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First insights on Black Soldier Fly (*Hermetia illucens* L.) larvae meal dietary administration in Siberian sturgeon (*Acipenser baerii* Brandt) juveniles

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

First insights on Black Soldier Fly (*Hermetia illucens* L.) larvae meal dietary administration in Siberian sturgeon (*Acipenser baerii* Brandt) juveniles / Caimi C.; Renna M.; Lussiana C.; Bonaldo A.; Gariglio M.; Meneguz M.; Dabbou S.; Schiavone A.; Gai F.; Elia A.C.; Prearo M.; Gasco L.. - In: AQUACULTURE. - ISSN 0044-8486. - STAMPA. - 515:(2020), pp. 734539.1-734539.10. [10.1016/j.aquaculture.2019.734539]

Availability:

This version is available at: <https://hdl.handle.net/11585/741322> since: 2020-02-29

Published:

DOI: <http://doi.org/10.1016/j.aquaculture.2019.734539>

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This is the final peer-reviewed accepted manuscript of:

Caimi, Christian, et al. «First Insights on Black Soldier Fly (*Hermetia Illucens* L.) Larvae Meal Dietary Administration in Siberian Sturgeon (*Acipenser Baerii* Brandt) Juveniles». *Aquaculture*, vol. 515, gennaio 2020, p. 734539.

The final published version is available online at:

<https://doi.org/10.1016/j.aquaculture.2019.734539>

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1 **First insights on Black Soldier Fly (*Hermetia illucens* L.) larvae meal**
2 **dietary administration in Siberian sturgeon (*Acipenser baerii* Brandt)**
3 **juveniles**

4

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30

31 **Abstract**

32 The *Hermetia illucens* (L.) larvae meal (HIM) has been tested on different fish species but its use on
33 Siberian sturgeon has not been investigated yet. The aim of this study was to evaluate the **effects**
34 of fish meal (FM) substitution with a highly defatted HIM on growth performance, biometric and
35 morphometric indices, apparent digestibility of diets, whole body proximate and fatty acid
36 compositions of *Acipenser baerii* (Brandt) juveniles. Five experimental groups were fed with a FM-
37 based diet without HIM (HIM0), three diets with 25% (HIM25), 50% (HIM50) and 100% (HIM100)
38 of FM substitution with HIM, or a vegetable protein based diet (VEG) without HIM. The feeding
39 trial lasted 118 days and 4 replicates per diet were used. The HIM100 diet was refused by the fish
40 and therefore this experimental group was excluded from statistical evaluation. Moreover, a
41 decrease in feed consumption was recorded with the increase of HIM inclusion. The HIM50 diet
42 negatively affected the growth performance of the fish. The somatic indices were not affected by
43 treatment. Increasing levels of HIM showed increases of dry matter and ether extract contents in
44 the whole body. Compared to HIM0, HIM diets caused modification in lauric acid (up to 65-fold
45 increase) and total saturated fatty acids (up to 1.4-fold increase) contents in the fish **whole body**.

46 The apparent digestibility coefficients of dry matter, crude protein and gross energy were the
47 highest for the VEG diet (77.0%, 90.4% and 85.8%, respectively). HIM25 and HIM50 showed lower
48 apparent digestibility coefficients of crude protein (86.5% and 86.6%, respectively) when
49 compared to HIM0 (88.5%). Overall, this study showed that it is possible to replace up to 25% of
50 FM with HIM in the diet of Siberian sturgeons (equal to 18.5% HIM inclusion level) without
51 affecting the growth performance, condition factor, biometric and morphometric indices, and
52 whole body proximate composition of the fish. The fatty acid composition of the sturgeons' whole
53 body was significantly modified already at 18.5% dietary HIM inclusion level.

54

55 *Keywords:* Insect meal; Fishmeal substitution; Animal performance; Fatty acid profile; Apparent
56 digestibility coefficient.

57

58 *Abbreviations:* AA, amino acid; ADC, apparent digestibility coefficient; ADF, acid detergent fibre;
59 ADL, acid detergent lignin; ANFs, antinutritional factors; BCFA, branched chain fatty acids; *c, cis*;
60 CP, crude protein; DM, dry matter; EE, ether extract; FA, fatty acid; FAME, fatty acid methyl ester;
61 FBW, final body weight; FC, feed consumption; FCR, feed conversion ratio; FM, fish meal; FR,
62 feeding rate; GE, gross energy; HI, *Hermetia illucens*; HIM, *Hermetia illucens* larvae meal; HSI,
63 hepatosomatic index; IBW, initial body weight; K, Fulton's condition factor; MCFA, medium chain
64 fatty acids; MUFA, monounsaturated fatty acids; nd, not detected; NFE, Nitrogen free extracts;
65 PAPs, processed animal proteins; PER, protein efficiency ratio; PUFA, polyunsaturated fatty acids;
66 SEM, standard error of the mean; SFA, saturated fatty acids; SGR, specific growth rate; *t, trans*;
67 TFA, total fatty acids; VEG, vegetable protein based diet; VSI, viscerosomatic index; WG, weight
68 gain.

69

70 1. Introduction

71 By 2050, the demographic growth will result in an increase of 60% in the consumption of products
72 of animal origin and aquaculture is considered as one of the livestock sectors able to support the
73 global demand of animal products (Engle et al., 2017). Between 2001 and 2016, aquaculture
74 production grew about 5.8% per year and such trend is set to grow (FAO, 2018). The
75 intensification of production has led to an increase in the demand for raw materials, especially
76 protein sources, to produce aquafeeds. For many years, fishmeal (FM) represented the main
77 protein source in the production of feed for carnivorous farmed fish. However, in the next few
78 years FM production will not be able to support aquaculture growth anymore (Gasco et al., 2018).
79 To reduce both ecological impact and feed costs, at commercial level FM is partially replaced by
80 vegetable protein meals (Soliman et al., 2017). However, plant feedstuffs raised some nutritional
81 issues that reduce their potential in fish feed formulation (Soliman et al., 2017). The technological
82 advances in plant ingredient processing and the feed extrusion process have solved most of these
83 problems (Merrifield et al., 2011; Gai et al., 2016), but the formulation of diets containing 100%
84 vegetable proteins still causes performance and health issues **in carnivorous species where FM can**
85 **hardly be totally replaced by vegetable proteins** (Gai et al., 2012). Globally, terrestrial processed
86 animal proteins (PAPs) are largely used in aquaculture. However, under European regulations only
87 PAPs from non-ruminant animals (poultry and pigs - category 3) are allowed in fish feed
88 **formulation** (EC No 56/2013).

89 Alternative protein ingredients of animal origins, such as insect meals, may be an alternative
90 solution to overcome this problem and replace, at least partly, the amount of FM in aquafeeds
91 (Henry et al., 2015). Insect meals are rich in essential aminoacids (in particular lysine, methionine
92 and leucine), have a fatty acid (FA) profile that can be manipulated choosing appropriate rearing
93 substrates (Liland et al., 2017; Meneguz et al., 2018) for insects, and do not have any anti-

94 nutritional factors (Spranghers et al., 2017). One of the most promising insect species to partially
95 replace FM is the Black Soldier Fly (*Hermetia illucens* L. - HI; Stratiomyidae family). HI is able to
96 convert low value by-products and wastes into protein and fat sources (Spranghers et al., 2017;
97 Meneguz et al., 2018) representing a sustainable way to produce edible proteins for livestock
98 feeding. The partial substitution of FM with HI larvae meal (HIM) has been successfully tested in
99 various fish species including rainbow trout (*Oncorhynchus mykiss* Walbaum) (Renna et al., 2017;
100 Elia et al., 2018; Huyben et al., 2018), Atlantic salmon (*Salmo salar* L.) (Lock et al., 2016; Belghit et
101 al., 2018a), European seabass (*Dicentrarchus labrax* L.) (Magalhães et al., 2017), yellow catfish
102 (*Pelreobagrus fulvidraco* Richardson) fry (Xiao et al., 2018), Jian carp (*Cyprinus carpio* var. Jian) (Li
103 et al., 2017; Zhou et al., 2018), and Nile tilapia (*Oreochromis niloticus* L.) (Devic et al., 2018).

104 The production of caviar and sturgeon's meat is a financially relevant aquaculture sector.
105 Compared to other sturgeon's species, Siberian sturgeon (*Acipenser baerii* Brandt) has a short
106 reproductive cycle (7 to 8 years) and can be reared in fresh water (Bronzi et al., 2011). For these
107 reasons, Siberian sturgeon is one of the most commonly farmed sturgeons (Şener et al., 2006;
108 Bronzi et al., 2011). Compared to other species (e.g., Atlantic salmon, rainbow trout, and European
109 sea bass), less attention has been paid to the nutrition requirements of sturgeons. However, the
110 research of FM substitutes is a crucial point for the future of sturgeon rearing and production
111 (Sicuro et al., 2015). In the last ten years, several authors have evaluated the use of vegetable
112 ingredients other than soybean meal (Liu et al., 2009), like spirulina microalgae (Palmegiano et al.,
113 2008), rice concentrate (Sicuro et al., 2015) and sesame oil cake or corn gluten (Jahanbakhshi et
114 al., 2013) or animal proteins such as meat and bone, poultry by-products or feather meals (Liu et
115 al., 2009; Zhu et al., 2011) as FM substitutes in sturgeon's diets concluding that a partial FM
116 replacement with these alternative protein sources is feasible without adverse effects.

117 So far, the use of HIM in sturgeon's feeds has not been investigated. Therefore, the purpose of the
118 present study is to assess the effects of the dietary inclusion of *H. illucens* larvae meal as FM
119 replacer on growth performance, biometric and morphometric indices, whole body composition
120 (proximate constituents and FA profile) and apparent digestibility of diets of *A. baerii* juveniles.

121

122 **2. Materials and methods**

123 A growth trial and a digestibility trial were conducted at the experimental facility of the
124 Department of Agricultural, Forest and Food Sciences (DISAFA) of the University of Torino (Italy).
125 The experiment was designed according to the guidelines of the current European Directive
126 (2010/63/EU) on the protection of animals used for scientific purposes. The experimental protocol
127 was approved by the Ethical Committee of the University of Turin (Italy) (protocol N° 143811).

