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How concerned should we be about broiler breeder fertility declines?

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A B S T R A C T

Broiler breeder fertility is the bedrock on which modern broiler production rests. Over the last decade, fertility and hatchability issues have emerged as key topics of interest for both breeders and producers. In this study, we took an analytical approach to interrogate declining fertility trends among U.S. broiler breeders from 2013 to 2022, leveraging data from the USDA National Agricultural Statistics Service (NASS). Despite an increase in the number of eggs set and broilers raised to meet the rising demand for poultry, projections indicate that hatchability rates could decrease to approximately 60 % by 2050 without corrective action. Our Markov Chain Monte Carlo (MCMC) analysis reveals significant declines in essential production metrics, including hatchability, chick livability, and production efficiency. The analysis also includes 95 % credible intervals that confirm a persistent downward trend across these parameters. We developed the Broiler Breeder Performance Index (BBPI) to deepen our understanding of these trends, utilizing both Gaussian and Cauchy models to evaluate predictive performance. The BBPI projections suggest a decline below baseline values over time, underscoring the urgent need for interventions to counteract the fertility crisis in the broiler industry. Several factors contribute to this decline, including management practices and genetic selection strategies. Effective flock management techniques, such as sex-separate feeding and careful weight monitoring, are vital for improving reproductive viability among broiler breeders. Our findings highlight the necessity of addressing these fertility issues to ensure the long-term sustainability of U.S. poultry production. As the global demand for poultry meat grows, the poultry industry faces significant challenges in maintaining productivity. By pinpointing the causes of fertility decline and implementing effective management strategies, stakeholders can better navigate the complexities of poultry production and contribute to food security. This study aims to draw attention to the urgency of addressing broiler breeder fertility issues. It encourages further research into solutions that can enhance reproductive performance across various genetic stocks in the industry.

Introduction

Significance of fertility and hatchability in poultry

The livestock sector relies heavily on reproduction to meet the global demand for animal protein. Poultry is the most consumed animal protein source globally ("Global meat projections to 2050 - FAO – processed by Our World in Data.,"). Global consumption of poultry is projected to increase to 181 million tonnes by 2050 ("Global meat projections to 2050 - FAO – processed by Our World in Data.,"). The poultry industry is under constant pressure to maintain production of high-quality chicken to meet consumer demand. Many improvements in the poultry industry in the last 70 years, through selective breeding, have succeeded in producing larger birds more rapidly than ever before (Zuidhof et al., 2014). Selection for desired traits contributed to higher meat yield but has come at the cost of several livability traits, such as muscle (Petracci et al., 2015) and skeletal defects (Julian, 1998), meat quality (Petracci et al., 2015), and fertility (Decuypere et al., 2003). High fertility rates, hatchability, and livability are essential for the viability and sustainability of commercial livestock production, regardless of species (Killian, 2012). In poultry, fertility directly affects the number of eggs placed and hatched for broiler production, and a decrease in fertility directly influences the quantity of chicken available for consumption (Leeson and Summers, 2010).

Reproductive performance varies between species and strains, but they are fundamentally similar in the desired outcomes - to produce sufficient animals to meet demand. Fertility and hatchability are key indicators of reproductive performance influenced by environmental and genetic factors (Stromberg, 1975). Fertility and hatchability are correlated heritable traits that differ across breeds, varieties, and

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individual birds (King`ori, 2011). Other factors, such as egg age (Tarongoy and Gemota, 1990), storage conditions (Brah and Sandhu, 1989), flock age (Buhr et al., 1994; Roque and Soares, 1994), husbandry systems and rearing techniques (Weis, 1991), mating systems (Gebhardt-Henrich and Marks, 1991), as well as incubation humidity and egg turning angle (Permsak, 1996), also impact poultry egg hatchability. While there is a robust debate regarding the main approaches used to improve fertility - e.g., management, nutrition, or genetics (Hunton, 2006), the emerging consensus recognizes the ongoing challenges affecting broiler production.

