



**HAL**  
open science

## Improving animal health and welfare in the transition of livestock farming systems: towards social acceptability and sustainability

Christian Ducrot, François Charrier, Alain Boissy, Maria Belén Barrio, Sergine Even, Marie-Hélène Pinard-van Der Laan, Pierre Mormède, Sandrine Petit, François Schelcher, François Casabianca, et al.

### ► To cite this version:

Christian Ducrot, François Charrier, Alain Boissy, Maria Belén Barrio, Sergine Even, et al.. Improving animal health and welfare in the transition of livestock farming systems: towards social acceptability and sustainability. 2023. hal-04198999v1

**HAL Id: hal-04198999**

**<https://hal.inrae.fr/hal-04198999v1>**

Preprint submitted on 7 Sep 2023 (v1), last revised 24 Jan 2024 (v2)

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Improving animal health and welfare in the transition of livestock farming**  
2 **systems: towards social acceptability and sustainability**

3 C. Ducrot<sup>a</sup>, M. B. Barrio<sup>b</sup>, A. Boissy<sup>c</sup>, F. Charrier<sup>d</sup>, S. Even<sup>e</sup>, P. Mormède<sup>f</sup>, S. Petit<sup>g</sup>, M.-  
4 H. Pinard-van der laan<sup>h</sup>, F. Schelcher<sup>i</sup>, F. Casabianca<sup>j</sup>, A. Ducos<sup>k</sup>, G. Foucras<sup>i</sup>, R.  
5 Guatteo<sup>l</sup>, J.-L. Peyraud<sup>m</sup>, M. Vayssier<sup>n</sup>, P. Veysset<sup>c</sup>, N.C. Friggens<sup>o</sup>, X. Fernandez<sup>k</sup>

6

7 <sup>a</sup> ASTRE, Univ Montpellier, INRAE, CIRAD, Campus international de Baillarguet, 34980  
8 Montferrier sur Lez, France

9 <sup>b</sup> Département Santé animale, INRAE, 31326 Castanet-Tolosan, France

10 <sup>c</sup> Herbivores, Université Clermont Auvergne, INRAE, VetAgro Sup, 63122 Saint-Genès-  
11 Champanelle, France

12 <sup>d</sup> LISIS, Université Paris-Est Marne-la-Vallée, INRAE, 77454 Marne-la-Vallée, France

13 <sup>e</sup> STLO, INRAE, Institut Agro, 35042 Rennes, France

14 <sup>f</sup> Département de Génétique animale, INRAE, 31326 Castanet-Tolosan, France

15 <sup>g</sup> CESAER, INRAE, Institut Agro, Univ. Bourgogne-Franche-Comté, 21000 Dijon, France

16 <sup>h</sup> GABI, INRAE, AgroParisTech, Université Paris-Saclay, 78350 Jouy-en-Josas, France

17 <sup>i</sup> IHAP, Ecole vétérinaire de Toulouse, INRAE, 31076, Toulouse, France

18 <sup>j</sup> LRDE, INRAE, 20250 Corte, France

19 <sup>k</sup> Département Physiologie Animale et Systèmes d'Élevage (Phase), INRAE, 37380 Nouzilly,  
20 France

21 <sup>l</sup> BIOEPAR, Oniris, INRAE, 44300 Nantes, France

22 <sup>m</sup> PEGASE, INRAE, Institut Agro Rennes, 35590 St Gilles, France

23 <sup>n</sup> Département santé animale, INRAE, 37380, Nouzilly, France

24 ° Modélisation Systémique Appliquée aux Ruminants, Université Paris-Saclay, INRAE,  
25 AgroParisTech, 91120 Palaiseau, France

26

27 Corresponding author: Christian Ducrot Email: Christian.ducrot@inrae.fr

28

## 29 **Abstract**

30 The need to integrate more clearly societal expectations on livestock farming has led  
31 the authors of this article to consider that livestock farming systems must be  
32 redesigned to position health and welfare at the heart of their objectives. This article  
33 proposes a vision of the advances in knowledge required at different scales to  
34 contribute to this transformation. After defining health and welfare of animals, the article  
35 emphasizes the need to consider health in a broader perspective, to deepen the  
36 question of positive emotional experiences regarding welfare, and raises the question  
37 of how to assess these two elements on farms. The positive interactions between  
38 health and welfare are presented. Some possible tensions between them are also  
39 discussed, in particular when improving welfare by providing a more stimulating and  
40 richer environment such as access to outdoor increases the risk of infectious diseases.  
41 Jointly improving health and welfare of animals poses a number of questions at various  
42 scales, from the animal level to the production chain. At the animal level, the authors  
43 highlight the need to explore: the long-term links between better welfare and  
44 physiological balance, the role of microbiota, the psycho-neuro-endocrine mechanisms  
45 linking positive mental state and health, and the trade-off between the physiological  
46 functions of production, reproduction and immunity. At the farm level, in addition to  
47 studying the relationships at the group level between welfare, health and production,  
48 the paper supports the idea of co-constructing innovative systems with breeders, as

49 well as analyzing the cost, acceptability and impact of improved systems on their  
50 working conditions and well-being. At the production chain or territory levels, various  
51 questions are raised. These include: studying the best strategies to improve animal  
52 health and welfare while preserving economic viability, the labelling of products and  
53 the consumers' willingness to pay, the consequences of heterogeneity in animal traits  
54 on the processing of animal products, and the spatial distribution of livestock farming  
55 and the organization of the production and value chain. At the level of the citizen and  
56 consumer, one of the challenges is to better inter-relate sanitary and health  
57 perspectives on the one hand, and welfare concerns on the other hand. There is also  
58 a need to improve citizens' knowledge on livestock farming, and to develop more  
59 intense and constructive exchanges between breeders, the livestock industry and  
60 citizens. These difficult issues plead for interdisciplinary and transdisciplinary research  
61 involving various scientific disciplines and the different stakeholders, including public  
62 policy makers through participatory research.

63

#### 64 **Keywords**

65 Health, welfare, animal, livestock farming systems, production chain, value chain,  
66 territory, society

67

#### 68 **Implications**

69 This collective reflection was performed to push interdisciplinary research in order to  
70 improve both the health and welfare of farm animals. The goal is to place health and  
71 welfare of the animals at the core of the livestock farming systems, and to favour  
72 transitions in the livestock farming systems and sectors. These goals are key elements  
73 in the acceptability of animal farming for the citizen and important aspects for the

74 sustainability of animal farming in the coming years. An interdisciplinary research  
75 programme was launched and funded by INRAE on the basis of this work.

76

## 77 **Introduction**

78

79 Livestock farming is currently the subject of increasing concern by society and citizens.  
80 Questions are being raised about the environmental footprint of livestock production  
81 as well as about our stewardship of the animals under our care and their resulting well-  
82 being. These questions are given urgency by the twin challenges of ensuring global  
83 food security and dealing with the climate change. FAO (Food and Agriculture  
84 Organization of the United Nations, 2006) drew attention on the land used for livestock  
85 and the competition with crops to feed humans, on the contribution of livestock to global  
86 warming, water depletion and pollution, and its impact on biodiversity. In France,  
87 according to Delanoue and Roguet (2015), the primary societal concerns regarding  
88 livestock farming relate to the so-called intensive and industrial farming (i.e. high  
89 productivity, high animal density, high drug use and indoor breeding). The main worries  
90 with these systems are about the welfare of animals, their health and the sanitary  
91 crises. Underpinning the concerns related to animal health and welfare, there is a  
92 societal demand for a healthy diet that will not lead to adverse effects on human health  
93 and even provide some benefits. Animal safety is directly related to the livestock  
94 farming systems, as illustrated by sanitary crises such as those related to influenza  
95 (Sidik, 2023). Animal health management such as the large use of antimicrobials also  
96 contributes to antimicrobial resistance dissemination, which is a major threat for the  
97 coming decades. In a systematic review on public perceptions regarding production  
98 diseases associated with farm animal welfare, Clark et al (2016) mention that citizens

99 have a holistic view of welfare and health of animals, and they consider that what is  
100 bad for animals is also bad for consumers. Furthermore, efforts to protect the health of  
101 animals at the expense of more open livestock farming systems (e.g. closed systems  
102 to limit disease exposure of the animals) is not supported by citizens. Clark et al (2016)  
103 indicate that more welfare friendly systems are associated with additional benefits for  
104 the consumer (quality, safety). However, at the same time, welfare is not a priority  
105 when shopping, with barriers to consumption such as price, availability and perceived  
106 personal influence remaining. The expectations of the society concerning the health  
107 and welfare of animals are shared by breeders. The latter are concerned by the welfare  
108 of their animals and try to give them the best life from their point of view (Buddle et al.,  
109 2021). Indeed, without any constraints and regulations, breeders may innovate in this  
110 field, as in the case of dam-rearing systems (Vaarst et al., 2020) or by the use of  
111 alternative practices in health management (Hellec et al., 2021). This invites us to  
112 consider animal health through a global “one health” approach. Also, under the treaty  
113 on the functioning of the European Union (Article 13 of Lisbon Treaty), animals are  
114 recognized as sentient beings and consequently the EU and the Member States must  
115 pay due regard to the welfare requirements of animals when preparing and  
116 implementing EU policies in agriculture or internal markets, for examples.

117

118 Given the societal loss of trust towards livestock farming, it must change quite strongly  
119 in the coming years to regain respect for its stewardship of the animals involved. Now  
120 more than ever, it seems urgent and important to consider animal health and animal  
121 welfare in the design of future livestock farming systems. In this transformation  
122 process, we consider that livestock farming systems must be completely redesigned  
123 by all stakeholders in the sector to position health and welfare at the heart of their

124 objectives, as well as the well-being of breeders. Some authors even call for a real  
125 paradigm shift, and propose a new conceptual framework called "circular welfare  
126 economy" involving a complete overhaul of the agricultural system, the economy and  
127 even society as a whole (Bracke et al., 2023). More concretely, synergies and tensions  
128 with the other dimensions of performance must be determined in order to guide choices  
129 towards the most multi-performing systems. Health and welfare need to be taken into  
130 account simultaneously, because they are tightly linked and interact with each other,  
131 not always in a positive way, and because they are critical points in the acceptability of  
132 livestock farming systems by the citizens and consumers. This raises the question of  
133 knowing under what conditions it will be possible to jointly improve the health and  
134 welfare of the animals, and to consider them as fully-fledged components of the  
135 sustainability of production systems. The purpose of the present paper is to address  
136 this question and to propose a conceptual framework in which the corresponding  
137 research questions are situated.

138

139 The process of innovation to achieve improved health and welfare of the animals within  
140 sustainable systems can take an incremental and progressive path, made of small  
141 steps, to optimize the system without making it deviate from its trend, with possible  
142 forms of substitution of one element by another. Alternatively, it can make a break and  
143 fundamentally modify the livestock farming system in a more disruptive way, even  
144 through a progressive path. Both paths can be useful, though some voices claim that  
145 no significant improvement can be expected from small steps changes to intensive  
146 livestock farming systems (Leterrier et al., 2022 ; Bracke et al., 2023). There is already  
147 knowledge and experience in the domains of health and welfare of farmed animals,  
148 and the interactions between health and welfare at animal level have been studied for

149 some time (Broom, 2007). However, simultaneously taking into account health and  
150 welfare as the main objective in designing new livestock farming systems requires  
151 multiple expertises. In this paper, we propose a research strategy centered on this  
152 goal. We first define animal health and animal welfare, and the research questions  
153 raised to evaluate them on farms. Then we address the questions linked to the  
154 interactions between health and welfare of animals, both positive and negative. Finally,  
155 we consider how the transformation of livestock farming activities toward health and  
156 welfare scales up to research questions at the farm level, at the industry and territory  
157 levels, and ultimately on the society's view of livestock farming and its evolution.

158

## 159 **What do we mean by animal health and animal welfare?**

160

### 161 ***What does animal health refer to?***

162

#### 163 *Historical perspective from Human medicine*

164

165 Western medicine has been dominated by two conceptions of disease, termed  
166 "ontological" and "physiological", both considering health as the absence of disease.  
167 In the ontological conception, disease is seen as a distinct entity, exogenous to the  
168 organism, such as a spirit, a parasite, a germ, a poison, which "penetrates" the  
169 individual to cause disturbances (symptoms). The treatment and the cure (the return  
170 to health) consist in eliminating, expelling this foreign "element". "Disease enters and  
171 leaves humans, as if through the door" (Canguilhem, 2005). In primitive and archaic  
172 societies, the supernatural, represented by gods, demons, wizards, was frequently  
173 invoked, especially during epidemics. At the end of the 19th century, the emergence

174 of modern microbiology and infectiology (L. Pasteur, R. Koch, etc.) brought scientific  
175 evidence to support this conception.

