Investigating Animal Welfare and Ammonia Emissions in Cage-Free Egg Facilities

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Abstract

Cage-free eggs facilities were investigated for ammonia emission levels and hen welfare standards. Research and secondary data were used to explore varying issues associated with cage-free facilities and looked to enriched colony cages as a solution to these. Enriched colony cages allow for reduced ammonia emissions and improved hen welfare through their facility design and features compared to cage-free facilities. Further regulations need to be researched and enforced in order for cage-free eggs or enriched colony cages to continue to improve these issues. Based on this research, cage-free facilities do not improve ammonia emissions or welfare conditions for hens.

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Introduction

In 2022, consumers now have the luxury of selecting their eggs based on a multitude of options. Color, animal welfare practices, organic/non organic, and Omega-3 enriched are some of the choices they have, as opposed to just price. The rise of brown, cage-free, organic eggs has taken over the dairy industry as consumers become more intent on knowing where their food comes from. Yet, it would come as a shock to many that “cage-free” does not mean the animals have outdoor access, and few members of the public understand what different egg labels mean. Egg facilities have evolved immensely over the last decade, specifically in Europe. Alternative housing methods such as cage-free, free range, pasture raised, and furnished cages have peaked consumer interest globally. While these egg trends remain on the rise, conventional battery cages are still legal in the US (Fig 1). These cages have been criticized worldwide through the spread of videos and articles that have led to increased consumer interest in hen welfare. While alternative egg facilities can provide more space for the birds than conventional cages, both the advantages and disadvantages must be looked at. It will take the egg industry billions of dollars to replace conventional cage systems with alternative ones, therefore a full analysis from all angles must be done. This manuscript aims to inspect the process of cage-free egg production and determine the animal welfare aspects associated with it. Specifically, ammonia emissions and hen welfare will be looked at as an indicator of animal well-being. Enriched colony cages (furnished cages), a new alternative housing method developed in Europe, will be studied as a solution to the concerns that arise with cage-free egg facilities. It is widely observed that consumer marketing promotes cage-free egg systems as the most ethical facility compared to other housing systems. I aim to explore various sides of cage-free egg facilities to help identify whether this system is the most beneficial for the hens.

Fig. 1 Conventional Battery Cages

Taken from https://www.al.com/news/2015/04/alabama_fights_californias_ban.html

Literature Review

Eggs are a staple in nearly every diet around the world. Newly released 2020-2025 Dietary Guidelines for Americans shows that eggs are one of the most important nutrient packed foods aiding in infant brain development (American Egg Board, 2020). In recent years, there has been more consumer interest towards where their eggs are coming from and the treatment of the laying hens. Previous studies have shown that consumers do not use science-backed claims to select their eggs, but rather color, animal welfare conditions, and packaging (Guyonnet, 2021). It has even been shown consumers believe brown, organic, cage-free eggs are safer than white conventional eggs, even though both eggs are well below the Maximum Residue Limits for pesticides set by the EPA (Guyonnet, 2021). The idea of cage-free eggs has become so popular that some of the world's largest companies, such as Kellogg and General Mills, have vowed to use only cage-free (CF) eggs in their products by 2025 (Graber, 2016). As consumers demand these changes, it is going to cost the egg industry nearly $7 billion to convert all hen facilities into ones that meet CF requirements (Postmedia News, 2019). As this specialty egg trend continues to rise, it presents the animals and farmers with a variety of options. The environmental and animal welfare aspects involved with a CF egg facility have not been fully investigated. Ammonia emissions and hen welfare are the top concern associated with these facilities. Enriched colony cages (ECC), also known as furnished cages, are a new solution for farmers that are a hybrid of CF and conventional egg facilities. These cages contain hen enrichment and private nests, while offering more space than conventional cages (Yilmaz et al., 2016). ECC are being investigated as an alternative option for farmers and consumers alike.

Cage-Free Housing Facilities

Cage-free eggs must meet specific criteria as defined by the US Department of Agriculture (USDA), United Egg Producers (UEP), and/or the USDA's Agricultural Marketing Service (AMS) depending on how many certifications the farmers want to be recognized by. The UEP has become one of the most important egg organizations since its creation in 1968 (UEP, 2020). It is a national organization that works alongside US egg farmers to improve egg safety, environmental issues, and hen-wellbeing in the egg industry. In 2002, the UEP established the first UEP Certified guidelines created by their scientific advisory committee. This committee implemented hen welfare standards through previously done research, as well as their own done at egg farms, breeder companies, and equipment manufacturers. Today, farmers voluntarily participate in the UEP certified program and undergo USDA audits to get the UEP certified seal on their cartons. The International Egg Commission, an organization of every major egg producing country in the world, endorses the UEP as the

blueprint for egg-laying hen guidelines (UEP, 2017). The guidelines, which are voluntarily followed by more than 90% of US egg producers, have been updated in 2019 and 2023 for cage-free facilities. The most common CF facilities are 1) multi-tiered aviaries with a litter floor and a slatted floor over manure belts, 2) partially slatted systems with a litter area and a slatted-floor area over a manure pit, and 3) a single-level all-litter floor system (UEP, 2017) (Fig. 2). The most recent UEP guidelines state that hens need to be able to roam vertically and horizontally while having a minimum of 1.0-1.5 sq ft of usable floor space per bird. The birds need to have unlimited access to fresh food and water. Nests at a minimum of 9 sq ft/ 100 hens are required to prevent the birds from laying their eggs on the floor and should be dark and draft-free inside. Hens prefer privacy while laying their eggs and there must be curtains/dividers around the nest that prevent them from seeing the outside when sitting. Perches should allow 6 inches of elevated space/hen and be made of easily cleanable materials that minimizes keel, nail, and foot damage (UEP, 2023). 15% of the total facility space must be used for litter, which should be replaced between flock cycles. The litter depth should be thick enough that the birds do not have direct contact with the floor, but not so thick that it encourages egg laying (UEP, 2017). The hens should have protection from predators and environmental exposure so that they can maintain their natural body temperature without difficulty. Lastly, fresh air ventilation is necessary and ammonia concentration should be around 10 ppm with a maximum of 25 ppm. Natural behaviors, such as dust bathing and foraging, are allowed to occur to an extent when the hens are placed in these circumstances (Gonzalez-Mora et al., 2020). The CF regulations do not require the hens to go outside, which is typically not advertised to consumers. Farmers that voluntarily choose to be under the UEP guidelines undergo yearly audits for the criteria listed above. If an audit is failed, the farm has 30 days to correct the issue and undergo a re-audit (UEP, 2017). Failure to pass the re-audit results in the farm's UEP certified status undergoing deliberation by a committee.

