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1 EFFECT OF THE ARACHIDONIC ACID/VITAMIN E INTERACTION ON THE  
2 IMMUNE RESPONSE OF JUVENILE ATLANTIC SALMON (*Salmo salar*)  
3 CHALLENGED AGAINST *Piscirickettsia salmonis*

4  
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21

22 **Keywords:** Atlantic salmon, vitamin E, Arachidonic acid, fish nutrition, disease  
23 resistance, health

24

25 **Abstract**

26

27 Atlantic salmon (*Salmo salar*) were fed 6 experimental diets containing three levels of  
28 arachidonic acid (ARA) (0.18, 0.28 and 0.63 % for low, medium and high levels  
29 respectively) and two levels of vitamin E (150 and 730 mg kg<sup>-1</sup> for low and high levels  
30 respectively). At the end of the experimental period, fatty acids in the liver and  
31 immunity markers (lysozyme activity, respiratory burst and phagocytic activity) were  
32 determined and fish subjected to a challenge test against the salmonid rickettsial  
33 syndrome (SRS) pathogen. ARA, vitamin E or their interaction did not exert an effect  
34 on fish performance, whereas ARA alone clearly increased the deposition of ARA.  
35 Dietary vitamin E only enhanced liver vitamin E deposition, while the interaction of  
36 ARA and vitamin E influenced lysozyme activity and EPA/ARA ratio pointing out the  
37 effect of both nutrients on the fish immune system and metabolism. Only the medium  
38 concentration contributed to reducing mortality when the fish were exposed to the SRS  
39 pathogen. In conclusion, different levels of supplementation with ARA and vitamin E in  
40 the diet had no effect on productivity, but did have effects on immune markers and  
41 cumulative mortality when fish were exposed to the SRS pathogen.

42

43

44 **Introduction**

45

46 With the growth of the aquaculture industry, more attention has been paid to fish  
47 welfare and health in order to avoid negative impacts on fish performance and  
48 consequently economic losses. Use of properly balanced diets seems to be a feasible  
49 approach for allowing fish to have improved immunological response and thus greater  
50 ability to cope with disease. Although the role of lipids in immune function in fish has  
51 been studied, the results are not always conclusive because their effect apparently  
52 depends on environmental conditions, the genetic status of the studied organism as well  
53 as the interaction among different types of fatty acids and other nutrients (Montero *et al.*  
54 1999; Kiron *et al.* 2004; Bureau *et al.* 2008).

55

56 It is known that lipids, in addition to being an excellent source of energy and a vehicle  
57 for fat soluble vitamins, are the source of polyunsaturated fatty acids (PUFA) such as  
58 di-homo-gamma-linolenic acid (DHGLA; 20:3n-6), arachidonic acid (ARA; 20:4n-6)  
59 and eicosapentaenoic acid (EPA; 20:5n-3), which are the precursors of two groups of  
60 eicosanoids: those derived from the cyclooxygenase action such as prostaglandins (PG)  
61 and thromboxanes (TX) and those derived from the lipoxygenase action such as  
62 lipoxins (LX) and leukotrienes (LT) (Bell *et al.* 1995). These compounds are part of the  
63 defence systems of the organisms and therefore play a role in certain pathophysiological  
64 processes such as resistance to stress stimuli, the immune response and inflammatory  
65 processes (Lall 2000). It has been stated that depending on the type of the individual  
66 fatty acids, their concentrations and the relationships among them, eicosanoids can have  
67 pro- or anti-inflammatory effects. Therefore, diets rich in n-6 fatty acids, primarily

68 ARA, produce pro-inflammatory effects derived from higher levels of PGE<sub>2</sub>, LT<sub>4</sub> and  
69 LX, whereas diets high in n-3 PUFAs, particularly EPA, produce anti-inflammatory  
70 effects derived from PGE<sub>3</sub> and LT<sub>5</sub> (Lall 2000). Although overproduction of PGE<sub>2</sub> due  
71 to high dietary ARA can also have an immunosuppressant effect (Bell *et al.* 1996), this  
72 effect can be mitigated depending on the concentrations of EPA and DHGLA given that  
73 both fatty acids have an inhibitory effect on ARA. Because ARA is generally the  
74 preferred substrate of lipoxygenases for LT synthesis (Bell *et al.* 1994) and products  
75 derived from these enzymes produce stronger immune stimulatory effects than those  
76 derived from cyclooxygenases (Hwang 1989), one would expect that incorporating  
77 ARA into the diet would contribute to an improved immune response in fish and  
78 therefore increased resistance against attack from pathogens. Thus, n-6 fatty acids play  
79 an important role in inflammatory processes, stimulating the production of pro-  
80 inflammatory cytokines such as the tumour necrosis factor-alpha (TNF- $\alpha$ ) and  
81 interleukins (IL) 1 and 6 and consequently leading to pro-inflammatory events such as  
82 vasodilation and increased vascular permeability (Calder 2002).

83

84 Although anadromous teleost fish such as rainbow trout (*Oncorhynchus mykiss*) and  
85 Atlantic salmon (*Salmo salar*) have the ability to elongate and desaturate short-chain  
86 fatty acids to long chain PUFA (LC-PUFA) in their fresh water phase and their  
87 requirements can be satisfied by fatty acids such as linoleic acid (LA; 18:2n-6) and  $\alpha$ -  
88 linolenic acid (LNA; 18:3n-3) (Bell & Sargent 2003), it is not clear whether these fatty  
89 acids are sufficient for maintaining fish in adequate physiological condition. Thus,  
90 supplementation with LC-PUFA, such as ARA, EPA and docosahexaenoic acid (DHA;  
91 22:6n-3) is always appropriate and recommended. Furthermore, Bell *et al.* (2003)

92 suggested the potential impact of ARA in restoring normal immune function in  
93 freshwater fish fed low-ARA diets despite of their ability to synthesize LA to ARA.  
94 Thus, the use of feeds with an unadjusted n-6/n-3 fatty acids ratio, mainly ARA, can  
95 alter the fish immune system and resilience when exposed to pathogens.

96

97 Given that PUFAs are susceptible to oxidation due to their high unsaturation degree,  
98 and that oxidation products can be toxic to fish, the high levels of these fatty acids in  
99 aquafeeds need to be accompanied by adequate amounts of dietary antioxidants. Among  
100 them, vitamin E ( $\alpha$ -tocopherol) is a powerful antioxidant that is commonly included in  
101 feeds formulation as a form of protection against fatty acid oxidation (Kiron *et al.* 2004;  
102 Betancor *et al.* 2011; Hamre 2011). In addition, vitamin E can improve the fish immune  
103 response as this nutrient is involved in preventing lipid peroxidation of cell membranes,  
104 the regulation of the specific immunity, nonspecific resistance factors and disease  
105 resistance capacity (Sahoo & Mukherjee 2002). The relationships among LC-PUFA,  
106 vitamin E and the immune response have been studied in rainbow trout (Kiron *et al.*  
107 2004; Puangkaew *et al.* 2004, 2005; Trenzado *et al.* 2009), Japanese flounder  
108 (*Paralichthys olivaceus*) (Wang *et al.* 2006) and gilthead seabream (*Sparus aurata*)  
109 (Montero *et al.* 2004). However most of these studies have not evaluated the effect of  
110 the LC-PUFA/vitamin E ratio when fish are challenged against pathogens, and  
111 furthermore, no studies have linked an increase of specific dietary fatty acids (such as  
112 ARA) with vitamin E requirements. However, there is evidence that vitamin E  
113 participates in the conversion of ARA into prostaglandins via cyclooxygenase action in  
114 mammals (O'Leary *et al.* 2004) and similar action could also happen in teleost fish.