Status of fertility and hatchability in broiler breeders

Avian species are unique in having high metabolic rates and maintaining fertility levels until the end of life (Ricklefs, 2003). This feature would suggest that reproductive performance should remain high until late in life. However, domesticated avian species do not seem to conform to this life-history trait found in their wild ancestors. A common characteristic of fertility in domestic poultry is a gradual rise during the first 3-5 weeks of the reproductive period, reaching a peak before leveling off. This peak is maintained until about two-thirds of the reproductive period is completed. After this stage, fertility progressively declines (Brillard, 2003), but it is unclear if this also coincides with the end of life in domesticated birds.

Previous studies over the decades have recorded and highlighted the relationship between broiler breeder flock age and fertility and the hatchability of fertile eggs. The fertility and hatchability of fertile eggs vary with the age of the parent flock (Kirk et al., 1980) and also with natural behaviors among hens, such as molting and broodiness. When it comes to molting – a natural cycle of shedding feathers, hens will cease laying eggs, which would also affect the egg output of the flock. While forced molts have been explored for rejuvenating egg output (Attia et al., 1994, Ga et.al., 2022) there is limited recent data on the role it plays in fertility declines. Broodiness is another natural behavior where hens incubate their eggs, and cease new egg laying (Romanov et.al., 2002). While this trait is observed in many indigenous and heritage breeds (Jiang et.ak., 2010), commercial strains have been selected against broodiness to maintain higher egg production. Peebles and Brake (1987) recorded eggshell quality and hatchability of eggs from broiler breeders 31 to 63 weeks of age. They found that the hatchability of total eggs at 63 weeks of age was 78.4 % (Peebles and Brake, 1987). Another study from 1992 recorded 79.83 % hatchability of total eggs when broiler breeders were 54 weeks of age. A more recent study recorded that the hatchability of eggs laid by 44-week-old broiler breeders was 70.4 % (Abudabos, 2010). The literature suggests that the age of fertility drop-offs are occurring earlier than several decades ago. However, this must be viewed through the lens of the rapid change in poultry breeds due to selection over this same period. Table 1 gives a summary of broiler breeder fertility and hatchability reported over the last four decades. While these studies do not suggest a clear directional trend, the hatchability percentages during the peak production phase shows an overall declining trend, and a reduction of hatch percentage in the late productive stage (Abudabos, 2010; Kirk et al., 1980).

Current approaches to improve fertility

Broiler producers employ various strategies to enhance breeder fertility, from replacing breeder males to dietary supplementation to feeding management. Sometimes, a combination of approaches is required to achieve the desired productivity levels for the specific Abudabos, 2010 breed or line.

The most well-documented and implemented approach is the practice of spiking, a technique used to enhance flock fertility by replacing older males with younger ones (Chung et al., 2012). The choice of spiking method and time of spiking are based on trends relating to declining hatchability and age of the broiler breeders. Traditional spiking introduces younger males from a different flock to compensate for the fertility decline after peak production (Iowa State University et al., 2013). Different spiking methods are implemented in broiler breeder flocks to increase male mating behavior and improve declining fertility: spiking with young roosters, single interspike of similarly aged roosters, and double interspike (Sabah and Yilmaz Dikmen, 2023; Ordas et al., 2015) implemented a spiking program by introducing young male broiler breeders to a 44-week-old flock, resulting in higher hatchability between 47 and 50 weeks. Similarly, (Jafari et al., 2015) reported a significant increase in hatchability when 24-week-old males were added to a 45-week-old flock. This technique can slightly improve the fertility issues seen in broiler breeders, but there are biosecurity concerns with introducing new males into a flock. Another issue with this spiking method is disrupting the flock's hierarchical order, leading to increased mortality due to aggressive behavior from older roosters toward younger ones (Chung, 2010; Mphepya et al., 2019).

Due to issues like biosecurity risks and disruption of social hierarchy emerging from using younger males, intra-spiking has been another alternate strategy in use. Intra-spiking involves relocating roosters of the same age between houses on the same farm, replacing 25–30 % of the male breeders without introducing new ones from outside the farm (Casanovas, 2002; Güçbilmez and Elibol, 2008; Mphepya et al., 2019). Intra-spiking offers three critical advantages over regular spiking: a) it incurs no additional costs as no new males need to be housed, b) it poses lower biosecurity risks, and allows for quicker, more efficient integration of the introduced males since they already have mating experience (Casanovas, 2002), and c) the new males boost mating activity temporarily(4-8 weeks) (Casanovas, 2002).