128

129 *2.1 Experimental diets*

130 A highly defatted HIM (ether extract – EE: 4.03 g 100g⁻¹, as fed) purchased from Hermetia
131 Deutschland GmbH & Co. KG (Baruth/Mark, Germany) was used in the trials. The HIM was
132 defatted with a mechanical method; no solvent was used for this purpose. Five experimental diets
133 were formulated to be isonitrogenous (crude protein – CP: on average 50.5 g 100g⁻¹, on as fed
134 basis), isolipidic (EE: on average 12.4 g 100g⁻¹) and isoenergetic (gross energy – GE: on average
135 20.84 MJ kg⁻¹). The five experimental diets were the following: (i) a FM based diet (HIM0), without
136 HIM inclusion; (ii, iii, iv) three diets with an inclusion, on as fed basis, of 18.5% (HIM25), 37.5%
137 (HIM50) and 75.0% (HIM100) of HIM, with the purpose to replace the 25%, 50% and 100% of FM
138 in the HIM0 diet, respectively; and (v) a vegetable protein based diet (VEG), without HIM inclusion,
139 formulated to replicate currently available commercial feeds. Due to the different chemical
140 composition of HIM compared to FM, and in order to maintain diets isonitrogenous, isolipidic and

141 isoenergetic, the amounts of some other dietary ingredients (i.e. wheat meal and fish oil) were
142 modified with the increase of HIM inclusion in the diets.

143 The experimental diets were prepared at the experimental facility of DISAFA. The ground
144 ingredients were individually weighed and subsequently mixed with fish oil. From 250 to 500 mL
145 kg⁻¹ of water was added to promote greater malleability and to obtain a suitable compound for
146 pellet preparation. The pellets were obtained using a 3.0 mm die meat grinder and were dried at
147 50°C for 48 h. The diets were stored in dark bags at -20°C until utilization. The ingredients of the
148 experimental diets are listed in Table 1.

149

150 *2.2 Fish feeding and management*

151 A 118 day growth trial was carried out using 20 square fibreglass tanks of 400 L supplied by
152 artesian well water (constant temperature of 13 ± 1°C) in an open system (flow-through) with
153 each tank having a water inflow of 8 L min⁻¹. Dissolved oxygen was measured every week and
154 ranged between 8.5 and 9.3 mg L⁻¹ while water pH was equal to 7.6. The fish were exposed to
155 natural photoperiod (April to July 2016). *A. baerii* juveniles were purchased from a private
156 sturgeon farm (Cislano (MI), Italy), transported to the experimental facility of DISAFA and
157 acclimated to the rearing conditions for 2 weeks. After the acclimatization period, 440 fish were
158 lightly anaesthetised (MS-222 100 mg L⁻¹; PHARMAQ Ltd, Fordingbridge, UK), individually weighed
159 (mean individual initial body weight - iIBW: 24.2 ± 7.59 g) and randomly distributed to each tank
160 (22 fish per tank). The experimental diets were randomly assigned to the tanks (four replicate
161 tanks per diet). The fish were fed by hand to apparent visual satiation, three times a day (8:00,
162 14:00 and 20:00 h), six days per week. Not ingested feed was siphoned, dried and weighed to
163 record the actual feed consumption (FC) per tank. The fish were weighed individually at the end of
164 the trial (individual final body weight – iFBW). Mortality was checked every day.

165

166 *2.3 Sampling*

167 At the end of the growth trial, after 24 h of fasting, 6 fish per tank (24 fish per treatment) were
168 sacrificed by over anaesthesia (MS-222, 300 mg L⁻¹), individually weighed (KERN PLE-N v. 2.2; KERN
169 & Sohn GmbH, Balingen-Frommern, Germany; d: 0.001), photographed orthogonally (Lumix G1;
170 Panasonic Corp., Kadoma, Osaka, Japan) with a metric scale (mm) and measured to record fish
171 length (i.e. from mouthpart to the bottom of the caudal fin) with 1 mm accuracy. Data were
172 elaborated using ImageJ software (ImageJ 1.50b, Wayne Rasband, Public domain, National
173 Institute of Health, USA) for the calculation of the Fulton's condition factor (K). Subsequently, 3 of
174 the 6 fish sampled (12 fish per treatment) were frozen, finely ground with a knife mill (Grindomix
175 GM200; Retsch GmbH, Haan, Germany), freeze-dried and stored (-80°C) for final whole body
176 proximate composition and FA profile analyses. The remaining 3 fish (12 fish per treatment) were
177 eviscerated; the liver and viscera were weighed to calculate the hepatosomatic (HSI) and
178 viscerosomatic (VSI) indices, respectively.

179

180 *2.4 Data calculation*

181 The growth performance indices were calculated as follows:

- 182 • Survival rate (SR, %) = (number of final fish / number of fish at start) × 100;
- 183 • Weight gain (WG, g) = iFBW (g) – iIBW (g);
- 184 • Specific growth rate (SGR, % day⁻¹) = [(lnFBW - lnIBW) / number of days] × 100;
- 185 • Feed conversion ratio (FCR) = total feed supplied (g, dry matter (DM)) / tank WG (g);
- 186 • Protein efficiency ratio (PER) = tank WG (g) / total protein fed (g, DM).

187 Individual initial (iIBW) and final body (iFBW) weight were used to calculate the WG while SGR,
188 FCR and PER were calculated per tank.

189 The Fulton's condition factor and somatic indices were calculated as follows:

- 190 • $K = [\text{fish weight (g)} / (\text{body length})^3 \text{ (cm)}] \times 100$;
- 191 • $\text{HSI (\%)} = [\text{liver weight (g)} / \text{fish weight (g)}] \times 100$;
- 192 • $\text{VSI (\%)} = [\text{viscera weight (g)} / \text{fish weight (g)}] \times 100$.

193

194 *2.5 Diets digestibility*

195 At the end of the growth trial, the remaining fish (on average 16 per tank) were used for the
196 digestibility trial. The fish were maintained in their respective tanks and fed the same
197 experimental diets added with 1% celite® (Fluka, St. Gallen, Switzerland) as inert marker. The diets
198 were prepared as described in section 2.1, and the inert marker was added at the expense of 1%
199 of starch gelatinized. Feed was administered by hand to apparent visual satiation three times per
200 day (8:00, 14:00 and 20:00 h), six days per week. After the first feed administration, all the fish
201 were placed in a metal cage that was perforated on the bottom side, and placed on a rigid plastic
202 tray. In this way, the faeces were settled in the plastic tray, allowing their sampling. As described
203 in Guo et al. (2012), four hours after the meal, the faeces were collected using a suction pipe,
204 placed on blotting paper to remove the excess water and immediately frozen (-80°C) until
205 analysed. After the first faeces collection, the fish were released in their tanks and the same
206 procedure was performed after the second feed administration. To avoid digestibility
207 overestimation, only intact faeces were collected, and faeces collection lasted 20 days. The
208 apparent digestibility coefficients (ADC) of DM, CP and GE were calculated as reported by Renna et
209 al. (2017) and expressed as a percentage.

210

211 *2.6 Chemical analyses of dietary ingredients, diets and fish whole body*

212 The chemical analyses of the dietary ingredients were performed before diet formulation. Feed
213 samples were ground using a cutting mill (MLI 204; Bühler AG, Uzwil, Switzerland) and analysed
214 for DM (#934.01), CP (#984.13) and ash (#942.05) contents according to AOAC International
215 (2000); EE (#2003.05) was analysed according to AOAC International (2003). The GE content was
216 determined using an adiabatic calorimetric bomb (C7000; IKA, Staufen, Germany). Chitin was
217 estimated according to Finke (2007) by correction considering the amino acid (AA) content of the
218 acid detergent fibre (ADF) fraction and assuming the remainder of the ADF fraction is chitin.

219 The FA composition of HIM and of the experimental diets was assessed as described by Renna et
220 al. (2017). Fatty acid methyl esters (FAME) were separated, identified and quantified on the basis
221 of the chromatographic conditions reported by Renna et al. (2014). The results were expressed as
222 mg 100 g⁻¹ DM (Table 2).

223 The proximate composition of the fish whole body was determined according to the same
224 procedures implemented for feed analyses (AOAC International, 2000; 2003). The freeze-dried and
225 ground samples of the fish whole bodies were also used to assess their FA composition, as
226 reported by Renna et al. (2017). FAME were separated using the same analytical instruments and
227 temperature program previously described for the FA analysis of feeds. Peaks were identified by
228 injecting pure FAME standards as detailed by Renna et al. (2012). The results were expressed as
229 mg 100 g⁻¹ ww. All chemical analyses were performed in duplicate.

230

231 *2.7 Statistical analyses*

232 Data were analysed by one-way ANOVA using IBM SPSS Statistics v. 25.0 for Windows. The
233 following model was used: $Y_{ij} = \mu + D_i + \epsilon_{ij}$

234 where Y_{ij} = observation; μ = overall mean; D_i = effect of diet (HIM0, HIM25, HIM50, VEG); ϵ_{ij} =

235 residual error.

236 The Kolmogorov–Smirnov test was used to check the assumption of normality. The assumption of
237 equal variances was assessed by Levene’s homogeneity of variance test. If such an assumption did
238 not hold, the Brown-Forsythe statistic was applied to test the equality of group means instead of
239 the F one. Pairwise multiple comparisons were performed to test the difference between each
240 pair of means (Tukey’s test and Tamhane’s T2 in the cases of equal variances assumed or not
241 assumed, respectively). The results were expressed as mean and pooled standard error of the
242 mean (SEM). Significance was declared at $p \leq 0.05$.

243

244 **3. Results**

245 *3.1 Chemical composition of insect meal and experimental diets*

246 The proximate composition of HIM and of the experimental diets are reported in Table 1. The DM,
247 CP and EE contents were comparable among the diets. The ash content showed a reduction at the
248 increase of HIM inclusion in the diet (13.15 to 7.90 g 100g⁻¹ in HIM0 and HIM100, respectively),
249 while the chitin content increased at increasing inclusion levels of HIM.

