REPORT: A SURVEY OF EXISTING DIGITALLY INTEGRATED TOOLS FOR ANIMAL MONITORING

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WHAT DO BOILERS WELFARE ASSESSMENT METHODS MEASURE?

WELFARE QUALITY

Animal welfare policy in the EU is based on the five freedoms, i.e. freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury, or disease; freedom to express normal behavior; and freedom from fear and distress. Recently, Welfare Quality has gained popularity as a method of assessing animal welfare. Its use has increased especially in research, but also some marketing labels have started to adopt the methods as part of their certification processes. Also Welfare Quality has its foundations in the five freedoms. The key aspect of Welfare Quality is that it measures welfare, to a large extent, from the animals (animal-based measures), and only to small extent from their environment (resource-based measures).

Welfare Quality approaches animal welfare through though four principles (good feeding, good housing, good health, appropriate behavior) and 12 criteria which fall under one of these criteria. Each of four principles represents different dimension of animal welfare, is expected to be independent of other principles, respond to a specific question:

- Are the animals properly fed and supplied with water?
- Are the animals housed properly?
- Are the animals healthy?
- Does the behaviour of the animals reflect optimised emotional states?

Four principles should be impartial. This means that compensations and linkages between the welfare criteria and especially between the principles, should be limited. Four principles, 12 welfare criteria, and their meanings (clarified in parenthesis) are:

- Good feeding
  - 1. Absense of prolonged hunger (i.e. animals should have a sufficient and appropriate diet).
  - 2. Absense of prolonged thirst (i.e. animals should have a sufficient and accessible water supply).
- Good housing
  - 3. Comfort around resting.
  - 4. Thermal comfort (i.e. in terms of environment, the animals should neither be too hot nor too cold).
  - 5. Ease of movement (i.e. animals should have enough space to be able to move around freely).
- Good health
  - 6. Absence of injuries (i.e. animals should be free of physical injuries).
  - 7. Absence of disease (i.e. farmers should maintain high standards of hygiene and care).
  - 8. Absence of pain induced by management practices (i.e. animals should not suffer pain induced by inappropriate management, handling, slaughter, or surgical procedures (e.g. castration, dehorning)).
- Appropriate behavior
  - 9. Expression of social behaviours (i.e. animals should be able to express normal, non-harmful, social behaviours, e.g. grooming).
  - 10. Expression of other behaviours (i.e. it should be possible for animals to express species-specific natural behaviours such as foraging).
  - 11. Good human-animal relationship (i.e. animals should be handled well in all situations and handlers should promote good human-animal relationships).
  - 12. Positive emotional state (i.e. negative emotions such as fear, distress, frustration or apathy should be avoided whereas positive emotions such as security or contentment should be promoted).

In broiler production, measurements leading to the Welfare Quality score are taken both at the farm and at the slaughterhouse (slaughterhouse indicators or farm indicators based on slaughter data). Measurements at the farm are carried out by selecting a sample of birds and observing them on the farm. Measurements on the farm include observing:

- Number of birds per drinker

- Litter quality
- Dust sheet test
- Stocking density kg/m^2
- Plumage cleanliness
- Panting (% birds)
- Huddling (% birds)
- On farm mortality
- Culls on farm
- Lameness (gait score)
- Hock burn
- Foot pad dermatitis
- Avoidance distance test (number of birds who approach the assessor within 1 m of the observer))
- Qualitative behavioural assessment during which the observer counts the number of birds showing specific behaviors. The monitored behaviors are: Active, Calm, Friendly, Relaxed, Content, Positively occupied, Helpless, Tense, Scared, Comfortable, Inquisitive, Drowsy, Fearful, Unsure, Playful, Agitated, Energetic, Nervous, Confident, Frustrated, Distressed, Depressed, Bored

Data collected at slaughter or slaughterhouse include:

- Emaciation (% birds)
- Breast blisters (% birds)
- Hock burn (score)
- Foot pad dermatitis (score)
- Ascites (% birds)
- Dehydration (% birds)
- Septicaemia (% birds)
- Hepatitis (% birds)
- Pericarditis (% birds)
- Abscesses (% birds)
- Feed withdraval time (minutes)
- Water withdraval time (minutes)
- Panting on lorry/at lairage (%)
- Stocking density in crates
- Wing damage (fractures, %)
- Bruising (%)
- Dead on arrival (%)
- Pre-stun shocks (%)
- Effectiveness of stunning (%)
- Flapping on the line(%)

After recording all the measurements, the scores are calculated first for each welfare criteria, then for principles and finally for the overall assessment score. The scoring procedure is explained in the assessment protocol. Overall it is quite complex procedure, because different observations are given a weight and they are transformed to scores by using a set of functions, scoring tables, splines in some cases. Finally, Choquet integrals, which are used to calculate the scores for each principle (see poultry assessment protocol, page 20) to obtain the principle scores. The scores are formed from welfare criteria so that the score is between zero (poorest level) and 100 (best level), and the score of 50 corresponds to a neutral situation. The scoring is non-linear and in practice it leads to the situation where both extremes (very low score or very high score) are difficult to achieve. When calculating different scores, weights are assigned to the measurements and subscores. When Welfare Quality protocols were developed several about a decade ago, this weighing for the different criteria was formed based on expert opinion. In we are going to develop specific welfare index for HKScan, similar exercise could be done in Finland or in Scandinavia e.g. by using Delphi methods.

SOME OTHER PROTOCOLS

The challenge of Welfare Quality is that the assessment procedure is time-consuming. Because of this, *simplified or lighter protocols* for animal welfare assessment have been developed (simplified but based on the idea of Welfare Quality). They don't seem to be better or more complete than Welfare Quality because the main focus seems to be in reducing the effort needed to carry out a Welfare Quality assessment. De Jong et al. (2015, see the graphs copy-pasted below) tested the full Welfare Quality protocol and a simplified protocol, and found reasonable correlations between the scores of the simplified protocol and full protocol, when indicators of Foot pad dermatitis, hock burn, cleanliness and gait score were considered. They also estimated or redefined methods used to calculate the welfare scores. They considered the prediction of gait scores using hock burn scores as a possible simplification strategy (strategy 1). Moreover, the on-farm measurements of foot pad dermatitis, hock burn, cleanliness and gait score correlated moderately to highly with measurements of footpad dermatitis and/or hock burn at the slaughter plant. This was concluded to support the substitution of on-farm measurements with slaughter plant data. A simplification analysis was performed using footpad dermatitis, hock burn, cleanliness and gait scores measured on-farm predicted from slaughter plant measurements of footpad dermatitis and hock burn (strategy 2). Simplification strategies were compared with the full assessment protocol. Close agreement was found between the full protocol and both simplification strategies although large confidence intervals were found for specificity of the simplified models. It is concluded that the proposed simplification strategies are encouraging; strategy 1 could reduce the time to complete the on-farm assessment by about 1 h (25% to 33% reduction) and strategy 2 can reduce on-farm assessment time by about 2 h (50% to 67% reduction) and still provide reasonable estimates on broiler welfare. The simplification strategies should, however, be validated further and tested on farms with a wide distribution across the different welfare categories of Welfare Quality.