115 Furthermore, given that ARA is a minor component of fish cell membranes and that is  
116 required in small amounts compared to DHA and EPA, its importance has been  
117 underestimated (Bell *et al.* 2003; Xu *et al.* 2010). However, the limited studies on ARA  
118 have suggested an important contribution of this fatty acid fish growth, survival and  
119 bone formation as well as its influence on modulating the immune response and disease  
120 resistance in several teleost fish species (Khozing – Goldberg *et al.* 2006; Van Anholt *et*  
121 *al.* 2004, 2012; Xu *et al.* 2010; Li *et al.* 2012; Boglino *et al.* 2014; Tian *et al.* 2014).  
122 Nevertheless, there is not enough evidence linking dietary ARA and vitamin E levels in  
123 freshwater fish species. Therefore, it is expected that appropriately balanced  
124 incorporation of this fatty acid with vitamin E could improve processes in which ARA  
125 is involved such as a favourable immune response.

126 Salmonid rickettsial syndrome (SRS), caused by *Piscirickettsia salmonis*, is considered  
127 to be the most important sanitary problem in the Chilean salmon farming industry, with  
128 economic losses up to \$100 million per year. Thus, the impact of SRS on salmon  
129 farming in Chile could be mitigated by strengthening the immune activity in the fish  
130 through an appropriate balance between dietary ARA and vitamin E. In the present  
131 study, we aimed to elucidate the interaction between ARA and vitamin E on juvenile  
132 Atlantic salmon immune response and their protective effect when fish were challenged  
133 with the causative agent of SRS.

134

## 135 **Materials and methods**

136

### 137 *2.1. Experimental fish*

138

139 One thousand five hundred and thirty juvenile Atlantic salmon were obtained from a  
140 local fish farm (Pesquera los Fiordos; commune of Curarrehue, region IX, Chile) and  
141 transferred to the Quimey-Co de Sociedad Nalcahue Ltda. fish farm (commune of  
142 Pucón, Caburga sector, region IX, Chile). The fish were acclimatised for two weeks and  
143 fed a commercial diet (BIOMAR S.A., Chile). Prior to the start of the experimental  
144 trial, the fish were distributed among eighteen 100 L tanks at a ratio of 85 fish tank<sup>-1</sup>  
145 with an average weight of  $6.5 \pm 1.1$  g to reach an initial density of 5.5 kg m<sup>-3</sup>. Tanks  
146 had a continuous water supply at a rate of 1.5 L h<sup>-1</sup> and fish were maintained under a 24  
147 h light photoperiod, being the water the temperature in tanks  $9.9 \pm 0.2$  °C and dissolved  
148 oxygen concentrations above 10 mg L<sup>-1</sup>.

149

## 150 *2.2 Experimental diets and feeding*

151

152 Six experimental feeds were formulated and manufactured to contain three dietary  
153 levels of ARA (1.05, 1.73 and 3.73 % for low, medium and high respectively) and two  
154 levels of vitamin E as  $\alpha$ -tocopherol acetate (0.12 - 0.19 and 0.72 - 0.76 g kg<sup>-1</sup>, for low  
155 and high respectively). Feeds were isolipidic and isoproteic, and levels of other fatty  
156 acids held constant. A set of 5 different oils was employed to obtain the desired levels  
157 of ARA altering minimally the levels of other PUFA. In this sense, an ARA-enriched  
158 oil was employed in ARA3 diets, whereas a n-6-rich oil (Yardquim oil) was used in  
159 ARA2 and ARA3 feeds. All the feeds contained n-3-rich oil (ROPUFA<sup>®</sup> n-3 INF oil) to  
160 help maintain adequate levels on n-3 PUFA as well as olive oil to equalize the fat  
161 content of all the feeds. Finally, the diets containing the lowest ARA levels were  
162 supplemented with an oil rich in EPA (ROPUFA<sup>®</sup> n-3 EPA oil) to maintain similar

163 EPA levels to the other feeds. The diets were labelled as ARA1/E1 (low ARA/low  
164 vitamin E), ARA1/E2 (low ARA/high vitamin E), ARA2/E1 (medium ARA/low  
165 vitamin E), ARA2/E2 (medium ARA/high vitamin E), ARA3/E1 (high ARA/low  
166 Vitamin E) and ARA3/E2 (high ARA/high vitamin E). The diets were formulated and  
167 manufactured in the feed pilot plant of the School of Aquaculture of the Catholic  
168 University of Temuco (Chile) using a CLEXTRAL experimental extruder, model B21  
169 (Firminy Cedex, France), and oiled by a Dinissen vacuum oiler (Pegasus Menger, 400 l,  
170 Sevenum, Holland). Each diet was tested in triplicate for 12 weeks. Fish were fed to  
171 apparent visual satiety, ten times per day by hand, and uneaten feed was removed by  
172 siphoning, dried and weighed to calculate fish feed intake. VEVODAR<sup>®</sup> (DSM  
173 nutritional products S.A., Puerto Varas, Chile) was used as the source of ARA and  
174 Rovimix E-50<sup>®</sup> for vitamin E (DSM nutritional products S.A., Puerto Varas, Chile).  
175 The formulation, proximal composition, fatty acid profile and vitamin E concentration  
176 of the diets were analysed in the fish nutrition laboratory of the School of Aquaculture  
177 at the Catholic University of Temuco and are shown in Tables 1 and 2.

178

### 179 *2.3. Productive indicators*

180 The following productive variables were evaluated:

- 181 • Increase in weight (%) = [(final weight – initial weight) / initial weight] × 100.
- 182 • Feed conversion factor = increase in weight (g)/total food intake (g).
- 183 • Specific growth rate (% day<sup>-1</sup>) = [(ln final weight - ln initial weight) / days] ×  
184 100.
- 185 • TGC (thermal growth coefficient) = [(final weight<sup>1/3</sup> – initial weight<sup>1/3</sup>) × 1000] /  
186 ∑ (temperature × days)

- 187 • Condition index = (final weight / final length<sup>3</sup>) × 100
- 188 • Hepatosomatic index = (liver weight (g) / final weight) × 100
- 189 • Protein efficiency ratio = gain in body mass (g) / protein intake (g)
- 190 • Percent survival (%) = (N° final specimens/initial number of specimens) × 100

191

## 192 2.4. Analysis and measurements

### 193 2.4.1. Collection of blood and tissue samples for analysis.

194 At the end of the experimental period, fish were starved for 24 hours prior to the final  
195 sampling. Six fish per tank (n =18 per treatment) were anesthetized with 20%  
196 benzocaine (BZ-20; Veterquimica S.A., Santiago, Chile) and bled by puncturing the  
197 caudal vein with 1 mL syringes. Blood samples were immediately placed in Eppendorf  
198 tubes containing 5 µL of heparin to prevent blood clotting. The tubes containing blood  
199 were centrifuged at 3500 rpm for 10 minutes at a constant temperature of 4 °C to  
200 separate the plasma from the cells. Fresh plasma was frozen at -80 °C until lysozyme  
201 activity was determined.