Fig. 2 Single-Tier Cage-Free Aviary

Taken from https://uepcertified.com/cage-free-housing-systems/

Ammonia Emissions

Air quality is an important aspect of farming for the hens and workers. Potentially dangerous emissions such as ammonia are created in hen facilities from their feces. CF facilities typically allow their hens unlimited litter access at all hours of the day, and the UEP

requires litter to be replaced only between flock cycles. The litter is usually composed of feathers, bedding, wood shavings, and poultry waste (Winkel et al., 2016). As the hens roam around, the litter materials start to decompose and become airborne due to natural activities such as dust bathing and foraging (Fig 3). Furthermore, the hens expel droppings, and nitrogen is excreted as uric acid in their feces (Ritz et al., 2019). In conventional battery cage facilities, there is a manure belt that would remove this litter. Depending on if the cage-free facility has a manure belt, this waste could sit on the litter floor for an extended period until workers clean it (Oliveira et al., 2019). As the feces decomposes, *Bacillus pasteurii,* uric acid, water, and oxygen react to release NH_3 and CO_2 emissions (Ritz et al., 2019). NH_3 is water soluble which causes it to dissolve in the mucous membranes and eyes of the hens and workers. NH_3 formation is generated through temperature, moisture, pH, and manure nitrogen levels, while the emission rates are determined by the ammonia concentration and the ventilation exhaust flow rate of the facility (Ritz et al., 2019; Wheeler et al., 2006). A quality and well-maintained ventilation system is important for poultry housing as it removes heat, moisture, and other gasses that are generated throughout the fluctuating seasonal temperatures (Goselink & Ramirez, 2019). On average, hens are exposed to 20-50 ppm NH_3 in a standard egg facility and as high as 200 ppm in poorly ventilated systems (Beker et al., 2004). Keratoconjunctivitis, the inflammation of the cornea and conjunctiva, has been seen at 46 to 102 ppm in hens. 20 ppm for 42 days has shown decreased feed efficiency and subsequent air sac inflammation (Ritz et al., 2019). The UEP suggests that the levels remain between 10-25 ppm for USA hen standards, and the established human threshold limits are set at 25 ppm for 8-10 hours (UEP, 2017; Ritz et al., 2019). When placed in a high ammonia environment, hens have been seen closing their eyes and rubbing them which suggests keratoconjunctivitis symptoms (Bullis et al., 1950). Hens have been observed to select areas with lower ammonia concentrations when given the choice (Jones, et al., 2005). This indicates it is a presence that they can detect and will actively avoid.

Fig. 3 Hens Dust Bathing

Taken from https://www.dineachook.com.au/blog/what-is-a-chicken-dust-bath-easy-steps-to-make-one/

Ammonia levels in CF facilities are found to be higher due to farmers housing fewer birds (than conventional cages) and using lower ventilation rates as an effort to conserve heat, especially in the winter (Xin et al., 2011). One US study set up a CF system to measure ammonia concentrations and litter conditions when the birds were provided litter

either part time litter access (PLA) or full-time litter access (FLA) (Oliveira et al., 2019). By collecting litter samples and using emission detection instruments, they found that when the birds had FLA, the ammonia levels were at their highest. Litter moisture content increased in FLA, and 33.1% of the FLA was considered “caked” compared to 0% caked for PLA. This hindered the hen’s ability to dust bathe, which is an important selling point for CF facilities. The ammonia concentration was 17.2% for FLA and 13.5% for PLA. Quality ventilation systems are necessary for hen facilities, but especially CF ones since the constant movement of the hens produces more heat. Ventilation systems also cycle out odors, moisture, and emissions while bringing in fresh air (Grubinger & Sanford, 2019).

To understand how much manure alone creates most ammonia emissions, a series of US studies led by the Coalition for Sustainable Egg Supply (CSES) monitored the air quality of conventional, cage-free, and enriched colony cages set up on a single farm. The conventional facility contained 200,000 hens with a manure belt, the enriched colony had 50,000 hens with a manure belt, and the cage-free facility had 50,000 hens with part-time litter access and a manure belt (Zhao et al., 2015). Manure belts collect all droppings below the birds and move the waste out of the facility on a conveyor belt (Fig 4). All belt accumulated manure was removed from the facilities every 3-4 days, and in the CF facility the floor litter was not removed until the end of the experiment. Using a multi-gas analyzer to collect air from the exhaust systems and from within the barn, the CF facility showed the highest ambient daily mean NH_3 concentration of 6.7 ppm. The conventional cage facility showed a daily mean of 4 ppm, and the enriched colony cage mean was 2.8 ppm. The NH_3 concentration in the conventional and enriched colony facilities never exceeded 25 ppm, which is the UEP recommended threshold. The CF facility exceeded it for 12 days in the winter. The ammonia levels in this study were found to be below that of previous literature due to the presence of the manure belts.