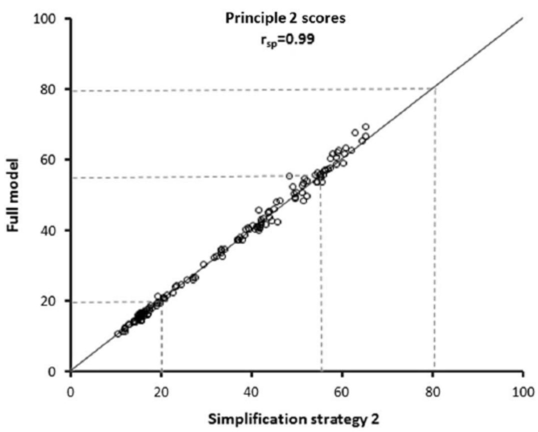


Figure 1 Principle 2 (good housing) assessment scores based on the full model (y axis) plotted against assessment scores according to simplification strategy 2. The graph shows distribution of flocks over classification groups ⩽20, 20 to 55, ⩾55 and the correlation (Spearman rank correlation; r_{sp}) between the full model and the simplified model.

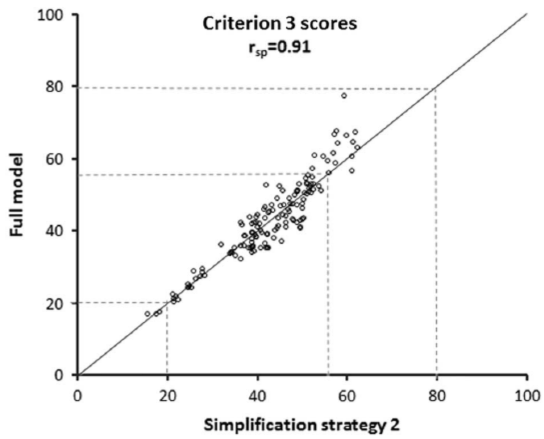


Figure 3 Criterion 3 (comfort around resting) assessment scores based on the full model (y axis) plotted against assessment scores according to simplification strategy 2. The graph shows distribution of flocks over classification groups ⩽20, 20 to 55, ⩾55 and the correlation (Spearman rank correlation; r_{sp}) between the full model and the simplified model.

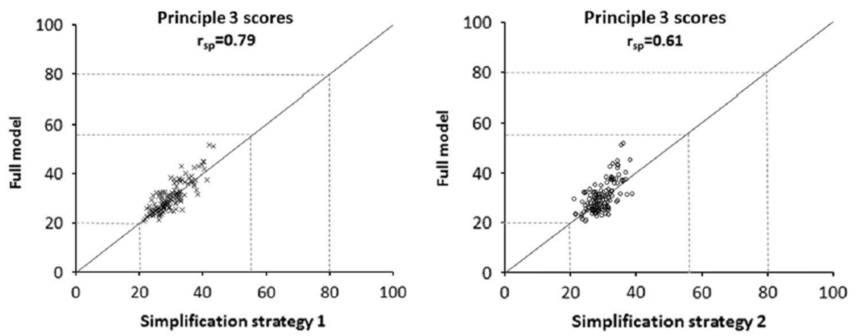


Figure 2 Principle 3 (good health) assessment scores based on the full model (y axis) plotted against assessment scores according to simplification strategy 1 (graph A) or 2 (graph B). The graphs show distribution of flocks over classification groups ⩽20, 20 to 55, ⩾55 and the correlation (Spearman rank correlation; r_{sp}) between the full model and the simplified models.

FIGURE: Correlation diagrams for selected welfare criteria measured by using full and simplified Welfare Quality protocol (De Jong et al. 2015).

AssureWel project (2010-2016) has developed another animal welfare assessment protocol. The project was conducted in the UK by the RSPCA, Soil Association and University of Bristol. The assessment is much more limited that the Welfare Quality assessment. In conventional indoor production the assessment consists of four parts

a) Whole flock assessment (first overall look within the house, paying attention to evenness of (spatial) bird distribution in the house, air quality (ammonia and dust), presence of panting, dirtiness of birds, and the use of enrichments by the birds)

b) Defined walk (a systematic walk around the house observing all birds within the path: birds' walking ability, birds requiring culling, runt and dead birds, activeness and interaction of birds' behavior).

c) Individual measures (a randomly selected group of 25 birds to look for hock burn and pododermatitis lesions)

d) Checking on-farm records (antibiotics use, mortality, post-slaughter information on DOA's, rejects, breast blisters, wing and leg damage, Hock burn, and pododermatitis).

This approach has some similarities with the transect walk method that has been tested in turkeys (Marchewka et al., 2015).

BEHAVIOR AS WELFARE INDICATOR

BEHAVIOURAL NEEDS

Animals including broilers have an inner need (motivation) to express natural behavior. If the animals are not able to express behaviors due to physiological or space restriction, it leads to decreased welfare and can lead to development of abnormal behaviors. The basic behavioral needs and their expression in slow and fast-growing broilers was studied in the thesis of Bokkers (2004), (Bokkers & Koene 2003) with the following main conclusions:

- Apart from having an abnormal high motivation to eat, broilers have similar behavioral needs to chickens. Broilers eat to their maximal physical capacity and the feeding is controlled by satiety but not hunger.
- Broilers are restricted to display behaviors which they are motivated by their fast growth or by environmental conditions which they are usually kept.
- Fast and slow growing broilers express similar behaviors, however:
  - Fast growing broilers performed preening, stretching and ground pecking in sitting posture
  - Fast growing broilers walked and perched less and sat more on the floor when over 1 week of age.

E.A.M. Bokkers, P. Koene / Applied Animal Behaviour Science 81 (2003) 59–72 63

Table 1
Ethogram of recorded behaviours. Also is shown if posture was noted (yes/no), which could be either standing or sitting

Behaviour	Description	Posture
Eating	With head above or in the feeder	Yes
Drinking	Pecking to a drinking nipple or drinking out of the cup beneath the drinking nipple	Yes
Preening	Grooming of own feathers with the beak	Yes
Scratching	Scraping of the litter with the claws	Yes
Ground pecking	Pecking movements directed at ground	Yes
Stretching	Stretching of wing and/or leg	Yes
Aggression	Pecks directed to the head of a pen mate or sparring	Yes
Standing idle	Standing without any other activity	No
Sitting idle[a]	Sitting with hocks resting on ground without any other activity	No
Walking	Locomotion with a normal speed or with quick steps	No
Wing flapping	Bilateral up-and-down wing flapping	No
Dust bathing	Performed with fluffed feathers while lying, head rubbed on floor, wings opened, scratching at ground	No
Lying[a]	With the head flat on the bedding or with the head under a wing either with eyes open or closed	No
Other	All other behaviours not mentioned above	Yes

Besides behaviour and posture, the position in the pen (floor or perch) of each individual was noted at the same time.

[a] Sitting idle and lying together are named resting.