202 Then, fish were sacrificed in 10 L containers with an overdose of benzocaine together  
203 with ice to maintain a temperature of 4 °C in order to obtain fresh samples. Liver  
204 samples were collected for determination of fatty acids (6 fish tank<sup>-1</sup>, n = 18 per  
205 treatment), and samples stored at -80 °C until further analysis. Kidney samples were  
206 also obtained for immune parameters analysis and quickly frozen at -80 °C until further  
207 analysis.

208

### 209 2.4.2 Total lipids and fatty acid analysis.

210 Total lipids were extracted using a chloroform:methanol mixture (2:1) according to the  
211 method by Folch *et al.* (1957). Fatty acids were methylated according to the method  
212 proposed by Morrisony Smith (1964). Fatty acids were separated using a Hewlett  
213 Packard 5890 series II Plus (Wilmington NC, USA) gas chromatograph with a capillary  
214 column of 30\*0.25\*0.20 mm (SPTM 2380, SUPELCO, Bellafonte, PA USA). Helium  
215 gas was used as a carrier. Fatty acids were identified by comparison to a SUPELCO 37  
216 fatty acid standard (Sigma Aldrich, St. Louis, MO, USA). Fatty acids are expressed as  
217 percentage of the total fatty acids identified.

218

#### 219 *Vitamin E analysis*

220 The free  $\alpha$ -tocopherol level of the diets and liver tissues were determined at the Quality  
221 Control Laboratory, DSM Nutritional Products S.A. (Puerto Varas, Los Lagos Region,  
222 Chile), according to the company analytical methods and procedures for vitamins and  
223 carotenoids. Analysis equipment included an HPLC Perkin Elmer series 200 (Shelton,  
224 CT, USA) with auto sampler, a UV-visible detector, a Link interface 600 series data  
225 system recollection "Totalchrom Workstation" version 6.2.1., and a column Lichrosorb  
226 Si 60.5  $\mu\text{m}$  \* 25 \* 4 mm Alltech brand- Grom (Germany). Briefly, the HPLC conditions  
227 used for the vitamin assessment were as follows: reflux extraction with potassium  
228 hydroxide solution in methanol and continuation with a hexane:toluene (1:1) solution,  
229 room temperature conditions, and a mobile phase with a hexane:dioxane (97:3) solution  
230 injected (20  $\mu\text{L}$ ) through an automatic nozzle. The results are expressed as  $\text{mg kg}^{-1}$  of  
231 free  $\alpha$ -tocopherol.

232

#### 233 *2.4.3. Immune parameters*

234

235 • *Extraction of leucocytes to determine phagocytosis and respiratory burst*

236

237 Leucocytes from the anterior portion of the kidney were used to determine phagocytic  
238 activity and respiratory burst following the method proposed by Sakai *et al.* (1996).

239 Leucocytes were extracted from the same specimens used for blood sampling. Kidneys  
240 were aseptically removed and placed in L-15 medium (Sigma, St. Louis, MO, USA)  
241 supplemented with 10% foetal bovine serum, 0.2% heparin (Sigma, St. Louis, MO,  
242 USA) and 0.1% penicillin/streptomycin (Sigma, St. Louis, MO, USA). Maceration was  
243 conducted and the resulting cellular suspension was layered onto a 34/51% Percoll  
244 gradient (Pharmacia, Uppsala, Sweden). After centrifugation, the interphase cells were  
245 isolated, washed in Hanks medium and number adjusted to  $10^7$  cells  $\text{mL}^{-1}$ . Viable  
246 phagocytic cells were quantified by trypan blue exclusion (viability > 95%).

247

248 • *Leucocytes respiratory burst activity*

249

250 To measure intracellular superoxide anion production, the method developed by Yin *et*  
251 *al.* (2006) was used. The leucocyte suspension was distributed into 96-well plates and  
252 the reduction of nitroblue tetrazolium (NBT) was evaluated. Untreated leucocytes were  
253 used as a negative control and leucocytes treated with  $0.5 \text{ mg mL}^{-1}$  phorbol myristate  
254 acetate (PMA) were used as a positive control. The cell culture was maintained at  $18^\circ \text{C}$   
255 for 18 h. The extract, PMA treatments and cell monolayer were washed twice with  
256 Hank's saline solution (HBSS, Sigma). Then,  $100 \text{ }\mu\text{L}$  of NBT solution ( $1 \text{ mg mL}^{-1}$  in  
257 RPMI 1640) were added per well and incubated for 60 min at  $18^\circ \text{C}$ . After incubation,

258 the NBT solution was removed and the cells were fixed with methanol for 10 min. The  
259 cells were air-dried and the formazan in each well was dissolved in 120  $\mu$ L of 2 M  
260 KOH and 140  $\mu$ L of dimethyl sulphoxide (Sigma). Optical density was measured with a  
261 Multiscan spectrophotometer (Spectra, Count, Pakard USA) at 630 nm.

262

263 • *Phagocytic activity*

264

265 The phagocytic activity of the leucocytes was determined by the direct count method,  
266 which involves co-incubating leucocytes isolated from the anterior kidney with yeast  
267 cells stained with Congo red in 96-well plates. The mixtures were incubated at 18 °C for  
268 3 hours and the percentage of leucocytes with phagocytosed cells was counted and  
269 considered a direct measure of the level of immune stimulation of the cells. The counts  
270 involved a total of 15 optical fields in triplicate for each specimen tested.

271

272 • *Lysozyme activity*

273 The turbidimetric assay for measuring lysozyme (Parry *et al.* 1965) was performed in a  
274 96-well plate. A volume of 200  $\mu$ L of a suspension of *Micrococcus lysodeikticus* (0.2  
275 mg mL<sup>-1</sup> in 50nM sodium phosphate buffer) and 5, 10, 20 or 40  $\mu$ L of blood plasma  
276 were mixed in different wells, and then absorbance recorded at 520 nm at 1, 3, 6 and 9  
277 min with a microplate reader (Elx808BioTex USA). One unit of activity was defined as  
278 the amount of sample causing a 0.001 min<sup>-1</sup> decrease in absorbance.

