^a	2.4 ± 0.1 ^a	2.6 ± 0.0 ^a	2.5 ± 0.0 ^a	2.5 ± 0.0 ^a	0.309	0.768	0.018
PER ³ D168	2.3 ± 0.0	2.2 ± 0.1	2.2 ± 0.0	2.2 ± 0.0	2.3 ± 0.0	2.2 ± 0.1	0.279	0.253	0.649
HSI ⁴ D21	1.2 ± 0.1	1.3 ± 0.1	1.0 ± 0.0	1.1 ± 0.1	1.1 ± 0.0	1.1 ± 0.0	0.937	0.072	0.373
HSI ⁴ D168	0.9 ± 0.0	0.9 ± 0.0	0.9 ± 0.0	0.8 ± 0.0	0.9 ± 0.0	0.9 ± 0.0	0.457	0.729	0.729
SR ⁵ D21	99 ± 2	98 ± 2	97 ± 3	99 ± 1	100 ± 0	99 ± 1	0.826	0.990	0.499
SR ⁵ D168	95 ± 4	98 ± 2	97 ± 3	97 ± 3	96 ± 4	98 ± 2	0.278	0.934	0.743
<i>Body composition⁶</i>									
Dry matter D21	31 ± 0	31 ± 1	31 ± 1	31 ± 0	32 ± 1	31 ± 1	0.455	0.511	0.933
Dry matter D168	33 ± 1 ^b	35 ± 0 ^{ab}	37 ± 0 ^a	35 ± 0 ^{ab}	36 ± 0 ^{ab}	37 ± 0 ^a	0.693	0.021	0.036
Protein D21	15 ± 0	16 ± 0	15 ± 0	15 ± 0	16 ± 0	16 ± 0	0.164	0.173	0.167
Protein D168	17 ± 1	17 ± 0	17 ± 0	17 ± 0	17 ± 0	17 ± 0	0.978	0.877	0.263
Lipid D21	14 ± 0	13 ± 1	14 ± 0	13 ± 0	14 ± 1	13 ± 0	0.190	0.827	0.892
Lipid D168	15 ± 1 ^b	16 ± 0 ^{ab}	18 ± 0 ^a	17 ± 1 ^{ab}	17 ± 1 ^a	18 ± 0 ^a	0.577	0.004	0.029
Energy D21	9.1 ± 0.1	8.9 ± 0.2	9.0 ± 0.2	8.7 ± 0.1	9.1 ± 0.4	9.0 ± 0.3	0.353	0.640	0.833
Energy D168	9.7 ± 0.4 ^b	10.5 ± 0.0 ^{ab}	11.2 ± 0.1 ^a	10.5 ± 0.2 ^{ab}	10.7 ± 0.2 ^a	10.9 ± 0.0 ^a	0.780	0.010	0.017
Ash D21	1.9 ± 0.0	2.0 ± 0.1	1.9 ± 0.0	2.1 ± 0.2	2.0 ± 0.1	1.8 ± 0.1	0.997	0.779	0.273
Ash D168	2.1 ± 0.0	2.0 ± 0.1	2.0 ± 0.0	2.0 ± 0.0	2.0 ± 0.1	2.0 ± 0.0	0.958	0.522	0.345
<i>Body retention⁷</i>									
Dry matter D21	41 ± 1	37 ± 2	36 ± 1	38 ± 2	42 ± 3	39 ± 3	0.258	0.355	0.350
Dry matter D168	38 ± 2	39 ± 1	41 ± 0	39 ± 0	41 ± 1	40 ± 1	0.733	0.366	0.366
Protein D21	40 ± 0	41 ± 2	38 ± 2	40 ± 1	42 ± 2	41 ± 1	0.520	0.211	0.697
Protein D168	39 ± 2	39 ± 1	38 ± 1	37 ± 0	38 ± 1	37 ± 1	0.397	0.506	0.817
Lipid D21	81 ± 7	65 ± 10	74 ± 2	67 ± 5	79 ± 11	74 ± 8	0.165	0.754	0.771
Lipid D168	78 ± 5	86 ± 2	93 ± 2	84 ± 3	89 ± 4	94 ± 2	0.615	0.036	0.066
Energy D21	51 ± 2	44 ± 3	46 ± 1	44 ± 2	50 ± 5	48 ± 4	0.227	0.502	0.736
Energy D168	45 ± 3	48 ± 1	50 ± 1	46 ± 1	49 ± 2	49 ± 1	0.814	0.246	0.130
Ash D21	39 ± 6	30 ± 5	35 ± 4	46 ± 10	43 ± 3	30 ± 5	0.514	0.620	0.160
Ash D168	38 ± 1 ^a	28 ± 0 ^c	34 ± 1 ^b	34 ± 0 ^b	34 ± 1 ^b	35 ± 1 ^b	<0.001	0.183	<0.001

766 PC, not supplemented; PH, supplemented with MeHg; PI, supplemented with Se(IV); PHI,

767 supplemented with both MeHg and Se(IV); PO, supplemented with SeMet; PHO, supplemented

768 with both MeHg and SeMet.