FIGURE: Ethogram for broiler behavior (Bokkers & Koene 2003).

E.A.M. Bokkers, P. Koene/Applied Animal Behaviour Science 81 (2003) 59–72 65

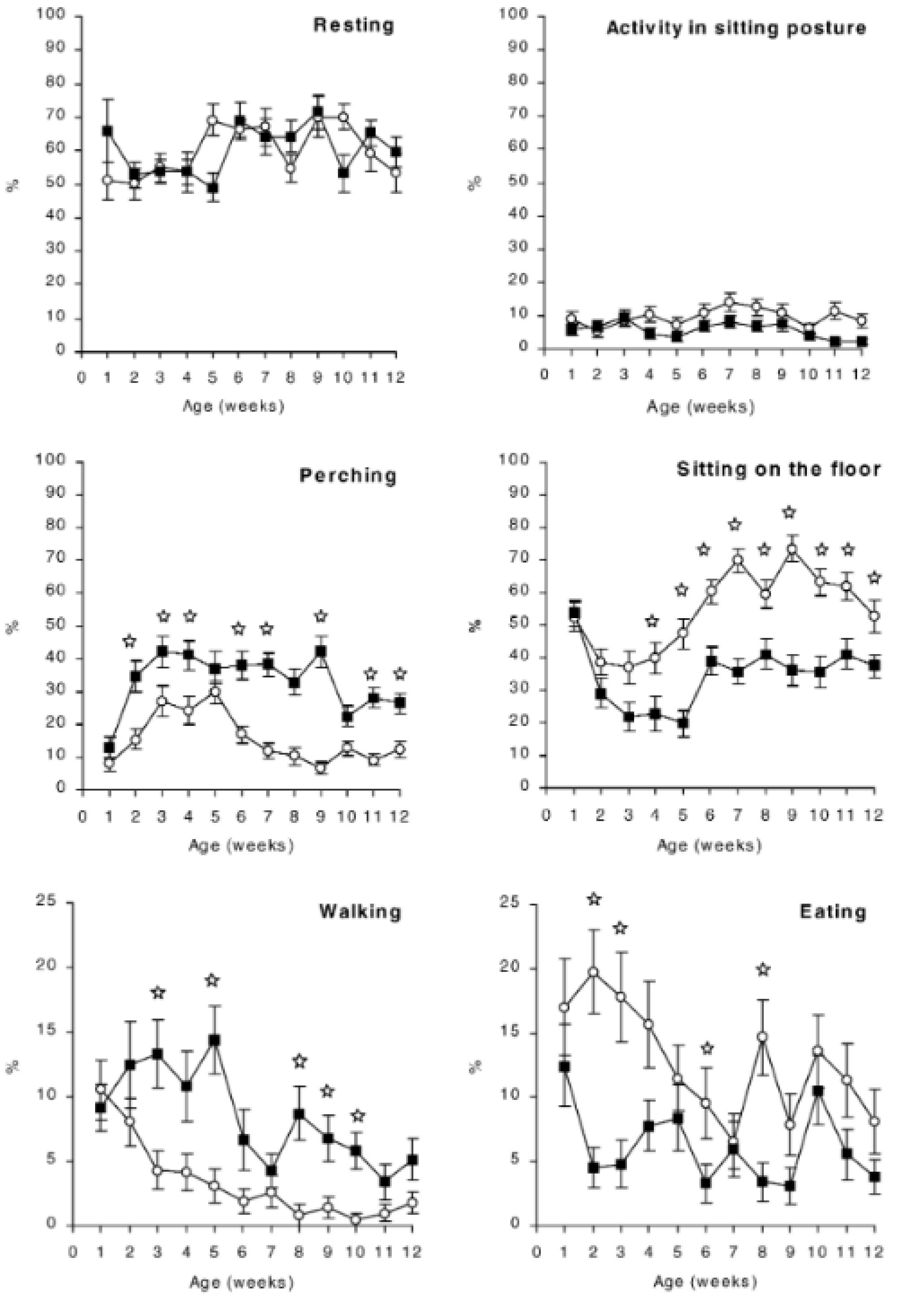


Fig. 1. From top left to bottom right: resting, activity in sitting posture, perching, sitting on the floor, walking and preening as percentage of observed behaviour in fast growing (○) and slow growing (■) broilers. The symbol (☆) means a significant difference of at least $P < 0.05$ at a certain age.

FIGURE: Comparison of behavioral change of fast and slow growing broilers over time (Bokkers & Koene 2003).

COMPARISON OF FAST AND SLOW GROWING BIRDS IN ENRICHED ENVIRONMENT

Bergmann et al. 2017 studied behavior as welfare indicator in farms with and without environmental enrichment and with slow (Cobb Sasso 175) and fast (Ross 308) growing broilers.

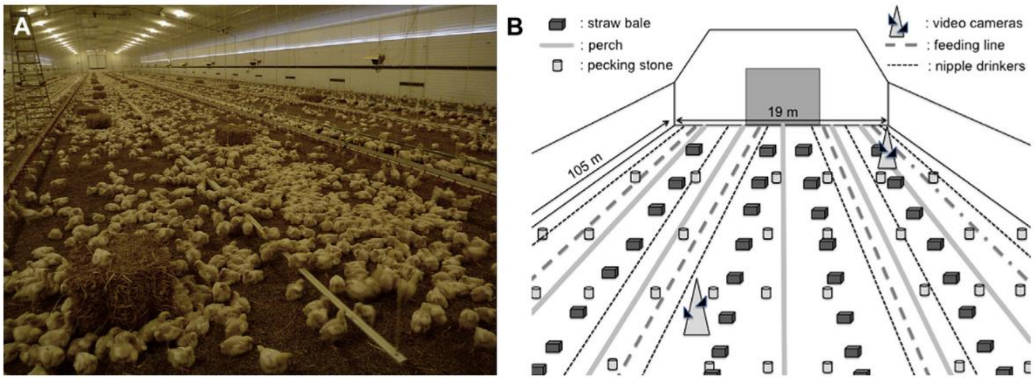


Figure 1. (A) Photographic and (B) schematic illustration (not true to scale) of the equipment inside the alternative barn with perches, straw bales, pecking stones, feeding pans, and nipple drinkers, openings to the roofed outside run on each side of the barn and video observation devices.

FIGURE: Study environment from Bergmann et al. 2017

Main findings:

- Both slow and fast growing broilers use the enrichments, slow growing birds use bales more bales and fast growing use perches more.
- The use of enrichments allows the expression of more natural behaviours for both slow and fast growing birds.
- Fast growing broilers show a decrease in locomotion and foraging during the growth period. The amount of those behaviors is fairly constant in slow growing birds.