279

280 2.4.4. *Bacterial challenge test*

281 At the end of the experimental period, 18 specimens per treatment (6 fish per tank) were  
282 transported from the hatchery of the Catholic University of Temuco to the Aquadvice  
283 Experimental Unit of Fundación Chile (Puerto Montt, region X, Chile). Fish were  
284 marked with PIT-tags system (Trovan<sup>®</sup>, Trovan Ltd., United Kingdom) and placed in a  
285 720 L tank with a turnover rate of 1.2 L h<sup>-1</sup>. The oxygen concentration was maintained  
286 between 90 and 100% saturation and the water temperature at 14.5 °C. The temperature  
287 was higher because the SRS challenge model requires 14.5 to 15 °C to develop optimum  
288 pathogen replication in the fish. The acclimatisation period lasted 6 days, after which  
289 the fish were challenged by intraperitoneal injection using a strain of *Piscirickettsia*  
290 *salmonis* (SRS) as a salmonid pathogen at a dose of 0.2 mL SRS per fish at a 10<sup>-2</sup>  
291 dilution considering previous LD50 results. During the SRS challenge, all the fish of the  
292 same treatment were kept in the same tank. The inoculum was provided by the  
293 “Fundación Ciencia para la Vida” (Science for Life Foundation). To verify the cause of  
294 death, head kidney of deceased fish were analysed by the direct immunofluorescence  
295 technique SRS FluoroTest Direct (Bios Chile, Santiago, Chile) wherein monoclonal  
296 antibodies are conjugated to fluorescein isothiocyanate (FITC). This test is highly  
297 sensitive and specific for detecting *Piscirickettsia salmonis* in tissue samples (Marshall  
298 et al., 2007).

299  
300

### 301 *2.5 Statistical analysis.*

302 The results were statistically analysed using a two-factor ANOVA after prior  
303 confirmation of theoretical assumptions of data normality through histograms and  
304 homogeneity of variances by Bartlett’s test. Once these theoretical assumptions were  
305 satisfied, analyses of variance were performed to determine significant differences

306 among the treatments at the 95% confidence level. If there were differences, Duncan's  
307 test was then used to differentiate the means among the three different ARA levels,  
308 revealing those treatments that exhibited significant differences (Sokal & Rohlf 1995).  
309 For vitamin E levels, a student t-test was employed to denote significant differences  
310 between the two vitamin levels. The arcsine transformation was applied to data  
311 expressed as percentages to achieve homoscedasticity. The statistical software MS  
312 STATISTICA 12 was used in the statistical analyses.

313

## 314 **Results**

315

### 316 *3.1. Growth and dietary utilisation.*

317 Fish growth in terms of final weight did not differ ( $P>0.05$ ) among the different  
318 experimental groups or their replicates. All fish groups increased their weight up to  
319 three times relative to initial weight, reaching an average value between 21.8 and 23.9g.  
320 The specific growth rate (SGR) varied between 1.27 and 1.37% per day. The  
321 conversion factor rate (CF) was similar among the experimental diets, ranging from  
322 1.01 to 1.13. Hepatosomatic index (HSI) values were within the normal range (0.95 to  
323 1.11) without showing significant differences ( $P>0.05$ ). None of the evaluated  
324 performance parameters showed significant differences ( $P>0.05$ ) when subjected to  
325 statistical analysis (Table 3).

326

### 327 *3.2 Liver fatty acids and vitamin E contents*

328 Table 4 shows the fatty acid composition and measured vitamin E content in the liver of  
329 juvenile Atlantic salmon fed the six dietary treatments. The levels of vitamin E

330 concentrations in the liver were directly proportional to its dietary incorporation, and  
331 higher ( $P<0.05$ ) in the high vitamin E group. Fish fed diets containing a high  
332 concentration of ARA showed significantly higher ( $P<0.05$ ) accumulation of this fatty  
333 acid than fish fed low and medium levels of ARA, together with a reduction in the  
334 EPA/ARA ratios (Table 4). Besides, there was no interaction between the two nutrients,  
335 ARA concentration did not affect ( $P>0.05$ ) the vitamin E concentration in liver tissue  
336 and vitamin E dietary levels did not affect ( $P>0.05$ ) the ARA content in the tissue. The  
337 only interaction between both nutrients was found in the EPA/ARA ratios ( $P<0.05$ ;  
338 Table 4), whereas ARA levels did affect C14, total monounsaturated, EPA, DHA  
339 ( $P<0.005$ ), as well as ARA ( $P<0.01$ ) percentages according to the two-way ANOVA  
340 performed.

341

### 342 *3.3 Fish health: Immune parameters and challenge test.*

343

344 No significant differences ( $P>0.05$ ) or interactions between ARA and vitamin E were  
345 found for phagocytic activity in fish fed any of the dietary treatments (Table 5).  
346 However, a significant effect ( $P<0.05$ ) of vitamin E was found on lysozyme activity,  
347 with the group fed ARA2/E1 displaying significantly ( $P<0.05$ ) higher lysozyme  
348 enzymatic activity (Table 5), although no differences were observed with fish fed  
349 ARA3/E2. Besides, ARA levels significantly ( $P<0.05$ ) affected leucocyte respiratory  
350 burst activity with the lowest ( $P<0.05$ ) activity corresponding to fish fed the lowest  
351 ARA level (Table 5). Furthermore, an interaction between ARA and vitamin E levels  
352 was observed in lysozyme activity ( $P<0.01$ ; Table 5), whereas individual ARA did exert  
353 an effect on the leucocytes respiratory burst ( $P<0.01$ ; Table 5).

354

355 Regardless of the level of dietary vitamin E, fish fed diets containing low concentrations  
356 of ARA displayed cumulative mortality between 56 and 65% when exposed to the SRS  
357 pathogen (Fig. 1). In all cases where the concentration of ARA in the diet was low or  
358 high, cumulative mortality was below 50%. However, when the ARA concentration in  
359 the diet was medium and the vitamin E concentration was high, higher survival rates  
360 were achieved. It was determined that 100% of the recorded mortality was confirmed  
361 for the presence of the SRS pathogen.

362

### 363 **Discussion**

364 Despite of the relevance of vitamin E, studies assessing its relationship with PUFA,  
365 particularly ARA, and how this relationship may affect fish growth are scarce. In the  
366 present study 6 different experimental feeds containing two levels of vitamin E and  
367 three levels of ARA were fed to Atlantic salmon to evaluate the single effect of these  
368 nutrients as well as their interaction on fish performance, liver composition and  
369 immunological response after challenge with SRS. ARA and vitamin E supplementation  
370 did not affect the growth of juvenile Atlantic salmon in terms of length or weight,  
371 showing that there was no independent or synergistic effect between the two nutrients  
372 on fish performance. This indicates that low dietary concentrations of ARA (circa 1% of  
373 the total fatty acids) and vitamin E (circa 150 mg kg<sup>-1</sup>) were sufficient for supporting  
374 adequate fish growth. These results are in line with previous studies where increases in  
375 ARA levels over 12 times in terms of total fatty acids together with constant levels of  
376 vitamin E did not enhance any of the studied growth performance parameters in Atlantic  
377 salmon post-smolts (Glencross *et al.* 2014).