769 Values represent means \pm SEM (n = 3). Means not sharing a common superscript letter are
770 significantly different ($P_{\text{Hg} \times \text{Se}} < 0.05$) according to two-way ANOVA to test the effect of MeHg
771 supplementation (P_{Hg}), Se supplementation (P_{Se}) and the interaction ($P_{\text{Hg} \times \text{Se}}$) followed by a
772 Tukey's post hoc test. ¹FI, absolute feed intake expressed as g per fish per day = total dry feed
773 intake per tank / (number of fish in tank \times number of days over the experimental period). ²FCR,
774 feed conversion ratio = dry feed intake / wet weight gain. ³PER, protein efficiency ratio = fish
775 weight gain / crude protein intake. ⁴HSI, hepatosomatic index expressed as % = liver weight /
776 fish weight. ⁵SR, survival rate expressed as %. ⁶Body composition expressed as % for dry
777 matter, crude protein, total lipid and ash and kJ/g for gross energy. ⁷Body nutrient retention
778 expressed as % = [(final weight \times final body nutrient content) - (initial weight \times initial body
779 nutrient content)] / (total feed intake \times feed nutrient content) \times 100.

780 **Table 3**

781 Growth performance, proximate body composition and retention of rainbow trout juveniles fed

782 tuna-based diets for 21 (D21) or 168 days (D168).

Tuna based-diets	TC	TH	TI	THI	TO	THO	p_{Hg}	p_{Se}	p_{Hg×Se}
Growth performance									
FI ¹ D21	0.7 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.677	0.097	0.060
FI ¹ D168	2.6 ± 0.0	2.6 ± 0.2	2.3 ± 0.1	2.8 ± 0.0	2.7 ± 0.0	2.7 ± 0.1	0.047	0.427	0.062
FCR ² D21	0.73 ± 0.01 ^a	0.76 ± 0.01 ^a	0.88 ± 0.09 ^a	0.74 ± 0.02 ^a	0.75 ± 0.01 ^a	0.78 ± 0.02 ^a	0.878	0.427	0.028
FCR ² D168	0.84 ± 0.01 ^{ab}	0.88 ± 0.01 ^a	0.88 ± 0.01 ^a	0.86 ± 0.01 ^{ab}	0.85 ± 0.01 ^{ab}	0.83 ± 0.00 ^b	0.960	0.012	0.010
PER ³ D21	2.7 ± 0.0 ^a	2.6 ± 0.0 ^a	2.3 ± 0.2 ^a	2.7 ± 0.1 ^a	2.6 ± 0.0 ^a	2.5 ± 0.1 ^a	0.460	0.255	0.046
PER ³ D168	2.3 ± 0.0 ^{ab}	2.2 ± 0.0 ^b	2.2 ± 0.0 ^b	2.3 ± 0.0 ^{ab}	2.3 ± 0.0 ^{ab}	2.4 ± 0.0 ^a	0.922	0.006	0.017
HSI ⁴ D21	1.6 ± 0.1	1.6 ± 0.0	1.5 ± 0.0	1.6 ± 0.1	1.7 ± 0.1	1.7 ± 0.0	0.951	0.069	0.778
HSI ⁴ D168	1.3 ± 0.0	1.1 ± 0.0	1.2 ± 0.0	1.1 ± 0.1	1.2 ± 0.0	1.1 ± 0.0	<0.001	0.406	0.287
SR ⁵ D21	99 ± 1	99 ± 1	100 ± 0	100 ± 0	100 ± 0	99 ± 1	0.990	0.138	0.398
SR ⁵ D168	96 ± 2	92 ± 7	90 ± 1	90 ± 6	94 ± 0	84 ± 9	0.073	0.298	0.266
Body composition⁵									
Dry matter D21	30 ± 1	31 ± 0	31 ± 1	30 ± 0	30 ± 0	29 ± 0	0.196	0.217	0.470
Dry matter D168	33 ± 1	33 ± 0	34 ± 1	33 ± 0	34 ± 1	33 ± 1	0.405	0.935	0.950
Protein D21	16 ± 0	16 ± 0	16 ± 0	16 ± 0	16 ± 0	16 ± 0	0.955	0.704	0.727
Protein D168	17 ± 0	17 ± 0	17 ± 0	17 ± 0	17 ± 0	17 ± 0	0.386	0.444	0.440
Lipid D21	16 ± 0	16 ± 0	16 ± 0	16 ± 0	16 ± 0	16 ± 0	0.955	0.704	0.727
Lipid D168	17 ± 0	17 ± 0	17 ± 0	17 ± 0	17 ± 0	17 ± 0	0.386	0.444	0.440
Energy D21	8.4 ± 0.2	8.3 ± 0.2	8.7 ± 0.2	8.2 ± 0.1	8.5 ± 0.2	8.1 ± 0.1	0.048	0.596	0.567
Energy D168	9.7 ± 0.4	9.5 ± 0.1	9.9 ± 0.3	9.7 ± 0.1	9.7 ± 0.3	9.5 ± 0.3	0.440	0.826	0.978
Ash D21	2.2 ± 0.1	2.2 ± 0.2	2.1 ± 0.0	2.0 ± 0.1	2.2 ± 0.0	2.1 ± 0.0	0.351	0.496	0.788
Ash D168	2.2 ± 0.1	2.3 ± 0.1	2.1 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	2.0 ± 0.0	0.824	0.078	0.806
Body retention⁶									
Dry matter D21	40 ± 2	39 ± 1	34 ± 5	38 ± 2	38 ± 2	33 ± 1	0.692	0.243	0.261
Dry matter D168	41 ± 1	38 ± 0	39 ± 1	39 ± 0	40 ± 1	41 ± 1	0.416	0.261	0.241
Protein D21	47 ± 2	44 ± 1	42 ± 1	47 ± 1	44 ± 1	45 ± 4	0.558	0.881	0.152
Protein D168	40 ± 1	38 ± 1	37 ± 1	38 ± 0	40 ± 0	40 ± 0	0.437	0.012	0.130
Lipid D21	69 ± 5	65 ± 5	55 ± 16	58 ± 7	62 ± 10	40 ± 7	0.335	0.250	0.406
Lipid D168	98 ± 7	87 ± 0	95 ± 7	97 ± 2	94 ± 6	92 ± 5	0.398	0.789	0.511
Energy D21	45 ± 3	41 ± 4	42 ± 6	41 ± 3	44 ± 4	35 ± 2	0.158	0.678	0.473
Energy D168	49 ± 2	46 ± 0	48 ± 1	48 ± 0	49 ± 2	49 ± 2	0.431	0.633	0.449
Ash D21	48 ± 4	59 ± 14	40 ± 3	38 ± 7	47 ± 2	39 ± 3	0.962	0.148	0.405
Ash D168	33 ± 2	40 ± 2	29 ± 1	29 ± 2	28 ± 3	29 ± 1	0.078	<0.001	0.134