176

177 In the physiological or dynamic conception, the disease reflects an imbalance of the  
178 organism, a disturbance of its "internal environment", of its anatomical and functional  
179 integrity. This conception is therefore centered on the "sick person", and not on the  
180 "disease, external and distinct element". Illness and health are a continuum and not  
181 strictly independent (Conti, 2018). The treatment (and therefore the restoration of  
182 health) aims to return to harmony, the balance of "humors" which explains the  
183 systematic use of purgatives, emetics, bloodletting in ancient times. Identified since  
184 Greco-Roman antiquity (Hippocrates, Galen, etc.), this conception, transmitted by Arab  
185 medicine from the Middle Ages, has been enriched over the centuries. At the end of  
186 the 19th century, the advent of experimental physiology (C. Bernard, R. Virchow, etc.)  
187 brought scientific and explanatory elements to support this conception. In Oriental or  
188 Asian medicine (traditional Chinese; Indian called Ayurvedic - from âyur = longevity  
189 and veda = knowledge -) the notions of illness and health can be compared to the  
190 physiological conception (Mazars, 1994; Saylor, 2004). These two complementary  
191 conceptions (ontological and physiological) have largely contributed and continue to  
192 contribute to nourishing biomedical research.

193

194 In human medicine, in addition to the biological components of health, the "holistic  
195 theory" of health gives a preponderant part to a "subjective" component; without  
196 denying the biological aspects, this approach considers that health depends essentially  
197 on the perception of the subject, and therefore on socio-cultural values and references  
198 that vary in space, time, and according to individuals. The definition of health

199 established in 1946 by the World Health Organization goes beyond the absence of  
200 disease and traditional, strictly physical and biological criteria, and displays a positive  
201 and plural dimension in nature (physical and mental integrity, well-being) and scale  
202 (individual and population): "*Health is a state of complete physical, mental and social*  
203 *well-being, and not merely the absence of disease or infirmity*" (World Health  
204 Organization, 2017).

205

### 206 *Health and disease of farm animals*

207

208 The two historical approaches to health mentioned previously echo two important  
209 dimensions of the health of farm animals. The first one is the exposure to external,  
210 infectious, and toxic agents, which are the main causes of transmissible diseases,  
211 some of which are zoonotic and may involve wildlife (for example African swine fever,  
212 bovine tuberculosis, avian influenza, brucellosis). This includes the transmission,  
213 asymptomatic in animals, of pathogenic agents to humans (eg salmonella, hepatitis E  
214 virus, trichina). The second dimension refers to the physiological imbalances, that can  
215 be increased by deficient rearing conditions of animals highly selected for production  
216 potential in highly intensive livestock farming systems. These disorders can result  
217 (Calavas and Rosner, 1997) in excess morbidity and mortality thus altering longevity  
218 (Rostellato et al., 2022), sudden drops in performance (lack of robustness), and are  
219 often linked to physiological imbalance or common metabolic or infectious diseases  
220 (for example diarrhea in piglets at weaning, mortality of one-day chicks, mastitis in  
221 dairy cows, bronchopneumonia in young cattle).

222

223 The philosophical approaches developed for human health emphasize the importance  
224 of well-being, subjectivity, socio-cultural values and contexts to characterize the health  
225 status or the presence of disease, particularly for benign or chronic diseases. Perhaps  
226 because these values and contexts were not readily accessible in animals – one  
227 cannot ask an animal how it feels – they have not traditionally featured in the  
228 characterization of animal health status. The perception of health of farm animals can  
229 be quite different depending on whether it is made by the breeder, the veterinarian, or  
230 the citizen/consumer (Mahon et al., 2021). Taking the health of the udder of dairy cows  
231 as an example, different breeders do not necessarily consider the same criteria to  
232 determine that a cow has a sub-clinical infection, the veterinarian will tend to retain  
233 objective indicators (somatic cell count) based on a consensus standard of the  
234 profession, and the consumer will have the expectation that the cow has not undergone  
235 any treatment that could alter the quality of the milk. In broiler flocks as another  
236 example, different breeders may consider different levels of mortality to be normal, and  
237 the level of productivity achieved is an indicator of health for some of them.

238

239 Based on the World Health Organisation (WHO) definition of health, and also placing  
240 animal health in the perspective of the supply of animal products that are safe for  
241 human health, it seems important to consider an integrated ("holistic") approach to  
242 farm animal health, to consider the two components of health (risk of exposure to  
243 pathogens and physiological balance) and to focus on the best balance to be found in  
244 livestock farming practices. Furthermore, it is important to consider both the individual  
245 dimension of animal health and the herd level. Mental state of the animals has not until  
246 now been considered for farm animals, apart from abnormal behaviours generally  
247 observed under intensive farming conditions (for example feather pecking, bites,

248 stereotypies, self-mutilation). In connection with the animal welfare approach, it would  
249 also seem useful to take an interest in the concept of “mental states” of production  
250 animals.

251

252 Given the variety of livestock farming systems and species raised, and the diversity of  
253 points of view (breeder, veterinarian, citizens), it seems illusory to search for a generic  
254 and universal definition of animal health. In agreement with van der Linden and  
255 Schermer (2022), a pragmatic vision seems appropriate to make progress on the issue  
256 of the health of farmed animals. This vision must nevertheless be clearly explained by  
257 indicating which points of view are considered (breeder, veterinarian, citizen), which  
258 dimensions are taken into account (for example risk with respect to major regulated  
259 diseases, impact on the career of the animal (i.e. longevity)). Further, any definition  
260 should also be clearly framed in terms of the operational context in which it is to be  
261 used, such as research, health monitoring, etc.

262

### 263 *Practical assessment of animal health*

264

265 The integrated conception of animal health presented above is important if we are to  
266 move beyond a narrow focus on the presence or absence of specific diseases.  
267 However, this raises research questions with respect to measuring the health of an  
268 animal and of a herd in farming conditions. The choice of parameters and their  
269 combinations needs to be considered and evaluated, for the different animal species  
270 and for different periods of life of the animals. The relationships and boundaries  
271 between health and disease should be explored, with the concept that healthy and sick  
272 are (opposed) points on a continuum. Accepting that health status is a continuum offers

273 the prospect of defining objective, nuanced and operational criteria on which to build  
274 improved diagnostic and intervention tools, tuned according to the domains and  
275 biological functions considered (metabolism, reproduction, robustness, longevity, etc).  
276 Significant opportunities to achieve this are offered by the advent of on-farm monitoring  
277 technologies, and more recently the “Internet of Things” (Tuytens et al., 2022). These  
278 provide high-frequency repeated measures allowing health status of animals to be  
279 monitored and quantified on a continuous scale (Højsgaard and Friggens, 2010).

280

281 It would also be useful to consider how to define health at the level of the lifespan of  
282 the animal (or key stages of its career). Studies are emerging that make use of the  
283 repeated measures that are increasingly available, including the monitoring of the  
284 maintenance of good health or the capacity of the animals to recover quickly after a  
285 disease (Vaarst and Alrøe, 2012).

286

287 These research questions focused on evaluating the health status of the animal should  
288 go hand-in-hand with research on the different perceptions of what health is for  
289 different stakeholders, which can be extremely contrasted depending on who they are:  
290 breeders, veterinarians, or citizens. These perceptions can also vary within the same  
291 social group, for example between breeders in conventional and organic livestock  
292 farming. This implies the need for dialogue between these actors and the co-  
293 construction of consensus in order to move towards approaches that suit all actors.

294

295

296 ***What does animal welfare refer to?***

297

298 *Historical perspective*

299

300 The relationship between humans and animals, both domestic and wild, is multi-  
301 millennial. In fact, the mutual dependence between human societies and certain animal  
302 populations have been such that animals have gradually changed in their physiology  
303 and behaviour through the process of domestication (e.g., Price, 1984; Mignon-  
304 Grasteau et al., 2005 ; Larson and Burger, 2013; Ahmad et al., 2020). In the same  
305 way, the presence of animals has been intimately involved in the development of  
306 human cultures to the point of shaping them (Patou-Mathis, 2009). The process of  
307 domestication is far from being reduced to its purely economic aspects, even in current  
308 livestock farming systems, but also includes symbolic and affective dimensions. This  
309 tension at the heart of the human-animal relationship between a utilitarian perspective  
310 of exploitation and a more affective feeling has long exercised philosophers. Their most  
311 significant concerns about the human-animal relationship led to efforts to elucidate the  
312 ethical dimension of farming animals.

313

314 Philosophical thought has particularly focused on the goal of limiting suffering (where  
315 suffering is defined as experiencing pain, affliction or distress: Anonymous, 1971) but  
316 beyond it, tended more widely to relate this concern to the presence of sentience in  
317 animals in common with humans. During the 18th century, Rousseau (1754) was  
318 particularly important in putting very clearly in light this ethical basis: *"It appears, in*  
319 *fact, that if I am bound to do no injury to my fellow-creatures, this is less because they*  
320 *are rational than because they are sentient beings: and this quality, being common to*  
321 *men and beasts, ought to entitle the latter at least to the privilege of not being wantonly*  
322 *ill-treated by the former."* Along these lines but more restrictively, Bentham (1789)

323 claimed about animals in a very famous sentence: "*The question is not: Can they*  
324 *reason? Or: Can they talk? but: Can they suffer?*" More recently, the scientific results  
325 of investigations into animal skills in terms of sentience and awareness or  
326 consciousness (see below) confirm the validity of this ethical concern and increase its  
327 scope by extending it from the negative aspect (minimizing pain / suffering) to the  
328 inclusion of a positive aspect (maximization of pleasures) of mental states. For  
329 example, Larrère (2007) states: "*Sentience, this capacity to feel (and express) mental*  
330 *states like pain and pleasure, suffering and satisfaction, common to men and animals,*  
331 *precedes in the first what distinguishes them from the second (speech, reason,*  
332 *symbolization, etc.)."*

333

334 At the European level, the principle of sentient beings was enshrined in 2009 in Article  
335 13 of the Treaty on the Functioning of the European Union (2016): "*the Union and the*  
336 *Member States shall, since animals are sentient beings, pay full regard to the welfare*  
337 *requirements of animals".* Animal welfare has become a political issue, with both the  
338 development of animal protection associations and the appropriation of this issue by  
339 legislators in the Member States." The sentient nature of animals was already  
340 recognized in French law by the addition of positive and preventive obligations of  
341 animal suffering to the texts already in force, being the fruit of the law of 10 July 1976  
342 on the protection of nature which recognized in its article 9 that: "... *every animal being*  
343 *a sentient being must be placed by its owner in conditions compatible with the*  
344 *biological imperatives of his species."* It was finally introduced in the Civil Code:  
345 "*Animals are living beings endowed with sentience."* (Law of 16 February 2015, Article  
346 515-14), opening the way towards an evolution of the legal status of animals.

347

348 Today, animal welfare has become one of the objectives of the European Union: “*In*  
349 *formulating and implementing the Union's agriculture, fisheries, transport, internal*  
350 *market, research and technological development and space policies, the Union and*  
351 *the Member States shall, since animals are sentient beings, pay full regard to the*  
352 *welfare requirements of animals, while respecting the legislative or administrative*  
353 *provisions and customs of the Member States relating in particular to religious rites,*  
354 *cultural traditions and regional heritage.” (Article 13 of the Treaty on the Functioning of*  
355 *the European Union, which has consolidated in one single text all the founding*  
356 *Treaties; the Treaty of Lisbon: European Union, 2007). Indeed, all the current*  
357 *legislation on animal protection and welfare was elaborated at the level of the*  
358 *European Union and then implemented into national legislation in the Member States.*

359

360 Concern for welfare can however take several forms: either reducing itself to  
361 minimizing as much as possible the supposed causes of suffering or discomfort, or  
362 seeking to promote the expression of behaviours specific to the species, by providing  
363 in their environment the means for this purpose. Nevertheless, some authors still argue  
364 that the actual benefit of animals' ability to exercise “natural behaviour” on its welfare  
365 needs to be evidenced (Dawkins, 2023). The latter perspective is one of ethics of  
366 integrity (Bovenkerk et al., 2002) that can go so far as to recommend the return - within  
367 the limits of what is possible after the impact of the domestication process - to the  
368 conditions of a natural/outdoor environment. This even extends to the point of  
369 reintroducing the risks associated with it (for example the health risk and the presence  
370 of predators in semi-open flocks). Thus, the possibility of contradictions between the  
371 concern for animal welfare and provision of a natural environment have to be  
372 addressed. In the search for improved welfare, a more moderate vision consists of

373 respecting certain environmental conditions allowing the expression of the behaviours  
374 specific to the species.