250 The FA composition of HIM and of the experimental diets is shown in Table 2. The most
251 represented FA in HIM was lauric acid (C12:0), followed by palmitic (C16:0), myristic (C14:0) and
252 oleic (C18:1 c9) acids (2020.65, 435.36, 325.51 and 303.20 mg 100g⁻¹ DM, respectively). In the
253 experimental diets containing HIM, lauric acid increased proportionally at the inclusion of insect
254 meal. The concentrations of C12:0 in the diets containing HIM were noticeably higher than those
255 observed in HIM0 and VEG. When compared to the other diets, the HIM0 diet showed a higher
256 amount of total n3 FA (1348.15 mg 100g⁻¹ DM), with C22:6 n3 as the most represented individual
257 FA in this group (666.59 mg 100g⁻¹ DM). The total n3 polyunsaturated fatty acids (PUFA) decreased
258 proportionally at increasing levels of HIM. The VEG diet showed a lower concentration of total
259 saturated fatty acids (SFA) and was richer in total n6 PUFA (in particular linoleic acid, C18:2 n6)

260 when compared to the other diets. HIM0 showed the highest $\Sigma n3 / \Sigma n6$ PUFA ratio among the
261 considered experimental diets.

262

263 *3.2 Growth trial*

264 The fish fed HIM100 showed a low diet acceptance, rapidly decreased the voluntary ingestion of
265 feed and, few weeks after the beginning of the trial, they refused the diet. Therefore, to avoid
266 stress or suffering in the animals, we decided to stop this dietary treatment. These fish were fed
267 again with a commercial diet and excluded from further investigations.

268 The survival and growth performance of the fish are reported in Table 3. Siberian sturgeons fed
269 the HIM0, HIM25, HIM50, and VEG diets easily accepted the experimental diets. Nevertheless, a
270 decrease in feed consumption (FC) was recorded in diets added with HIM (-5.3% for HIM25 and -
271 6.0% for HIM50). This led to a worsening of FBW (-10.9%), WG (-12.9%) and SGR (-6.9%) in the
272 HIM50 group compared to HIM0. Nevertheless, FCR and PER were similar among the treatments.
273 The fish fed the VEG diet reported values comparable to the fish fed the control diet for all the
274 considered dependent variables.

275

276 *3.3 Biometric and morphometric indices*

277 The Fulton's condition factor, HSI and VSI are reported in Table 4. All the biometric and
278 morphometric indices were not significantly affected by treatment.

279

280 *3.4 Proximate composition and fatty acid profile of fish whole body*

281 The proximate composition and FA profile of the fish whole body are reported in Table 5. The
282 substitution of FM by HIM progressively increased the DM and EE contents of the fish. Particularly,
283 the fish fed with HIM50 showed a significantly higher DM (+10.0%) content when compared to

284 those fed with HIM0 and VEG, and a significantly higher EE (+38.4%) content when compared to
285 those fed with HIM0. The DM and EE contents were comparable among HIM0, HIM25 and VEG.
286 The CP and ash contents were unaffected by the treatment.

287 As far as the FA composition is concerned, the concentration of C12:0 significantly increased (from
288 2.70 to 61.23 and 151.61 mg 100 g⁻¹ ww in HIM0, HIM25 and HIM50, respectively) as the level of
289 HIM increased in the diet, while VEG and HIM0 showed comparable values. The fish fed with
290 HIM50 showed a higher concentration of C14:0 when compared to the fish fed with HIM0 and VEG
291 (+47.9% in both cases), while the fish fed with HIM25 showed intermediate values. Various
292 branched chain fatty acids (BCFA) were detected, but only a few of them (C17 *anteiso* and C18 *iso*)
293 were affected by the diet. The concentration of total BCFA in the fish whole body did not
294 significantly differ among the treatments. The concentration of C18:1 *c9* was significantly higher in
295 the fish fed with HIM50 than in those fed with HIM0 (869.27 and 600.58 mg 100g⁻¹ww,
296 respectively), while the fish fed with HIM25 and VEG showed intermediate values. The
297 concentrations of C18:2 n6, C18:3 n6, and total n6 PUFA were the highest in the fish fed with VEG,
298 followed by the fish fed with HIM50 and HIM25, and finally by those fed with HIM0. As regard to
299 individual long-chain n3 PUFA, the absolute lowest values were recorded in the fish fed with VEG
300 (C20:5 n3) and HIM0 (C22:5 n3 and C22:6 n3), while the absolute highest values were observed in
301 the fish fed with HIM25. The Σ n3 / Σ n6 FA ratio in fish whole body ranked in the order HIM0 =
302 HIM25 > HIM50 > VEG.

303

304 *3.5 Digestibility trial*

305 The ADCs of the experimental diets are reported in Table 6. The VEG diet showed significantly
306 higher values than all the other diets for all the considered ADCs. ADC_{DM} and ADC_{GE} did not differ

307 significantly among HIM0, HIM25 and HIM50, while ADC_{CP} was significantly lower in HIM25 (-
308 2.3%) and HIM50 (-2.1%) when compared to HIM0.

309

310 **4. Discussion**

311 Insects, such as Diptera and Coleoptera, are part of the natural diet of Siberian sturgeons (Pyka
312 and Kolman, 2003). To our knowledge no studies using HIM as protein source have been carried
313 out with sturgeons yet, and our results indicate that up to 18.5% of highly defatted HIM can be
314 included without impairing survival rate and growth performance in this species. Nevertheless,
315 **WG and SGR** decreased with the increase of HIM in the diets as a consequence of a decrease in
316 feed consumption. At 75% of HIM inclusion (total FM substitution – HI100), we observed a
317 noticeable decrease in feed ingestion by the sturgeons. The decrease in feed consumption
318 recorded with the increase of HIM could be attributable to different causes. One factor could be
319 the chitin content of the diets. It has been reported how even low levels of chitin could decrease
320 feed consumption in fish (Gopalakannan and Arul, 2006; Olsen et al., 2006; Kroeckel et al., 2012).
321 In particular, when feeding turbot juveniles (*Psetta maxima*) with diets containing insect meals,
322 Kroeckel et al. (2012) faced a decrease of feed acceptance at increasing levels of insect meal, and
323 the diet with 75.6% of inclusion of HI prepupae meal showed the lowest daily feed intake and
324 performances. These authors argued that the dietary level of chitin could have been one of the
325 reasons due to the fact that turbot is a fish without gut chitinase activity. Chitin, an indigestible
326 polysaccharide, is a primary component of the exoskeleton of arthropods (such as insects and
327 shrimps). In insects, the amount of chitin varies according to the species and the development
328 stage (Finke, 2007). **In the current trial, following the method proposed by Finke (2007), the chitin**
329 **contents of the experimental diets were equal to 0 (HIM0 and VEG), 0.72 (HIM25), 1.92 (HIM50)**
330 **and 3.75 (HIM100) g 100g⁻¹ as fed.** Not all studies performed using insect meals reported

331 palatability problems (Lock et al., 2016; Magalhães et al., 2017; Renna et al., 2017; Belghit et al.,
332 2018a; Devic et al., 2018). It could be argued that these inconsistent results are due to differences
333 in meal composition and processing (as already reported for other PAPs) or as a consequence of
334 the presence/absence of endogenous chitinases in the investigated fish species such as Atlantic
335 salmon, European seabass, rainbow trout and Nile tilapia. Another cause could be the excessive
336 hardness of the pellet observed in the production phase, particularly in the experimental diet
337 where HIM completely substituted FM (HIM100). In white sturgeons (*A. transmontanus*
338 Richardson) larvae, Gawlica et al. (2002) reported that the physical texture of the diet significantly
339 affected feed intake, with negative effects being associated with dry and hard diets.

340 The absolute lowest FC recorded in the fish fed with HIM50 (37.5% of HIM inclusion) reduced the
341 nutrients intake and thus the final fish weight and SGR (1.48). The fish fed HIM25 (18.5% of HIM
342 inclusion) showed comparable FC values than those fed HIM50. They also suffered a reduction of
343 iFBW and SGR when compared to the fish fed HIM0, but such difference was not statistically
344 significant, as it was instead for the fish fed HIM50. On the contrary, Renna et al. (2017) showed
345 that an inclusion of up to 40% of a partially defatted HIM did not affect the FBW and SGR of
346 rainbow trout. Moreover, Xiao et al. (2018) reported better weight gain rate and SGR than a
347 control diet (containing fish and soybean meals as primary protein sources) when yellow catfish
348 were fed with diets containing up to 22.3% of HIM inclusion while, when the inclusion level was
349 higher than 34.3%, a decrease of growth performance was observed. The inconsistency among
350 available literature may be also due to the different fish species considered in the trials.