783 TC, not supplemented; TH, supplemented with MeHg; TI, supplemented with Se(IV); THI,

784 supplemented with both MeHg and Se(IV); TO, supplemented with SeMet; THO,

785 supplemented with both MeHg and SeMet.

786 Values represent means \pm SEM (n = 3). Means not sharing a common superscript letter are
787 significantly different ($P_{\text{Hg} \times \text{Se}} < 0.05$) according to two-way ANOVA to test the effect of MeHg
788 supplementation (P_{Hg}), Se supplementation (P_{Se}) and the interaction ($P_{\text{Hg} \times \text{Se}}$) followed by a
789 Tukey's post hoc test. ¹FI, absolute feed intake expressed as g per fish per day = total dry feed
790 intake per tank / (number of fish in tank \times number of days over the experimental period). ²FCR,
791 feed conversion ratio = dry feed intake / wet weight gain. ³PER, protein efficiency ratio = fish
792 weight gain / crude protein intake. ⁴HSI, hepatosomatic index expressed as % = liver weight /
793 fish weight. ⁵SR, survival rate expressed as %. ⁶Body composition expressed as % for dry
794 matter, crude protein, total lipid and ash and kJ/g for gross energy. ⁷Body nutrient retention
795 expressed as % = [(final weight \times final body nutrient content) - (initial weight \times initial body
796 nutrient content)] / (total feed intake \times feed nutrient content) \times 100.

797

798 **Table 4**

799 Hg and Se whole body retention, faecal content and apparent digestibility coefficient in fish fed
 800 plant-based diets for 21 (D21) and 168 (D168) days.

Plant based-diets	PC	PH	PI	PHI	PO	PHO	<i>P_{Hg}</i>	<i>P_{Se}</i>	<i>P_{Hg×Se}</i>
Hg retention ¹ D21	-	74 ± 6	-	74 ± 2	-	77 ± 2	-	-	-
Hg retention ¹ D168	-	56 ± 2	-	66 ± 1	-	69 ± 0	-	-	-
Faecal Hg content ² D168	1 ± 0	96 ± 4	3 ± 1	115 ± 7	3 ± 0	98 ± 5	<0.001	0.041	0.053
ADC _{Hg} ³ D168	-	87 ± 0	-	86 ± 0	-	87 ± 0	-	-	-
Se retention ⁴ D21	16 ± 7	24 ± 7	34 ± 0	38 ± 7	66 ± 9	67 ± 4	0.352	<0.001	0.812
Se retention ⁴ D168	49 ± 2 ^b	51 ± 3 ^b	21 ± 1 ^d	32 ± 1 ^c	47 ± 1 ^b	57 ± 1 ^a	<0.001	<0.001	0.041
Faecal Se content ⁵ D168	42 ± 2 ^e	39 ± 0 ^e	371 ± 4 ^a	172 ± 14 ^b	140 ± 10 ^c	104 ± 5 ^d	<0.001	<0.001	<0.001
ADC _{Se} ⁶ D168	58 ± 2	67 ± 0	70 ± 1	82 ± 1	81 ± 1	87 ± 0	<0.001	<0.001	0.247

801 PC, not supplemented; PH, supplemented with MeHg; PI, supplemented with Se(IV); PHI,
 802 supplemented with both MeHg and Se(IV); PO, supplemented with SeMet; PHO, supplemented
 803 with both MeHg and SeMet.