Table 3
Percentage of the general behavioral parameters observed in the alternative, enriched rearing concept, Cobb Sasso and Ross 308 in comparison, by age in days

Behavioral parameter	Day 2	Day 9	Day 16	Day 23	Day 30	Day 37
Cobb Sasso—alternative rearing concept						
Lying/resting[a]	23.30 (5888)	32.86 (8113)	34.15 (4928)	42.51 (6868)	48.75 (5862)	55.47 (1288)
Locomotion	2.80 (707)	2.43 (601)	3.91 (564)	2.73 (439)	1.80 (217)	0.52 (12)
Grooming/dust bathing	0 (1)	0.40 (98)	0.58 (84)	0.71 (114)	0.71 (85)	0.60 (14)
Foraging by standing/scratching/pecking	13.13 (3318)	8.61 (2127)	9.99 (1441)	9.60 (1547)	8.57 (1031)	5.94 (138)
Eating	5.48 (1384)	10.46 (2583)	11.59 (1673)	12.68 (2042)	11.93 (1435)	12.06 (280)
Drinking	3.84 (971)	3.38 (834)	3.80 (549)	3.85 (620)	3.53 (424)	2.63 (61)
Ross 308—alternative rearing concept						
Lying/resting[a]	18.88 (1588)	37.74 (1855)	40.71 (2459)	40.84 (2161)	44.61 (2500)	—
Locomotion	3.19 (283)	1.38 (68)	1.52 (92)	0.89 (47)	0.37 (21)	—
Grooming/dust bathing	0.03 (3)	0.18 (9)	0.35 (21)	0.77 (41)	0.46 (26)	—
Foraging by standing/scratching/pecking	11.34 (1007)	9.20 (452)	6.87 (415)	5.18 (274)	5.17 (290)	—
Eating	5.06 (449)	8.14 (400)	10.10 (610)	11.96 (634)	11.99 (672)	—
Drinking	3.99 (354)	3.95 (194)	3.51 (212)	4.16 (220)	3.57 (200)	—

—, Investigation was not performed because animals were already slaughtered at that age.
Total number of observed birds is provided in parentheses. All performed rearing periods (n = 6 for Cobb Sasso and n = 2 for Ross 308) are summarized.
[a] Data in the table exclude lying/resting around straw bales and pecking stones.

FIGURE: Comparison of behavioral time allocation between Cobb Sasso and Ross 308 in enriched environment. Bergmann et al. 2017

S. Bergmann et al. / Journal of Veterinary Behavior 19 (2017) 90–101 95

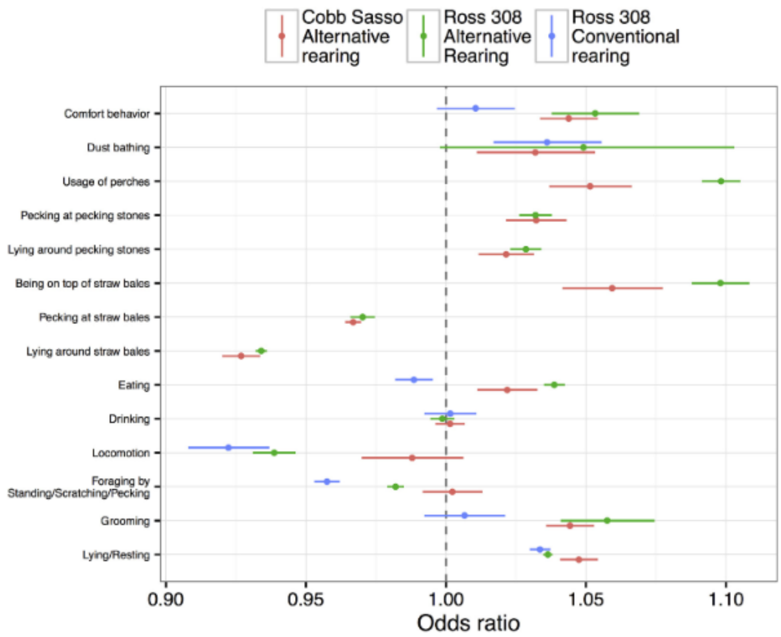


Figure 3. Diagram showing the odds ratios for every behavior pattern in the course of time of the performed and summarized rearing periods (n = 6 for Cobb Sasso enriched [farm 1], n = 2 for Ross 308 enriched [farm 1], and n = 6 for Ross 308 conventional [farm 2]).

FIGURE: Behavioral change when broilers grow. Fast growing broilers show a decrease in locomotion and foraging during the growth period. The amount of those behaviors is fairly constant in slow growing birds. Bergmann et al. 2017).

Positive behaviours and growth rate tend to be negatively associated, although the association is in most studies indirect (i.e. it is studied the relationship between behavior and some factor of causing slow growth (such as slow-growing breed) rather than the association between behavior and growth itself. For instance, Wallenbeck et al. (2016) studied the behavioural time budgets, presence of comfort behaviours and social behaviours in two different broiler genotypes (the fast-growing Ross 308 (R) and the slower growing Rowan Ranger (RR)) fed organic diets with high (17.0% crude protein (CP)) or low (14.5% CP) protein content during a 10-week rearing period. The results showed no effect of diet treatments but that R broilers were less active and sat, ate and drank more frequently than RR broilers, which stood and perched more frequently. However, both hybrids showed decreasing activity and foraging behaviour with increasing age, while time spent eating and sleeping was approximately similar over the entire rearing period.

MEASURING BEHAVIOUR USING SAMPLING

The behavior of birds is usually either conducted by using focal birds or scan sampling a group of birds to assess the effect of production system, enrichment, breed etc. on flock behavior. The behavior of birds is typically assessed by a human from video recordings.

- Bach et al. (2019) used 50 focal birds from flocks of 500 birds
- Norring et al. (2016) followed focal birds from video for 2 minute periods to determine the use of perches
- Bergman et al. (2017) used scan sampling for coding the behavior of all birds from video sampled for 12s with 1 hour intervals in between. The sampling was done from 6 different cameras

CONCLUSIONS ABOUT BEHAVIOR

- Works of Bokkers and Bergman provide initial reference values for expected time allocation across different behaviors
- Expression of all behaviors listed in Ethogram used by Bokkers should be present

- There are mixed results from the use of perches in different studies, probably due to different perch design and physical ability of the used birds. In a Finnish study platforms were used more than perches and can satisfy the broiler need of using elevated platforms (Norring et al. 2016)
- Decrease of locomotion, use of perches and increased sitting during the growth period are indicators of decreased welfare (inability to express behavioral needs)
- Grooming and dust bathing are part of broilers normal behavior and both behaviors should be seen in flocks. Their proportion of the daily time budget is quite low.

TECHNOLOGIES FOR BEHAVIOR MONITORING

Within precision livestock farming (PLF) research published in scientific papers and evaluating either health or welfare of broilers as the main goal, locomotory behavior-based sensors are clearly the most studied sensors (considered in 43.8% of studies according to Rowe et al., 2019). Sensors based on vocalisations or bird sounds (21%) and physiology (12.4%) have received less attention in research. Other approaches such as perching or resting behavior or latency to lie have received attention in only few studies. The technologies however are generic and exist even if they have not been studied and adopted in broilers to the same extent than for instance for dairy cattle. PLF technology can be used to monitor many parameters, such as behaviour, but whether and how the measurements taken by a PLF system are linked to a parameter, i.e. the internal validity of the measure is not always clear. Furthermore, whether and how the monitored parameters are linked to welfare (i.e. the external validity of the measure; for example, what different patterns of optical flow tell us about the birds' welfare status) must be established (Rowe et al., 2019). Validation is important also because farms can differ in housing and management. Although there is evidence that genetic and management factors (e.g. housing, light, rewarding birds for certain behaviors) influence welfare and behavior of broilers (e.g. the time used for expressing natural behaviours), it is important to recognize whether the system can provide reliable information in different conditions. Sensor-based system should acknowledge these differences and aim towards a consistent assessment. It is also important to specify whether the sensors are used to verify whether the farm is making improvements when compared to its past performance, or whether the sensors are used to verify the level of welfare on individual farms when compared to predefined (external) performance standards.