375

376 In the field of animal farming, the highlighting by Harrison (1964) of the prevailing  
377 conditions of intensive livestock production in Great Britain followed by the  
378 establishment of the Brambell Committee (1965) marked a turning point in way that  
379 citizens considered the animals they share or use for their own purposes. The mission  
380 of this committee was to make recommendations and propose minimum welfare  
381 standards that meet the basic needs of animals under intensive livestock farming  
382 conditions. In 1965, the committee produced a report rightly considered to be the  
383 foundation of reflections and approaches relating to the welfare of farmed animals in  
384 Europe (1965). The first contribution of this report is an often-overlooked definition  
385 (Chapter 4, paragraph 25): *“Welfare is a wide term that embraces both the physical  
386 and mental well-being of the animal. Any attempt to evaluate welfare therefore must  
387 take into account the scientific evidence available concerning the feelings of animals  
388 that can be derived from their structure and functions and also from their behaviour.”*

389 This definition already referred to the existence of mental states in animals, a recurring  
390 point of controversy between stakeholders (Fernandes et al., 2019). It can also be  
391 noted that this definition considers the animal as a sensitive and conscious individual.  
392 Animal sentience includes the ability to perceive sensations through sight, hearing,  
393 smell, taste and touch, as well as the ability to feel emotions, bearing in mind that an  
394 animal's emotional capacities depend above all on its sensory world (Boissy et al,  
395 2007). Consciousness (Le Neindre et al, 2017) relates to the ability of the animal to  
396 reflect on its actions, to have a subjective or phenomenal experience of its  
397 environment, its own body and/or its own knowledge; it enables it to adapt to a

398 changing and often unpredictable environment. The definition distinguishes 'welfare'  
399 as a concept from 'well-being' that describes the state of the individual animal. Further  
400 scientific advances in the knowledge about sentience (Le Neindre, 2009) and  
401 consciousness (Le Neindre et al., 2017) of animals have reinforced these concepts,  
402 now widely accepted, both by national (Agence nationale de sécurité sanitaire de  
403 l'alimentation de l'environnement et du travail, 2018; Mormede et al., 2018) and  
404 international agencies (World Organisation for Animal Health, 2022).

405

#### 406 *Current definition of welfare*

407

408 Thus, the latest definition of 'animal welfare' by the World Organisation for Animal  
409 Health (WOAH) thus states "*Animal welfare means the physical and mental state of an*  
410 *animal in relation to the conditions in which it lives and dies*" (World Organisation for  
411 Animal Health, 2022). This definition is completed by the statement that "*While animal*  
412 *welfare refers to the state of the animal, the treatment that an animal receives is*  
413 *covered by other terms such as animal care, animal husbandry, and humane*  
414 *treatment.*" In France, according to the opinion of the French Agency for Food,  
415 Environmental and Occupational Health & Safety (Agence nationale de sécurité  
416 sanitaire de l'alimentation de l'environnement et du travail, 2018), "*an animal's well-*  
417 *being is the positive mental and physical state linked to the satisfaction of its*  
418 *physiological and behavioural needs, as well as its expectations. This state varies*  
419 *according to the perception of the situation by the animal.*" This definition reinforces  
420 the importance of the mental dimension of the feeling of the animal considered in its  
421 environment. Thus, good health, a satisfactory level of production and an absence of  
422 stress are not enough to ensure the well-being of the animal. We must also worry about

423 what the animal feels, namely its unpleasant subjective perceptions (fear, pain and  
424 suffering) but also its positive emotions (satisfaction, pleasure, etc.). This means that  
425 improving the welfare of animals should no longer be limited to reducing their suffering  
426 and stress, but also to developing living conditions that give them positive emotional  
427 experiences.

428

429 *Practical assessment of animal welfare: from the individual to the group*

430

431 The framework that historically underlies the practical approach to animal welfare,  
432 known as the "Five freedoms", was first published by FAWC in 1979, then in 2009 in  
433 its current form (Animal Welfare Committee, 2009). This statement includes, in general  
434 terms, indications of what human beings must offer animals to ensure their welfare:

- 435 - Lack of hunger and thirst by having free access to safe water and food to  
436 maintain a good level of health and vigour;
- 437 - No discomfort through proper environment, including a comfortable shelter and  
438 rest area;
- 439 - Absence of pain, injury and illness through preventive measures or rapid  
440 diagnosis, followed by appropriate treatment;
- 441 - Freedom of expression of normal behaviour thanks to sufficient space, adapted  
442 facilities and the company of other congeners;
- 443 - Absence of fear and distress by ensuring living conditions and treatment of  
444 animals avoiding mental suffering.

445

446 The current definitions of welfare reported above are suitable for the animal as an  
447 individual, but the practical assessment is often in the context of groups of animals

448 both at the farm and at the slaughterhouse for production animals. The first step is to  
449 assess the state of welfare at the level of the individual in its environment. A second  
450 step is the integration of individual data at the group level (e.g. the context of the farm).

451  
452 The assessment of welfare at the individual level is based on the assessments of the  
453 physiological and health status of the animal, as well as its behaviour and its reactivity  
454 to humans (animal-based measures). Assessing welfare also implies to take into  
455 account the characteristics of the environment as risk factors to animal welfare and  
456 levers to improve it (Whay, 2007). An important question is how to move from acquired  
457 understanding by studying the welfare of individuals to assessing the overall welfare  
458 of a group. Several farm animal welfare assurance schemes have been developed and  
459 used on a large scale. The approach adopted in the EU-funded Welfare Quality®  
460 project illustrates the degree of complexity of an evaluation tool and the question of an  
461 overall evaluation (Veissier et al., 2010). The initial protocols were built for a limited  
462 number of production species (pork, laying hens and broilers for fattening, cattle other  
463 than calves) as the beginning of a complete evaluation process of the livestock farming  
464 systems shared at the European scale and with a decision-making objective in actions  
465 to improve welfare. At the European level, these first protocols (Welfare Quality®,  
466 2009a, 2009b and 2009c) constitute a reference system, from which new protocols  
467 have been developed, with improvements in procedures and adjustments to other  
468 species (goats, horses, sheep, turkeys), which have for example also been developed  
469 in the AWIN project (AWIN, 2015a, 2015b, 2015c and 2015d). Numerous simplified  
470 tools have been derived from these protocols to make evaluations of welfare easier  
471 and available to all actors, including the breeders (e.g. BEEP for pigs, EBENE for

472 poultry and rabbits, BOVIWEL for cattle, '*cheval bien-être*' for horses), and the advent  
473 of on-farm monitoring technologies opens new perspectives.

474

#### 475 **To which extent are animal health and animal welfare connected?**

476

477 There are conceptual links between animal health and animal welfare, based on the  
478 definitions seen previously. The concept of "mental well-being" in connection with  
479 positive mental states, is an integral part of the WHO definition of health that includes  
480 the mental and social well-being (World Health Organization, 2017). At the same time,  
481 the most recent definitions of welfare by Agence nationale de sécurité sanitaire de  
482 l'alimentation de l'environnement et du travail (Anses) (2018) or the WOAHA (2022), are  
483 based, among other things, on a need to achieve a positive physical state (thus a good  
484 health). Apart from these links, there are other connections between health and  
485 welfare.

486

#### 487 ***Causal Links between health and welfare***

488

489 A causal link is observed mostly, and described first, in one direction, i.e., the adverse  
490 effects of altered animal welfare on disease susceptibility, in particular via a  
491 deterioration in immune function, to the point that disease susceptibility and immune  
492 function are used as indicators of welfare (Broom and Kirkden, 2004). Advances in the  
493 field of psychoneuroimmunology shed light at a functional level on the link between the  
494 hypothalamus, the reticular formation and the immune response, suggesting that the  
495 immune response is partially under the control of psychological processes (Zachariae,

496 2009). Conversely, the immune system exerts control over the central nervous system,  
497 primarily through the cytokine pathway (Dantzer, 2018).

498 Andrew Fraser and Donald Broom, two pioneers in the field of farm animal welfare,  
499 were among the first to address this link between welfare, animal behaviour and health,  
500 particularly in their book *Farm Animal Behaviour and Welfare* (first published in 1974;  
501 (Fraser and Broom, 1997). They rely on some observations suggesting that certain  
502 animal husbandry practices affect both animal welfare and disease incidence. For  
503 example, they cite a 1974 study that reported an increase in chronic infections in  
504 poultry, as livestock farming systems were intensified. And intensification of production  
505 systems is very often associated with higher antimicrobial use. A recent review by  
506 Rodrigues da Costa and Diana (2022) suggests that, in farm animals, better welfare  
507 often leads to lower antimicrobial use, as was hypothesized, and that, generally, poor  
508 welfare is associated with higher antimicrobial use. Diseases linked to physiological  
509 imbalances, with or without an infectious component, are very dependent on  
510 husbandry practices and, in this sense, are possibly in strong interaction with the state  
511 of animal welfare.

512

513 Data on the effects of improved welfare on disease resistance are less abundant, this  
514 is probably at least partly due to the fact that research in the field of positive welfare  
515 started late (Boissy et al., 2007). Results from Lutgendorf (2001) and Sachser (2001),  
516 as cited by Broom (Dahlem Workshop, 2001) indicate that improved welfare status,  
517 aided by social support from conspecifics, reduces the risk of disease. There is indeed  
518 some evidence that improved welfare can be a means to improve immune function,  
519 without the use of drug inputs, and a means to improve immunocompetence, including  
520 response to treatment, when needed, and to vaccines or infection. However, the

521 relationships between welfare, immunity and disease resistance are more complex  
522 than they appear (Berghman, 2016).

523

524 Consequently, there seems to be no simple relationship between measures of immune  
525 activity and welfare (Boissy et al., 2007). As stated by Dawkins (2019): *"Research is*  
526 *urgently needed into the relationship between animal welfare, immunity, gut microbiota*  
527 *and disease and we are not yet in a position to claim that improving welfare will improve*  
528 *resistance to disease. 'Boosting' the immune system is not straightforward and an*  
529 *interdisciplinary approach is needed"*.

530

### 531 ***Health and welfare may respond differently to livestock farming practices***

532

533 Changes in husbandry practices associated with a change in environmental living  
534 conditions, like access to outdoors, have profound, but complex and ambiguous,  
535 effects on animal health and welfare, and on their interactions. Typically, animals can  
536 be given access to outdoors to increase their welfare, but it may have many detrimental  
537 effects on their health state. For instance, giving access to an outdoor area and pasture  
538 to growing pigs increases the incidence of osteochondrosis as compared to confined  
539 indoor housed pigs (for a review, see Etterlin et al., 2016). More generally, access to  
540 outdoors increases the risk of exposure to pathogens (parasites, pathogens external  
541 to the farm). Moving to outdoor systems in chickens, allows the expression of positive  
542 behaviours (Lay Jr et al., 2011) but increases the incidence of parasites like coccidiosis  
543 (Sossidou et al., 2015) and red lice (Knierim, 2006). These complex relationships  
544 between health and welfare, and production systems have been recently reviewed in  
545 the case of alternative pig (Delsart et al., 2020) and organic chicken farming (Holt,

546 2021), where outdoors access increased the risk of injury from predators and from  
547 flock mates, the risk and severity of diseases, and the mortality rate. There is therefore  
548 a possible level of negative interaction with welfare if biosecurity measures constrain  
549 farming practices (e.g. African swine fever, avian influenza, diseases affecting wildlife).  
550 The transformation of breeding conditions, to better meet the animals' need for access  
551 to external and therefore more complex environments, must be designed in  
552 conjunction with a genetic approach to improve the animals' physiological adaptation  
553 to less controlled external living conditions (see below).

554

555 Apart from links discussed above, that all show that welfare and health usually vary in  
556 the same direction (bad welfare equal to bad health and probably vice versa), the  
557 question of possible tensions between them may be raised when thinking about the  
558 likely effects of profound changes in breeding practices. This raises research questions  
559 at the different scales at which these interactions, and potential tensions, are studied,  
560 from the animal to the livestock farming system in his territory. These research  
561 questions are presented below.

562

### 563 **Improving animal health and animal welfare in the transformation of farming** 564 **activities**

565

566 There is already a considerable body of knowledge that can be mobilized to improve  
567 conjointly animal health and welfare of livestock. However, various questions arise at  
568 the scientific level. It will be necessary to not only deepen our knowledge of the  
569 interactions between health and welfare at the animal level but also to consider  
570 different levels of organization. Health and welfare interactions need to also be  
571 considered and quantified at the group, herd, farm, value chain and regional levels.