Another key part of broiler breeder management is maintaining body weight within the flock. Unlike layers, which can regulate feed intake

Table 1.
Recorded hatchability percentages: Data on fertility from a literature survey focusing on broiler breeders with reported fertility rates at young, mature, and old age classifications. The corresponding source is cited in the column labeled 'Citation'.

	Recorded Hatchability Percentages at Different Ages (Weeks)				
Year of Publication	Young (Age 24-34)	Mature (Age 35-43)	Old (Age 44-65)	Breed	Citation
1980	NA	NA	88.8 (fertile of total) 81.9 (hatch of fertile)	Ross 1	Kirk et al. (1980)
1987	85.8 (hatch of total)	89.6 (hatch of total)	78.3 (hatch of total)	Arbor Acres and Indian River	Peebles et al. (1987)
1992	92.45 (hatch of total)	85.81 (hatch of total)	79.83 (hatch of total)	Indian River	Fasenko et al. (1992)
1994	84 (hatch of total)	89.5 (hatch of total)	87.5 (hatch of total)	Cobb 500	Roque et al. (1994)
1997	91.2 (hatch of fertile)	NA	94.3 (hatch of fertile)	Commercial Broiler Breeder Flock	Reis et al. (1997)
2010	85.2 (hatch of total)	NA	70.4 (hatch of total)	Cobb 500	Abudabos (2010)
2010	87.3 (hatch of total)	80.8 (hatch of total)	NA	Ross 308	Abudabos (2010)
2016	89.81 (hatch of total)	88.37 (hatch of total)	81.04 (hatch of total)	Cobb	Araújo et al. (2016)

based on metabolic needs, broiler breeders are prone to overconsumption and obesity. Feed intake must be carefully managed to avoid obesity-related fertility declines (Richards et al., 2010). Therefore, feeding management is a critical aspect of managing breeder fertility, and regimens such as restricted feeding, skip-a-day, or timed feeding are employed to maintain reproductive performance in broiler breeder hens. This method helps mitigate excessive body weight, thus improving fertility by reducing obesity, ovarian dysfunction, and reduced egg production (Silveira et al., 2014; Soltanmoradi et al., 2013; Taherkhani et al., 2010). Additionally, increasing feeding frequency is associated with improved reproductive outcomes, as it can positively affect metabolic processes during peak egg production (Moradi et al., 2013). However, this intervention poses challenges for management and raises concerns for animal welfare (Renema et al., 2007).

Aside from these techniques, dietary supplementation is a frequently attempted but rarely successful approach. This involves the supplementation of essential vitamins and minerals. For instance, the inclusion of vitamins A and E has been shown to positively influence fertility traits in broiler breeder hens, particularly during the late production phase. This supplementation can putatively help maintain or even improve egg production under standard rearing conditions (Yaripour et al., 2018). Similarly, zinc supplementation has been linked to improved semen quality and testicular health in broiler breeder roosters, with studies indicating that organic zinc sources enhance sperm viability and overall reproductive performance (Jafari and Ghobadi, 2021; Li et al., 2019). Furthermore, adding betaine to the diet increases fertility and hatchability rates, as it helps reduce homocysteine levels, which are detrimental to embryonic survivability (Rokade et al., 2020).

Despite the continued application of numerous approaches, fertility and hatchability issues persist, and its unclear whether these are minor issue or large-scale trends. To determine if large-scale trends support the perceived decline in fertility, we need a systematic review of the available data. Additionally, to determine if such declines merit further attention, we need to understand the long-term consequences better if the trends are not reversed. Our study addressed these questions using statistical analysis and simulation-based methods to illuminate the potential impacts of declining fertility. Our results show that sustaining broiler production at the current scale will likely become highly challenging unless fertility declines are remedied.