378

379 EPA, ARA and DHGLA are fatty acids precursors of eicosanoids *via* the actions of  
380 lipoxygenases and cyclooxygenases. It is known that eicosanoids derived from ARA,  
381 mainly LTB<sub>4</sub> and PGE<sub>2</sub>, are pro-inflammatory, whereas those derived from EPA and  
382 DHGLA have an anti-inflammatory action (Hwang 1989). Thus it is expected that  
383 altering the EPA/ARA ratio in cell membranes may alter the production of eicosanoids  
384 and modulate the inflammatory response (Bell *et al.* 1995). Some studies have shown  
385 that ARA is the preferred precursor for the synthesis of eicosanoids in fish, competing  
386 with EPA (Bell *et al.* 1994). In the present study, the changes in liver fatty acid  
387 composition largely reflected that of the diets, showing variations in the ARA contents,  
388 which were increased with increasing ARA dietary levels. Although in the present study  
389 only fatty acids from total lipids were determined, a previous study in Atlantic salmon  
390 showed that the ARA content of phospholipids fatty acids of several tissues was  
391 correlated to the ARA dietary intake (Betancor *et al.* 2014). Thus, taking into account  
392 that the percentage of neutral and polar lipids in Atlantic salmon fed fish oil-profile diet  
393 is around 30 and 60% respectively (Torstensen *et al.* 2004), a considerable amount of  
394 ARA will be available in the Atlantic salmon membranes for its bioconversion to  
395 reactive eicosanoids.

396 Furthermore, dietary ARA influenced the deposition of other fatty acids such as oleic  
397 acid (18:1n-9), EPA and DHA. It must be noted that liver is considered an important  
398 site for LC-PUFA synthesis and lipid metabolism in Atlantic salmon (Monroig *et al.*  
399 2010). Hepatic levels of ARA did not differ between fish fed low and medium ARA  
400 levels which could be attributed to enhanced biosynthesis from 18:2n-6. Besides, as the  
401 same  $\Delta 6$  and  $\Delta 5$  –desaturase and fatty acyl elongase enzymes participate in the synthesis

402 of both the n-3 and n-6 LC-PUFA (Zheng et al. 2005), the activation of one pathway  
403 could also enhance the final and intermediate products of the other, what could account  
404 for the increased EPA and DHA contents found in low ARA-fed fish. Enhanced  
405 conversion from 18:2n-6 to 20:3n-6 was greater than for 18:4n-3 to 20:4n-3 in Atlantic  
406 salmon fed diets devoid of n-3 LC-PUFA, which resulted in significantly higher  
407 concentrations of ARA in liver (Miller et al. 2008).

408 Dietary ARA also elicited an effect in leucocytes respiratory activity, medium and high  
409 levels leading to up-regulation of the respiratory burst activity. However ARA did not  
410 trigger an effect on any of the other health-related parameters, which could indicate that  
411 up-regulation of burst activity alone is not sufficient to enhance bactericidal activity  
412 against SRS by Atlantic salmon leucocytes. Similarly, yeast  $\beta$ -glucans, known to have  
413 an immune stimulatory effect in fish (Magnadóttir 2006) only elicited macrophages  
414 respiratory burst, not eliciting any effect on bactericidal activity (Jørgensen and  
415 Robertsen, 1995)

416 Low levels of ARA combined with high or low levels of vitamin E lead to low  
417 concentrations of ARA in the liver, low stimulation of macrophages as well as  
418 cumulative mortality between 56 and 65% from the SRS pathogen. Thus an increase in  
419 vitamin E did not contribute to stimulate the immune response in the presence of low  
420 levels of ARA, nor improved the response against the SRS pathogen as indicated by the  
421 two-way ANOVA analysis. Blazer & Wolke (1984) found that T and B lymphocytes  
422 function in rainbow trout was suppressed under vitamin E deficiency and that this  
423 vitamin requirement may increase during immune stimulation. Furthermore, a  
424 combination of medium levels of ARA with high or low levels of vitamin E not only  
425 improved macrophage activity but also allowed better resistance to the pathogen SRS,

426 decreasing mortality by 40% and 24%, respectively. Accordingly, a reduction in  
427 vitamin E concentration in the diet to near 200 mg kg<sup>-1</sup> can contribute to maintaining an  
428 active immune response provided that ARA is maintained at medium levels. In turn,  
429 when the ARA concentration in the diet is high, its concentration in liver tissue  
430 increases, the immune response remains high and mortality against the pathogen is  
431 maintained only between 45 and 50% regardless of the vitamin E level in the diet.  
432 Generally, an increase in ARA in cell membranes enhances the availability of ARA as a  
433 substrate for eicosanoid production, resulting in greater availability of PGE<sub>2</sub> (Bell &  
434 Sargent 2003), which has been shown to have immune stimulatory effects, directly  
435 influencing macrophage action (Montero *et al.* 1996). Evidence that ARA incorporation  
436 in the diet improves nonspecific immunity has been recently shown in carp  
437 (*Ctenopharyngodon idellus*) and in yellow croaker (*Larimichthys crocea*) (Tian *et al.*  
438 2014; Xu *et al.* 2014), however none of these studies have monitored indicators of  
439 immunity in response to combined ARA and vitamin E or how this is reflected when  
440 fish are exposed to a specific pathogen.

441 According to the results of the present study, vitamin E and ARA act synergistically to  
442 stimulate lysozyme activity particularly with medium concentrations of ARA and low  
443 concentrations of vitamin E. Similarly, high macrophage activity was observed as  
444 improved resistance to the pathogen SRS only when ARA was present at a medium  
445 concentration in the diet. Thus high supplementation of vitamin E is unnecessary for  
446 immune stimulation when dietary ARA level is medium or high. This coincides with the  
447 finding of Pungkaew *et al.* (2005), who suggested that high supplementation of vitamin  
448 E is not necessary for proper immune stimulation when the level of PUFA is adequate,  
449 although these authors did not expose fish to a pathogen which would allow immune

450 response to be evaluated. Curiously, the EPA/ARA ratio was also affected by the  
451 interaction of ARA and vitamin E contents. A relationship between vitamin E and LC-  
452 PUFA levels has been described in several fish species (Mourente et al., 2007; Lebold  
453 et al., 2011), hypothesizing that tocopherols may influence the biosynthesis of PUFA,  
454 especially n-3 PUFA, through alteration of cellular oxidation potential or peroxide tone.

455

456 In summary, inclusion of ARA in Atlantic salmon feeds improved some indicators of  
457 non-specific immunity such as respiratory burst, being this effect independent of the  
458 vitamin E concentration. ARA inclusion also seemed to elicit an effect on LC-PUFA  
459 biosynthesis by enhancing EPA and DHA levels in fish fed low ARA feeds. Medium  
460 inclusion of ARA combined with a high concentration of vitamin E was found to reduce  
461 cumulative mortality by 65%. An interaction between ARA and vitamin E was observed  
462 on lysozyme activity and EPA/ARA ratio probably indicating an effect of vitamin E on  
463 LC-PUFA biosynthesis. To conclude, the interactive effect between vitamin E and ARA  
464 was shown to be limited, although each nutrient, particularly ARA, proved to exert a  
465 marked effect on Atlantic salmon immune response.