572 This includes going as far as considering impacts and questions involving the citizen  
573 and consumer. This is the overall framework of the research agenda that we propose  
574 below with the following themes:

575

- 576 - Interactions between animal health and animal welfare at the animal level.
- 577 - Interactions between animal health and animal welfare at the herd level
- 578 - Consideration of the expertise and well-being at work of breeders
- 579 - Interactions at the territory and production and value chain levels
- 580 - Research regarding the link between farming activities and society

581

582 ***Interactions between animal health and animal welfare at the animal level***

583

584 As seen previously, different studies already explored positive interactions between  
585 health and welfare. However, this field of research remains fully open and among the  
586 various questions that can be addressed, we identify two that we consider as pushing  
587 at the boundaries of the scientific state-of-the-art. Does improving the state of animal  
588 welfare, in particular by facilitating the induction of prolonged or repeated positive  
589 emotions, impact their health, in terms of physiological balance and of their resistance  
590 to external aggressors, including pathogens? In addition, the role of the microbiota in  
591 the psycho-neuro-endocrine mechanisms, through the “gut-brain” axis, that link  
592 different aspects of welfare and health should be further explored.

593

594 Another important issue is to explore the trade-off between the physiological functions  
595 of production, reproduction and immunity, as well as to find the best possible  
596 equilibrium between efficiency of production, welfare and resilience of the animal (for

597 a review, see Rauw, 2008). Working on the physiological and genetic bases for these  
598 trade-offs could help identifying means of action. There are a few examples of such  
599 studies investigating trade-offs between production traits and immune function (e.g.,  
600 Zerjal et al., 2021), but very few studies that include welfare as well. These questions  
601 concern both the short and longer stages over the entire animal's life, and a specific  
602 focus should be made in exploring the roles of the prenatal and juvenile periods, and  
603 transition phases in sub-adults or adults (weaning, gestation). Another dimension is to  
604 analyze the sensitivity of the animals to environmental conditions, such as their  
605 average harshness and variability.

606

#### 607 ***Interaction between animal health and animal welfare at the herd level***

608

609 Moving from the individual to the group of individuals, or to the farm, changes the scale  
610 and raises specific research questions. Research is needed on how do interactions  
611 between individuals, and between individuals and their environment, impact the health  
612 and welfare of the group. Key areas of focus are on positive emotions, microbiota flows,  
613 and exchanges of pathogens between animals and their environment. The context in  
614 which group livestock farming systems increasingly favour outdoors access to animals  
615 for promoting welfare, and the emergence of mixed species groups in extensive  
616 systems clearly pose questions. One paradigm that has gained traction in recent years  
617 is that the resilience of the livestock farm may be enhanced by encouraging a broader  
618 variability in the adaptive capacities of the individual animals in the group. If shown to  
619 be the case, this will be important especially in agro-ecological livestock farming  
620 systems where the group of animals will be more confronted by, and need to be able  
621 to cope with, environmental fluctuations.

622

623 If we consider the perspective of developing livestock farming systems that place  
624 animal health and welfare at the heart of the objectives, it will be necessary to do so  
625 whilst guaranteeing performance on all the pillars of sustainability (i.e. social,  
626 environmental and economic). This implies not only characterizing the synergies and  
627 tensions between health and welfare but also between these two components and the  
628 other performance parameters of the livestock farming system that contribute to its  
629 sustainability. The compromises that will have to be made in the choice of innovations  
630 in rearing practices can only be made in consultation with all the stakeholders. Given  
631 the ambition is to design systems that prioritize health and welfare, it will be necessary  
632 to know what is the cost of this choice on the other dimensions of performance and,  
633 thus, on the acceptability of these innovative systems. It will therefore be necessary to  
634 rely on open innovation methods such as living labs, which allow the co-conception of  
635 livestock farming systems taking into account the points of view and motivations of all  
636 stakeholders (including breeders, upstream and downstream industries, but also  
637 citizens' associations and consumers) considered as key players in the research and  
638 innovation process (e.g., Leminen, 2015) for general considerations on the living lab  
639 concept, and Chiron et al. (2022) for an example of participatory research project in  
640 rabbit production).

641

642 As highlighted in the 1.1 and 1.2 sections, a potentially powerful tool for measuring  
643 health status and welfare status is the on-farm technology that is being increasingly  
644 deployed as part of the general move towards precision livestock farming. These  
645 technologies can provide high-frequency objective measures on large numbers of  
646 animals (Højsgaard and Friggens, 2010). They already include measuring systems to

647 detect specific health events (e.g. onset of mastitis) and also use behavioural changes  
648 to detect events such as onset of oestrus. For these tools to realise their full potential  
649 for quantifying the interactions between health status and behavioural status the  
650 following research developments are needed. These technologies are currently used  
651 to detect specific events rather than to assess in a continuous way how health and  
652 behavioural status evolve in response to different farm environments. Achieving the  
653 latter requires that the algorithms used to process these data are 're-tuned' to give a  
654 more nuanced evaluation of health and behavioural status. Another scientific challenge  
655 lies in the interpretation of technology-based behaviour data and animals' emotions.  
656 These technologies have been best developed in indoors housing systems (with easy  
657 access to power supply and data transmission). Although there has been significant  
658 progress, there remains a need to further develop these technologies for use in  
659 outdoors, extensive, situations (Bocquier et al., 2014). Further research is also needed  
660 to better make the link between measures made on individual animals and those made  
661 on groups of animals. For example, camera-based measurements of groups can  
662 reveal behaviours like dispersion of the group and average speed of movements (e.g.,  
663 Sadoul et al., 2015) but it is not clear how to best combine group and individual  
664 measures, or indeed when it is beneficial to do so. Advances on this would improve  
665 the tools that could help breeders identify behavioural disorders that can be indicators  
666 of disease or poor welfare conditions within the group.

667 The final area for development is not to do with these technologies *per se* but rather to  
668 do with their interest and acceptance by breeders; the way they impact their work and  
669 their mental workload with these new multiple data and the complexity of the  
670 information to analyze, if they are adapted to the needs and skills of breeders and  
671 reinforce their ability to observe the animals, or imply new learning and skills (Hostiou

672 et al., 2014). At present, there still remains an unwillingness to accept the measures  
673 coming from automated technologies amongst some experts in both fields. In our view,  
674 there is a need to provide the proofs that allow these researchers to accept that the  
675 benefits of having objective measures available on large-scale can often outweigh any  
676 perceived lack of specificity of said measures.

677

### 678 ***Consideration of the expertise and the well-being at work of breeders***

679 Because of their daily work with, and dependence on animals, breeders have an  
680 expertise, an extended spectrum of skills, emotions, knowledge that should be  
681 considered with a real interest by scientists, farm advisors and veterinarians (O’Kane  
682 et al., 2017; Hansen and Østerås, 2019; Mahon et al., 2021) and more generally by  
683 society. Salmona (1985) pointed out the key role of breeders’ fear of diseases and  
684 strong emotional concern about animal pain and health in farming practice. In their job,  
685 care and disease with pain management are consubstantial; consequently, breeders  
686 must practically and emotionally cope with this reality. New ideas and practices emerge  
687 as breeders evolve in the way they define themselves as ‘good’ livestock rearers. Their  
688 insight skills in animal handling and management are also changing. Experimenting  
689 with practices, breeders develop new knowledge areas about animal health and  
690 behaviour, but their own interpretations of animal welfare and health are often poorly  
691 considered.

692 Consideration for animal health and rearing conditions vary according to a diversity  
693 and heterogeneity of farm types, productions and sizes. These range from mainstream  
694 agriculture to alternative-small-holding farms. Small-holders are considered by  
695 commercial farming as threats to the biosecurity because of a lack of disease-risk

696 awareness and bioinsecure practices. Going beyond those simplistic representations,  
697 Holloway (2019) insisted on the hybrid knowledge that small-holders acquire in the  
698 relationships with veterinarians and described how health management is bound up  
699 with practices of care. Opposing small-scale farming to commercial farming in terms of  
700 biosecurity is reductive as health and care practices are complex and heterogenous in  
701 farms (Holloway, 2019). It depends also on the way each farmer is considering how to  
702 be a “good farmer”, and a large diversity of farming styles have been identified in some  
703 studies (Commandeur, 2006). Moreover, breeders treat the health and welfare of  
704 different species, types and groupings of livestock in different ways, with differences  
705 between species, between animals of the same species, and between different life-  
706 stages or ages (Mahon et al., 2021). A large range of breeders, animal species,  
707 geographic situations, and local conditions create infinite combinations of animal-  
708 human relationships and ways of rearing. In that context, the challenge is to shift from  
709 an advisor-to-breeder knowledge transfer to a recognition and consideration of peer-  
710 to-peer systems and to encourage breeders’ exchanges. We make a plea here for  
711 setting up research projects on improving conjointly health and welfare of animals at  
712 the farm level that are co-constructed with breeders in order to benefit from their skills  
713 and expertise. One way to achieve this is to investigate farm situations and results with  
714 breeders that have already tested and made strong innovations in health and welfare  
715 on their farm, *i.e.* , by tracking breeder’s innovations (Salembier et al., 2021). Another  
716 way to achieve this is to use the living labs conception process (see above).

717

718 If animal welfare is a component of sustainability (Buller et al., 2018), the breeders’  
719 well-being should be a legitimately associated goal, with a focus on the capability of  
720 breeders to create knowledge and competences and to innovate in the field of animal

721 welfare. This is an important aspect to be integrated under the banner of “One Welfare”  
722 (Buller et al., 2018). A key question is to what extent does an improvement in the health  
723 and welfare of their animals contribute to improving the well-being of breeders, their  
724 representation of work, personal and societal beliefs and satisfactions, and comfort at  
725 work. However, the contrary may also apply, that innovating on animal health and  
726 welfare can introduce new constraints for the breeders such as increased time or  
727 arduousness of the work. In parallel, it would be important to analyze what are the  
728 obstacles and drivers underlying changes to practices by breeders and transitions  
729 towards practices that are sustainable in terms of animal health and welfare; and what  
730 kind and extent of innovation are accomplished on the real farms. Porcher (2017)  
731 proposed to look in a new way at the relationships between farmers and animals, with  
732 the assumption that farm animals such as milking cows work. In this perspective,  
733 working conditions of both farmers and animals are considered, animals are respected  
734 as workers and the farmers rely on the intelligence of animals without exploiting them.

735

### 736 ***Interactions at the territory and production and value chain levels***

737

738 With the emergence of societal concerns on animal health and welfare, breeders have  
739 appeared to initially be quite isolated with respect to providing answers and producing  
740 change in their farming practices (Quéméré and Le Neindre, 2013). Indeed, changes  
741 in regulations have often been the main driver for change in favour of animal welfare  
742 (Mounaix et al., 2013). Initially not involved in the debate (ethics, welfare), breeders  
743 and their organizations are fully engaged with it (Quéméré and Le Neindre, 2013).  
744 Indeed, co-operative organizations, as well as Standards Formulating Organizations  
745 (SFO), but also breeder groups initiatives, have been playing an important role in the

746 standards negotiations between breeders and retailers and in the implementation of  
747 welfare assessment tools like the Welfare Quality references (Aramyan et al., 2013;  
748 Bertrandias et al., 2021). Acknowledging that multi-stakeholder approaches are key to  
749 improve animal health and welfare, we then identify three main research topics at the  
750 regional and production sector levels that underlie the expected transition process  
751 towards livestock farming systems that promote both animal health and welfare.

752

753 *Social, legal, economic and institutional processes involved*

754

755 Changes in farming practices toward better health and welfare of animals must take  
756 account of all the diversity of farms in terms of their technical and economic  
757 orientations, the networks to which they belong (trading, strategic, technical, etc.) and  
758 any product differentiations that result with respect to their marketing. For the breeders,  
759 improving animal health and welfare should not penalize business returns. It could  
760 bring benefits, e.g. better animal productivity, reduction of drug use, and would thus  
761 allow breeders to gain the initiative in the animal welfare debate (Lawrence and Stott,  
762 2009). However, improving animal health and welfare in livestock farms requires  
763 practices and/or system adaptations, new investments (Johan Lagerkvist et al., 2011),  
764 and maybe more workforce. These costs must usually be economically compensated  
765 by supports, as suggested for the European Common Agricultural Policy (Guyomard  
766 et al., 2023), or premiums and state product labelling. The health and welfare  
767 differentiation of the products, managed by the downstream part of the supply chain  
768 may affect consumer prices. There is a gap between the consumers' stated willingness  
769 to pay more for animal health and welfare products and their real purchasing acts that  
770 remain price-oriented (Deblitz et al., 2021). Animal welfare labelling will inform

771 consumers and give the opportunity to make conscious consumer choices. This can  
772 have the consequence of them consuming fewer animal products (Deblitz et al., 2021).  
773 This raises the question of the best productive and industrial strategies, the best public  
774 policies to set up to improve animal health and welfare while preserving the economy  
775 of the sectors, such as using market-led approaches or relying on supply-side  
776 solutions. The issues and questions raised here all relate to how to translate the  
777 challenges of emerging new paradigms such as the Eco-Health concept (“human-  
778 animal-ecosystem” interface) – for example by focusing on the example of  
779 antimicrobial resistance – into organizational processes for livestock rearing in different  
780 sectors and regions.