No commercial systems for capable of measuring distinct broiler behaviors aimed at commercial farms was found in this survey. In research the most promising sensors capable of recording behavior of individual animals are: wearable sensors (positioning and accelerometers) and computer vision. Operating principle and pros and cons of each technology is summarized briefly in this section.

The suitability of different methods to classify each behavioral need (by using the needs defined by Bokkers and Koene (2003) as the starting point) was evaluated in this review. The results are summarized in table below. Very limited number of papers was found in poultry and the estimate is based on our experience and publications on other species. Luke has experience in working with UWB systems in dairy cows, accelerometers in cows, calves, pigs and foals and computer vision in pigs, dairy and fish.

Table: Evaluation of different technologies for measuring the occurrence of main behavioral needs. (-) can't be done, (+) can give some estimate but not differentiate all behaviors, (++) can give moderately good estimate, (+++) can give very good estimate.

Behaviour (list of Bokkers and Koene 2003)	Positioning tags	Accelerometers	Computer vision: Object detection	Computer vision: Action classification
Eating	++	++	++	+++
Drinking	++	++	++	+++
Preening	-	+	+	+++
Scratching	-	++	+	+++
Ground pecking	-	++	+	+++
Stretching	-	+	+	+++
Aggression	-	+	-	+++
Standing idle	+	++	+++	+++
Sitting idle	+	++	+++	+++
Walking	++	++	+++ (combined with tracking)	+++
Wing flapping	-	+	++	+++
Dust bathing	-	+	++	+++
Lying	+	++	+++	+++
Perching (perch or platform)	++	-	+++	+++

WEARABLE SENSORS

POSITIONING TAGS

Radio based indoor localization is used commercially for cattle and pigs. Most accurate systems are based on Ultra-wideband UWB tags which operate at high frequency using time difference of arrival to calculate the position of the tag. The accuracy of the system depends on the environment and the number of anchors (signal receivers) used.

UWB tags have been used by Stadig et al. (2018) to monitor the location of chickens in free range area of 100x100m using Sensolus UWB system with tags weighing 36g. The system used 11 anchors and achieved < 30cm median accuracy. The accuracy is good enough to estimate the time that birds spend feeding, drinking (time at feeders and drinkers, but not direct measurement) and on platforms as well measuring time spent walking and estimate walking distance.

Fig. 2. From left to right: a tag, its casing, the backpack, and a chicken with the backpack. The weight of tag and its casing is 36 g.

Figure: UWB tag attachment from Stadig et al. (2018).

Pros UWB	Cons UWB
Allows monitoring of specific indicator birds	System cost typically > 20 000€
Allows quite accurate monitoring of location	Requires tags on birds and anchors
Enables detecting behaviors based on location in the barn	Probably not suitable for young birds
Works reliably once set up (installation takes 1 day)	
Can cover the entire building with one set up	

ACCELEROMETERS

An accelerometer measures the change in velocity as well as the static acceleration component of gravity. The position of the sensor can be determined with high accuracy when the sensor is not moving. If the sensor is moving the position can only be calculated if the orientation of the device with respect to gravity is known. Accelerometers attached to the animals have seen a rise in popularity during the last 10 years as the technology has improved to the level where reasonable battery life can be reached with sensors that are small enough to be attached to animals. Behavior can be recognized based on dynamic patterns from the accelerometer data with machine learning algorithms. Accelerometer based sensor are routinely used for behavior monitoring of dairy cows with accuracy of 70% - 95% depending on study and behavioral class. For poultry only preliminary studies were found e.g. (Abdoli et al. 2020). Based on this publication and on our prior experience the suitability of accelerometers for measuring broiler behaviors is shown in technology comparison table.

Pros accelerometer	Cons accelerometer
Allows monitoring of specific indicator birds	Requires tags on birds
Allows accurate monitoring of clearly distinct movement patterns and body position (sitting, standing, walking)	Probably not suitable for young birds
Usually can’t differentiate behaviors with similar movement patterns (e.g drinking, eating, pecking)	Can’t measure location in barn
Works reliably once set up	
Can cover the entire building with one set up	
Tag cost below 50€/bird	

COMPUTER VISION

Recent developments in the applications of Artificial Intelligence (AI) and machine learning permits the use of video data to gain insight into behavior of broilers by storing and annotating pictures or video sequences. Deep learning has quickly become the most successful method in artificial intelligence (Schmidhuber 2015) with applications e.g. in speech recognition, computer vision and disease diagnostics.

Development of deep learning-based computer vision method requires representative training images for each behavior that needs to be recognized. In practice this means that annotated images are required from birds of different age from different lighting conditions and possibly different bedding materials. Typically, at least 500 training images are needed for each behavior and in practice a lot more (1000s of images) can be needed to obtain robust performance when transfer learning is used.

The development of a computer vision system is typically an iterative process where the model can be deployed after initial training, the performance is evaluated, and more training data is used to improve the model if needed. The system can be developed to initially focus on fewer behaviors and improved with more training data in the future. With the limitation that the image quality must be high enough differentiate necessary details.

OBJECT DETECTION

Object detection is a general name for algorithms for recognizing and finding the location of an object (person, car, dog etc.) in individual images. However, the object classes can also be distinct behaviors: standing, sitting etc. and the method has been used for behavioral classification e.g. in pigs (Riekert et al. 2020). There are several well established algorithms, some more focused on performance and some low computational cost. Object detection model is relatively simple to train, and works when:

- When a human annotator can classify the behavior from still images
- The movement of the same bird can also be tracked between consecutive frames of a video. In livestock this has been applied e.g. by Guzhva et al.(2018) to cows

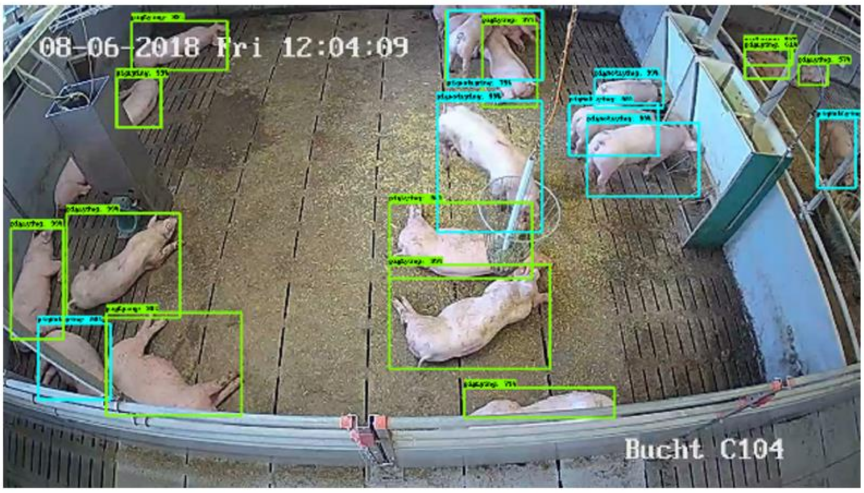


Fig. 8. Detections of the deep learning system on a test set image for fattening pen C104. Images of this pen were in the training set.