466

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684

685 **Figure legends**

686 Figure 1. Effect of dietary ARA/Vitamin E content on the cumulative mortality of  
687 Atlantic salmon (*Salmo salar*) juveniles after challenge test with *Piscirickettsia*  
688 *salmonis* (SRS) at a dose of 0.2 mL SRS fish<sup>-1</sup> at a 10<sup>-2</sup> dilution.

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692

693 Table 1. Formulation of experimental diets

<i>Ingredients (g kg<sup>-1</sup> diet)</i>	<b>ARA1/E1</b>	<b>ARA1/E2</b>	<b>ARA2/E1</b>	<b>ARA2/E2</b>	<b>ARA3/E1</b>	<b>ARA3/E2</b>
Fish meal <sup>a</sup>	619	618	626	625	621	620
Feather meal <sup>b</sup>	50	50	50	50	50	50
Corn Gluten <sup>c</sup>	40	40	40	40	40	40
Wheat meal <sup>d</sup>	140	140	140	140	140	140
Astaxantin <sup>e</sup>	1	1	1	1	1	1
Vitamin premix <sup>f</sup>	2	2	2	2	2	2
Mineral premix <sup>g</sup>	5	5	5	5	5	5
Olive oil <sup>h</sup>	50	50	50	50	40	40
Vevodar ® ARA oil <sup>i</sup>	-	-	-	-	15	15
Yardquim oil <sup>j</sup>	-	-	21	21	21	21
ROPUFA® <i>n</i> -3 INF oil <sup>k</sup>	83	83	65	65	65	65
ROPUFA® <i>n</i> -3 EPA oil <sup>l</sup>	10	10	-	-	-	-
Vitamin E ( $\alpha$ -tocopherol) <sup>m</sup>	0.015	0.65	0.015	0.65	0.015	0.65

694 <sup>a</sup>Supplied by Alimentos Marinos (ALIMAR) S.A. Jack mackerel meal, Super Prime  
695 (Protein 68%, Lipids 9.9%, Ashes 14.5%).

696 <sup>b</sup>Supplied by Härting S.A., Santiago, Chile.

697 <sup>c</sup>Supplied by BIOMAR Chile S.A., Puerto Montt, Chile.

698 <sup>d</sup>Supplied by Molinos Gorbea S.A., Gorbea, Chile.

699 <sup>e</sup>Supplied by DSM Nutritional Product Chile S.A, Puerto Varas, Chile.

700 <sup>f</sup>Supplied by DSM Nutritional Product Chile S.A. (IU/kg or g/kg of premix): Vitamin A  
701 1.0 MIU; Vitamin D3, 0.5 MIU; Vitamin E, 0.04 MIU; Vitamin K 3. 4 g; Vitamin B1,  
702 4 g; Vitamin B2, 6 g; Vitamin B5, 10 g; Vitamin B6, 2 g; Vitamin B9, 1.6 g; Vitamin  
703 B12, 0.00 4g; Niacin, 40 g; Biotin, 0.1 g; Vitamin C 100 g; Choline, 200 g; Inositol 50  
704 g.

705 <sup>g</sup>Supplied by BIOMAR Chile S.A (per g mixture: mg; Cu: 8.3 mg; Mn: 67 mg; Co: 1.7  
706 mg; y: 1.7; Zn: 200 mg)

707 <sup>h</sup>Carbonell, Spain (SAFA: 17.00 MUFA: 73.16; PUFA *n*-3: 0.00; PUFA *n*-6: 8.65).

708 <sup>i</sup>Supplied by DSM Food Specialities (SAFA: 34.16; MUFA : 11.89; *n*-3 PUFA: 2.62;  
709 *n*-6; 51.33)

710 <sup>j</sup>Supplied by Yargas División Química LTDA (SAFA: 6.30; MUFA: 25.43; PUFA *n*-3:  
711 55.68; PUFA *n*-6: 12.59).

712 <sup>k</sup>Supplied by DSM Food Specialties (SAFA: 40.71; MUFA: 32.60; *n*-3 PUFA : 22.98;  
713 *n*-6 PUFA: 5.60).

714 <sup>l</sup>Supplied by DSM Nutritional Product Chile S.A. (SAFA: 38.80; MUFA: 32.60; *n*-3  
715 PUFA: 22.98; *n*-6 PUFA :5.60).

716 <sup>m</sup>Supplied by DSM Nutritional Product Chile S.A. Rovimix E-50 (1g is equivalent to  
717 500 mg of  $\alpha$ -tocopherol acetate)

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719

720 Table 2. Chemical (g kg<sup>-1</sup>) and fatty acids (% of total fatty acid identified) composition  
 721 of the experimental diets.

	ARA1/E1	ARA1/E2	ARA2/E1	ARA2/E2	ARA3/E1	ARA3/E2
Proximal composition						
Protein (N × 6.25)	553	553	558	556	556	558
Nitrogen free extract	120	117	118	122	121	114
Ash	102	102	102	102	102	102
Lipid	219	220	215	213	216	220
α-tocopherol acetate	<b>0.12</b>	<b>0.76</b>	<b>0.19</b>	<b>0.73</b>	<b>0.19</b>	<b>0.72</b>
Fatty acid composition						
C14:0	3.91	3.57	3.02	3.10	3.16	3.05
C15:0	0.58	0.43	0.45	0.46	0.46	0.45
C16:0	21.81	21.24	18.16	18.42	18.95	18.45
C17:0	0.97	0.90	0.83	0.82	0.85	0.82
C18:0	4.29	4.01	4.11	4.14	4.46	4.46
C20:0	0.27	0.26	0.33	0.32	0.33	0.34
C21:0	0.91	0.71	0.63	0.56	0.87	0.75
C22:0	0.08	0.08	0.13	0.13	0.33	0.33
C24:0	0.29	0.27	0.26	0.27	0.30	0.31
Total SAFA	33.11	31.46	27.91	28.23	29.71	28.96
C16:1 <i>n-7</i>	4.80	4.39	3.88	3.98	3.92	3.79
C18:1 <i>n-9</i>	22.10	20.66	21.63	21.83	19.94	19.31
C20:1 <i>n-9</i>	0.83	0.76	3.17	3.11	2.58	3.06
C22:1 <i>n-9</i>	0.13	0.13	0.86	0.73	0.61	0.91
C24:1 <i>n-9</i>	0.59	0.52	1.01	1.00	0.83	0.98
Total MUFA	28.45	26.47	30.55	30.65	27.89	28.06
C18:2 <i>n-6</i>	6.80	6.36	6.09	6.15	6.36	6.19
C18:3 <i>n-3</i>	0.68	0.63	0.63	0.64	0.60	0.60
C18:3 <i>n-6</i>	0.15	0.14	0.10	0.14	0.35	0.34
C20:4 <i>n-6</i>	1.05	1.06	1.77	1.73	3.73	3.75
C20:5 <i>n-3</i>	10.16	10.43	12.21	12.55	11.44	12.21
C22:2 <i>n-6</i>	0.09	0.10	0.05	0.04	0.04	0.04
C22:6 <i>n-3</i>	16.23	16.04	19.11	19.40	17.89	18.87
Total PUFA	35.17	34.77	39.96	40.66	40.42	42.00
EPA/ARA	9.64	9.86	6.91	7.27	3.06	3.26

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 723 SAFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA,  
 724 polyunsaturated fatty acids; EPA, eicosapentaenoic acid; ARA, arachidonic acid.