351 The overall reduction of the growth performance observed in this study can also be related to the
352 reduction of ADC_{CP}, which occurred already at 18.5% level of HIM inclusion in the diet. The
353 observed decrease of protein digestibility could be determined by the presence of chitin in the
354 insect meal (Renna et al., 2017; Zhou et al., 2018). In European seabass, the inclusion up to 19.5%

355 of HI prepupae meal did not negatively affect the performances or the ADCs of the diets
356 (Magalhães et al., 2017). Renna et al. (2017) reported significant differences for ADC_{DM} and ADC_{CP}
357 between diets with 25 and 50% inclusion of HIM, with the lowest values found in the diet with
358 50% of HIM inclusion. Chitin interferes with the digestibility of proteins (Marono et al., 2015), but
359 it has also been observed that several fish species are able to synthesize endogenous chitinases,
360 **probably due to differences in their gut microbiota**. This may explain the apparently contrasting
361 results obtained by different authors while working with different fish species (Henry et al., 2015).
362 To our knowledge, no chitinase activity has been reported in sturgeons. The fish fed with the VEG
363 diet reported similar values than those fed with HIM0 in terms of performance while, as far as
364 digestibility is concerned, the fish fed with the VEG diet showed the highest ADC values. Our
365 results indicate that Siberian sturgeons have good capability to use raw plant materials. A
366 comparative study between rainbow trout and *Acipenser naccarii* Bonaparte showed that
367 sturgeons digest proteins and lipids like carnivorous fish and carbohydrates like omnivorous fish
368 (Furnè et al., 2009). Such a good capability to digest raw plant materials by sturgeons has already
369 been observed by other authors (Liu et al., 2009). Kaushik et al. (1989) showed how Siberian
370 sturgeon juveniles are not able to use complex carbohydrates (such as crude starch) fully, but
371 these authors suggested that the inclusion of pre-treated starch or cereals in diets for sturgeons
372 improve the growth rate and nutrient utilization. It is well known that extrusion can strongly
373 improve the availability of complex carbohydrates. In our trial, the diets were not extruded and, to
374 balance diets, the level of wheat meal inclusion was reduced from 140 (HIM0) to 100 (HIM50) g kg⁻¹
375 of wet feed. Considering average starch values found in literature for the individual feed
376 ingredients used in our experimental diets (ARRAINA 2015; Xie et al., 2017), we were able to
377 estimate the starch content of the diets that were equal to 111.6, 95.6, 79.7 and 30.8 (g kg⁻¹, as
378 fed) for HIM0, HIM25, HIM50 and VEG respectively. Compared to the VEG diet, the other diets

379 contained a considerable amount of complex carbohydrates that could have contributed to the
380 decrease of ADCs. Even if the VEG diet contained high levels of vegetable meals, no wheat meal
381 was used, obtaining a diet with an overall lower content of complex carbohydrates and then likely
382 more digestible by the sturgeons. Moreover, about 30% of the vegetable feed ingredients used to
383 produce the VEG diet was soybean meal, and it has been reported how sturgeons are able to
384 digest soybean meal efficiently (Degani, 2002; Liu et al., 2009). In particular, Liu et al. (2009)
385 demonstrated that, in sturgeons, the ADC_{DM} and ADC_{CP} of soybean meal are higher than those of
386 FM and PAPs, such as meat and bone meal or poultry by-product meal.

387 Considering the Fulton's condition factor, rainbow trout and yellow catfish fed with HIM showed K
388 ranging from 1.18 to 1.21 (Renna et al., 2017) and from 1.00 to 1.09 (Xiao et al., 2018),
389 respectively. K is an index of the health status of fish and, in some species, values less than 1 are
390 considered indicators of bad health status. In the present trial, K values averaged 0.25 - 0.26, being
391 lower than those found in other fish species. In agreement with our results, in other studies
392 conducted on sturgeons, K values were always less than 1. Indeed, in a growth trial performed by
393 Zhu et al. (2011) on Siberian sturgeons fed with a blend of rendered animal protein, K values equal
394 to 0.7-0.8 were reported. In a study conducted on lake sturgeons (*Acipenser fulvescens*
395 Rafinesque), K measured at fork length or total length was equal to 0.58 and 0.73 respectively
396 (Jackson et al., 2002). In sturgeons, K values lower than 1 seem then to be a direct consequence of
397 fish morphology (narrow and elongated body) and not a symptom of bad health status. This
398 assumption is confirmed by the high survival rate and overall good performance observed in all
399 the considered treatments.

400 The lack of significant differences in the morphometric indices among dietary treatments confirms
401 the findings of other authors in other fish species fed with insect meals (Renna et al., 2017; Xiao et
402 al., 2018).

403 Results on the effects of the dietary inclusion of insect meals on the proximate composition of fish
404 lack consistency in the available literature. Similarly to what previously found by Renna et al.
405 (2017) in rainbow trout fillets, in the current trial the increase of HIM in the diets caused a
406 progressive increase of the DM and EE contents of the sturgeons whole body. In European sea
407 bass juveniles, no significant differences were observed in DM and EE contents of whole body at
408 different inclusion levels of a full-fat *Tenebrio molitor* larvae meal (Gasco et al., 2016). Kroeckel et
409 al. (2012) found decreasing DM and EE contents in the whole body of turbot juveniles while
410 increasing the inclusion level of HI prepupae meal in the experimental diets. As far as HIM0 and
411 diets containing HIM are concerned, the results obtained in our trial are somehow ambiguous.
412 Even if not statistically significant, from Table 4 we can observe an increase in HSI and VSI values
413 from HIM0 to HIM50. Contemporarily, a general decrease of the **growth** performance of the fish
414 was observed (Table 3). An increase in the TFA content of the whole body was observed in the
415 sturgeons fed with insect meal when compared to the sturgeons fed with the control diet,
416 supporting the recent findings of Belghit et al. (2018b) on freshwater Atlantic salmon. The
417 observed sharp increase (from 0.11% to 4.56% of TFA) in the content of lauric acid at the increase
418 of HIM inclusion in the diet was expected. In fact, as outlined in Table 2, the HIM used in this trial
419 was very rich in lauric acid. This confirms the recent findings of other authors who investigated the
420 chemical composition of HI larvae and prepupae when fed different rearing substrates (**Liland et**
421 **al., 2017; Spranghers et al., 2017; Meneguz et al., 2018**). Concerning SFA, a significant increase in
422 the fish whole body was also found for the contents of myristic and arachidic (C20:0) acids, even if
423 to a lesser extent. Particularly because of the substantial increase in C12:0, the total SFA
424 concentration of the sturgeon whole body was found to increase while increasing the level of
425 dietary HIM inclusion. Similar findings were reported by other authors on rainbow trout (Mancini
426 et al., 2017; Renna et al., 2017), Jian carp (Zhou et al., 2018) and Atlantic salmon (Belghit et al.,

2018b, 2019) fed *H. illucens* larvae or prepupae meal. The chromatographic conditions applied in our trial allowed us detecting various BCFA with a number of carbon atoms ranging between 15 and 18 (both *iso* and *anteiso* forms) in the sturgeons whole body. Such findings are in line with the individual BCFA found by Wang et al. (2016) in other common freshwater fish species. Other authors previously reported the FA composition of different sturgeon species, such as white sturgeon (Xu et al., 1993; 1996; Gawlicka et al., 2002), Russian sturgeon (*A. gueldenstaedtii* Brandt) (Şener et al., 2005; Zhu et al., 2017), Gulf sturgeon (*A. oxyrinchus desotoi* Vladykov) (Chen et al., 1995), and the hybrid *A. naccarii* × *A. baerii* (Vaccaro et al., 2005). To the best of our knowledge, only two studies previously investigated the FA composition of Siberian sturgeons (Nieminen et al., 2014; Aidos et al., 2019). Despite the available above-mentioned literature on the FA composition of sturgeons, information on BCFA is very scant. Until now, only Chen et al. (1995) reported BCFA in the muscle samples of cultured and wild Gulf sturgeons. The overall amount of BCFA found in the Siberian sturgeons in our trial (up to 2.30% of TFA) was comparable to that found in ruminant-derived food products (usually considered the most important source of BCFA in the human diet), most probably because we analysed the fish whole body. Indeed Wang et al. (2016) found that fish skin contains on average higher amounts of BCFA compared to different muscle types. Some BCFA were also detected in the insect meal (Table 2). Also Spranghers et al. (2017) found variable amounts of total BCFA in *H. illucens* prepupae reared on different organic waste substrates. However, these authors reported no details regarding the detected individual *iso* and *anteiso* forms, and therefore no comparisons at this regard can be made with our findings. The dietary treatment did not affect the total amount of BCFA, nor the majority of the detected individual *iso* and *anteiso* forms, in the Siberian sturgeons in our trial. In the current trial, the amount of C17 *anteiso* slightly differed in the experimental diets, ranking in the order HIM50 > VEG = HIM25 > HIM0 (Table 2), thus mostly mirroring the concentration of this

451 FA found in the whole body of the fish (Table 5). Regarding MUFA, from a quantitative point of
452 view the most interesting result found in the sturgeon whole body was the proportional increase
453 in the concentration of oleic acid at the increase of HIM inclusion in the diet. Such increase
454 reflected the oleic acid concentration in the experimental diets (Table 2). Oleic acid is by far the
455 most abundant individual MUFA in *H. illucens* larvae and prepupae, and the amount detected in
456 the HIM used in our trial (about 8% of TFA) was very similar to that found in the available
457 literature (Spranghers et al., 2017; Meneguz et al., 2018). As far as PUFA are concerned, the
458 highest total n6 PUFA concentration found in the whole body of the sturgeons fed with the VEG
459 diet was expected. The VEG diet used in this trial contained corn and soybean as plant materials,
460 linoleic acid being the most abundant FA in both corn and soybean. It is also interesting to notice
461 that the concentrations of C18:2 n6 and total n6 PUFA were higher in the whole body of the
462 sturgeons fed HIM25 and HIM50 when compared to HIM0, most probably as the consequence of
463 the C18:2 n6 content (195.96 mg 100g⁻¹ DM) found in HIM. Regarding the n3 PUFA, in HIM C18:3
464 n3 was detected in very low amounts, while EPA, DPA and DHA were not detected (Table 2). The
465 total n3 PUFA in HIM only reached the 0.7% of TFA and this has to be considered a big issue from
466 the point of view of both fish dietary requirements of essential fatty acids and human health
467 related outcomes, when trying to replace fishmeal with insect meal in aquafeed. In the whole
468 body of the sturgeons used in our trial, the total n3 PUFA concentration, as well as the
469 concentrations of EPA, DPA, and DHA did not decrease while increasing HIM in the diet because,
470 with the aim of maintaining the diets isolipidic and isoenergetic, we contemporarily increased the
471 amount of fish oil (Table 2). Adding even low amounts of fish oil while replacing fishmeal with
472 insect meal in commercial aquafeeds may be a strategy to meet the lipid nutritional requirements
473 of the fish and to prevent the lowering of the quality of the lipid fraction of the fish destined to

474 human consumption. Another very promising strategy may be the modulation of the n3 FA
475 concentration in the insects using appropriate growth media (Liland et al., 2017).