Figure: Standing and lying pigs detected using object detection algorithm from Riekert et al. 2020.

ACTION CLASSIFICATION

If the performance of object detection is not good enough for recognizing all behaviors (video is required instead of pictures) and action classification model can be used. Action classification methods use the data from several consecutive frames to classify behavior based on video sequences. Typically, body parts (e.g. head, neck, torso, wing) of each tracked individual are first identified from the image and the behavior is recognized based on the movement of the skeleton e.g. pecking could be recognized by modeling the simultaneous movement of head and body. Annotating the data for action classification takes more work than for object detection and more computational power is required to run the model.

Pros: Computer vision	**Cons:** Computer vision
The only technology that can reach high accuracy for all behaviours	Tracking individual broilers for long time impractical (birds look too similar, in any case would require training data for each tracked bird).
Can reach human level accuracy with enough training data	Requires a lot of computational power: • Hardware cost of embedded camera + computing unit solution under 2000 €. • Cloud computing cost from continuous model operation at least 3500 – 15 000€ depending on the complexity of the model and number of cameras. Cloud computing also requires high speed internet connection.
Can reach good performance with relatively low amount of training data using transfer learning	Probably requires additional training data from first pilot before good performance is reached in different broiler houses. The performance of the model can depend e.g. on the background material and lightning conditions.
	A lot of cameras are required to track the entire house with good image quality.

CONCLUSION ON TECHNOLOGY

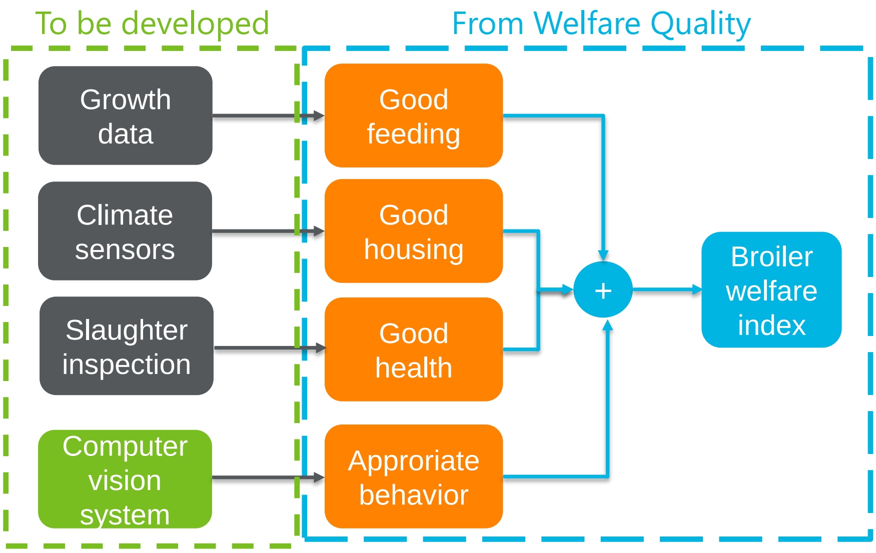
Computer vision is the best technology option for behavioral monitoring of broilers, which are reared in large flocks in commercial operations.

- It can be used for birds of all ages
- Sensors don’t need to be attached to animals
- It has the potential to classify all behaviors listed in the ethogram

The main technological limitation is that monitoring will be on group level and not on individual level. The operational cost of the system can be high if e.g. a cloud provider is used. In practice it’s probably best to develop a system that runs on the farm e.g. building an embedded system where the camera and computer are housed in a single box that is installed in the broiler house.

Developing an object detection model requires least work with potential for good results for several behaviors, however detecting the behaviors from the full ethogram likely needs an action classification model and significantly more work.

Based on reviews conducted in the ClearFarm project, sensor systems tend to operate individual without utilizing all the possibilities to utilize information from different data sources. An interesting option could be to utilize broiler house climate data, growth data and slaughter data to provide information on feeding, housing and health dimensions of animal welfare. This could be complemented computer vision-based system to monitors the most important positive behavioural trait(s). In this manner, the monitoring system could provide an overall view of animal welfare on the farm (figure below).



MARKETING VIEWS TO ANIMAL WELFARE AND SENSORS IN BROILERS

EXISTING MARKETING LABELS

Precision livestock farming technologies are not very widely used in marketing livestock products to the consumers. An internet and document search indicated at least two products where sensors are used to provide information to the consumers. Sensors are probably used in some other cases too, but they do not have high visibility in the marketing. Both identified cases are from the dairy sector:

- Arla yhden tilan maito collects environmental and animal welfare information and disseminates that to the consumers on-line: https://www.arla.fi/tikantila
- Grana Padano cheese says that the farms are achieve the correct herd management "by adopting automatic systems for assessing their animals' morpho-physiological parameters with the increasingly widespread use of special sensors that ensure constant herd monitoring and immediate intervention in the case of specific needs of individual animals, with clear benefits for the herd." It is not explained in detail what this entails in practice (there ae some documents in Italian explaining this in more detail, but also these are quire unspecific). However, since 2019 all milk destined for Grana Padano must come from farms assessed in terms of well-being and biosecurity with the CRenBA method (which is an Italian welfare assessment approach). https://www.granapadano.it/en-ww/animal-welfare.aspx

Heinola et al. (2020) reviewed animal welfare labels on the markets in a number of different countries. Regarding the principle of behaviour, the broiler labels pay a lot of attention to dust bathing opportunity and the use of enrichments.