804 Values represent means ± SEM (n = 3). Means not sharing a common superscript letter are
 805 significantly different ($P_{Hg*Se} < 0.05$) according to two-way ANOVA performed in each dietary
 806 basis at each time to test the effect of methylmercury supplementation (P_{Hg}), selenium
 807 supplementation (P_{Se}) and the interaction ($P_{Hg×Se}$) followed by a Tukey's post hoc test. ¹Hg
 808 retention = $100 \times [(final\ body\ weight \times final\ body\ Hg\ content) - (initial\ body\ weight \times initial$
 809 $body\ Hg\ content)] / (total\ feed\ intake \times dietary\ Hg\ content)$. ²Hg faeces content (pg/kg wet
 810 weight). ³ADC_{Hg}, apparent digestibility coefficient for Hg = $100 - [100 \times (faecal\ Hg\ content /$
 811 $dietary\ Hg\ content) \times (dietary\ vanadium\ content / faecal\ vanadium\ content)]$. ⁴Se retention =
 812 $100 \times [(final\ body\ weight \times final\ body\ Se\ content) - (initial\ body\ weight \times initial\ body\ Se$
 813 $content)] / (total\ feed\ intake \times dietary\ Se\ content)$. ⁵Se faecal content (µg/kg wet weight).
 814 ⁶ADC_{Se}, apparent digestibility coefficient for Se = $100 - [100 \times (faecal\ Se\ content / dietary\ Se$
 815 $content) \times (dietary\ vanadium\ content / faecal\ vanadium\ content)]$.

816

817 **Table 5**

818 Hg and Se whole body retention, faecal content and apparent digestibility coefficient of in fish
 819 fed tuna-based diets for 21 (D21) and 168 (D168) days.

Tuna based-diets	TC	TH	TI	THI	TO	THO	<i>P_{Hg}</i>	<i>P_{Se}</i>	<i>P_{Hg×Se}</i>
Hg retention ¹ D21	55 ± 3 ^b	57 ± 1 ^b	75 ± 2 ^a	40 ± 2 ^c	67 ± 8 ^{ab}	60 ± 3 ^b	<0.001	0.156	<0.001
Hg retention ¹ D168	57 ± 3	55 ± 3	94 ± 21	54 ± 1	78 ± 2	52 ± 5	0.010	0.180	0.141
Faecal Hg content ² D168	62 ± 9	366 ± 34	81 ± 12	402 ± 35	63 ± 4	366 ± 49	<0.001	0.536	0.943
ADC _{Hg} ³ D168	49 ± 4	58 ± 1	38 ± 8	61 ± 2	48 ± 2	51 ± 7	0.007	0.667	0.129
Se retention ⁴ D21	17 ± 1	16 ± 1	18 ± 1	16 ± 1	25 ± 2	22 ± 2	0.026	<0.001	0.647
Se retention ⁴ D168	9 ± 0	10 ± 1	10 ± 1	12 ± 1	16 ± 1	18 ± 1	0.036	<0.001	0.880
Faecal Se content ⁵ D168	2264 ± 159	2247 ± 137	2571 ± 286	3026 ± 224	2464 ± 150	2388 ± 128	0.453	0.038	0.339
ADC _{Se} ⁶ D168	23 ± 1	33 ± 6	40 ± 4	38 ± 2	37 ± 2	38 ± 1	0.352	0.009	0.191

820 TC, not supplemented; TH, supplemented with MeHg; TI, supplemented with Se(IV); THI,
 821 supplemented with both MeHg and Se(IV); TO, supplemented with SeMet; THO,
 822 supplemented with both MeHg and SeMet.

823 Values represent means ± SEM (n = 3). Means not sharing a common superscript letter are
 824 significantly different ($P_{Hg*Se} < 0.05$) according to two-way ANOVA performed in each dietary
 825 basis at each time to test the effect of methylmercury supplementation (P_{Hg}), selenium
 826 supplementation (P_{Se}) and the interaction ($P_{Hg×Se}$) followed by a Tukey's post hoc test. ¹Hg
 827 retention = $100 \times [(final\ body\ weight \times final\ body\ Hg\ content) - (initial\ body\ weight \times initial$
 828 $body\ Hg\ content)] / (total\ feed\ intake \times dietary\ Hg\ content)$. ²Hg faeces content (pg/kg wet
 829 weight). ³ADC_{Hg}, apparent digestibility coefficient for Hg = $100 - [100 \times (faecal\ Hg\ content /$
 830 $dietary\ Hg\ content) \times (dietary\ vanadium\ content / faecal\ vanadium\ content)]$. ⁴Se retention =
 831 $100 \times [(final\ body\ weight \times final\ body\ Se\ content) - (initial\ body\ weight \times initial\ body\ Se$
 832 $content)] / (total\ feed\ intake \times dietary\ Se\ content)$. ⁵Se faecal content (µg/kg wet weight).
 833 ⁶ADC_{Se}, apparent digestibility coefficient for Se = $100 - [100 \times (faecal\ Se\ content / dietary\ Se$
 834 $content) \times (dietary\ vanadium\ content / faecal\ vanadium\ content)]$.