476

477 **5. Conclusion**

478 In this first study performed on Siberian sturgeons, results showed that it is possible to replace up
479 to 25% of FM with a highly defatted HIM without impairing the growth performance, condition
480 factor, biometric and morphometric indices, and whole body proximate composition of the fish.
481 Only few variations were observed in the fatty acid composition of the sturgeon whole body
482 already at 25% of fishmeal substitution with the insect meal. For future practical applications, it
483 will be necessary to evaluate different insect species and lower levels of insect meal inclusion in
484 the diets for Siberian sturgeons.

485

486 **Funding**

487 This study was supported by the University of Torino (Italy) founding (CORP_RILO_17_01) and
488 Cassa di Risparmio di Torino project BioSin (GASL_RIC_N_COMP_18_02).

489

490 **References**

491

492 Aidos, L., Vasconi, M., Abbate, F., Valente, L.M.P., Lanfranchi, M., Di Giancamillo, A., 2019. Effects
493 of stocking density on reared Siberian sturgeon (*Acipenser baerii*) larval growth, muscle
494 development and fatty acids composition in a recirculating aquaculture system. *Aquacult. Res.* 50,
495 588-598. <https://doi.org/10.1111/are.13936>.

496

497 AOAC International, 2000. Official methods of analysis of AOAC International. 16th ed.
498 Gaithersburg: Association of Official Analytical Chemists.

499

500 AOAC International, 2003. Official methods of analysis of AOAC International. 17th ed.
501 Gaithersburg: Association of Official Analytical Chemists.

502

503 ARRAINA, 2015. Arraina 1st Technical booklet. A database of Aquaculture feed ingredients.
504 http://arraina.eu/images/ARRAINA/Media_Center/ARRAINA_1st_Technical_Booklet_web.pdf
505 (accessed 25 February 2019).

506

507 Belghit, I., Liland, N.S., Gjesdal, P., Biancarosa, I., Menchetti, E., Li, Y., Waagbø, R., Krogdahl, Å.,
508 Lock, E.-J., 2019. Black soldier fly larvae meal can replace fish meal in diets of sea-water phase
509 Atlantic salmon (*Salmo salar*). Aquaculture 503, 609–619.
510 <https://doi.org/10.1016/j.aquaculture.2018.12.032>.

511

512 Belghit, I., Liland, N.S., Waagbø, R., Biancarosa, I., Pelusio, N., Li, Y., Krogdahl, A., Lock, E.J., 2018a.
513 Potential of insect-based diets for Atlantic salmon (*Salmo salar*). Aquaculture 491, 72-81.
514 <https://doi.org/10.1016/j.aquaculture.2018.03.016>.

515

516 Belghit, I., Waagbø, R., Lock, E.-J., Liland, N.S., 2018b. Insect-based diets high in lauric acid reduce
517 liver lipids in freshwater Atlantic salmon. Aquacult. Nutr. 1-15 <https://doi.org/10.1111/anu.12860>

518

519 Bronzi, P., Rosenthal, H., Gessner, J., 2011. Global sturgeon aquaculture production: an overview.
520 J. Appl. Ichthyol. 27, 169-175. <https://doi.org/10.1111/j.1439-0426.2011.01757.x>.

521

522 Chen, I.-C., Chapman, F.A., Wei, C.-I., Portier, K.M., O’Keefe, S.F., 1995. Differentiation of cultured
523 and wild sturgeon (*Acipenser oxyrinchus desotoi*) based on fatty acid composition. J. Food Sci. 60,
524 631-635. <https://doi.org/10.1111/j.1365-2621.1995.tb09844.x>.

525

526 Degani, G., 2002. Availability of protein and energy from three protein sources in hybrid sturgeon
527 *Acipenser gueldenstadtii* x *A. bester*. Aquac. Res. 33 (9), 725-727. [https://doi.org/10.1046/j.1365-](https://doi.org/10.1046/j.1365-2109.2002.00709.x)
528 2109.2002.00709.x.

529

530 Devic, E., Leschen, W., Murray, F., Little, D.C., 2018. Growth performance, feed utilization and
531 body composition of advanced nursing Nile tilapia (*Oreochromis niloticus*) fed diets containing
532 Black Soldier Fly (*Hermetia illucens*) larvae meal. Aquac. Nutr. 24, 416–423.
533 <https://doi.org/10.1016/j.anifeedsci.2015.08.006>.

534

535 Elia, A.C., Capucchio, M.T., Caldaroni, B., Magara, G., Dörr, A.J.M., Biasato, I., Biasibetti E., Righetti,
536 M., Pastorino P., Prearo, M., Gai F., Schiavone, A., Gasco, L., 2018. Influence of *Hermetia illucens*
537 meal dietary inclusion on the histological traits, gut mucin composition and the oxidative stress
538 biomarkers in rainbow trout (*Oncorhynchus mykiss*). Aquaculture 496, 50-57.
539 doi.org/10.1016/j.aquaculture.2018.07.009

540

541 Engle, R.C., D’Abramo, L., Ponniah, A.G., Slater, M., 2017. Global Aquaculture 2050. J. World.
542 Aquac. Soc. 48 (1), 3-6. <https://doi:10.1111/jwas.12400>.

543

544 FAO, 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable
545 development goals. Rome.

546

547 FEEDIPEDIA. Feedipedia: an on-line encyclopedia of animal feeds; 2019.
548 <http://www.feedipedia.org/> Accessed 17 September 2019.

549

550 Figueiredo-Silva, A.C., Kaushik, S., Terrier, F., Schrama, J.W., Médale, F., Geurden, I. 2012. Link
551 between lipid metabolism and voluntary food intake in rainbow trout fed coconut oil rich in
552 medium-chain TAG. Br J Nutr. 107(11), 1714-25. [https://doi: 10.1017/S0007114511004739](https://doi.org/10.1017/S0007114511004739)

553

554 Finke, M.D., 2007. Estimate of chitin in raw whole insects. Zoo Biol. 26 (2), 105–115.
555 <https://doi.org/10.1002/zoo.20123>.

556

557 Furnè, M., Sanz, A., García-Gallego, M., Hidalgo, M.C., Domezain, A., Domezain, J., Morales, A.E.,
558 2009. Metabolic organization of the sturgeon *Acipenser naccarii* – A comparative study with
559 rainbow trout *Oncorhynchus mykiss*. Aquaculture 289 (1-2), 161–166.
560 <https://doi.org/10.1016/j.aquaculture.2008.12.028>.

561

562 Gai, F., Gasco, L., Daprà, F., Palmegiano, G.B., Sicuro, B., 2012. Enzymatic and histological
563 evaluations of gut and liver in rainbow trout *Oncorhynchus mykiss*, fed with rice protein
564 concentrate based diets. J. World. Aquac. Soc. 43 (2), 218–229. [https://doi.org/10.1111/j.1749-](https://doi.org/10.1111/j.1749-7345.2012.00557.x)
565 [7345.2012.00557.x](https://doi.org/10.1111/j.1749-7345.2012.00557.x).

566

567 Gai, F., Peiretti, P.G., Brugiapaglia, A., Gasco, L., 2016. Effects of dietary protein source and feeding
568 regime on growth performance, nutrient digestibility, fatty acids, and quality characteristics of
569 rainbow trout, *Oncorhynchus mykiss*, filets. J. World. Aquac. Soc. 47 (4), 496-507.
570 <https://doi.org/10.1111/jwas.12294>.

571

572 Gasco, L., Henry, M., Piccolo, G., Marono, S., Gai, F., Renna, M., Lussiana, C., Antonopoulou, E.,
573 Mola, P., Chatzifotis, S., 2016. *Tenebrio molitor* meal in diets for European sea bass (*Dicentrarchus*
574 *labrax* L.) juveniles: growth performance, whole body composition and *in vivo* apparent
575 digestibility. Anim. Feed Sci. Technol. 220, 34-45.
576 <https://doi.org/10.1016/j.anifeedsci.2016.07.003>.

577

578 Gasco L., Gai F., Maricchiolo G., Genovese L., Ragonese S., Bottari T., Caruso G., 2018. Fish meal
579 alternative protein sources for aquaculture feeds: current situation and alternative sources. In:
580 Feeds for the Aquaculture Sector. Springer International Publishing, Cham, pp. 1-28.

581

582 Gawlicka, A., Herold, M.A., Barrows, F.T., De La Noüe, J., Hung, S.S.O., 2002. Effects of dietary
583 lipids on growth, fatty acid composition, intestinal absorption and hepatic storage in white
584 sturgeon (*Acipenser transmontanus* R.) larvae. J. Appl. Ichthyol. 18, 673-681.
585 <https://doi.org/10.1046/j.1439-0426.2002.00371.x>.

586

587 Gopalakannan, A., Arul, V., 2006. Immunomodulatory effects of dietary intake of chitin, chitosan
588 and levamisole on the immune system of *Cyprinus carpio* and control of *Aeromonas hydrophila*
589 infection in ponds. Aquaculture 255, 179–187. <https://doi.org/10.1016/j.aquaculture.2006.01.012>

590

591 Guo, Z., Zhu, X., Liu, J., Han, D., Yang, Y., Lan, Z., Xie, S., 2012. Effects of dietary protein level on
592 growth performance, nitrogen and energy budget of juvenile hybrid sturgeon, *Acipenser baerii* ×
593 *A. gueldenstaedtii*. *Aquaculture* 338, 89-95.
594 <https://doi.org/10.1016/j.aquaculture.2012.01.008>.

595
596 Henry, M.A., Gasco, L., Chatzifotis, S., Piccolo, G., 2018. Does dietary insect meal affect the fish
597 immune system? The case of mealworm, *Tenebrio molitor* on European sea bass, *Dicentrarchus*
598 *labrax*. *Dev. Comp. Immunol.* 81, 204-209. <https://doi.org/10.1016/j.dci.2017.12.002>.

599
600 Henry, M., Gasco, L., Piccolo, G., Fountoulaki, E., 2015. Review on the use of insects in the diet of
601 farmed fish: past and future. *Anim. Feed Sci. Technol.* 203, 1–22.
602 <https://doi.org/10.1016/j.anifeedsci.2015.03.001>.