781

### 782 *Technical, organizational innovations and coordination mechanisms*

783

784 Various approaches can exist to push changes on animal health and welfare in the  
785 industry and in different regions. Research may be useful to analyze their efficacy or  
786 to support the process, among others different types of coordination (integration, “spot”  
787 markets, networks, etc.), the internationalization of agricultural and food markets, and  
788 different types of local cooperation between a variety of actors (agricultural or not). It  
789 can also be hypothesized that the multiplication of initiatives can potentially blur  
790 breeders and consumers perceptions, especially given the poor knowledge of citizens  
791 about farming methods (Cornish et al., 2016).

792 Changes to organisational systems will need to take into account: the diversity of  
793 systems co-existing in a same rural area (e.g. co-existence of indoor and outdoor  
794 systems); actor strategies (e.g. living with pathogens or eradicating them); the  
795 knowledge generated on health data (e.g. interactions with wild fauna); and technical

796 innovations (e.g. precision livestock farming) or organisational innovations (e.g. fab lab  
797 or networks of breeders). They must also be designed in the context of knowing what  
798 options can be developed for documenting or certifying the animal products, i.e. the  
799 monitoring and management of infectious diseases and welfare in the different sectors  
800 and regions. Likewise they will need to take into account what is the acceptability, by  
801 the downstream elements of the supply-chain including consumers, of “new” animal  
802 products from adapted livestock farming systems. Indeed, innovative, ground-  
803 breaking, systems that focus on health and welfare can be based on non-standard  
804 genetic types, produce animals that are heavier or lighter, fatter, older, altered  
805 seasonal production patterns. The consequences of these non-standardized animals  
806 on the processing of animal products need to be addressed. Finally, the feasibility and  
807 acceptability by field actors of new animal management philosophies, such as  
808 providing “retirement opportunities” for old animals, should be investigated.

809

810 *Spatial distribution of farms, global conception of agricultural/food systems*

811

812 The spatial distribution of livestock farming, the evolution of the herds' size and the  
813 emissions from the livestock industry, or, more globally, the question of the safe  
814 operating space for livestock production (Buckwell and Nadeu, 2018), must also be  
815 included in the debate (Deblitz et al., 2021), otherwise new disputes will arise again  
816 soon afterwards. These concern all the risks linked to the concentration of animals and  
817 industry: excessive effluents, impossibility of closing cycles in a circular economy,  
818 epizootics and other health risks. This evaluation can be carried out through stimulating  
819 the involvement of actors in different regions and sectors. It may involve developing  
820 the joint construction of organisational changes within certain sectors or regions so that

821 account can be taken of the health and welfare of animals throughout their lives. This  
822 includes issues such as the euthanizing animals of little economic value (male chicks,  
823 female ducklings, male kids, etc.) or alternatives to slaughtering animals for health  
824 reasons should also be considered. The potential interest of some practices that are  
825 almost non-existent today, such as “smallholders slaughters” managed by the  
826 breeders themselves, needs to be evaluated and this requires an environmental as  
827 well as an economic and social assessment. In a more holistic way, the structuring and  
828 functioning of our global food systems (from farm to fork) should be reexamined and  
829 democratically discussed (within the framework of citizens' conferences, for instance).  
830 Topics such as the place, size and structure of livestock farming activities, the place of  
831 animal products in our diet, for instance, should be discussed. Various prospective  
832 studies could be mobilized to enlighten these reflections (Aubert et al., 2019).

833

### 834 ***Research regarding the link between farming activities and society***

835

#### 836 *Combined consideration for societal concerns of health and welfare of animals*

837 There is a growing societal concern for human health on the one hand, and animal  
838 welfare including farm animals in the other hand. They both gradually appear on policy  
839 agendas but these two trends, interrelated in this paper, are quite separated in society,  
840 science and political debates. Animal welfare concerns the way animals are farmed,  
841 transported, slaughtered and finally consumed (Buller and Roe, 2018). These topics  
842 are of increasing interest to many people in most parts of the world. Following non-  
843 governmental Organizations (NGOs) campaigns, the European Commission intends  
844 to propose to phase out and finally prohibit the use of cage systems, for all the species  
845 and categories mentioned in the End the Cage Age European Citizens' Initiative

846 (European Commission, 2021). In parallel, dedicated structures and new regulations  
847 assigning to animals a status “as subjects”, and commercial standards promoting  
848 ethical market segmentation are emerging. These are collectively driving towards a  
849 movement of standardization and institutionalization of animal health and welfare.

850 Regarding health, and from a societal perspective, there are two public health threats.  
851 One major concern is the use of antimicrobials on livestock farms, with husbandry  
852 challenges associated with a drastic reduction in antimicrobial use in livestock to avoid  
853 resistance to antimicrobials used for humans (McEwen and Collignon, 2018). Another  
854 important health threat is the fact that emerging infectious diseases are dominated by  
855 zoonoses (Jones et al., 2008), which are diseases transmissible between animals and  
856 humans, directly or indirectly (e.g. food-borne, vector-borne zoonoses).

857 In our view, both challenges, animal health and welfare, could be better inter-related  
858 in an integrative perspective of improving farming sustainability (Buller et al., 2018),  
859 taking into account societal challenges, and providing better conditions for animal  
860 health and farming. However, this is no easy task as animal welfare and health also  
861 involve the entirety of the food chain, transcending the traditional divisions between  
862 production and consumption (Buller and Roe, 2018), with concern on ethical food and  
863 consumption. For instance, in 2016, the United Nations Committee on World Food  
864 Security Draft Recommendation has included an animal health and welfare article  
865 (Buller et al., 2018). This is in line with Haraway (2008) who proposed the statement  
866 of ‘response-ability’ both on farm and beyond into the supply chain. Here we propose  
867 to adopt an enlarged view that would include all stakeholders: breeders, processors,  
868 retailers, public institutions, consumers. In addition, to integrate animal welfare and

869 health issues, the panel of stakeholders should be further expanded to include  
870 scientists, veterinarians, civil society and NGOs, farm advisors, etc.

871 *Dialogue between the various stakeholders and society*

872 As seen previously, a discordance exists between citizens and breeders' perceptions  
873 of animal health and welfare due to an increasing dissociation of citizens living in urban  
874 contexts far removed from farming practices reality (Vanhonacker et al., 2008).  
875 Physical health, an adequate and sufficient food and drinking water to meet animal  
876 needs are included in animal welfare, both by citizens and breeders. Citizens tend to  
877 include additional values: freedom to move and freedom to fulfil natural desires  
878 (Vanhonacker et al., 2008), that are integrated in the current definition of welfare. Also,  
879 citizens do not have a clear vision of animal health, apart from the fact that poor  
880 husbandry conditions and intensive farming increase the risk of disease and overuse  
881 of antimicrobials (Clark et al., 2016). Coming back to the idea of improving the  
882 knowledge of society and citizens on farming activities, as well as their image of  
883 livestock farming, there is a strong need for more intense and constructive exchanges  
884 between breeders, livestock industry and citizens. These different parties need to  
885 better know each other, to exchange their points of view, maybe to reconcile their  
886 midterm vision of what livestock farming could be ideally, and to work together to break  
887 up conflicts. Only a concerted path of this type will improve the vision of citizens about  
888 farming. In this respect, and as previously mentioned, the organization of citizens'  
889 conventions (on livestock farming, and/or agricultural/food systems), including  
890 substantial training periods for participants, could be useful.

891 These challenges for the animal health and welfare sciences and for the humanities  
892 and social sciences are so vast that they cannot be met by individual disciplines, nor

893 by single or small groups of actors and stakeholders. We believe that, for specific  
894 research projects on cutting-edge farming-societal issues, transdisciplinarity research  
895 is required. Transdisciplinarity research addresses a complex, socially relevant issue,  
896 considers diverse perspectives and disciplinary approaches, links abstract and case-  
897 specific knowledge, and develops a common-good-oriented descriptive knowledge to  
898 address the issue (Pohl, 2011). A key point is recognizing the limits of science (and its  
899 experts) and respecting the expert knowledge of 'lay people' (i.e. citizens).

900

## 901 **Perspectives and conclusion**

902

903 To date, animal health and welfare have been treated as incidental issues in livestock  
904 farming systems. Taking into consideration these two components as a key and central  
905 point of the livestock farming systems has various and important implications. It  
906 questions the nature of the dominant production systems as well as the organization  
907 of the livestock sectors, through four complementary challenges (Figure 1).

908

909 Instead of correcting health and well-being damages, the approach is first to define  
910 what is considered good health and good welfare by stakeholders, and then to find  
911 practical and objective means of assessing these two components (Figure 1A). Health  
912 and welfare are partly linked given their definitions but also because they have positive  
913 effects on each other. The mechanisms involved need further investigation. In addition,  
914 the desire to improve both raises specific questions because they sometimes interact  
915 negatively and considering them together may lead to trade-offs that need to be  
916 explored throughout the animal's life (Figure 1B).

917

918 Transforming livestock farming systems to improve animal welfare and health also  
919 raises a number of questions about: the design of livestock farming systems to ensure  
920 good health and welfare, the economic profitability of these improved systems, the  
921 well-being of breeders at work, and the adaptation of the livestock sectors to  
922 incorporate these innovations (Figure 1C). Work is needed to study the levers for action  
923 and to support these approaches, including the role of public policies in facilitating the  
924 transformations.

925

926 Finally, the evolution of livestock farming systems to improve animal health and welfare  
927 needs to be considered in the context of a broader vision of livestock production, with  
928 a view to multi-performance and sustainability (Figure 1D). This point relates notably  
929 to the acceptability of animal farming by the society, and its place in a one health and  
930 one welfare perspective. Working with citizen and consumers on the co-construction  
931 of a common vision of acceptable and environmentally friendly livestock farming is an  
932 important and urgent task.

933

934 Some of the research questions raised in this paper refer to biology, for example  
935 psycho-neuro-endocrinal mechanisms linking positive mental state and health, and  
936 many others relate to animal sciences. However, some of them undeniably involve  
937 cultural aspects that can differ from place to place. These include options available in  
938 some countries that might not be applicable in others. Part of the questioning presented  
939 here calls for regionally-focused research, that can take place in different cultural  
940 contexts. It also pleads for an interdisciplinary approach involving Human sciences and  
941 economics in close collaboration with animal and veterinary sciences, and for  
942 transdisciplinary research involving all stakeholders.

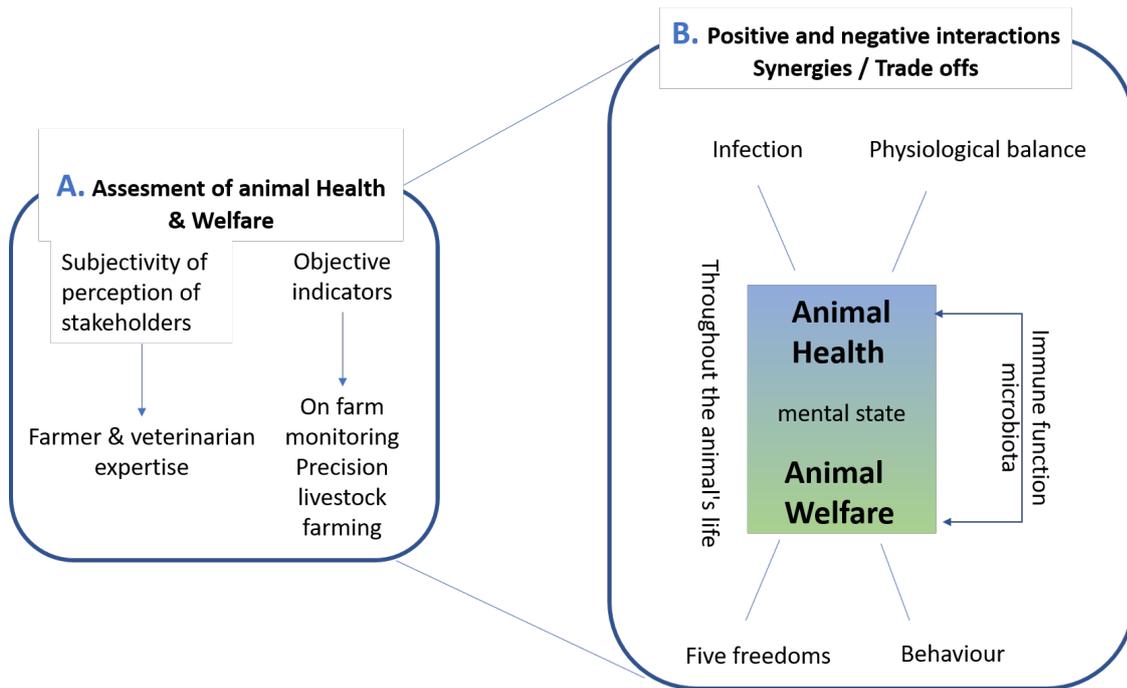
943 **Figure 1.** Challenges to address in moving livestock farming towards greater consideration of  
 944 animal health and welfare.