835

836 **Table 6**

837 Plasma and blood health parameters in fish fed plant-based diets for 21 (D21) and 168 (D168)
838 days.

Plant based-diets	PC	PH	PI	PHI	PO	PHO	<i>P_{Hg}</i>	<i>P_{Se}</i>	<i>P_{Hg×Se}</i>
Lysozyme ¹ D21	23 ± 6	15 ± 6	20 ± 5	19 ± 6	17 ± 2	9 ± 4	0.120	0.349	0.742
Lysozyme ¹ D168	16 ± 7	9 ± 4	11 ± 3	5 ± 1	11 ± 2	7 ± 2	0.111	0.467	0.885
Total protein ² D21	23 ± 1	24 ± 1	24 ± 0	25 ± 1	24 ± 1	23 ± 2	0.399	0.702	0.666
Total protein ² D168	34 ± 1 ^b	31 ± 1 ^b	31 ± 2 ^b	37 ± 1 ^a	33 ± 1 ^b	31 ± 1 ^b	0.686	0.478	0.002
Immunoglobulin ³ D21	17 ± 2	13 ± 1	14 ± 1	16 ± 1	16 ± 1	13 ± 2	0.149	0.931	0.134
Immunoglobulin ³ D168	14 ± 0 ^{ab}	17 ± 1 ^{ab}	18 ± 1 ^a	14 ± 1 ^b	17 ± 2 ^{ab}	17 ± 1 ^{ab}	0.764	0.495	0.022
Albumin ⁴ D21	66 ± 3	73 ± 3	68 ± 3	65 ± 2	70 ± 6	64 ± 3	0.833	0.703	0.147
Albumin ⁴ D168	65 ± 2	73 ± 3	67 ± 2	65 ± 3	67 ± 2	70 ± 2	0.094	0.362	0.104
Glucose ⁵ D21	1.2 ± 0.0	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.498	0.683	0.860
Glucose ⁵ D168	0.9 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	1.0 ± 0.0	0.9 ± 0.1	0.205	0.402	0.949
ASAT ⁶ D21	233 ± 24	231 ± 11	208 ± 9	194 ± 32	225 ± 15	216 ± 16	0.563	0.271	0.942
ASAT ⁶ D168	176 ± 21	155 ± 13	161 ± 4	209 ± 67	204 ± 11	151 ± 20	0.641	0.701	0.132
ALAT ⁷ D21	370 ± 41	279 ± 167	316 ± 57	470 ± 52	198 ± 11	339 ± 166	0.467	0.559	0.466
ALAT ⁷ D168	278 ± 83	295 ± 33	299 ± 93	136 ± 92	274 ± 68	215 ± 78	0.299	0.678	0.533
Haemoglobin ⁸ D21	96 ± 4	101 ± 2	100 ± 6	99 ± 11	102 ± 1	93 ± 4	0.765	0.917	0.462
Haemoglobin ⁸ D168	33 ± 16 ^b	69 ± 4 ^{ab}	78 ± 21 ^{ab}	110 ± 9 ^a	110 ± 10 ^a	82 ± 7 ^{ab}	0.216	0.006	0.046

839 PC, not supplemented; PH, supplemented with MeHg; PI, supplemented with Se(IV); PHI,
840 supplemented with both MeHg and Se(IV); PO, supplemented with SeMet; PHO, supplemented
841 with both MeHg and SeMet.

842 Values represent means ± SEM (n = 3). Means not sharing a common superscript letter are
843 significantly different ($P_{Hg*Se} < 0.05$) according to two-way ANOVA performed in each dietary
844 basis at each time to test the effect of methylmercury supplementation (P_{Hg}), selenium
845 supplementation (P_{Se}) and the interaction ($P_{Hg×Se}$) followed by a Tukey's post hoc test.
846 ¹Lysozyme (mg/L), ²total protein (g/L), ³immunoglobulin (% total protein), ⁴albumin (% total
847 protein), ⁵glucose (g/L), ⁶ASAT, aspartate amino-transferase (UI/L), ⁷ALAT, alanine
848 aminotransferase (UI/L). ⁸Haemoglobin (g/L).