603
604 Huyben, D., Vidaković, A., Hallgren, S.W, Langeland, M., 2018. High-throughput sequencing of gut
605 microbiota in rainbow trout (*Oncorhynchus mykiss*) fed larval and pre-pupae stages of black soldier
606 fly (*Hermetia illucens*). *Aquaculture* 500, 485-491.
607 <https://doi.org/10.1016/j.aquaculture.2018.10.034>.

608
609 Jahanbakhshi, A., Imanpoor, M.R., Taghizadeh, V., Shabani, A., 2013. Hematological and serum
610 biochemical indices changes induced by replacing fish meal with plant protein (sesame oil cake
611 and corn gluten) in the Great sturgeon (*Huso huso*). *Comp. Clin. Pathol.* 22, 1087–1092.
612 <https://doi.org/10.1007/s00580-012-1532-4>.

613

614 Jackson, J.R., VanDeValk, A.J., Brooking, T.E., VanKeeken, O.A., Rudstam, L.G., 2002. Growth and
615 feeding dynamics of lake sturgeon, *Acipenser fulvescens*, in Oneida Lake, New York: results from
616 the first five years of a restoration program. *J. Appl. Ichthyol.* 18 (4-6), 439-443.
617 <https://doi.org/10.1046/j.1439-0426.2002.00394.x>.

618

619 Kaushik, S.J., Luquet, P., Blanc, D., Paba, A., 1989. Studies on the nutrition of Siberian sturgeon,
620 *Acipenser baeri*. I. Utilization of digestible carbohydrates by sturgeon. *Aquaculture* 76 (1-2), 97-
621 107. [https://doi.org/10.1016/0044-8486\(89\)90254-8](https://doi.org/10.1016/0044-8486(89)90254-8).

622

623 Kroeckel, S., Harjes, A.G.E., Roth, I., Katz, H., Wuertz, S., Susenbeth, A., Schulz C., 2012. When a
624 turbot catches a fly: Evaluation of a pre-pupae meal of the Black Soldier Fly (*Hermetia illucens*) as
625 fish meal substitute - Growth performance and chitin degradation in juvenile turbot (*Psetta*
626 *maxima*). *Aquaculture* 364, 345-352. <https://doi.org/10.1016/j.aquaculture.2012.08.041>.

627

628 Li, S., Ji, H., Zhang, B., Zhou, J., Yu, H., 2017. Defatted black soldier fly (*Hermetia illucens*) larvae
629 meal in diets for juvenile Jian carp (*Cyprinus carpio* var. Jian): Growth performance, antioxidant
630 enzyme activities, digestive enzyme activities, intestine and hepatopancreas histological structure.
631 *Aquaculture* 477, 62-70. <https://doi.org/10.1016/j.aquaculture.2017.04.015>.

632

633 Liland, N.S., Biancarosa, I., Araujo, P., Biemans, D., Bruckner, C.G., Waagbø, R., Torstensen, B.E.,
634 Lock, E.-J., 2017. Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae
635 by feeding seaweed-enriched media. *PLoS ONE* 12(8): e0183188.
636 <https://doi.org/10.1371/journal.pone.0183188>.

637

638 Liu, H., Wu, X., Zhao, W., Xue, M., Guo, L., Zheng, Y., Yu, Y., 2009. Nutrient apparent digestibility
639 coefficients of selected protein sources for juvenile Siberian sturgeon (*Acipenser baerii* Brandt),
640 compared by two chromic oxide analyses methods. *Aquac. Nutr.* 15 (6), 650-656.
641 <https://doi.org/10.1111/j.1365-2095.2008.00634.x>.

642

643 Lock, E.J., Arsiwalla, T., Waagbø, R., 2016. Insect larvae meal as an alternative source of nutrients
644 in the diet of Atlantic salmon (*Salmo salar*) postsmolt. *Aquac. Nutr.* 22 (6), 1202-1213.
645 <https://doi.org/10.1111/anu.12343>.

646

647 Magalhães, R., Sánchez-López, A., Leal, R.S., Martínez-Llorens, S., Oliva-Teles, A., Peres, H., 2017.
648 Black soldier fly (*Hermetia illucens*) pre-pupae meal as a fish meal replacement in diets for
649 European seabass (*Dicentrarchus labrax*). *Aquaculture* 476, 79-85.
650 <https://doi.org/10.1016/j.aquaculture.2017.04.021>.

651

652 Mancini, S., Medina, I., Iaconisi, V., Gai, F., Basto, A., Parisi, G., 2017. Impact of black soldier fly
653 larva meal on the chemical and nutritional characteristics of rainbow trout fillets. *Animal* 12 (8), 1–
654 10. <https://doi.org/10.1017/S1751731117003421>.

655

656 Marono, S., Piccolo, G., Loponte, R., Di Meo, C., Attia, Y.A., Nizza, A., 2015. *In vitro* crude protein
657 digestibility of *Tenebrio molitor* and *Hermetia illucens* insect meals and its correlation with
658 chemical composition traits. *Ital. J. Anim. Sci.* 14 (3), 338-343.
659 <https://doi.org/10.4081/ijas.2015.3889>.

660

661 Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M., Gasco, L., 2018. Effect of
662 rearing substrate on growth performance, waste reduction efficiency and chemical composition of
663 black soldier fly (*Hermetia illucens*) larvae. J. Sci. Food Agric. 98, 776-5784.
664 <https://doi.org/10.1002/jsfa.9127>.

665

666 Merrifield, D.L., Olsen, R.E., Myklebust, R., Ringø, E., 2011. Dietary effect of soybean (*Glycine max*)
667 products on gut histology and microbiota of fish, in: El-Shemy, H.A. (Ed.), Soybean and Nutrition.
668 InTech, Rijeka, Croatia, pp. 231-250. doi: 10.5772/20101.

669

670 Nieminen, P., Westenius, E., Halonen, T., Mustonen, A.-M., 2014. Fatty acid composition in tissues
671 of the farmed Siberian sturgeon (*Acipenser baerii*). Food Chem. 159, 80-
672 84.<http://dx.doi.org/10.1016/j.foodchem.2014.02.148>.

673

674 Olsen, R., Suontama, J., Langmyhr, E., Mundheim, H., Ringo, E., Melle, E., Malde, M., Hmre, G.,
675 2006. The replacement of fish meal with Antarctic krill, *Euphausia superba* in diets for Atlantic
676 salmon, *Salmo salar*. Aquac. Nutr. 12, 280–290. [https://doi.org/10.1111/j.1365-](https://doi.org/10.1111/j.1365-2095.2006.00400.x)
677 [2095.2006.00400.x](https://doi.org/10.1111/j.1365-2095.2006.00400.x)

678

679 Palmegiano, G.B., Gai, F., Daprà, F., Gasco, L., Pazzaglia, M., Peiretti, P.G., 2008. Effects of Spirulina
680 and plant oil on the growth and lipid traits of white sturgeon (*Acipenser transmontanus*)
681 fingerlings. Aquac. Res. 39 (6), 587-595. <https://doi.org/10.1111/j.1365-2109.2008.01914.x>.

682

683 Pyka, J., Kolman, R., 2003. Feeding intensity and growth of Siberian sturgeon *Acipenser baerii*
684 Brandt in pond cultivation. Arch. Pol. Fish. 11 (2), 287-294.

685

686 Renna, M., Cornale, P., Lussiana, C., Malfatto, V., Fortina, R., Mimosi, A., Battaglini, L.M., 2012. Use
687 of *Pisum sativum* (L.) as alternative protein resource in diets for dairy sheep: effects on milk yield,
688 gross composition and fatty acid profile. *Small Ruminant Res.* 102, 142–150.
689 <https://doi.org/10.1016/j.smallrumres.2011.07.007>.

690

691 Renna, M., Gasmi-Boubaker, A., Lussiana, C., Battaglini, L.M., Belfayez, K., Fortina, R., 2014. Fatty
692 acid composition of the seed oils of selected *Vicia* L. taxa from Tunisia. *Ital. J. Anim. Sci.* 13 (2),
693 308–316. <https://doi.org/10.4081/ijas.2014.3193>.

694

695 Renna, M., Schiavone, A., Gai, F., Dabbou, S., Lussiana, C., Malfatto, V., Prearo, M., Capucchio,
696 M.T., Biasato, I., Biasibetti, E., De Marco, M., Brugiapaglia, A., Zoccarato, I., Gasco, L., 2017.
697 Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae
698 meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. *J. Anim. Sci.*
699 *Biotechnol.* 8, 57. <https://doi.org/10.1186/s40104-017-0191-3>.

700

701 Şener, E., Yildiz, M., Savaş, E., 2005. Effects of dietary lipids on growth and fatty acid composition
702 in Russian sturgeon (*Acipenser gueldenstaedtii*) juveniles. *Turk. J. Vet. Anim. Sci.* 29, 1101-1107.

703

704 Şener, E., Yildiz, M., Savaş, E., 2006. Effect of vegetable protein and oil supplementation on growth
705 performance and body composition of Russian sturgeon juveniles (*Acipenser gueldenstaedtii*
706 Brandt, 1833) at low temperatures. *Turk. J. Fish. Aquat. Sci.* 6, 23–27.