945 A. Better assessment of animal health and welfare

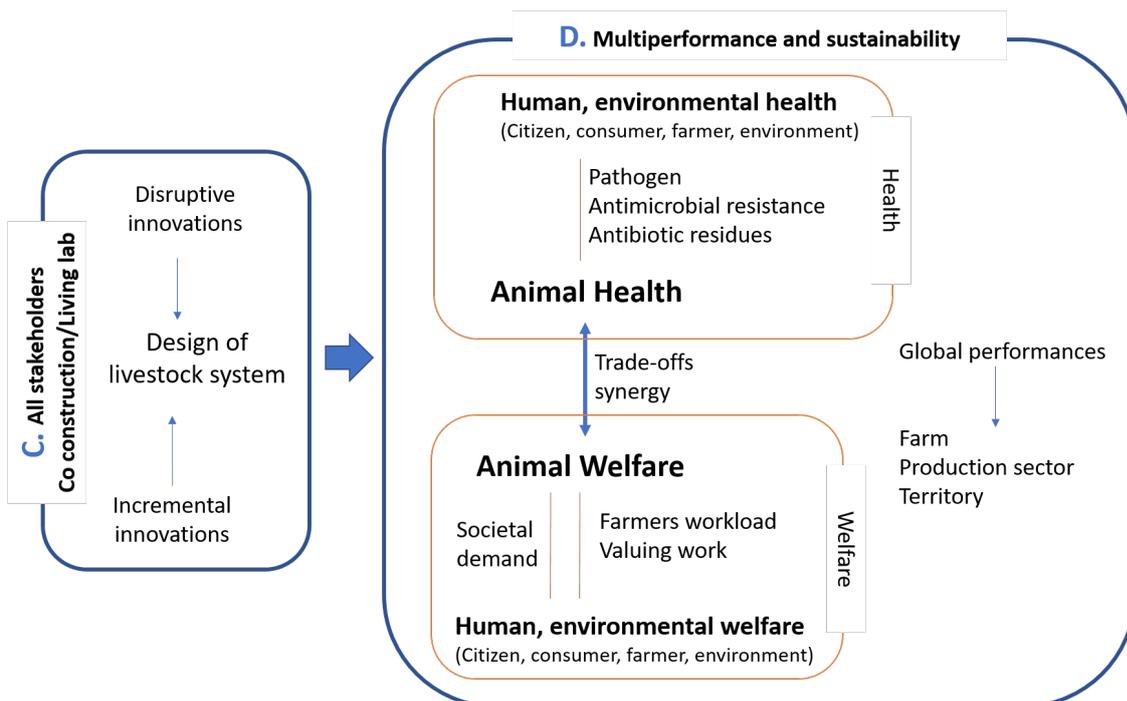
946 B. Understanding the positive and negative interactions between animal health and welfare  
 947 (synergies and trade-off)

948 C. Co-design of innovative livestock farming systems improving animal health and welfare

949 D. Multiperformance and sustainability of livestock farming systems improving animal health  
 950 and welfare



951



952

953 **Ethics approval**

954 This work was conducted without carrying any experiment on animals.

955 **Data and model availability statement**

956 This work was not grounded on data and model.

957 **Author ORCIDs**

958 Christian Ducrot <https://orcid.org/0000-0003-1418-7446>

959 Xavier Fernandez <https://orcid.org/0000-0002-1841-1647>

960

961 **Author contributions**

962 J.-L.P., M.V., X.F. and C.D. wrote the initial project for the INRAE interdisciplinary  
963 programme on animal health and welfare (SANBA), basis of this article. A.B. and P.M.  
964 wrote the chapter on the history and definition of animal welfare. F.S. and C.D. wrote  
965 the chapter on the history and definition of animal health. M.-B.B., F.Ch., S.P., M.-H.P.,  
966 P.V., X.F. and C.D. wrote the initial version of the other chapters. F.Ca., A.D., S.E.,  
967 G.F., N.C.F., R.G., and I.M. contributed to the improvement of the text and figure.  
968 N.C.F. edited the English writing.

969 **Declaration of interest**

970 The authors declare that they have no competing interests.

971 **Acknowledgements**

972 **Financial support statement**

973 This work was supported by the metaprogramme “SANté et Bien-être des Animaux en  
974 élevage” (SANBA) of the French National Research Institute for Agriculture, Food and  
975 Environment (INRAE).

976 **References**

- 977 Agence nationale de sécurité sanitaire de l'alimentation de l'environnement et du  
978 travail, 2018. Avis de l'Anses relatif au « Bien-être animal : contexte, définition et  
979 évaluation ». Agence nationale de sécurité sanitaire de l'alimentation, de  
980 l'environnement et du travail (ANSES), Paris, FR.  
981 <https://www.anses.fr/fr/system/files/SABA2016SA0288.pdf>.
- 982 Ahmad, H.I., Ahmad, M.J., Jabbar, F., Ahmar, S., Ahmad, N., Elokil, A.A., Chen, J.,  
983 2020. The Domestication Makeup: Evolution, Survival, and Challenges. *Frontiers in*  
984 *Ecology and Evolution* 8 <https://dx.doi.org/10.3389/fevo.2020.00103>.
- 985 Animal Welfare Committee, 2009. Farm Animal Welfare Council. Animal Welfare  
986 Committee (AWC). [https://www.gov.uk/government/groups/animal-welfare-](https://www.gov.uk/government/groups/animal-welfare-committee-awc)  
987 [committee-awc](https://www.gov.uk/government/groups/animal-welfare-committee-awc).
- 988 Aramyan, L., Ingenbleek, P., Backus, G., de Roest, K., Tranter, R., 2013. Evaluating  
989 the likelihood of the adoption of an animal welfare assessment system in European  
990 agri-food supply chains. *International Journal of Quality & Reliability Management*,  
991 59–79. <https://doi.org/10.1108/02656711311288423>.
- 992 Aubert, P.-M., Schwoob, M.-H., Poux, X., 2019. Agroecology and carbon neutrality in  
993 Europe by 2050: what are the issues? Findings from the TYFA modelling exercise.  
994 Study N°02/19. Institut du développement durable et des relations internationales  
995 (IDDRI), Paris, FR. [https://www.iddri.org/en/publications-and-](https://www.iddri.org/en/publications-and-events/study/agroecology-and-carbon-neutrality-europe-2050-what-are-issues)  
996 [events/study/agroecology-and-carbon-neutrality-europe-2050-what-are-issues](https://www.iddri.org/en/publications-and-events/study/agroecology-and-carbon-neutrality-europe-2050-what-are-issues).
- 997 AWIN, 2015a. AWIN welfare assessment protocol for goats.  
998 <https://air.unimi.it/retrieve/handle/2434/269102/384790/AWINProtocolGoats.pdf>.
- 999 AWIN, 2015b. AWIN welfare assessment protocol for horses.  
1000 <https://air.unimi.it/retrieve/handle/2434/269097/384836/AWINProtocolHorses.pdf>.
- 1001 AWIN, 2015c. AWIN welfare assessment protocol for sheep.  
1002 [https://www.researchgate.net/publication/275887069\\_AWIN\\_Welfare\\_Assessment\\_P](https://www.researchgate.net/publication/275887069_AWIN_Welfare_Assessment_Protocol_for_Sheep)  
1003 [rotocol\\_for\\_Sheep](https://www.researchgate.net/publication/275887069_AWIN_Welfare_Assessment_Protocol_for_Sheep).
- 1004 AWIN, 2015d. AWIN welfare assessment protocol for turkeys.  
1005 [https://www.researchgate.net/publication/279953184\\_AWIN\\_Welfare\\_assessment\\_pr](https://www.researchgate.net/publication/279953184_AWIN_Welfare_assessment_protocol_for_Turkeys)  
1006 [otocol\\_for\\_Turkeys](https://www.researchgate.net/publication/279953184_AWIN_Welfare_assessment_protocol_for_Turkeys).
- 1007 Bentham, J., 1789. *An Introduction to the Principles of Morals and Legislation*, Edition  
1008 2017. Johnathan Bennett.  
1009 <http://www.earlymoderntexts.com/assets/pdfs/bentham1780.pdf>.

- 1010 Berghman, L., 2016. Immune responses to improving welfare. *Poultry science* 95,  
1011 2216-2218. <https://doi.org/10.3382/ps/pew159>.
- 1012 Bertrandias, L., Cazes-Valette, G., Gurvey, P., 2021. La préoccupation du bien-être  
1013 animal, quels effets sur la consommation de viande? *Décisions Marketing* 103, 83-  
1014 105. <http://dx.doi.org/10.3917/dm.103.0083>.
- 1015 Bocquier, F., Debus, N., Lurette, A., Maton, C., Viudes, G., Moulin, C.H., Jouven, M.,  
1016 2014. Precision farming in extensive livestock systems. *INRAE Productions Animales*  
1017 27, 101-112. <http://dx.doi.org/10.20870/productions-animales.2014.27.2.3058>.
- 1018 Boissy, A., Manteuffel, G., Jensen, M.B., Moe, R.O., Spruijt, B., Keeling, L.J.,  
1019 Winckler, C., Forkman, B., Dimitrov, I., Langbein, J., 2007. Assessment of positive  
1020 emotions in animals to improve their welfare. *Physiology & behavior* 92, 375-397.  
1021 <http://dx.doi.org/10.1016/j.physbeh.2007.02.003>.
- 1022 Bovenkerk, B., Brom, F.W.A., van den Bergh, B.J., 2002. Brave New Birds: The Use  
1023 of 'Animal Integrity' in Animal Ethics. *Hastings Center Report* 32, 16-22.  
1024 <https://doi.org/10.2307/3528292>.
- 1025 Bracke, M.B.M., Boumans, I.J.M.M., Nijland, H.J., Bokkers, E.A.M., 2023. Review:  
1026 Connecting circularity to animal welfare calls for a 'novel' conceptual framework  
1027 based on integrity. *animal* 17, 100694. <https://doi.org/10.1016/j.animal.2022.100694>.
- 1028 Brambell, F.W.R., Technical Committee to Enquire into the Welfare of Animals kept  
1029 under Intensive Livestock Husbandry, S., 1965. Report of the Technical Committee to  
1030 Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry  
1031 Systems. Her Majesty's Stationery Office, London, UK. [http://docplayer.net/1260087-  
1032 Technical-committee-to-enquire-into-the-welfare-of-animals-kept-under.html](http://docplayer.net/1260087-Technical-committee-to-enquire-into-the-welfare-of-animals-kept-under.html).
- 1033 Broom, D.M., 2007. Welfare in relation to feelings, stress and health. *Revista*  
1034 *electrónica de Veterinaria VIII (12B)*, 1695-7504.  
1035 <https://www.veterinaria.org/index.php/REDVET>.
- 1036 Broom, D.M., Kirkden, R.D., 2004. Welfare, stress, behaviour and pathophysiology.  
1037 In *Veterinary pathophysiology* (ed. Dunlop, R.H.a.M., C.-H. ), Blackwell, p. 337-369.
- 1038 Buckwell, A., Nadeu, E., 2018. What is the Safe Operating Space for EU Livestock?  
1039 RISE Foundation, Brussels, BE. [https://risefoundation.eu/wp-  
1040 content/uploads/2020/07/2018\\_RISE\\_Livestock\\_Full.pdf](https://risefoundation.eu/wp-content/uploads/2020/07/2018_RISE_Livestock_Full.pdf).