Fig. 4 High Capacity Manure Belt Drying System

Taken from https://www.bigdutchmanusa.com/en/egg-production/products/manure-management/manure-drying/optisec/

To continue this project series, the CSES then monitored the emissions from ammonia storage bays. Typically, farms will store the manure on-site in large bays and eventually turn it into fertilizer (Shepherd et al., 2015). While this practice is efficient, it has

been shown to account for most ammonia emissions on farms since the manure can sit for up to 6 months. The CSES set up the same parameters as the previous study, but instead collected the manure from all 3 housing facilities and loaded it into separate storage bays for emission monitoring via a self-contained air emission system. Exhaust air samples from the storage bays and from the intake air into the bays were analyzed. The farm-level CF emissions (hen facility levels plus storage bay levels) were 0.30 g/hen/day compared to 0.16 g/hen/day for ECC. Conventional cages showed the highest manure storage ammonia levels (0.21 g/hen/day) followed by the cage-free facility (0.18 g/hen/day) and then the ECC (0.11 g/hen/day). Moisture content of the manure was 51.7% for CF and 45.6% for ECC.

While high NH_3 emissions can cause environmental/welfare issues within the farm and its surrounding area, it is an incredibly difficult emission to regulate. Since its production occurs naturally through various chemical and biological processes, it is hard to predict and control. Nitrogen levels can vary not only by farm management practices, but also through geographic location/climate and field variability (USDA, 2014). This has so far excused it from global regulations because the excess nitrogen produced has no minimum to be compared to. NH_3 is a necessary component of fertilizer which the domestic and global food supply relies on. Without it, modern day agriculture would not succeed. Therefore, certain amounts of nitrogen are required so that the food production chain can keep up with the increasing global population it needs to feed. Reducing NH_3 levels in fertilizer can end up increasing the global footprint as the food supply needs to continue at high levels to support the increasing population. Currently, there are a few methods for farmers to determine their ammonia levels, but none that are globally recognized as the standard by the EPA or any other government agencies. The most common lower cost methods include a Colorimetric tube which changes color after exposure to ammonia gas, and ammonia measuring probes that display the voltage which is then converted to concentration (EPA, 2023). These detection instruments should be measured at the barn floor level and in different areas of the farm several times per day. The cost per tube is around $8.

Hen Welfare

The unpredictability of cage-free egg systems continues to be a concern for animal health. When assessing hen welfare, one of the most common characteristics to observe is feather condition. Missing feathers that are unrelated to natural molting can indicate parasites or feather pecking.

Feather pecking is a direct result of overcrowding and is commonly found in cage-free floor systems. Free-living hens ground peck and forage naturally, so feather pecking is assumed to be an adaptation of this behavior in laying hens (English Monthly Magazine, 2020). Feather pecking typically occurs when the hens are stressed, bored, or overheated

(Louton et al., 2016). Pecking is defined as when a bird pecks and pulls at the feathers of another bird (Fig 5). Birds are attracted to blood therefore when a hen is pecked to the point of bleeding, the other birds will flock, and a cannibalism outbreak can occur. Vent pecking, where birds peck at the reproductive and excrement opening, is another vicious behavior that occurs right after a hen produces an egg. If tissue is broken in the process, other hens may flock to the injured bird and peck them to death, once again instigating cannibalism that is hard to eliminate once the flock is affected. These behaviors are common in cage-free systems since hens are social creatures and will overcrowd popular areas.

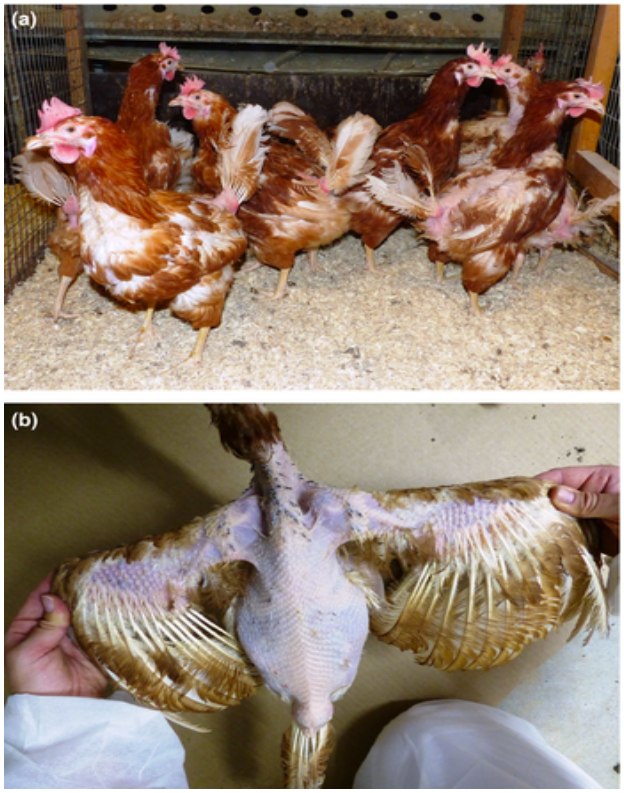

Fig. 5 Severe Feather Pecking and Plumage Damage
Taken from https://doi.org/10.1002/vms3.184