849

850 **Table 7**

851 Plasma and blood health parameters in fish fed tuna-based diets for 21 (D21) and 168 (D168)
 852 days.

Tuna based-diets	TC	TH	TI	THI	TO	THO	<i>P</i>_{Hg}	<i>P</i>_{Se}	<i>P</i>_{Hg×Se}
Lysozyme ¹ D21	15 ± 3 ^{ab}	13 ± 3 ^{ab}	21 ± 1 ^a	12 ± 3 ^{ab}	10 ± 4 ^b	19 ± 1 ^a	0.848	0.637	0.032
Lysozyme ¹ D168	16 ± 7	15 ± 2	13 ± 2	14 ± 13	23 ± 16	11 ± 2	0.523	0.878	0.727
Total protein ² D21	26 ± 1	26 ± 1	24 ± 2	26 ± 2	28 ± 2	25 ± 0	0.786	0.558	0.217
Total protein ² D168	37 ± 2	33 ± 2	35 ± 2	35 ± 3	32 ± 1	36 ± 2	0.827	0.901	0.228
Immunoglobulin ³ D21	15 ± 1	10 ± 2	14 ± 3	15 ± 0	13 ± 1	16 ± 1	0.714	0.428	0.128
Immunoglobulin ³ D168	14 ± 1	16 ± 1	14 ± 1	16 ± 2	16 ± 1	14 ± 1	0.515	0.865	0.232
Albumin ⁴ D21	64 ± 5	68 ± 3	61 ± 1	66 ± 1	59 ± 3	67 ± 3	0.039	0.597	0.711
Albumin ⁴ D168	69 ± 4	70 ± 4	77 ± 2	71 ± 3	76 ± 2	71 ± 3	0.145	0.412	0.865
Glucose ⁵ D21	1.2 ± 0.1	1.6 ± 0.1	1.1 ± 0.1	1.4 ± 0.0	1.4 ± 0.0	1.5 ± 0.1	0.007	0.110	0.335
Glucose ⁵ D168	0.8 ± 0.1	0.8 ± 0.2	0.8 ± 0.1	0.8 ± 0.0	0.7 ± 0.1	0.9 ± 0.1	0.604	0.981	0.433
ASAT ⁶ D21	184 ± 2	212 ± 24	195 ± 27	195 ± 2	207 ± 13	210 ± 18	0.563	0.764	0.763
ASAT ⁶ D168	263 ± 66	250 ± 13	372 ± 57	263 ± 63	303 ± 65	254 ± 62	0.253	0.600	0.725
ALAT ⁷ D21	445 ± 129	304 ± 72	312 ± 76	470 ± 39	342 ± 15	355 ± 81	0.875	0.841	0.203
ALAT ⁷ D168	372 ± 56	242 ± 101	312 ± 89	278 ± 88	341 ± 19	312 ± 56	0.308	0.911	0.739
Haemoglobin ⁸ D21	105 ± 4	110 ± 6	103 ± 7	104 ± 14	90 ± 2	101 ± 5	0.385	0.286	0.811
Haemoglobin ⁸ D168	14 ± 6	41 ± 19	45 ± 14	21 ± 11	33 ± 8	32 ± 9	0.948	0.894	0.221

853 TC, not supplemented; TH, supplemented with MeHg; TI, supplemented with Se(IV); THI,
 854 supplemented with both MeHg and Se(IV); TO, supplemented with SeMet; THO,
 855 supplemented with both MeHg and SeMet.

856 Values represent means ± SEM (n = 3). Means not sharing a common superscript letter are
 857 significantly different ($P_{Hg*Se} < 0.05$) according to two-way ANOVA performed in each dietary
 858 basis at each time to test the effect of methylmercury supplementation (P_{Hg}), selenium
 859 supplementation (P_{Se}) and the interaction ($P_{Hg×Se}$) followed by a Tukey's post hoc test.

860 ¹Lysozyme (mg/L), ²total protein (g/L), ³immunoglobulin (% total protein), ⁴albumin (% total
 861 protein), ⁵glucose (g/L), ⁶ASAT, aspartate amino-transferase (UI/L), ⁷ALAT, alanine
 862 aminotransferase (UI/L). ⁸Haemoglobin (g/L).

863

864 **Figure captions**

865

866 **Fig. 1.** Mean body weight of rainbow trout juveniles fed plant-based diets (P, □) or tuna-based
867 diets (T, □) not supplemented (PC and TC), supplemented with MeHg (PH and TH), Se(IV) (PI
868 and TI), both MeHg and Se(IV) (PHI and THI), SeMet (PO and TO) or both MeHg and SeMet
869 (PHO and THO) for 21 (A) or 168 days (B). Bars represent means \pm SEM (n = 3). Means not
870 sharing common superscript letter are significantly different ($P_{\text{Hg} \times \text{Se}} < 0.05$) according to two-
871 way ANOVA performed in each dietary basis at each time to test the effect of methylmercury
872 supplementation (P_{Hg}), selenium supplementation (P_{Se}) and the interaction ($P_{\text{Hg} \times \text{Se}}$) followed by
873 a Tukey's post hoc test. ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