TABLE. Criteria followed in different broiler welfare labels on the market in various countries (Heinola et al., 2020)

	Good health		Good housing				Stocking density			Appropriate behavior		Transport time
Broilers / chicken for meat prod	**Beak trimming prohibited**	**Growth rate, g per day**	**Continuos dark period daily, h**	**Outdoor access required[A]**	**Litter**	**Cage-free**	**Space inside, max number of birds per m^2**	**Space inside, max kg/m^2**	**Outdoor space, min[A]**	**Dust bathing conditions**	**Enrichments**	**Transport time, h**
Beter Leven *	?	45	8	covered	yes	yes	12**	25	-	yes	yes	3
Beter Leven **	?	45	8	yes	yes	yes	13**	27.5	1 m^2 per bird	yes	yes	3
Beter Leven ***	yes	45	8	yes	yes	yes	10-11	25	4 m^2 per bird	yes	yes	3
Coop Denmark 1	?	-	?	no	yes	yes	16	34	?	yes	yes	8
Coop Denmark 2	?	-	6	yes	yes	yes	13	27.5	1 m^2 per bird	yes	yes	
Coop Denmark 3	?	35	8	yes	yes	yes	10	21	4m^2 per bird	yes	yes	8
Für mehr tierschutz, basic	?	45 (35*)	8	yes	yes	yes	no	25	?	yes	yes	4
Für mehr tierschutz, premium	?	45 (35*)	8	yes	yes	yes	10	21	4 m^2 per bird	yes	yes	4
Label Rouge**	yes	?	?	yes	yes	yes	11	21	2 m^2 per bird	?	?	2
Naturafarm Coop	yes	?	?	yes	?	yes	?	25	?	?	?	8
Naturaplan Coop	yes	?	?	yes	?	yes	?	25	?	?	?	8
Neuland	yes	45	8	yes	yes	?	10/20	21	4 m^2 per bird	yes	yes	?
RSPCA	yes	?	6(-12)	yes[10]	yes	?	19 (13[11])	30 (27,5[11])	?	yes	yes	8
AWA	?	40	?	yes	?	yes	4-6	no	0,37 m^2 per bird	yes	?	4
Certified Humane	yes	?	6	?/yes[11]	yes	yes	?	30	hectare/1000 birds	yes	yes	10
GAP 1	yes	68	6	no	yes	yes	?	34[11]/32	?	yes	yes	8
GAP 3	yes	68	8	yes	yes	yes	?	29	at least 75% of inside	yes	yes	8
GAP 5	yes	45	8	yes(pasture)	yes	yes	?	24,5[10]/27	?	yes	yes	4

*recommendation

**on average

[10] Free range production

[11] Old standards before 1/2018

CONSUMERS VIEWS ABOUT WELFARE TRAINTS IN BROILERS

Relevant question is whether the consumers appreciate animal welfare and which welfare criteria to the place the highest value. Consumers typically associate good animal welfare with the concepts of naturalness and humane treatment. Naturalness is central to consumers' attitudes and concerns in relation to both the animals' behaviours and living conditions. Naturalness is associated with providing animals with enough space and freedom to allow the animals to behave according to their natural instincts, but it includes also having access outdoors and to un-adulterated feed. Intensive production systems are often viewed as unnatural if they breached one or more of these criteria (Clark et al., 2016) (comment: this is partly related to their knowledge bias). Similar observations have been made earlier by Mara Miele and her co-workers.

Regarding treatment, consumers tend to appreciate food care of animals. According to the review of Clark et al. (2016), good husbandry is thought to include regular animal contact and careful handling, and it is recognised that this can be more difficult in the context of modern farming. The majority of consumers believe that animals have the capability to suffer psychologically and emotionally. The animals' integrity and ability to express natural behaviours is perceived as an essential part of achieving psychological wellbeing. This is also associated with housing conditions, especially animals' ability to interact with other animals, space restrictions and freedom to move around housing area.

More recently, Clark et al. (2019) found that the consumers in Finland prefer natural and preventive measures to control for production diseases. Interestingly, providing the birds with materials and environment where they can express their natural behaviours; housing that allows the birds greater freedom of move; and improvements in housing design were among the top four measures. Hence, computer vision or sensors could be used to collect data that verifies to the consumers that the birds really do express their natural behaviours and that they have appropriate activity in the house. Despite the majority considering farm animal welfare as a concern, welfare is not a priority for many people when shopping, and a number of barriers to consumption are raised, such as price, availability and perceived personal influence.

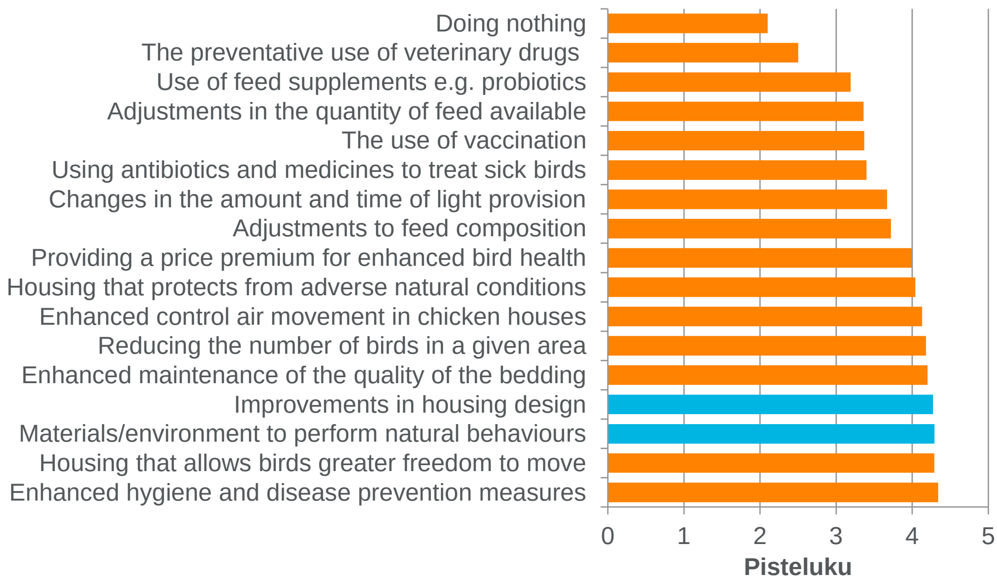


FIGURE. Survey results indicating whether Finnish consumers agree that specific measures are acceptable to control for production diseases in Broilers (1=Strongly disagree, 5=Strongly agree) (Clark et al. 2019).

Heinola et al. (2020b) studied whether consumers consider different welfare criteria as important part of animal welfare. The most important criteria in general (not related specifically to broilers) were those related to the basic needs of animals, i.e. principles of good health and good feeding. In this study, different behavioural criteria were considered equally important. Regarding specific measures in broilers, the use of enrichments, comfortable bedding and preventive health care were among the most important measures. The slow-growing breed was the least important trait among eight preselected traits presented to them.

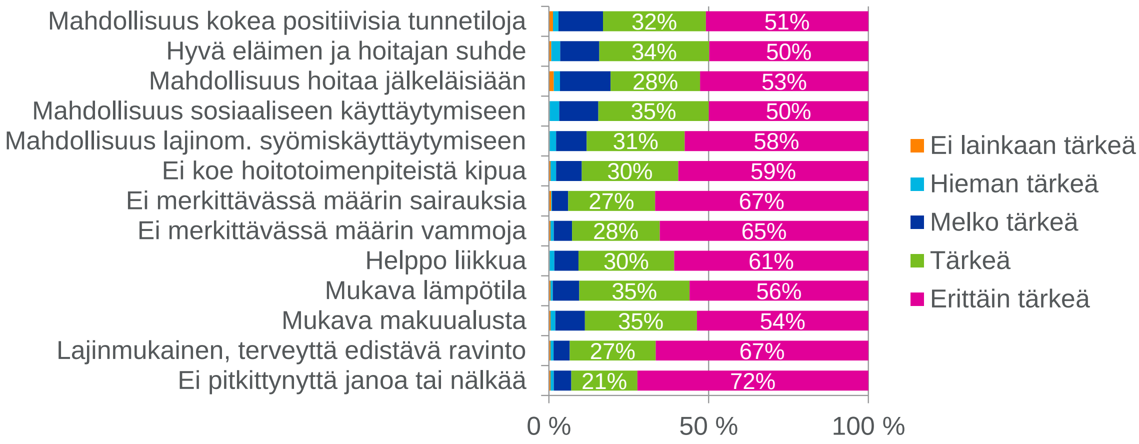


FIGURE. Results of a survey concerning how important consumers consider each welfare criteria is when they consider animal welfare as a concept (Heinola et al. 2020b).