- 1041 Buddle, E.A., Bray, H.J., Ankeny, R.A., 2021. "Of course we care!": A qualitative  
1042 exploration of Australian livestock producers' understandings of farm animal welfare  
1043 issues. *Journal of Rural Studies* 83, 50-59.  
1044 <https://doi.org/10.1016/j.jrurstud.2021.02.024>.
- 1045 Buller, H., Blokhuis, H., Jensen, P., Keeling, L., 2018. Towards farm animal welfare  
1046 and sustainability. *Animals* 8, 81. <https://doi.org/10.3390/ani8060081>.
- 1047 Buller, H., Roe, E., 2018. *Food and animal welfare*. Bloomsbury Publishing.
- 1048 Calavas, D., Rosner, G., 1997. Institutionalisation d'une recherche-action en santé  
1049 animale: l'expérience du Centre d'Ecopathologie Animale. 2738007600. INRA.
- 1050 Canguilhem, G., 2005. *Le Normal et le Pathologique, augmenté d'une autre étude*  
1051 *inédite, Nouvelles réflexions concernant le normal et le pathologique (1963-1966), 9e*  
1052 *réédition*. Presses Universitaires de France, Paris, FR.
- 1053 Chiron, P., Doré, A., Lamothe, L.F., 2022. Factors affecting French rabbit farmers'  
1054 adoption of pro-welfare innovations. *World Rabbit Science* 30, 249-265.  
1055 <https://doi.org/10.4995/wrs.2022.17882>.
- 1056 Clark, B., Stewart, G.B., Panzone, L.A., Kyriazakis, I., Frewer, L.J., 2016. A  
1057 Systematic Review of Public Attitudes, Perceptions and Behaviours Towards  
1058 Production Diseases Associated with Farm Animal Welfare. *Journal of Agricultural*  
1059 *and Environmental Ethics* 29, 455-478. [https://dx.doi.org/10.1007/s10806-016-9615-](https://dx.doi.org/10.1007/s10806-016-9615-x)  
1060 *x*.
- 1061 Commandeur, M.A.M., 2006. Diversity of pig farming styles: understanding how it is  
1062 structured. *NJAS: Wageningen Journal of Life Sciences* 54, 111-127.  
1063 [10.1016/S1573-5214\(06\)80007-2](https://doi.org/10.1016/S1573-5214(06)80007-2).
- 1064 Conti, A.A., 2018. Historical evolution of the concept of health in Western medicine.  
1065 *Acta Biomedica* 89, 352-354. <https://dx.doi.org/10.23750/abm.v89i3.6739>.
- 1066 Cornish, A., Raubenheimer, D., McGreevy, P., 2016. What we know about the  
1067 public's level of concern for farm animal welfare in food production in developed  
1068 countries. *Animals* 6, 74. <http://dx.doi.org/10.3390/ani6110074>.
- 1069 Dahlem Workshop, 2001. *Coping with challenge: welfare in animals including*  
1070 *humans;[report of the 87th Dahlem Workshop on Coping with Challenge-Welfare in*  
1071 *Animals Including Humans, Berlin, November 12-17, 2000; Dahlem Workshop report*  
1072 *87]*. Dahlem University Press.

- 1073 Dantzer, R., 2018. Neuroimmune Interactions: From the Brain to the Immune System  
1074 and Vice Versa. *Physiological Reviews* 98, 477-504.  
1075 <https://dx.doi.org/10.1152/physrev.00039.2016>.
- 1076 Dawkins, M.S., 2019. Animal welfare as preventative medicine. *Animal Welfare* 28,  
1077 137-141. <https://doi.org/10.7120/09627286.28.2.137>.
- 1078 Dawkins, M.S., 2023. Farm animal welfare: Beyond “natural” behavior. *Science* 379,  
1079 326-328. <http://dx.doi.org/10.1126/science.ade5437>.
- 1080 Deblitz, C., Efken, J., Banse, M., Isermeyer, F., Rohlmann, C., Tergast, H., Thobe,  
1081 P., Verhaagh, M., 2021. Policy Impact Assessment on the Recommendations of the  
1082 Livestock Farming Competence Network-Abstract. Thünen Working Paper 173,  
1083 Thünen Working Paper 173. <https://dx.doi.org/10.3220/WP1619424590000>.
- 1084 Delanoue, E., Roguet, C., 2015. Acceptabilité sociale de l'élevage en France :  
1085 recensement et analyse des principales controverses à partir des regards croisés de  
1086 différents acteurs. *INRAE Productions Animales* 28, 39-50.  
1087 <https://dx.doi.org/10.20870/productions-animales.2015.28.1.3009>.
- 1088 Delsart, M., Pol, F., Dufour, B., Rose, N., Fablet, C., 2020. Pig farming in alternative  
1089 systems: strengths and challenges in terms of animal welfare, biosecurity, animal  
1090 health and pork safety. *Agriculture* 10, 261.  
1091 <https://doi.org/10.3390/agriculture10070261>.
- 1092 Engelsen Etterlin, P., 2016. Osteochondrosis in pigs. Doctoral Thesis, Swedish  
1093 University of Agricultural Sciences, Uppsala, SE.  
1094 [https://pub.epsilon.slu.se/13316/1/etterlin\\_p\\_160428.pdf](https://pub.epsilon.slu.se/13316/1/etterlin_p_160428.pdf).
- 1095 European Commission, 2021. Communication from the commission the European  
1096 Citizens' Initiative (ECI) "End the Cage Age". European Commission, Brussels, BE.  
1097 [https://ec.europa.eu/transparency/documents-](https://ec.europa.eu/transparency/documents-register/detail?ref=C(2021)4747&lang=en)  
1098 [register/detail?ref=C\(2021\)4747&lang=en](https://ec.europa.eu/transparency/documents-register/detail?ref=C(2021)4747&lang=en).
- 1099 European Union, 2016. Consolidated version of the Treaty on the functioning of the  
1100 European Union. Part one - Principles, Title II - Provisions having general application.  
1101 Official Journal of the European Union OJ C 202, 7.6.2016, 54 p. [https://eur-](https://eur-lex.europa.eu/eli/treaty/tfeu_2016/art_13/oj)  
1102 [lex.europa.eu/eli/treaty/tfeu\\_2016/art\\_13/oj](https://eur-lex.europa.eu/eli/treaty/tfeu_2016/art_13/oj).
- 1103 Fernandes, J., Blache, D., Maloney, S.K., Martin, G.B., Venus, B., Walker, F.R.,  
1104 Head, B., Tilbrook, A., 2019. Addressing Animal Welfare through Collaborative  
1105 Stakeholder Networks. *Agriculture* 9, 132. <https://www.mdpi.com/2077-0472/9/6/132>.

- 1106 Food and Agriculture Organization of the United Nations, 2006. Livestock's long  
1107 shadow. Environmental issues and options. Food and Agriculture Organization of the  
1108 United Nations (FAO), Rome, IT. <https://www.fao.org/3/a0701e/a0701e00.htm>.
- 1109 Fraser, A.F., Broom, D.M., 1997. Farm animal behaviour and welfare, 3eme Edition.  
1110 CAB international, Wallingford, UK.
- 1111 Guyomard, H., Détang-Dessendre, C., Dupraz, P., Delaby, L., Huyghe, C., Peyraud,  
1112 J.-L., Reboud, X., Sirami, C., 2023. How the Green Architecture of the 2023–2027  
1113 Common Agricultural Policy could have been greener. *Ambio* 52, 1327-1338.  
1114 [10.1007/s13280-023-01861-0](https://doi.org/10.1007/s13280-023-01861-0).
- 1115 Hansen, B.G., Østerås, O., 2019. Farmer welfare and animal welfare-Exploring the  
1116 relationship between farmer's occupational well-being and stress, farm expansion  
1117 and animal welfare. *Preventive veterinary medicine* 170, 104741.  
1118 <https://doi.org/10.1016/j.prevetmed.2019.104741>.
- 1119 Haraway, D., 2008. *When Species Meet* University of Minnesota Press, Minnesota,  
1120 USA.
- 1121 Harrison, R., 1964. Book Reviews : Animal Machines: the new factory farming  
1122 industry. *Royal Society of Health Journal* 84 (VINCENT STUART PUBLISHERS LTD.  
1123 London, 1964. £1 1s. 0d), 186 p. <https://dx.doi.org/10.1177/146642406408400637>.
- 1124 Hellec, F., Manoli, C., Joybert, M.d., 2021. Alternative Medicines on the Farm: A  
1125 Study of Dairy Farmers' Experiences in France. *Frontiers in Veterinary Science* 8  
1126 <https://dx.doi.org/10.3389/fvets.2021.563957>.
- 1127 Højsgaard, S., Friggens, N.C., 2010. Quantifying degree of mastitis from common  
1128 trends in a panel of indicators for mastitis in dairy cows. *Journal of Dairy Science* 93,  
1129 582-592. <https://doi.org/10.3168/jds.2009-2445>.
- 1130 Holloway, L., 2019. Smallholder knowledge-practices and smallholding animals:  
1131 threats or alternatives to agricultural biosecurity? *Journal of Rural Studies* 69, 19-29.  
1132 <https://doi.org/10.1016/j.jrurstud.2019.04.013>.
- 1133 Holt, P.S., 2021. Centennial Review: A revisiting of hen welfare and egg safety  
1134 consequences of mandatory outdoor access for organic egg production. *Poultry*  
1135 *science* 100, 101436. <https://doi.org/10.1016/j.psj.2021.101436>.

- 1136 Hostiou, N., Allain, C., Chauvat, S., Turlot, A., Pineau, C., Fagon, J., 2014. L'élevage  
1137 de précision : quelles conséquences pour le travail des éleveurs ? INRAE  
1138 Productions Animales 27, 113-122. [https://dx.doi.org/10.20870/productions-](https://dx.doi.org/10.20870/productions-animales.2014.27.2.3059)  
1139 [animales.2014.27.2.3059](https://dx.doi.org/10.20870/productions-animales.2014.27.2.3059).
- 1140 Johan Lagerkvist, C., Hansson, H., Hess, S., Hoffman, R., 2011. Provision of farm  
1141 animal welfare: Integrating productivity and non-use values. Applied Economic  
1142 Perspectives and Policy 33, 484-509. <https://www.jstor.org/stable/41336221>.
- 1143 Jones, K.E., Patel, N.G., Levy, M.A., Storeygard, A., Balk, D., Gittleman, J.L.,  
1144 Daszak, P., 2008. Global trends in emerging infectious diseases. Nature 451, 990-  
1145 993. <https://www.nature.com/articles/nature06536>.
- 1146 Knierim, U., 2006. Animal welfare aspects of outdoor runs for laying hens: a review.  
1147 NJAS: Wageningen Journal of Life Sciences 54, 133-145.  
1148 [https://doi.org/10.1016/S1573-5214\(06\)80017-5](https://doi.org/10.1016/S1573-5214(06)80017-5).
- 1149 Larrere, R., 2007. Justifications éthiques des préoccupations concernant le bien-être  
1150 animal. INRAE Productions Animales 20, 11-16.  
1151 <https://dx.doi.org/10.20870/productions-animales.2007.20.1.3427>.
- 1152 Larson, G., Burger, J., 2013. A population genetics view of animal domestication.  
1153 Trends in Genetics 29, 197-205. <https://doi.org/10.1016/j.tig.2013.01.003>.
- 1154 Lawrence, A.B., Stott, A.W., 2009. Profiting from animal welfare: an animal-based  
1155 perspective. Journal of the Royal Agricultural Society of England 170, 40-47.
- 1156 Lay Jr, D., Fulton, R., Hester, P., Karcher, D., Kjaer, J., Mench, J.A., Mullens, B.,  
1157 Newberry, R.C., Nicol, C.J., O'Sullivan, N.P., 2011. Hen welfare in different housing  
1158 systems. Poultry science 90, 278-294. <https://doi.org/10.3382/ps.2010-00962>.
- 1159 Le Neindre, P., Bernard, E., Boissy, A., Boivin, X., Calandreau, L., Delon, N.,  
1160 Deputte, B., Desmoulin-Canselier, S., Dunier, M., Faivre, N., Giurfa, M., Guichet, J.-  
1161 L., Lansade, L., Larrère, R., Mormède, P., Prunet, P., Schaal, B., Servière, J.,  
1162 Terlouw, C., 2017. Animal Consciousness. EFSA Supporting Publications 14, 1196E.  
1163 <https://doi.org/10.2903/sp.efsa.2017.EN-1196>.
- 1164 Le Neindre, P., Guatteo, R., Guémené, D., Guichet, J.-L., Latouche, K., Leterrier, C.,  
1165 Levionnois, O., Mormede, P., Prunier, A., Serrie, A. & Servière, J., 2009. Douleurs  
1166 animales : Les identifier, les comprendre, les limiter chez les animaux d'élevage.  
1167 Expertises collectives.  
1168 <https://www.inrae.fr/sites/default/files/pdf/05e1f915d62a32c84cf9865b9d6c39.pdf>.