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727 Table 3. Growth, feed, utilization and survival in Atlantic salmon (*Salmo salar* L.) fed  
 728 the experimental diets  
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<i>Parameters</i>	<i>ARA1/ E1</i>	<i>ARA1/ E2</i>	<i>ARA2/ E1</i>	<i>ARA2/ E2</i>	<i>ARA3/ E1</i>	<i>ARA3/ E2</i>	<i>AR A</i>	<i>Vit E</i>	<i>ARAxV itE</i>
Final weight (g)	23.3 ± 0.9	22.8 ± 0.4	23.9 ± 1.4	23.8 ± 1.9	21.8 ± 0.6	22.4 ± 1.3	ns	ns	ns
Feed consumption (%BW day <sup>-1</sup> ) <sup>b</sup>	1.33 ± 0.0	1.29 ± 0.0	1.30 ± 0.1	1.29 ± 0.1	1.38 ± 0.0	1.28 ± 0.0	ns	ns	ns
FCR <sup>c</sup>	1.07 ± 0.0	1.03 ± 0.1	1.02 ± 0.1	1.01 ± 0.1	1.13 ± 0.0	1.03 ± 0.1	ns	ns	ns
SGR (% day <sup>-1</sup> ) <sup>d</sup>	1.34 ± 0.0	1.32 ± 0.0	1.37 ± 0.1	1.36 ± 0.1	1.27 ± 0.0	1.30 ± 0.1	ns	ns	ns
TGC (% day <sup>-1</sup> ) <sup>e</sup>	1.03 ± 0.0	1.01 ± 0.0	1.06 ± 0.1	1.05 ± 0.1	0.97 ± 0.0	0.99 ± 0.1	ns	ns	ns
K <sup>f</sup>	1.10 ± 0.0	1.09 ± 0.1	1.12 ± 0.1	1.03 ± 0.0	1.09 ± 0.1	1.09 ± 0.1	ns	ns	ns
HSI <sup>g</sup>	1.04 ± 0.1	0.98 ± 0.1	0.95 ± 0.0	1.06 ± 0.2	1.02 ± 0.0	1.11 ± 0.1	ns	ns	ns
PER <sup>h</sup>	1.70 ± 0.0	1.76 ± 0.0	1.76 ± 0.2	1.78 ± 0.1	1.59 ± 0.0	1.74 ± 0.1	ns	ns	ns
Survival (%)	98.4 ± 2.7	98.8 ± 1.2	98.8 ± 1.2	99.2 ± 0.7	98.4 ± 1.8	99.6 ± 0.7	ns	ns	ns

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731 Values are expressed as mean ±SD (n=3), ns : no significant effect (P> 0,05)

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<sup>a</sup>Weight gain(%): [(final weight – initial weight) / initial weight]×100.

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<sup>b</sup>Feed consumption (%Body weight/day): 100 × [(consumed feed / final weight/2 + initial weight/ 2) /days].

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<sup>c</sup>FCR (feed conversion ratio): weight gain (g) / total feed consumed (g).

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<sup>d</sup>SGR (Specific growth rate): [(Ln. final weight - Ln. initial weight) / days]×100.

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<sup>e</sup>TGC (Thermal growth coefficient): [(final weight<sup>1/3</sup> – initial weight<sup>1/3</sup>) × 1000] / ∑ (temperature × days).

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<sup>f</sup>K (Condition factor): (final weight / final length<sup>3</sup>) × 100

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<sup>g</sup>HSI (hepatosomatic index): (liver weight(g) / final weight) × 100

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<sup>h</sup>PER (protein efficiency ratio): gain in body mass (g) / protein intake (g)

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744 Table 4. Free alpha - tocopherol content (mg kg<sup>-1</sup> of tissue) and fatty acid profile (% of  
 745 total fatty acid identified) in liver of *Salmo salar* after being fed with the six  
 746 experimental diets during 12 weeks.