Red mites (*D. gallinae*) are ectoparasites that are interconnected with feather pecking, disease spread, and cannibalism leading to increased mortality (Heerkens et al., 2015). Red mites act by sucking the blood out of hens which induces skin irritation and stress. Stress results in aggressive behaviors between the hens, specifically feather pecking and cannibalism (Sigognault et al., 2017). Red mites can survive under harsh conditions without food and can persist between hen flocks if not eradicated. Furthermore, they can act as a zoonotic disease vector between the birds and the humans working with them. There are a few methods used to detect red mites: scoring systems, traps, waste examinations, and automatic counter devices (Oh et al., 2020). More techniques are being developed to identify mites at early infestation stages using cardboard traps that are economical and accurate. The required floor litter in CF systems increases the risk of red mite infestation since they can burrow deep within it (Heerkens et al., 2015). The quality of CF floor materials also plays a role in feather condition and red mites. Research on CF systems in Belgium showed multiple outcomes for feather condition based on the type of materials used to build the CF facility. There are typically areas where the food, water, and nests are located that require flooring, usually made of plastic or wire mesh. Red mite populations were higher in facilities with plastic flooring compared to wire mesh flooring. Both are commonly used materials for hen facilities and research is beginning to emerge on the welfare differences between plastic and mesh. The facility that contained wire mesh flooring also displayed hens with better plumage scores, fewer wounds, higher production rates, and lower mortality compared to

plastic slat flooring. It should be mentioned that plumage condition is also due to abrasion on the cages or the surrounding environment. Feather loss on the neck, back, tail, and vent however were more confidently linked to feather pecking. While red mites are currently not a pressing issue in the US due to caged systems, Europe is experiencing a resurgence due to their 2012 ban on conventional cages (Lay et al., 2011).

Contrasting research has also shown that feather condition improves in CF systems. A study comparing feather condition in aviary systems to conventional ones showed that most aviary hens had complete tight/ruffled plumage, compared to most conventional hens that had featherless spots (Taylor & Hurnik, 1994). It is thought this is due to less feather abrasion on cages.

Enriched Colony Housing

Enriched colony cages (ECC) or "furnished cages" are a new European-developed approach to cage-free facilities (Fig 6). They provide more space than conventional battery cages and can contain perches, private nesting areas, scratch pads, a manure belt, and space for dust bathing all while being enclosed (Heerkens et al., 2015). The development of ECC cages was a result of the European Union banning conventional battery cages in 2012 (Weimer et al., 2019). In these furnished cages, the birds can walk between areas that contain different enrichment and levels of privacy. In the EU, the cages are required to have 750 cm^2 of space per hen (European Union, 2017). This amount of space has been shown to produce hens with greater feather coverage which improves their welfare (Weimer et al., 2019). Furthermore, ECC drastically reduce mortality rates, disease transmission, and ammonia emissions (UEP, 2017). These facilities could be a middle ground solution for consumers concerned with animal welfare and for farmers that prioritize the health of their hens.

Fig. 6 Enriched Colony Housing

Taken from https://www.eggfarmers.ca/2016/08/the-5-things-you-find-in-enriched-housing/

As discussed previously, some of the most important aspects in determining hen welfare is their ability to perform natural behaviors and an environment with low ammonia levels. The CSES project study discussed above showed that ECC had lowest ammonia emission rates compared to conventional and CF facilities (Shepherd et al., 2015). Hen

stocking density and a manure belt plays a large role in regulating air emissions**.** The hen stocking density is the number of hens per unit area. In a European study looking at ECC, CF, and multilevel facilities, ECC showed the lowest ammonia emission levels measured with gas detection tubes (Nimmermark et al., 2009). The CF facility manure remained within the barn during the entire study period, whereas the ECC had a conveyor belt that removed manure every 5 days. Ammonia emissions per hen was 0.075 g/day in the ECC compared to 2.05 g/day in the CF facility. Daily average ammonia concentrations for ECC were 3-12 ppm, 21-42 ppm for multilevel housing, and 66-120 ppm for CF housing. Gas samples taken directly above the litter area in the CF facility showed NH_3 concentrations of more than 40 ppm, exceeding the UEP's suggested limit of 25 ppm.

One of the greatest supporting characteristics for furnished cages is the hen enrichment that they offer while still being enclosed. At a minimum, these cages have perches and private nesting areas. Extra features typically included are scratch pads to simulate foraging and dust bathing areas (Fig 7) (Pohle & Cheng, 2009). Cage-free facilities are only required to have perches and nests while all other enrichment is optional. A 2009 study in Indiana illustrated the importance of cage enrichment on hen well-being. White Leghorn chickens were used, as they are the top egg-producing birds in the US (Pohle & Cheng, 2009). Hens were housed in furnished cages with perches, a dustbathing area, scratch pads, and a private nest box, or a conventional battery cage with a similar stocking density for 50 weeks. The behavioral transition index, which showed how often the hens changed behaviors, was recorded. A high behavioral transition index alludes to stress since the animals are restless and constantly shifting activities. At 40-50 weeks, the hens in the conventional cages showed an increase in the behavioral transition index. They also showed higher walking and exploratory pecking levels as age increased, which could also infer stress and restlessness. Comfort behaviors, such as preening, were also lower in conventional cages compared to furnished ones. Furthermore, the hens in furnished cages were observed performing exploratory pecking, resting, and preening in their dust bath area. Further enrichment such as scratch pads has also been shown to reduce feather damage and loss. Cages without scratch pads showed an 18% increase in feather damage compared to those with one (Decina et al., 2019).

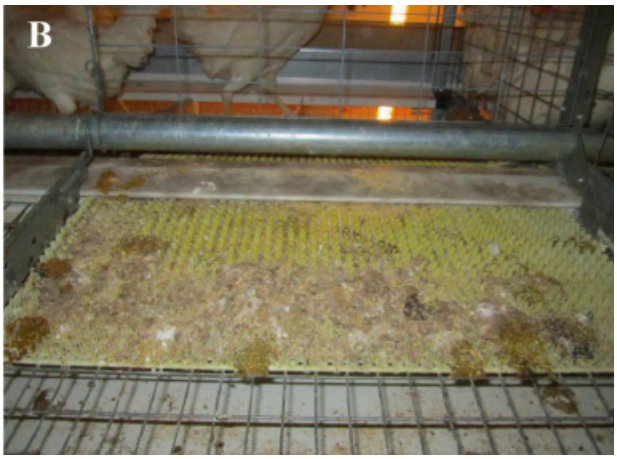

Fig 7. Scratch Pad from ECC

Taken from https://www.researchgate.net/figure/Two-examples-of-enriched-colony-cage-system-scratch-pads-that-were-scored-A-3-and-B_fig1_269170924

Materials and Methods

The methods in this manuscript will involve using published primary journal papers, book chapters, reviews, YouTube videos, magazine articles, and other reputable sources. I also will be using the USDA, CDC, United Egg Producers, and FDA websites for my official definitions and regulations.