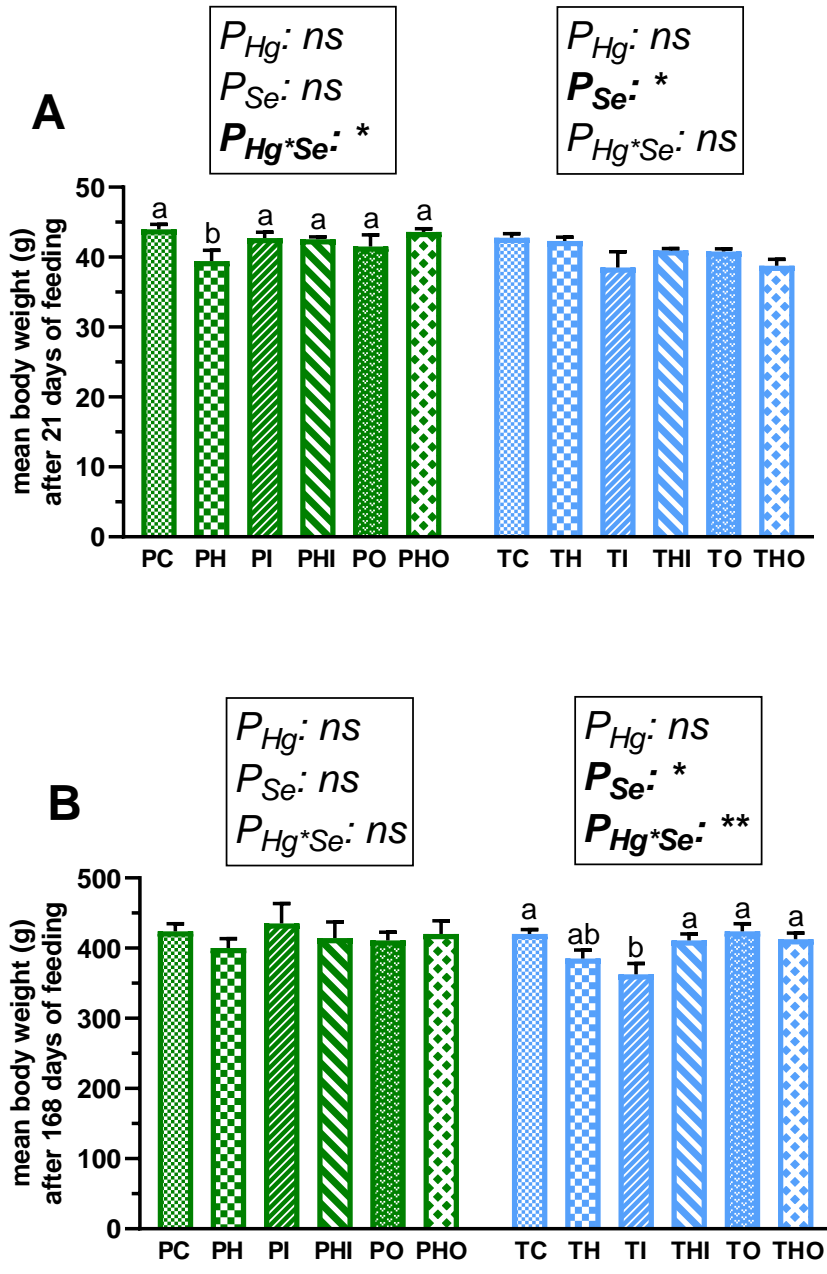
874

875 **Fig. 2.** Hg (A and B) and Se (C and D) body contents in rainbow trout juveniles fed plant-based
876 diets (P, □) or tuna-based diets (T, □) not supplemented (PC and TC), supplemented with MeHg
877 (PH and TH), Se(IV) (PI and TI), both MeHg and Se(IV) (PHI and THI), SeMet (PO and TO)
878 or both MeHg and SeMet (PHO and THO) for 21 (A and C) or 168 days (B and D). Bars
879 represent means \pm SEM (n = 3). Means not sharing common superscript letter are significantly
880 different ($P_{\text{Hg} \times \text{Se}} < 0.05$) according to two-way ANOVA performed in each dietary basis at each
881 time to test the effect of methylmercury supplementation (P_{Hg}), selenium supplementation (P_{Se})
882 and the interaction ($P_{\text{Hg} \times \text{Se}}$) followed by a Tukey's post hoc test. ns, not significant; *, $P < 0.05$;
883 **, $P < 0.01$; ***, $P < 0.001$.

884

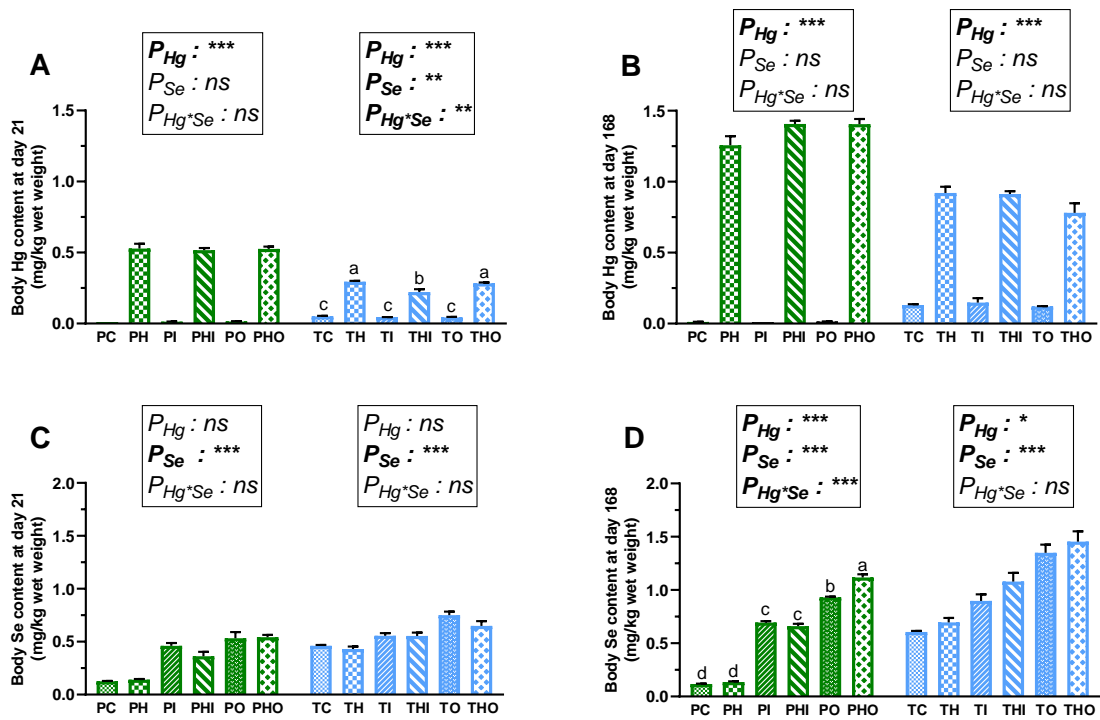
885 **Fig. 3.** Plasma cytokine concentrations, TNF- α (A and B), IL-1 β (C and D) and IL-6 (E and F),
886 in rainbow trout juveniles fed plant-based diets (P, □) or tuna-based diets (T, □) not
887 supplemented (PC and TC), supplemented with MeHg (PH and TH), Se(IV) (PI and TI), both
888 MeHg and Se(IV) (PHI and THI), SeMet (PO and TO) or both MeHg and SeMet (PHO and