707

708 Sicuro, B., Piccinno, M., Daprà, F., Gai, F., Vilella, S., 2015. Utilization of rice protein concentrate in
709 Siberian sturgeon (*Acipenser baerii* Brandt) nutrition. Turk. J. Fish. Aquat. Sci. 15, 313–319.
710

711 Soliman, N.F., Yacout, D., Hassaan, M., 2017. Responsible fishmeal consumption and alternatives
712 in the face of climate changes. Int. J. Mar. Sci. 7 (15), 130-140.
713 <https://doi.org/10.5376/ijms.2017.07.0015>.
714

715 Spranghers, T., Ottoboni, M., Klootwiik, C., Owyn, A., Deboosfere, S., De Meulenaer, B., Michiels, J.,
716 Eeckhout, M., De Clerq, P., De Smet, S., 2017. Nutritional composition of black soldier fly
717 (*Hermetia illucens*) prepupae reared on different organic waste substrate. J. Sci. Food Agric. 97,
718 2594–2600. <https://doi.org/10.1002/jsfa.8081>.
719

720 Vaccaro, A.M., Buffa, G., Messina, C.M., Santulli, A., Mazzola, A., 2005. Fatty acid composition of a
721 cultured sturgeon hybrid (*Acipenser naccarii* × *A. baerii*). Food Chem. 93, 627-631.
722 <https://doi.org/10.1016/j.foodchem.2004.09.042>.
723

724 Wang, D.H., Jackson, J.R., Twining, C., Rudstam, L.G., Zollweg-Horan, E., Kraft, C., Lawrence, P.,
725 Kothapalli, K., Wang, Z., Brenna, J.T., 2016. Saturated branched chain, normal odd-carbon-
726 numbered, and n-3 (Omega-3) polyunsaturated fatty acids in freshwater fish in the Northeastern
727 United States. J. Agric. Food Chem. 64, 7512–7519. <https://doi.org/10.1021/acs.jafc.6b03491>.
728

729 Xiao, X., Jin, P., Zheng, L., Cai, M., Yu, Z., Yu, J., Zhang, J., 2018. Effects of black soldier fly (*Hermetia*
730 *illucens*) larvae meal protein as a fishmeal replacement on the growth and immune index of yellow

731 catfish (*Pelteobagrus fulvidraco*). *Aquacult. Res.* 49 (4), 1569-1577.

732 <https://doi.org/10.1111/are.13611>.

733

734 Xie, WX, Gong, YX, Yu, KX (2017). Quantitative analysis of total starch content in wheat flour by
735 reaction headspace gas chromatography. *Anal. Bioanal. Chem.* 409 (22), 5195–5200.

736 <https://doi.org/10.1007/s00216-017-0494-4>.

737

738 Xu, R., Hung, S.S.O., German, J.B., 1993. White sturgeon tissue fatty acid compositions are affected
739 by dietary lipids. *J Nutr.* 123, 1685-1692. <https://doi.org/10.1093/jn/123.10.1685>.

740

741 Xu, R., Hung, S.S.O., German, J.B., 1996. Effects of dietary lipids on the fatty acid composition of
742 triglycerides and phospholipids in tissues of white sturgeon. *Aquacult. Nutr.* 2, 101-109.

743 <https://doi.org/10.1111/j.1365-2095.1996.tb00016.x>.

744

745 Zhou, J.S., Liu, S.S., Ji, H., Yu, H.B., 2018. Effect of replacing dietary fish meal with black soldier fly
746 larvae meal on growth and fatty acid composition of Jian carp (*Cyprinus carpio* var. Jian). *Aquacult.*

747 *Nutr.* 24 (1), 424–433. <https://doi.org/10.1111/anu.12574>.

748

749 Zhu, H., Gong, G., Wang, J., Wu, X., Xue, M., Niu, C., Guo, L., Yu, Y., 2011. Replacement of fish meal
750 with blend of rendered animal protein in diets for Siberian sturgeon (*Acipenser baerii* Brandt),

751 results in performance equal to fish meal fed fish. *Aquacult. Nutr.* 17 (2), 389–395.

752 <https://doi.org/10.1111/j.1365-2095.2010.00773.x>.

753

754 Zhu, H., Li, Q., Wang, H., Zhu, T., Qin, J., Li, E., Chen, L., 2017. Growth, fatty acid composition and
755 lipid deposition of Russian sturgeon (*Acipenser gueldenstaedtii*) fed different lipid sources.
756 Aquacult. Res. 48, 5126-5132. <https://doi.org/10.1111/are.13148>.

757

758 **Table 1. Ingredients and proximate composition of *H. illucens* larvae meal and experimental**
 759 **diets.**

	HIM	HIM0	HIM25	HIM50	HIM100	VEG
<i>Ingredients (g kg⁻¹)</i>						
Fish meal (Chile, super prime) ^a	-	700.0	525.0	350.0	0	320.0
HI larvae meal ^b	-	0	185.0	375.0	750.0	0
Wheat meal	-	140.0	120.0	100.0	55.0	0
Corn gluten meal	-	0	0	0	0	150.0
Soybean protein concentrate	-	0	0	0	0	200.0
Soybean meal	-	0	0	0	0	140.0
Starch gelatinized, D500	-	80.0	80.0	80.0	80.0	80.0
Fish oil	-	60.0	70.0	75.0	95.0	90.0
Vitamine mixture ^c	-	10.0	10.0	10.0	10.0	10.0
Mineral mixture ^d	-	10.0	10.0	10.0	10.0	10.0
<i>Proximate composition^e</i>						
DM (g 100g ⁻¹)	94.94	96.41	96.39	96.29	96.83	97.37
CP (g 100g ⁻¹ , as fed)	62.51	50.29	50.65	50.20	50.27	50.87
EE (g 100g ⁻¹ , as fed)	4.03	12.68	12.62	12.10	11.73	12.81
Ash (g 100g ⁻¹ , as fed)	8.20	13.15	11.71	10.24	7.90	9.91
CF (g 100g ⁻¹ , as fed) ^f	7.0	0.32	1.61	2.89	5.25	1.77
Chitin (g 100g ⁻¹ , as fed) ^g	4.97	nd	0.72	1.92	3.75	nd
NFE (g 100g ⁻¹ , as fed) ^h	18.26	23.56	23.41	24.57	24.85	24.65

GE (MJ kg ⁻¹ , as fed)	20.76	19.77	19.65	20.64	20.38	20.44
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760 Abbreviations: HI, *Hermetia illucens*; HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein
761 based diet; DM, dry matter; CP, crude protein; EE, ether extract; NFE, Nitrogen free extracts; GE,
762 gross energy.

763 ^a Purchased from Corpesca S.A. (Santiago, Chile). Proximate composition (g 100g⁻¹, as fed basis):
764 88.7 DM; 63.8 CP; 8.4 EE; 14.9 ash.

765 ^b Purchased from Hermetia Deutschland GmbH & Co. KG (Baruth/Mark, Germany).

766 ^c Vitamin mixture (IU or mg kg⁻¹ diet): DL- α tocopherol acetate, 60 IU; sodium menadione
767 bisulphate, 5 mg; retinyl acetate, 15,000 IU; DL-cholecalciferol, 3000 IU; thiamin, 15 mg; riboflavin,
768 30 mg; pyridoxine, 15 mg; B₁₂, 0.05 mg; nicotinic acid, 175 mg; folic acid, 500 mg; inositol, 1000
769 mg; biotin, 2.5 mg; calcium panthotenate, 50 mg (purchased from Granda Zootecnici S.r.l., Cuneo,
770 Italy).

771 ^d Mineral mixture (g or mg kg⁻¹ diet): dicalcium phosphate, 500 g; calcium carbonate, 215 g;
772 sodium salt 40, g; potassium chloride, 90 g; magnesium chloride, 124 g; magnesium carbonate,
773 124 g; iron sulphate, 20 g; zinc sulphate, 4 g; copper sulphate, 3 g; potassium iodide, 4 mg; cobalt
774 sulphate, 20 mg; manganese sulphate, 3 g; sodium fluoride, 1 g (purchased from Granda
775 Zootecnici S.r.l., Cuneo, Italy).

776 ^e Values are reported as mean of duplicate analyses

777 ^f Crude Fiber estimated according to Feedipedia and Arraina booklet ingredients database

778 ^g Estimated as ADF – ADFN (Finke, 2007)

779 ^h Nitrogen Free Extracts; Calculated as 100 – (CP + EE + Ash + Crude Fiber)

780

Table 2. Fatty acid profile (mg 100g⁻¹ DM) of *H. illucens* larvae meal and experimental diets.

	HIM	HIM0	HIM25	HIM50	HIM100	VEG
C12:0	2020.65	22.17	388.43	673.58	1402.94	16.65
C14:0	325.51	452.72	488.41	506.04	471.53	375.93
C15 <i>iso</i>	nd	16.61	17.65	15.51	11.18	14.71
C15 <i>anteiso</i>	nd	5.40	2.55	3.33	1.27	3.34
C14:1 <i>c9</i> + C15:0	15.24	46.20	44.70	45.20	34.13	36.39
C16 <i>iso</i>	9.14	16.99	14.42	12.65	14.98	22.64
C16:0	435.36	1102.78	1113.22	1148.65	800.06	942.69
C17 <i>iso</i>	nd	29.35	31.33	27.57	13.90	25.57
C17 <i>anteiso</i>	3.32	17.07	23.34	29.11	27.27	24.47
C16:1 <i>c9</i>	124.05	514.11	555.83	580.22	502.10	527.68
C17:0	3.33	38.92	43.13	44.51	26.63	31.82
C17:1 <i>c9</i>	nd	18.05	16.48	18.87	12.12	19.02
C18:0	64.87	271.14	260.78	265.69	165.27	227.11
C18:1 <i>t</i>	nd	85.72	103.68	123.01	108.05	124.49
C18:1 <i>c9</i>	303.20	930.75	1045.14	1203.62	984.07	1100.78
C18:1 <i>c11</i>	9.34	329.89	313.57	325.14	228.54	313.62
C18:1 <i>c12</i>	nd	nd	16.70	33.83	20.07	Nd
C18:1 <i>c14</i> + <i>t16</i>	nd	nd	139.64	275.37	161.70	Nd
C18:2 <i>n6</i>	195.96	195.35	263.29	274.97	253.95	383.26
C18:3 <i>n3</i>	25.08	64.47	81.94	99.46	76.93	79.69
C18:3 <i>n6</i>	nd	10.77	6.89	7.79	3.67	14.07
C20:0	15.84	16.69	36.05	67.64	33.27	17.09

C20:1 c9	nd	52.96	68.62	89.99	68.43	80.15
C20:1 c11	nd	370.41	437.66	545.61	432.73	512.71
C20:2 n6	7.33	154.85	172.02	148.84	101.83	147.51
C20:4 n6	nd	31.44	9.24	7.68	7.40	27.97
C20:5 n3	nd	580.27	573.06	481.13	301.52	469.54
C22:1 n9	nd	197.72	256.58	339.27	245.21	295.80
C22:5 n3	nd	36.82	43.17	41.52	17.64	40.86
C22:6 n3	nd	666.59	584.14	590.03	248.17	512.89
Σ SFA	2925.97	1989.84	2419.33	2794.26	2968.29	1702.01
Σ MUFA	451.82	2545.82	2998.59	3580.15	2797.14	3010.64
Σ PUFA	228.36	1740.57	1733.76	1651.42	1011.10	1675.79
Σ PUFA / Σ SFA	0.08	0.87	0.72	0.59	0.34	0.98
Σ n3	25.08	1348.15	1282.31	1212.14	644.26	1102.99
Σ n6	203.29	392.42	534.63	439.29	366.84	572.80
Σ n3 / Σ n6	0.12	3.44	2.40	2.76	1.76	1.93
TFA	3606.16	6276.23	7151.68	8025.84	6776.54	6388.44

782 Abbreviations: DM, dry matter; HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein based
783 diet; *c*, *cis*; *t*, *trans*; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA,
784 polyunsaturated fatty acids; TFA, total fatty acids; nd, not detected.
785 Values are reported as mean of duplicate analyses.