The American Egg Board also provided Virtual Egg Farm Field Trip videos that were also used to gain an insider perspective to different housing facilities.

Results

Ammonia Emissions

Cage-free facilities trend towards having higher ammonia emissions compared to housing facilities where the birds remain in their cages. Fewer birds are typically housed in cage-free facilities compared to caged ones. CF birds are constantly moving and the UEP requires 1-1.5 sq ft of space/hen (UEP, 2017). As a result, a lower density of birds must be housed in these facilities. To combat the potential heat loss from having a lower bird density, farmers will lower the ventilation rates in the facility, specifically in the winter (Xin et al., 2011). In the summer months, the ventilation system must also remove the excess heat the birds give off and keep emission levels in check. Ventilation systems cycle out odors, moisture, and emissions while bringing in fresh air (Grubinger & Sanford, 2019). Lowering the air removal rate allows ammonia emissions to build up and reach dangerous levels for the hens and the workers, especially in the winter.

Further reason for increased ammonia emissions in CF facilities is the accumulating floor litter. During cold winter days, the low ventilation rates and high humidity increases the moisture content of the floor litter, which creates favorable conditions for the conversion of uric acid to NH_3 (Zhao et al., 2015). The litter also contributes to ammonia emissions when it becomes caked and thick on the aviary floor. In facilities where full-time litter access is allowed, more caking has been seen and litter is unable to be dried quickly by the ventilation fans (Oliveira et al., 2019). This allows for increased ammonia emissions to be released into the air to further harm the hens and their workers. In facilities where high ammonia levels are not an issue, ventilation systems remove the excess moisture produced by various bird activities. Cage-free facilities have the potential to be incredibly beneficial for the birds and workers if ammonia levels are properly contained. Due to the decreased hen stocking density in them, the moisture production decreases and therefore lowers the ventilation rates (Zhao et al., 2015). This then helps the hens sustain their body heat and maintains the

desired indoor temperature. For CF facilities to uphold safe ammonia levels, established ventilation systems and frequent litter removal would need to be a UEP or USDA requirement. One of the largest CF facilities in the US is in Iowa. This facility is set between 68-78F internally and the ventilation is automatically controlled by a system from Poultry Management Systems Inc (King, 2019). Inlets and fans around the facility open depending on the ventilation readings and fresh air is introduced based on temperature. Up to date information can be provided to the farmers smartphone so they can constantly monitor the facility. While this is considered a state-of-the-art ventilation system, CF systems should use it as a benchmark for the minimum ventilation standards they should have.

Long-term storage of manure on a livestock farm contributes to 60-70% of the total ammonia emissions (Shepherd, 2015). Interestingly, the type of housing facility can affect the NH_3 emissions resulting from manure storage. Cage-free facilities show higher NH_3 levels from their manure storage due to floor litter and moisture content increasing uric acid conversion and therefore ammonia levels. To make up for the low stocking density in CF facilities, farmers will lower the ventilation rates which increases the humidity and increases the moisture content of the floor litter. When this litter is moved out and put into long term storage, it contains more moisture and will release higher ammonia emissions than litter that has been dried out more thoroughly. In ECC, the addition of a manure belt and drying fans allow the manure to enter the storage bays with less moisture and therefore less ammonia emissions.

Accurately measuring ammonia emissions provides a challenge to regulators, such as the USDA, and farmers. When on the farm, NH_3 emissions can come from a variety of sources such as type of animal facility, how the manure is handled and stored after it leaves the facility, and whether the manure is being turned into a fertilizer and going into the surrounding soil after (USDA, 2014). The most common method of measuring ammonia emissions uses a colorimeter to determine the concentration from a single area and then that value is multiplied by the number of openings in the facility, the airflow, and NH_3 concentration (Lefcourt, 2002). Errors have been found with this method and rates are significantly inaccurate. Currently, not even the USDA has a set practice for how they measure ammonia emissions from farms (USDA, 2014). Many research studies that have been done were under controlled environments and not on commercial farms. Therefore, any ammonia reduction strategies that could translate from these studies may not be applicable on a larger scale. As a result, emission level enforcement becomes a challenge, and the USDA does not enforce ammonia emissions for that reason. On a federal level, the Clean Air Act set by the EPA does not cover ammonia released from farms and only regulates anhydrous ammonia (EPA, 2022). A federal standard methodology is still yet to be developed for ammonia emission measurement.

The NH_3 levels due to animal production can be reduced through pre and post ammonia generation. Pre-generation reduction includes altering hen feed, increased manure removal, treating the manure with chemicals that delay nitrogen conversion, covered manure storage, housing facility type, and immediate injection of manure into soil (USDA, 2014). Post-generation reduction involves exhaust air treatment through filters, creating barriers such as vegetative buffers, and moving the facility location to a remote area.

Hen Welfare

As mentioned, the feather condition in hens plays an important role in their overall wellbeing. Missing or dirty feathers indicates a hen undergoing intense environmental stress or feather pecking. Research has indicated that cage-free facilities can have a negative effect on hen feather condition. With the hens roaming freely, fights can break out amongst the colony. More aggressive birds may feather peck until mortality occurs. Hens are social animals that will naturally crowd together for warmth and comfort, as well as congregate around nests, food, and water sources (Landsberg & Denenberg, 2023). This can then contribute to feather pecking since the stocking density can be higher in popular areas and lead to stress. Moreover, cage-free facilities provide little enrichment which contributes to boredom and restlessness. This can further lead to feather or vent pecking which can run rampant through a flock. Larger flocks of birds, such as those in a cage-free system, pose a greater risk as it is difficult to identify and take the feather-pecker out of the pack early on. Feather loss results in poor thermal protection, increased fear responses, and mortality (Taylor & Hurnik, 1994). Greater food consumption can also become a financial issue as the birds have been shown to eat more to combat the heat loss from missing feathers (Heerkens et al., 2015).