- 1169 Leminen, S., 2015. Q&A. What Are Living Labs? . Technology Innovation  
1170 Management Review 5 <https://timreview.ca/article/928>.
- 1171 Leterrier, C., Aubin-Houzelstein, G., Boissy, A., Deiss, V., Fillon, V., Lévy, F., Merlot,  
1172 E., Petit, O., 2022. Améliorer le bien-être des animaux d'élevage : est-ce toujours  
1173 possible ? Sciences et Société, Alimentation, Mondes Agricoles et Environnement  
1174 (SESAME) [https://revue-sesame-inrae.fr/ameliorer-le-bien-etre-des-animaux-  
1175 delevage-est-ce-toujours-possible/](https://revue-sesame-inrae.fr/ameliorer-le-bien-etre-des-animaux-delevage-est-ce-toujours-possible/).
- 1176 Lutgendorf, S., 2001. Life, liberty and the pursuit of happiness: good welfare in  
1177 humans. In *Coping with Challenge: Welfare in Animals including Humans* (ed.  
1178 Broom, D.), Dahlem University Press, Berlin, DE, p. 49-62.
- 1179 Mahon, N., Clark, B., Proctor, A., Holloway, L., 2021. Exploring farmers'  
1180 understanding of and responses to endemic animal health and welfare issues in the  
1181 UK. *Veterinary Record* 189, 1-8. <https://doi.org/10.1002/vetr.941>.
- 1182 Mazars, G., 1994. Traditional veterinary medicine in India. *Revue scientifique et  
1183 technique (International Office of Epizootics)* 13, 433-451.  
1184 <http://dx.doi.org/10.20506/rst.13.2.776>.
- 1185 McEwen, S.A., Collignon, P.J., 2018. Antimicrobial resistance: a one health  
1186 perspective. In *Antimicrobial resistance in bacteria from livestock and companion  
1187 animals - Chapter 25* (ed. Stefan Schwarz, L.M.C., Jianzhong Shen), ASM Press,  
1188 Washington, USA, p. 521-547. <https://dx.doi.org/10.1128/9781555819804.ch25>.
- 1189 Mignon-Grasteau, S., Boissy, A., Bouix, J., Faure, J.-M., Fisher, A.D., Hinch, G.N.,  
1190 Jensen, P., Le Neindre, P., Mormède, P., Prunet, P., Vandeputte, M., Beaumont, C.,  
1191 2005. Genetics of adaptation and domestication in livestock. *Livestock Production  
1192 Science* 93, 3-14. <https://doi.org/10.1016/j.livprodsci.2004.11.001>.
- 1193 Mormede, P., Boisseau-Sowinski, L., Chiron, J., Diederich, C., Eddison, J., Guichet,  
1194 J.-L., Le Neindre, P., Meunier-SalaÜN, M.-C., 2018. Bien-être animal : contexte,  
1195 définition, évaluation. *INRAE Productions Animales* 31, 145-162.  
1196 <https://dx.doi.org/10.20870/productions-animales.2018.31.2.2299>.
- 1197 Mounaix, B., Terlouw, C., Le Guenic, M., Bignon, L., Meunier-Salaün, M.-C.,  
1198 Courboulay, V., Mirabito, L., 2013. L'évaluation et la gestion du bien-être animal:  
1199 diversité des approches et des finalités. 20. Rencontres autour des Recherches sur  
1200 les Ruminants, Paris, FR Institut de l'Élevage-INRA.

- 1201 O’Kane, H., Ferguson, E., Kaler, J., Green, L., 2017. Associations between sheep  
1202 farmer attitudes, beliefs, emotions and personality, and their barriers to uptake of  
1203 best practice: The example of footrot. *Preventive veterinary medicine* 139, 123-133.  
1204 <http://dx.doi.org/10.1016/j.prevetmed.2016.05.009>.
- 1205 Patou-Mathis, M., 2009. *Mangeurs de viande : de la Préhistoire à nos jours*. Editions  
1206 Perrin, Paris, FR.
- 1207 Pohl, C., 2011. What is progress in transdisciplinary research? *Futures* 43, 618-626.  
1208 <https://doi.org/10.1016/j.futures.2011.03.001>.
- 1209 Porcher, J., 2017. *The Ethics of Animal Labor: A Collaborative Utopia*. Palgrave  
1210 Macmillan Cham, London, UK. <https://doi.org/10.1007/978-3-319-49070-0>.
- 1211 Price, E.O., 1984. Behavioral Aspects of Animal Domestication. *The Quarterly*  
1212 *Review of Biology* 59, 1-32. <http://www.jstor.org/stable/2827868>.
- 1213 Quéméré, P., Le Neindre, P., 2013. Le Bien-être Animal: Perception et Réponses  
1214 des Éleveurs et de leurs Organisations: Éthique et Bien-être Animal en Élevage.  
1215 *Ethnozootecnie*, 65-71.
- 1216 Rauw, W.M., 2008. *Resource allocation theory applied to farm animal production*.  
1217 CABI.
- 1218 Rodrigues da Costa, M., Diana, A., 2022. A Systematic Review on the Link between  
1219 Animal Welfare and Antimicrobial Use in Captive Animals. *Animals (Basel)* 12  
1220 <https://dx.doi.org/10.3390/ani12081025>.
- 1221 Rostellato, R., Lora, I., Promp, J., Cassandro, M., Ducrocq, V., Cozzi, G., 2022.  
1222 Factors affecting true and functional productive lifespan in Italian Holstein-Friesian  
1223 cows. *ITALIAN JOURNAL OF ANIMAL SCIENCE* 21, 1268-1276.  
1224 <https://doi.org/10.1080/1828051X.2022.2105264>.
- 1225 Rousseau, J.-J., 1754. *Discourse on the Origin of Inequality: What is the Origin of*  
1226 *Inequality Among Men, and is it Authorised by Natural Law?* In *The Social Contract &*  
1227 *Discourses* (1913). (ed. Rhys, E.), Dent & Sons Ltd, London, UK, p. 155-246.
- 1228 Sachser, N., 2001. What is important to achieve good welfare in animals. *Dahlem*  
1229 *Workshop Report* 87.

- 1230 Sadoul, B., Leguen, I., Colson, V., Friggens, N.C., Prunet, P., 2015. A multivariate  
1231 analysis using physiology and behavior to characterize robustness in two isogenic  
1232 lines of rainbow trout exposed to a confinement stress. *Physiology & behavior* 140,  
1233 139-147. <https://doi.org/10.1016/j.physbeh.2014.12.006>.
- 1234 Salembier, C., Segrestin, B., Weil, B., Jeuffroy, M.-H., Cadoux, S., Cros, C.,  
1235 Favrelière, E., Fontaine, L., Gimaret, M., Noilhan, C., 2021. A theoretical framework  
1236 for tracking farmers' innovations to support farming system design. *Agronomy for*  
1237 *Sustainable Development* 41, 61. <https://doi.org/10.1007/s13593-021-00713-z>.
- 1238 Salmona, M., 1985. *Les Paysans français: le travail, les métiers, la transmission des*  
1239 *savoirs*. L'Harmattan, Paris, FR.
- 1240 Saylor, C., 2004. The Circle of Health: A Health Definition Model. *Journal of Holistic*  
1241 *Nursing (Official journal of the American Holistic Nurses' Association)* 22, 97-115.  
1242 <https://dx.doi.org/10.1177/0898010104264775>.
- 1243 Sidik, S.M., 2023. How to stop the bird flu outbreak becoming a pandemic. *Nature*  
1244 615, 196-197. <https://dx.doi.org/10.1038/d41586-023-00591-3>.
- 1245 Sossidou, E., Dal Bosco, A., Castellini, C., Grashorn, M., 2015. Effects of pasture  
1246 management on poultry welfare and meat quality in organic poultry production  
1247 systems. *World's poultry science journal* 71, 375-384.  
1248 <https://doi.org/10.1017/S0043933915000379>.
- 1249 Tuytens, F.A.M., Molento, C.F.M., Benaissa, S., 2022. Twelve Threats of Precision  
1250 Livestock Farming (PLF) for Animal Welfare. *Frontiers in Veterinary Science* 9  
1251 <https://dx.doi.org/10.3389/fvets.2022.889623>.
- 1252 Vaarst, M., Alrøe, H.F., 2012. Concepts of Animal Health and Welfare in Organic  
1253 Livestock Systems. *Journal of Agricultural and Environmental Ethics* 25, 333-347.  
1254 <https://dx.doi.org/10.1007/s10806-011-9314-6>.
- 1255 Vaarst, M., Hellec, F., Verwer, C., Juni, R., E, Sørheim, K., 2020. Cow calf contact in  
1256 dairy herds viewed from the perspectives of calves, cows, humans and the farming  
1257 system. Farmers' perceptions and experiences related to dam-rearing systems.  
1258 *Journal of sustainable and organic agricultural systems* 70, 49-57.  
1259 <https://dx.doi.org/10.3220/lbf1596195636000>.
- 1260 van der Linden, R., Schermer, M., 2022. Health and disease as practical concepts:  
1261 exploring function in context-specific definitions. *Medicine, Health Care and*  
1262 *Philosophy* 25, 131-140. <https://dx.doi.org/10.1007/s11019-021-10058-9>.

- 1263 Vanhonacker, F., Verbeke, W., Van Poucke, E., Tuytens, F.A., 2008. Do citizens and  
1264 farmers interpret the concept of farm animal welfare differently? *Livestock Science*  
1265 116, 126-136. <https://doi.org/10.1016/j.livsci.2007.09.017>.
- 1266 Veissier, I., Botreau, R., Perny, P., 2010. Multicriteria evaluation applied to farm  
1267 animal welfare: difficulties and solutions from the Welfare Quality® project
- 1268 Evaluation multicritère appliquée au bien-être des animaux en ferme ou à l'abattoir :  
1269 difficultés et solutions du projet Welfare Quality®. *INRA Productions Animales* 23,  
1270 269-284. <https://hal.inrae.fr/hal-02659189>.
- 1271 Welfare Quality®, 2009a. Welfare Quality® assessment protocol for cattle. Welfare  
1272 Quality® Consortium, Lelystad, Netherlands.  
1273 [http://www.welfarequality.net/media/1088/cattle\\_protocol\\_without\\_veal\\_calves.pdf](http://www.welfarequality.net/media/1088/cattle_protocol_without_veal_calves.pdf).
- 1274 Welfare Quality®, 2009b. Welfare Quality® Assessment protocol for pigs (sows and  
1275 piglets, growing and finishing pigs). Welfare Quality® Consortium, Lelystad,  
1276 Netherlands. [http://www.welfarequality.net/media/1018/pig\\_protocol.pdf](http://www.welfarequality.net/media/1018/pig_protocol.pdf).
- 1277 Welfare Quality®, 2009c. Welfare Quality® Assessment protocol for poultry (broilers,  
1278 laying hens). Welfare Quality® Consortium, Lelystad, Netherlands.
- 1279 Whay, H.R., 2007. The journey to animal welfare improvement. *Animal Welfare* 16,  
1280 117-122. <https://dx.doi.org/10.1017/S0962728600031134>.
- 1281 World Health Organization, 2017. About World Health Organization. Constitution.,  
1282 May 19, 2023. <http://www.who.int/governance/eb/constitution/en/>.
- 1283 World Organisation for Animal Health, 2022. Introduction to the recommendations for  
1284 animal welfare - chapter 7.1 In *Terrestrial animal health code*, World Organisation for  
1285 Animal Health, [https://www.woah.org/en/what-we-do/standards/codes-and-](https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmlfile=chapitre_aw_introduction.htm)  
1286 [manuals/terrestrial-code-online-](https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmlfile=chapitre_aw_introduction.htm)  
1287 [access/?id=169&L=1&htmlfile=chapitre\\_aw\\_introduction.htm](https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmlfile=chapitre_aw_introduction.htm).
- 1288 Zachariae, R., 2009. Psychoneuroimmunology: A bio-psycho-social approach to  
1289 health and disease. *Scandinavian Journal of Psychology* 50, 645-651.  
1290 <https://doi.org/10.1111/j.1467-9450.2009.00779.x>.
- 1291 Zerjal, T., Härtle, S., Gourichon, D., Guillory, V., Bruneau, N., Laloë, D., Pinard-van  
1292 Der Laan, M.-H., Trapp, S., Bed'hom, B., Quéré, P., 2021. Assessment of trade-offs  
1293 between feed efficiency, growth-related traits, and immune activity in experimental  
1294 lines of layer chickens. *Genetics Selection Evolution* 53, 44.  
1295 <https://doi.org/10.1186/s12711-021-00636-z>.