786

787 **Table 3. Survival and growth performance of Siberian sturgeon juveniles fed the experimental**
 788 **diets (n = 4).**

	HIM0	HIM25	HIM50	VEG	SEM	<i>p</i> -value
Survival rate (%)	98.81	97.50	97.62	100.00	0.739	0.528
iIBW (g)	24.20	24.26	24.21	24.19	0.017	0.494
iFBW (g)	159.32 a	148.12 ab	141.94 b	153.32 ab	2.198	0.015
WG	135.12 a	123.86 ab	117.73 b	129.13 ab	2.203	0.015
FC (g DM)	3003.04 a	2844.81 b	2823.15 b	3052.78 a	27.879	0.000
SGR (% d ⁻¹)	1.59 a	1.51 ab	1.48 b	1.58 a	0.015	0.008
FCR	1.03	1.08	1.12	1.05	0.016	0.213
PER	1.94	1.84	1.78	1.88	0.028	0.236

789 Abbreviations: HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein based diet; SEM,
 790 standard error of the mean; *p*, probability; iIBW, individual initial body weight; iFBW, individual
 791 final body weight; FC, feed consumption; WG, weight gain; SGR, specific growth rate; FCR, feed
 792 conversion ratio; PER, protein efficiency ratio.

793 Different superscripts within a row indicate significant differences ($p \leq 0.05$).

794

795

796 **Table 4. Biometric (n = 24) and morphometric indices (n = 12) of Siberian sturgeon juveniles fed**
797 **the experimental diets.**

	HIM0	HIM25	HIM50	VEG	SEM	<i>p</i> -value
K	0.26	0.25	0.26	0.26	0.002	0.051
HSI	2.69	3.02	3.39	3.41	0.123	0.117
VSI	8.04	8.50	8.91	8.76	0.158	0.233

798 Abbreviations: HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein based diet; SEM,
799 standard error of the mean; *p*, probability; K, Fulton's condition factor; HSI, hepatosomatic index;
800 VSI, viscerosomatic index.

801 Different superscripts within a row indicate significant differences ($p \leq 0.05$).

802

803 **Table 5. Whole body proximate (g 100 g⁻¹ ww) and fatty acid (mg 100g⁻¹ ww) compositions of**
 804 **Siberian sturgeon juveniles fed the experimental diets (n = 12).**

	HIM0	HIM25	HIM50	VEG	SEM	<i>p</i> -value
<i>Proximate composition</i>						
DM	21.25 ^b	22.37 ^{ab}	23.37 ^a	21.30 ^b	0.239	0.002
CP	13.66	14.10	13.96	13.45	0.106	0.116
EE	4.50 ^b	5.13 ^{ab}	6.23 ^a	5.19 ^{ab}	0.198	0.016
Ash	2.33	2.39	2.40	2.14	0.041	0.095
<i>Fatty acid composition</i>						
C12:0	2.70 ^c	61.23 ^b	151.61 ^a	2.42 ^c	9.364	0.000
C14:0	140.46 ^b	178.88 ^{ab}	207.80 ^a	140.53 ^b	7.216	0.001
C15 <i>iso</i>	6.43	7.13	6.82	6.30	0.225	0.566
C15 <i>anteiso</i>	1.74	1.89	1.83	1.59	0.071	0.475
C14:1 c9 + C15:0	20.13 ^{ab}	23.75 ^{ab}	24.10 ^a	19.36 ^b	0.705	0.024
C16 <i>iso</i>	2.82	3.52	3.60	3.67	0.133	0.080
C16:0	531.70	640.78	642.28	551.19	22.924	0.183
C17 <i>iso</i>	15.20	16.63	14.20	13.09	0.534	0.110
C17 <i>anteiso</i>	16.95 ^b	20.76 ^{ab}	23.68 ^a	21.18 ^{ab}	0.791	0.021
C16:1 c9	209.56 ^b	264.07 ^{ab}	289.54 ^a	230.04 ^{ab}	10.732	0.036
C17:0	15.86	17.11	16.20	15.67	0.515	0.777
C18 <i>iso</i>	5.22 ^{ab}	5.47 ^a	4.08 ^b	4.12 ^{ab}	0.196	0.012
C17:1 c9	12.16	14.81	14.41	12.14	0.521	0.127
C18:0	87.63	104.56	94.80	93.03	2.988	0.245
C18:1 t9-11	4.45 ^b	6.10 ^{ab}	5.84 ^{ab}	7.15 ^a	0.258	0.001

C18:1 c9	600.58 ^b	828.26 ^{ab}	869.27 ^a	747.45 ^{ab}	34.283	0.024
C18:1 c11	142.82	180.69	180.24	168.59	5.705	0.059
C18:1 c12	7.04 ^c	13.68 ^b	16.34 ^{ab}	18.50 ^a	0.840	0.000
C18:2 n6	71.37 ^c	130.18 ^b	138.15 ^b	180.38 ^a	7.438	0.000
C18:3 n6	3.16 ^c	7.71 ^b	8.64 ^b	11.90 ^a	0.557	0.000
C18:3 n3	19.10 ^b	30.46 ^a	32.04 ^a	30.39 ^a	1.392	0.001
C20:0	12.21 ^c	19.97 ^b	22.26 ^{ab}	27.04 ^a	1.172	0.000
C20:1 c9	41.57 ^b	61.05 ^a	58.10 ^a	58.89 ^a	2.021	0.001
C20:1 c11	151.74 ^b	221.46 ^a	216.53 ^a	222.42 ^a	7.966	0.001
C20:2 n6	8.25 ^b	12.79 ^a	13.17 ^a	13.69 ^a	0.532	0.000
C20:3 n6	2.79 ^b	4.80 ^a	4.92 ^a	5.96 ^a	0.240	0.000
C20:4 n6	13.85 ^b	19.38 ^a	15.41 ^b	14.82 ^b	0.587	0.003
C20:5 n3	101.20 ^b	151.76 ^a	117.81 ^{ab}	88.02 ^b	6.348	0.001
C22:5 n3	23.96 ^b	42.46 ^a	39.59 ^a	33.15 ^{ab}	1.849	0.001
C22:6 n3	107.59 ^b	164.70 ^a	154.99 ^{ab}	128.53 ^{ab}	7.065	0.013
Σ SFA	859.05 ^b	1101.69 ^{ab}	1213.25 ^a	899.19 ^b	41.428	0.005
Σ BCFA	54.80	62.54	61.03	56.25	1.988	0.467
Σ MUFA	1162.89 ^b	1576.44 ^{ab}	1633.93 ^a	1446.68 ^{ab}	60.278	0.028
Σ PUFA	351.28 ^b	564.24 ^a	524.71 ^a	506.84 ^a	21.537	0.002
Σ PUFA / Σ SFA	0.42 ^c	0.53 ^{ab}	0.43 ^{bc}	0.57 ^a	0.015	0.000
Σ n3	251.86 ^b	389.38 ^a	344.42 ^{ab}	280.10 ^b	15.261	0.003
Σ n6	99.42 ^c	174.87 ^b	180.29 ^b	226.74 ^a	8.865	0.000
Σ n3 / Σ n6	2.51 ^a	2.29 ^a	1.87 ^b	1.24 ^c	0.084	0.000
TFA	2373.22 ^b	3242.37 ^a	3371.90 ^a	2852.71 ^{ab}	118.481	0.012

805 Abbreviations: HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein based diet; SEM,
806 standard error of the mean; *p*, probability; ww, wet weight; DM, dry matter; CP, crude protein; EE,
807 ether extract; *c*, *cis*; *t*, *trans*; SFA, saturated fatty acids; BCFA, branched chain fatty acids; MUFA,
808 monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; TFA, total fatty acids.

809 Values are reported as mean of duplicate analyses.

810 Different superscripts within a row indicate significant differences ($p \leq 0.05$).

811

812 **Table 6. Apparent digestibility coefficients (ADC) of the experimental diets (n = 4).**

	HIM0	HIM25	HIM50	VEG	SEM	<i>p</i> -value
ADC _{DM}	71.5 ^b	70.6 ^b	72.4 ^b	77.0 ^a	0.713	0.000
ADC _{CP}	88.5 ^b	86.5 ^c	86.6 ^c	90.4 ^a	0.436	0.000
ADC _{GE}	83.3 ^b	81.7 ^b	81.4 ^b	85.8 ^a	0.511	0.001

813 Abbreviations: HIM, *Hermetia illucens* larvae meal; VEG, vegetable protein based diet; SEM,

814 standard error of the mean; *p*, probability; DM, dry matter; CP, crude protein; GE, gross energy.

815 Different superscripts within a row indicate significant differences ($p \leq 0.05$).