	Experimental diets						p-value (two-way ANOVA)		
	ARA1/E1	ARA1/E2	ARA2/E1	ARA2/E2	ARA3/E1	ARA3/E2	ARA	VitE	ARA*VitE
α-tocopherol acetate	5.1 ± 0.1	224.0 ± 109.7 <sup>#</sup>	15.1 ± 8.2	209.9 ± 17.4 <sup>#</sup>	10.7 ± 1.6	90.2 ± 9.5 <sup>#</sup>	ns	**	ns
Fatty acid composition									
C14:0	1.4 ± 0.0	1.4 ± 0.1	1.5 ± 0.0	1.5 ± 0.1	1.4 ± 0.1	1.5 ± 0.0	*	ns	ns
C15:0	0.5 ± 0.0	0.4 ± 0.1	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	ns	ns	ns
C16:0	22.5 ± 0.5	20.6 ± 2.3	21.4 ± 0.0	21.2 ± 0.2	21.8 ± 0.2	21.5 ± 0.4	ns	ns	ns
C17:0	0.9 ± 0.0	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.0	0.9 ± 0.0	0.9 ± 0.0	ns	ns	ns
C18:0	4.7 ± 0.0	4.5 ± 0.6	4.5 ± 0.2	4.9 ± 0.2	4.8 ± 0.1	5.1 ± 0.1	ns	ns	ns
C21:0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	ns	ns	ns
C22:0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	ns	ns	ns
Total SAFA	30.5 ± 0.69	28.2 ± 2.9	29.2 ± 0.2	29.3 ± 0.3	29.8 ± 0.2	30.1 ± 0.3	ns	ns	ns
C16:1 <i>n</i> -7	1.6 ± 0.0	1.8 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	ns	ns	ns
C18:1 <i>n</i> -9	11.3 ± 0.4 <sup>b</sup>	12.5 ± 0.3 <sup>ab</sup>	12.7 ± 0.7 <sup>a</sup>	12.8 ± 0.8 <sup>a</sup>	11.7 ± 0.1 <sup>b</sup>	11.0 ± 0.8 <sup>b</sup>	*	ns	ns
C20:1 <i>n</i> -9	0.5 ± 0.1	0.6 ± 0.1	0.7 ± 0.0	0.6 ± 0.1	0.6 ± 0.0	0.6 ± 0.1	ns	ns	ns
C24:1 <i>n</i> -9	0.6 ± 0.0	0.9 ± 0.3	0.9 ± 0.0	0.9 ± 0.2	0.7 ± 0.2	0.8 ± 0.1	ns	ns	ns
Total MUFA	14.0 ± 0.6 <sup>b</sup>	15.8 ± 0.7 <sup>ab</sup>	16.0 ± 0.8 <sup>a</sup>	16.0 ± 1.0 <sup>a</sup>	14.7 ± 0.0 <sup>b</sup>	14.9 ± 1.0 <sup>b</sup>	*	ns	ns
C18:2 <i>n</i> -6	2.6 ± 0.0	2.6 ± 0.0	2.6 ± 0.1	2.7 ± 0.1	2.8 ± 0.0	2.6 ± 0.0	ns	ns	ns
C18:3 <i>n</i> -3	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	ns	ns	ns
C20:2	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	ns	ns	ns
C20:4 <i>n</i> -6	3.3 ± 0.2 <sup>a</sup>	3.3 ± 0.1 <sup>a</sup>	2.9 ± 0.21 <sup>a</sup>	3.3 ± 0.2 <sup>a</sup>	6.2 ± 0.2 <sup>b</sup>	5.7 ± 0.6 <sup>b</sup>	**	ns	ns
C20:5 <i>n</i> -3	5.8 ± 0.1 <sup>a</sup>	5.9 ± 0.1 <sup>a</sup>	6.2 ± 0.1 <sup>a</sup>	6.1 ± 0.1 <sup>a</sup>	5.1 ± 0.1 <sup>b</sup>	5.6 ± 0.6 <sup>ab</sup>	*	ns	ns
C22:6 <i>n</i> -3	42.8 ± 0.7 <sup>a</sup>	43.1 ± 2.7 <sup>a</sup>	41.6 ± 1.3 <sup>b</sup>	41.2 ± 0.8 <sup>b</sup>	40.6 ± 0.6 <sup>b</sup>	39.8 ± 1.0 <sup>b</sup>	*	ns	ns
Total PUFA	55.0 ± 0.7	55.4 ± 2.8	54.0 ± 1.3	54.0 ± 0.6	55.2 ± 0.1	54.5 ± 1.0	ns	ns	ns
EPA/ARA	1.7 ± 0.1 <sup>b</sup>	1.8 ± 0.0 <sup>b</sup>	2.2 ± 0.2 <sup>a</sup>	1.9 ± 0.1 <sup>ab</sup>	0.8 ± 0.0 <sup>c</sup>	1.0 ± 0.2 <sup>c</sup>	*	ns	*

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 749 Values are expressed as mean ± SD (n= 3 replicates). ARA1/E1, low ARA/low vitamin  
 750 E; ARA1/E2, low ARA/high vitamin E; ARA2/E1, medium ARA/low vitamin ;  
 751 ARA2/E2, medium ARA/high vitamin E; ARA3/E1, high ARA/low Vitamin E;  
 752 ARA3/E2, high ARA/high vitamin E. <sup>#</sup>Significantly different from liver of fish fed low  
 753 dietary vitamin E based on a student t-test. Different superscript letters within an  
 754 individual row denote significant statistical differences in fatty acid content according to  
 755 Duncan's post-hoc test. Asterisks indicate significant differences as \*P<0.05;  
 756 \*\*P<0.001; n.s. indicates non-significant differences. SAFA, saturated fatty acids;  
 757 MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA,  
 758 eicosapentaenoic acid; ARA, arachidonic acid.  
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761 Table 5. Effects of the dietary ARA and vitamin E levels as well as their interaction on  
 762 the studied immune parameters.  
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	ARA1/E1	ARA1/E2	ARA2/E1	ARA2/E2	ARA3/E1	ARA3/E2	ARA	Vit E	ARA*VitE
Respiratory burst	0.18±0.01 <sup>a</sup>	0.18±0.01 <sup>a</sup>	0.23±0.02 <sup>b</sup>	0.23±0.02 <sup>b</sup>	0.24±0.01 <sup>b</sup>	0.24±0.02 <sup>b</sup>	**	ns	ns
Phagocytic activity	19.7±4.5	22.7±5.2	18.6±4.5	16.1±4.9	17.5±4.7	24.0±6.5	ns	ns	ns
Lysozyme activity	0.07±0.03 <sup>a</sup>	0.06±0.01 <sup>a</sup>	0.12±0.03 <sup>b</sup>	0.06±0.03 <sup>a</sup>	0.06±0.02 <sup>a</sup>	0.09±0.01 <sup>a</sup>	ns	ns	**

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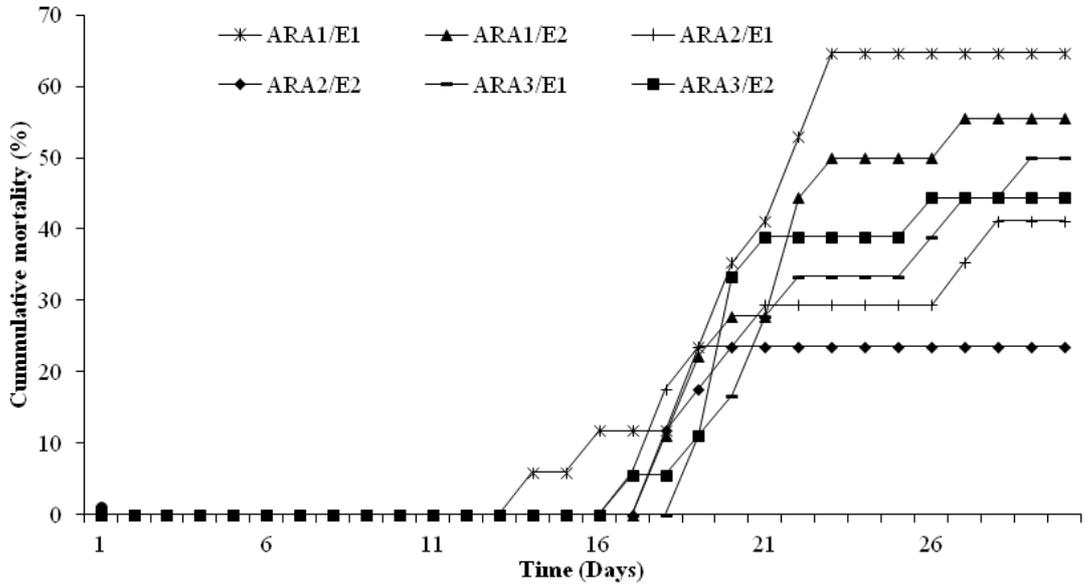
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769 Asterisks indicate significant differences as \*\*P<0.001; n.s. indicates non-significant  
 770 differences

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772 Figure 1. Effect of dietary ARA/Vitamin E content on the cumulative mortality of  
 773 Atlantic salmon (*Salmo salar*) juveniles after challenge test with *Piscirickettsia*  
 774 *salmonis* (SRS) at a dose of 0.2 mL SRS per fish at a 10<sup>-2</sup> dilution.  
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