CONCLUSION ON CONSUMER VIEWS

Consumers appreciate naturalness and humane treatment of animals. Hence, computer vision or sensors could be used to collect data that verifies to the consumers that the birds

- Do express their natural positive behaviours (likely focusing on the most important behaviours not related to eating or walking) such as grooming or dustbathing.
- Have an appropriate amount of activity in the house (and do not suffer from locomotory issues).
- Are healthy and that the farmers respond to emerging issues in a timely manner.

Alternative non-organic production systems are more cost-effective in producing animal welfare than the organic systems.

REFERENCES

Abdoli, A., Murillo, A.C., Yeh, C.-C.M., Gerry, A.C., Keogh, E.J., 2018. Time Series Classification to Improve Poultry Welfare, in: 2018 17th IEEE International Conference on Machine Learning and Applications (ICMLA). Presented at the 2018 17th IEEE International Conference on Machine Learning and Applications (ICMLA), IEEE, Orlando, FL, pp. 635–642. https://doi.org/10.1109/ICMLA.2018.00102

Assurewel protocol. Meat Chicken Assessment Protocol: instructions. http://www.assurewel.org/broilers.html.

Bach, M.H., Tahamtani, F.M., Pedersen, I.J., Riber, A.B., 2019. Effects of environmental complexity on behaviour in fast-growing broiler chickens. Applied Animal Behaviour Science 219, 104840. https://doi.org/10.1016/j.applanim.2019.104840

Bergmann, S., Schwarzer, A., Wilutzky, K., Louton, H., Bachmeier, J., Schmidt, P., Erhard, M., Rauch, E., 2017. Behavior as welfare indicator for the rearing of broilers in an enriched husbandry environment—A field study. Journal of Veterinary Behavior 19, 90–101. https://doi.org/10.1016/j.jveb.2017.03.003

Bokkers, E.A.M., Koene, P., 2003. Behaviour of fast- and slow growing broilers to 12 weeks of age and the physical consequences. Applied Animal Behaviour Science 81, 59–72. https://doi.org/10.1016/S0168-1591(02)00251-4

Bokkers, E.A.M., 2004. Behavioural motivations and abilities in broilers. PhD thesis, Wageningen University. https://edepot.wur.nl/19264

Clark, B., Stewart, G.B., Panzone, L.A., Kyriazakis, I., Frewer, L.J. 2017. A systematic review of public attitudes, perceptions and behaviours towards production diseases associated with farm animal welfare. J. Agric. Environ. Ethics, 29: 455-478. DOI 10.1007/s10806-016-9615-x

Clark, B., Stewart, G.B., Panzone, L.A., Kyriazakis, I., Frewer, L.J. 2017. Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. Food Policy 68: 112-127. https://doi.org/10.1016/j.foodpol.2017.01.006.

Guzhva, O., Ardö, H., Nilsson, M., Herlin, A., Tufvesson, L., 2018. Now You See Me: Convolutional Neural Network Based Tracker for Dairy Cows. Front. Robot. AI 5. https://doi.org/10.3389/frobt.2018.00107

Heinola, K., Kauppinen, T., Niemi, J.K., Wallenius, E., Raussi, S. 2020a Suomen Maataloustieteellisen Seuran Tiedote nro 38: Maataloustieteen päivät 2020. https://doi.org/10.33354/smst.89389

Heinola, K., Latvala, T., Raussi, S., Kauppinen, T., Niemi, J.K. 2020b. Kuluttajanäkökulmia eläinten hyvinvointimerkin kehittämiseen. Suomen Maataloustieteellisen Seuran Tiedote nro 38: Maataloustieteen päivät 2020. https://doi.org/10.33354/smst.89454

Marchewka J, Estevez I, Vezzoli G, Ferrante V, Makagon MM. The transect method: a novel approach to on-farm welfare assessment of commercial turkeys. *Poult Sci.* (2015) 94:7–16. https://doi.org/10.3382/ps/peu026

McGrath, N., Burman, O., Dwyer, C., Phillips, C.J.C. 2016. Does the anticipatory behaviour of chickens communicate reward quality? Applied Animal Behaviour Science 184: 80-90. https://doi.org/10.1016/j.applanim.2016.08.010.

Norring, M., Kaukonen, E., Valros, A., 2016. The use of perches and platforms by broiler chickens. Applied Animal Behaviour Science 184, 91–96. https://doi.org/10.1016/j.applanim.2016.07.012

Riekert, M., Klein, A., Adrion, F., Hoffmann, C., Gallmann, E., 2020. Automatically detecting pig position and posture by 2D camera imaging and deep learning. Computers and Electronics in Agriculture 174, 105391. https://doi.org/10.1016/j.compag.2020.105391

Rowe, E.; Dawkins, M.S.; Gebhardt-Henrich, S.G. A Systematic Review of Precision Livestock Farming in the Poultry Sector: Is Technology Focussed on Improving Bird Welfare? Animals 2019, 9, 614. https://doi.org/10.3390/ani9090614

Schmidhuber, Jürgen. “Deep Learning in Neural Networks: An Overview.” Neural Networks 61 (January 2015): 85–117. https://doi.org/10.1016/j.neunet.2014.09.003

Stadig, L.M., Ampe, B., Rodenburg, T.B., Reubens, B., Maselyne, J., Zhuang, S., Criel, J., Tuyttens, F.A.M., 2018. An automated positioning system for monitoring chickens’ location: Accuracy and registration success in a free-range area. Applied Animal Behaviour Science 201, 31–39. https://doi.org/10.1016/j.applanim.2017.12.010

Wallenbeck, A., Wilhelmsson, S., Jönsson, L., Gunnarsson, S., Yngvesson, J. 2016. Behaviour in one fast-growing and one slower-growing broiler (Gallusgallusdomesticus) hybrid fed a high- or low-protein diet during a 10-week rearing period, Acta Agriculturae Scandinavica, Section A — Animal Science, 66:3, 168-176, https://doi.org/10.1080/09064702.2017.1303081

Welfare Quality 2009. The Welfare Quality® assessment protocol for poultry (broilers, laying hens). The Welfare Quality® Consortium, Lelystad, The Netherlands. http://www.welfarequalitynetwork.net/media/1019/poultry_protocol.pdf