The floor litter in cage-free facilities presents another problem for hens and farmers: red mites. These parasites bite at the hens and irritate their skin leading to increased stress levels. Stress results in aggressive behaviors between the hens, specifically feather pecking and cannibalism (Sigognault et al., 2017). The required floor litter in CF systems increases the risk of red mite infestation since they can burrow deep within it (Heerkens et al., 2015). Depending on the litter removal frequency, these mites can persist and grow in population. Furthermore, the surface area of a CF facility allows more places for the mites to hide and avoid disinfection compared to conventional cages. In the areas of a CF facility where the food, water, and nests are located some sort of flooring, usually made of plastic or wire mesh, is required. Whether the flooring is made of plastic or mesh wire also contributes to red mite outbreaks. Plastic slat flooring shows increased mite infestations leading to increased feather pecking. Red mites can hide more easily under plastic slatting compared to wire mesh slatting. The feather condition is improved in facilities with wire mesh flooring

because the manure can be pushed through the holes, whereas manure in plastic floor facilities seems to stick to the plastic, resulting in dirtier feathers and disease spread.

Enriched Colony Housing

Ammonia Emissions

Enriched colony cages offer solutions to the multitude of issues in cage-free facilities. Hens in ECC are actively moving between the different areas in their cage and have a manure belt running under them to collect waste. This allows it to be dried out and removed from the facility swiftly to prevent ammonia formation.

The hen stocking density, which is the number of hens per unit area, trends lower in ECC (Shepherd et al., 2015). This implies that they are more mobile in ECC cages and that less manure is continually on the belt which allows it to dry therefore reducing ammonia emissions. The presence of the manure belt is the main reason for low ammonia emissions in ECC since the manure is constantly being moved out. When the excrement sits in litter, such as in CF cages, that is when uric acid formation begins and ammonia levels rise. Furthermore, when a manure belt is present there are typically ventilation fans located above it that will help dry the manure further. The combination of these two factors allows for decreased ammonia emissions.

In terms of long-term manure storage, ECC typically show lower NH_3 levels due to drier manure entering the storage bay. Once again, the manure belt allows for less moisture content in the waste. Furthermore, the lower stocking density in ECC cages allows for the manure to dry due to less waste on the belt. The lack of floor litter and constant manure removal make ECC a great solution to high ammonia levels.

Hen Welfare

By offering enrichment such as scratch pads and dust bathing areas, ECC provides hens a chance to perform comfort behaviors that reduce stress and potential feather pecking. When ECC were compared to conventional cages, ECC hens showed greater comfort behaviors such as preening, exploratory pecking, and resting (Pohle & Cheng, 2009). By creating a general space for dustbathing, it is thought the hens may have increased the frequency of their other comfort behaviors since they found they had the space for it. It has also been speculated that feather pecking decreases in ECC due to the birds ability to hide in different areas of the cage (Fig 8) (Li et al., 2015). This can help them avoid the stress, agitation, and overcrowding that typically leads to this issue. Incorporating scratch pads in ECC further improves hen welfare. These pads provide an opportunity for the hens to simulate foraging, an intrinsic behavior (Decina et al., 2019). Any enrichment that

allows birds to perform their natural behaviors will likely lower stress levels and prevent boredom-induced behaviors such as pecking. By designing a comfortable and spacious furnished environment for the hens, they can carry out natural behaviors that reduce their stress and aggression.

Such as with cage-free facilities, enriched colony cages present farmers and their hens with red mite challenges. No research has been done on red mite infestations in ECC cages. It is inferred that just as in CF facilities, ECC provide the mites with more places to hide and burrow. There are few treatments to control red mite infestations, especially in Europe where many product classes are banned or put under strict regulations. A spray treatment called Byemite is the sole medicinal product allowed in Europe. It is not legal in countries where most egg farms are located, such as Germany or the UK (Sigognault et al., 2017). The spray treatment requires a withdrawal period of 12 hours and cannot be sprayed directly on the birds which causes issues for large commercial farms. The mites are typically located in areas close to the birds or on their skin, and therefore the application of this product reduces its effectiveness. Furthermore, since Byemite is applied through spraying, uneven spraying may occur which can expose mites to sublethal concentrations that they can gain resistance to. Currently, the few non-chemical extermination approaches involve a vaccine that is still under development and heating of the unoccupied hen house to 60C. The latter provides challenges when facilities have plastic flooring and requires a significant amount of money.

Fig. 8 Aerial view of ECC

Taken from https://www.wattagnet.com/articles/8334-2011-ipe-focuses-on-colony-cage-systems