889 THO) for 21 (A, C and E) or 168 days (B, D and F). Bars represent means \pm SEM (n = 3 pooled
890 samples). Means not sharing common superscript letter are significantly different ($P_{\text{Hg} \times \text{Se}} <$
891 0.05) according to two-way ANOVA performed in each dietary basis at each time to test the
892 effect of methylmercury supplementation (P_{Hg}), selenium supplementation (P_{Se}) and the
893 interaction ($P_{\text{Hg} \times \text{Se}}$) followed by a Tukey's post hoc test. ns, not significant; *, $P < 0.05$; **, P
894 < 0.01 ; ***, $P < 0.001$.



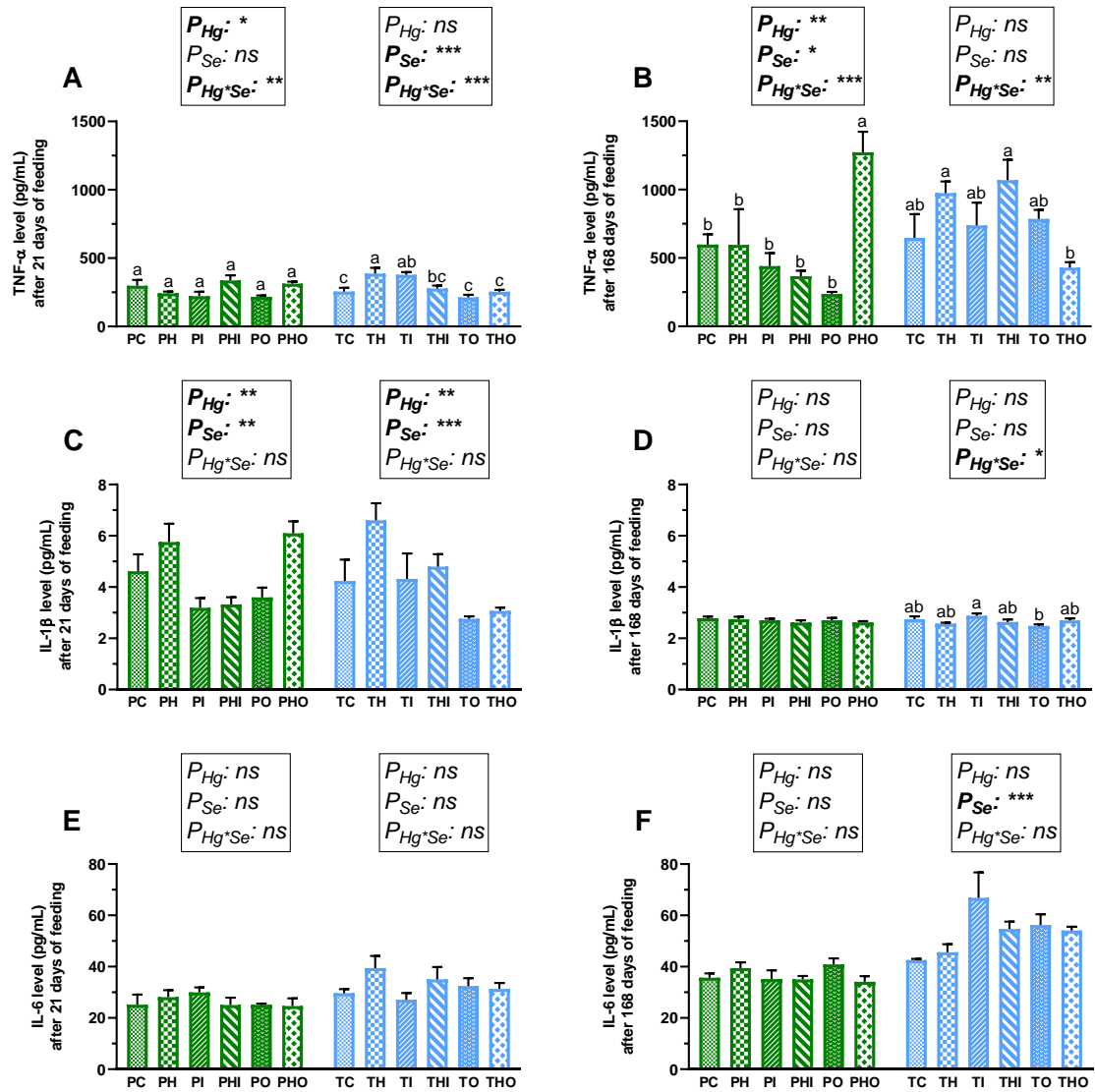
895

896 Fig. 1.



897

898 **Fig. 2.**



899

900 **Fig. 3.**