Discussion

Ammonia Emissions

Cage-free facilities have the chance to provide hens with beneficial welfare standards. Many animal welfare groups look to them as one of most humane housing alternatives for laying hens. They can move vertically and fly, unlike enriched colony cages where movement is restricted to be horizontal. Ammonia emissions in cage-free facilities are

ultimately determined by the initial design of the hen facility (through the inclusion of a manure belt) and by litter conditions/ handling. The first one is largely dependent on the amount of money a farmer can put into their farm. The USDA and the Agricultural Marketing Service performs yearly audits under UEP guidelines on farms that want to be UEP certified cage-free, and they must pass with a 90%. If an audit is failed, the farmers have 30 days to implement the correct action and schedule a re-audit. As previously mentioned, these guidelines suggest ammonia emissions be less than 10 ppm and must rarely exceed 25 ppm. The USDA/UEP does not enforce ammonia emissions because there is no official way to measure them. Therefore, it is unclear how strict the UEP/USDA upholds the ammonia levels of their farmers when they audit. A technique to curb high emission levels on farms could be to implement a fine when ammonia levels exceed recommended guidelines during an audit. By introducing a monetary penalty, CF farmers could be persuaded to improve their facility ventilation or litter removal tactics to reduce emissions. If the monetary fine does not help curb emissions, the UEP auditors could further penalize farms that have multiple strikes against this same issue. This could result in them being expelled from the UEP certified cage-free program or spur the implementation of surprise audits. Ammonia testing methods done by the UEP during their audits can be taught to farmers to initiate the spread of their techniques. Little information was found online regarding how the agencies test for ammonia when doing audits. By eliminating this gap in knowledge, it can help spread government standard techniques and allows for UEP certified CF farmers to agree with each other. Overall, the most unbiased method to combat this issue would be for the UEP or USDA to set a standard for ammonia measurement methods and find one that is accessible for a majority of farmers. Further research needs to be done on the accuracy of current techniques, such as a colorimeter, and if it can be used as the industry standard. Since they are the most affordable option, it would be in the best interest of the government to generate this standard since specialty egg facilities are only increasing in popularity.

As discussed, ammonia emissions can be reduced significantly with proper manure removal in the form of a manure belt. Any opportunity for manure to sit on the ground for an extended period will contribute to NH_3 formation. Manure belt systems range between a few thousand dollars and increase when drying mechanisms and scrapers are added. While this system comes at a cost, if farmers want to improve the health of their hens and workers, it is worth the investment. A manure belt is a necessary feature that helps dry out manure and allows it to be removed quickly. In addition to the manure belt, farmers can implement and enforce a cleaning schedule for their hen facilities to ensure dirty litter is being replaced frequently. This would not only improve ammonia emissions, but also hen feather condition. Frequent cleanings can help reduce red mite populations and allow birds to keep their feathers litter-free. The UEP or USDA can also look into making manure belts a requirement

since they are an integral part of studies that show reduced CF ammonia emissions. Alternatively, farmers and other members of the population can appeal to the EPA to regulate ammonia emissions beyond anhydrous ammonia used for fertilizer. Although the farmers are the ones that would be investigated for this, it is for the good of their hens, workers, and surrounding environment. The Clean Air Act was last amended in 1990 and should also be updated to include ammonia regulations. Reductions in ammonia will likely not occur until there is government involvement and fines against high emission farms.

A good ventilation system is necessary if a farm decides to go cage–free. An efficient system will remove ammonia, water vapor, and carbon dioxide from the hen house air and have fans blowing directly on the manure belt. It will also regulate the indoor temperature since CF facilities typically have less hens/ a lower stocking density and ventilation rates need to be adjusted accordingly. The costs of a good ventilation system are significant, and the pressure is put on the farmers to decide how much they spend. Farmers can look into solar powered fans or roof panels that can help save on electricity costs. A standard ventilation system for all cage-free farms is also a factor that the USDA can enforce. Similar emission curbing techniques such as fines or penalties for outdated ventilation systems can be implemented. If not already occurring, these systems should undergo weekly checks to ensure fresh air is actively flowing into the facility and emissions are being removed.

In-depth guidelines have not been set for cage-free facilities since they are still a new concept in the farming world. While the UEP has 2019 and updated 2023 cage-free guidelines, crucial regulations are missing that could solve the issues that arise with these facilities. While the current guidelines give farmers an overall idea of how to set up their CF systems, specifics need to be given for emission measuring, ventilation systems, and manure belt requirements. Since both the USDA and UEP are involved with monitoring cage-free eggs, creating a single set of guidelines would streamline this process.

Hen Welfare

Allowing hens the ability to freely roam a cageless, indoor barn comes at a cost. Being social creatures, they will congregate in certain areas and can become restless without proper enrichment. Cage-free facilities not requiring any enrichment, such as dust baths or scratch pads, contribute to feather pecking. To combat this, UEP cage-free guidelines should be updated so that farmers must provide mandatory enrichment for their hens. While this may increase labor for the farm workers, it can help decrease bird mortality which saves more money overall. By adding enrichment, stocking density will also decrease around popular areas where aggression may break out such as near food and water sources. More birds will be spread out amongst the barn either in the enrichment areas, perches, nest, or food/water troughs which allows for an even distribution. This simple

change can significantly decrease the chances of feather pecking and is what makes ECC so successful compared to CF. To further stress the importance of enrichment, red mite populations can potentially decrease when enrichment such as a dust bath is provided. Hens dust bathe to clean their feathers among other things, and it also helps remove parasites. A mandatory dust bath could decrease red mite populations that are amplified in CF facilities. Further studies can be done comparing CF and ECC red mite populations when dust baths are provided since little research has been done on both types of facilities.

In addition to supplying enrichment, maintaining a flock with clean feathers continues to rely heavily on the farmers. Facility cleanings between flocks need to occur to ensure red mite populations are exterminated. Cleaning schedules should be enforced and upheld by the farmers and workers. Red mites are also something that should be included in the UEP guidelines and checked for during the audits, as an uptick in them will likely be seen as more CF facilities are implemented. Cage-free facilities have the advantage of smaller hen populations. Workers may have a higher chance of noticing affected birds seen picking at their feathers or itching and could remove them for treatment. Furthermore, with fewer birds it is likely easier to temporarily remove them all for a facility cleaning. This can also occur for the floor litter, which should also be removed frequently to keep feathers clean and remove any hidden mites. The benefits of cage-free facilities can be fully conveyed when farmers take the time to care for their hens and environment.

For the poultry and greater food industry, implementing the suggestions discussed above will help placate consumer interest in hen welfare. Consumers are eager to know their cage-free eggs are coming from hens with extra enrichment, healthy feathers, and clean cages. So much controversy surrounds hen facilities since such little information is open to the public, and videos are usually released by aggressive animal activist groups. If farmers implement these changes and stay up to par with industry standards, they can help break down the secrecy surrounding the egg industry. They can provide the public with educational photos, videos, or tours of their hen facilities. This can only occur if the UEP goes into greater detail in their guidelines and sets a caliber for farmers to follow.

Enriched Colony Housing

Enriched colony cages offer an excellent alternative for egg producers and farmers. Yet, the benefits they provide are incredibly variable depending on the physical and environmental factors of each specific farm. As mentioned above, much of this relies on how much money the farm has and the state of their equipment. A study has been done that looked at converting conventional cages into enriched colony cages to save money and reuse materials. This is something that can be further researched so that this cage system can become more accessible and cheaper. Very little research has been put out on ECC

and it is likely that farmers are unaware this type of hen facility exists. Big Dutchman, one of the largest farm equipment suppliers, installed the first ECC facility at a farm in California in 2011. Beyond that, many other facilities have followed in their footsteps, yet little research has been done on them. For its popularity to increase in the US, the UEP would need to put out regulations just as they do for cage-free eggs. They can also look into funding studies regarding ECC so that more exposure can be cast on them. Organizations such as IFT can include ECC studies in their weekly newsletters to further highlight their benefits. Furthermore, the American Humane Association approves of ECC as a scientifically acceptable housing facility for hens due to nesting boxes, perches, and other enrichment (American Humane Association, 2018). This distinction is important regarding consumer purchasing power. If enriched colony cages had a UEP ECC certified or American Humane Association label on them, it is likely consumers would approve and buy the product. Therefore, official US guidelines need to be developed so farmers can begin to implement these facilities and the public can be introduced to them as an alternative to CF eggs.

The success of ECC for the hens and their farmers depends on enrichment. Ideally, all furnished cages would have the maximum amount of enrichment: perches, scratch pads, dust baths, private nesting areas, and a separate litter area. Currently, there are only requirements for the size of furnished cages and none for the enrichment. Therefore, farmers can include as much or as little enrichment as they want or can afford. If little enrichment is provided, the benefits of ECC are diminished and they become similar to conventional cages in terms of natural hen behaviors. Once again, regulations regarding the types and amount of enrichment need to be implemented. Future studies can observe hen feather condition when maximum enrichment is provided compared to minimal enrichment. There is also a research gap on ECC and red mite populations, as none has been published. While there may be more places for the mites to burrow in ECC, there is no floor litter compared to CF facilities. Research could be done to see if the red mite populations are lower in ECC due to mites not having floor litter to burrow in. Additionally, the addition of dust bath enrichment helps remove the mites. If mite populations were found to decrease, it would be a huge selling point for ECC since Europe is experiencing a rise due to their ban on cages.

Hen stocking density also determines whether furnished cages will provide the benefits they intend, as lower densities contribute to lower ammonia levels. The lower stocking density seen in ECC also yields more socializing, natural behaviors, and better feather condition. Additionally, the overall layout of the ECC cages impacts hen welfare. The location of dust baths, scratch pads, or perches are determining factors in whether the hens will use them. If the enrichment is located high up and the hens must jump to reach it, they will typically use it less.

Overall, the common theme amongst the issues with CF facilities and ECC is that the UEP and USDA need to work together to provide a detailed set of rules that results in a disciplinary action to the farm if not followed. Without the farmers having a basis of comparison, little enforcing can be done when audits occur.

Conclusion

Improvements to hen welfare in the egg industry are increasingly common as consumers use their dollar to dictate specialty egg trends. Cage-free egg facilities improve many issues consumers and farmers had with conventional cage systems. They are shown to encourage natural behaviors and grant hens the freedom to roam. While these aspects are significant, alternate issues arise as hens go cageless:

- Increased ammonia levels due to stagnant floor litter, lower ventilation rates, and high moisture litter creates unhealthy air quality that leads to disease and internal deterioration in the hens
- Allowing the hens to commingle with each other can result in deadly pecking behavior, feather loss, and red mite infestations

Enriched colony/furnished cage systems provide a better solution to these concerns through privacy and enrichment. They show lower ammonia levels due to the presence of a manure belt and fans which dry out the manure. The long-term manure storage bays release less ammonia emissions due to dryer litter entering them. Additionally, they have increased enrichment and privacy around their cages that allow the hens to practice comfort behaviors and reduce pecking scenarios. Space for dustbathing allows them to potentially remove red mites and scratch pads provide an opportunity for the hens to release stress. Different compartments among the ECC barn allow the hens to spread out and avoid overcrowding in popular areas. While more studies need to be done on them, they are a better option for hens than cage-free facilities and should be backed by the egg industry for implementation.

Cage-free egg facilities and enriched colony cages have many conclusive benefits. Yet, there are limitations to these benefits due to the USDA and UEP not having thorough guidelines for either hen facility. This allows for a presumed lax approach to enforcement and little public knowledge regarding these alternative facilities. Very few research articles, especially on ECC, also limit the success of these facility types. Given the information that was presented above, it is evident that farmers would need to invest a significant amount of money to maintain a successful CF or ECC barn up to government standards. Yet, it is impossible to know the extent to which the USDA/UEP upholds their regulations on these

novel farms. Furthermore, it is impossible to know whether the farmers are maintaining good animal welfare practices daily which leaves much of this in their hands.

Presently, the egg industry continues to be shrouded in secrecy which gives the public a skewed view of the happenings in a hen facility. The barriers surrounding the egg industry need to be broken down through exemplary welfare practices and a government issued standard to follow. This will allow for the welfare and environmental aspects of cage-free and enriched colony cages to be fully investigated, instead of research being pushed by consumer preference.

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