Materials and methods

To assess the evidence for changes in broiler breeder fertility over time, we first analyzed the U.S. broiler production data from the USDA National Agricultural Statistics Service ("USDA/NASS QuickStats Ad-hoc Query Tool,"). The NASS database provides economic and production data for agricultural products in the United States. The NASS database aggregates self-reported data on a national scale. While self-reported data can have inherent biases, the scale of the U.S. broiler production and the compilation of data from different commercial production companies and breeds provides a robust average for the metrics of interest. Therefore, this dataset provides a production-relevant and realistic view of national trends in broiler production. Using the available data for broiler production from 2013-2022, we estimated the hatchability which was computed by dividing the number of eggs hatching by the number of eggs set. As fertility is not measured at this scale, hatchability serves as the proxy for fertility. Chick Livability is the ratio of eggs set to the number of broiler chicks placed. Production Efficiency represents the number of broilers processed at the end of a production cycle divided by the number of chicks hatched. It captures the conversion rate of chicks to market-age broilers. We also calculated a composite efficiency parameter as (Hatched/Set)+ (Produced/Hatched), which considers two biologically and logistically distinct parts of the broiler production cycle. We performed a linear regression using a Generalized Linear Model (GLM) in R on each observed and calculated parameter and plotted the data along with the regression statistics. We did not include data from before 2013, as broiler egg statistics were not a part of the NASS before then.

Statistical modeling of future scenarios based on past trends

Statistical models are commonly used to forecast trends in livestock systems and natural populations. Time series analysis and GLM (linear regression models) have both been used to predict future trajectories based on past data trends. In the livestock or poultry context several recent studies have applied these approaches for forecasting; Na etal. (2023) used regression models to predicting live weight trends in cattle, whereas Klaharn etal. (2024) used time-series data in an autoregressive integrated moving average (ARIMA) approach to forecast poultry production and export volumes in Thailand.

In this study, we used a probabilistic approach to estimate posterior distributions for the parameters of interest based on past trends. We employed a Bayesian GLM to estimate the slope from past data. Then, we applied a Markov Chain Monte Carlo (MCMC) simulation approach to project hatchability rates up to the year 2050. Utilizing the `rstanarm` R package, we fitted a Bayesian GLM to the historical hatchability data, with the year as the predictor. This approach allowed us to integrate prior knowledge regarding the slope's variability over the last decade into our model. We then used the MCMC simulations to estimate the model parameters' posterior distributions.

We implemented the model with 2,000-100,000 iterations across 4-20 chains (testing for robustness), ensuring a thorough exploration of the parameter space and estimation of the posterior distributions. We used the posterior distributions to project hatchability rates from 2023 to 2050. For each year going forward, we simulated the hatchability outcomes up to 100,000 times based on the model's posterior predictive distribution. This approach allowed us to comprehensively encapsulate the uncertainty in our projections, considering the small number of prior observations (10 years of data points).

We calculated the 95 % credible intervals for each future year from these simulations, delineating the range within which the actual hatchability rates are expected to fall with 95 % probability, given the observed data and our Bayesian model assumptions. The analysis was visualized using the `ggplot2` package. In parallel, we applied a similar analytical procedure to assess Chick Livability and Production Efficiency, two additional metrics obtained directly from the NASS data. These projections are visualized in Figs. 1-3.

Broiler breeder performance index (BBPI)

To determine if a combination of the primary predictors (hatchability, chick livability, eggs set, etc.) provides better projections than the individual projections, we developed a composite index, termed the Broiler Breeder Performance Index (BBPI), to encapsulate multiple dimensions of broiler production into a singular metric. This approach facilitates an integrated assessment of the overall performance, potentially as a pivotal tool for decision-making and performance benchmarking over time or across disparate units/locations. The implementation of the BBPI involved the following steps:

1. Standardization: To ensure uniformity and comparability across diverse measures (Hatchability, Livability, Production Efficiency, Broiler Eggs Set), variables were standardized to a standard scale, either ranging from 0 to 100 or transformed into z-scores. This standardization process mitigates the dominance of any single variable due to scaling.
2. Weighting Scheme: The BBPI incorporates a weighting scheme to reflect the relative significance of each constituent variable to the overall index. The final weights were determined based on principal components analysis (PCA) to accurately represent each variable's contribution to broiler breeder performance.

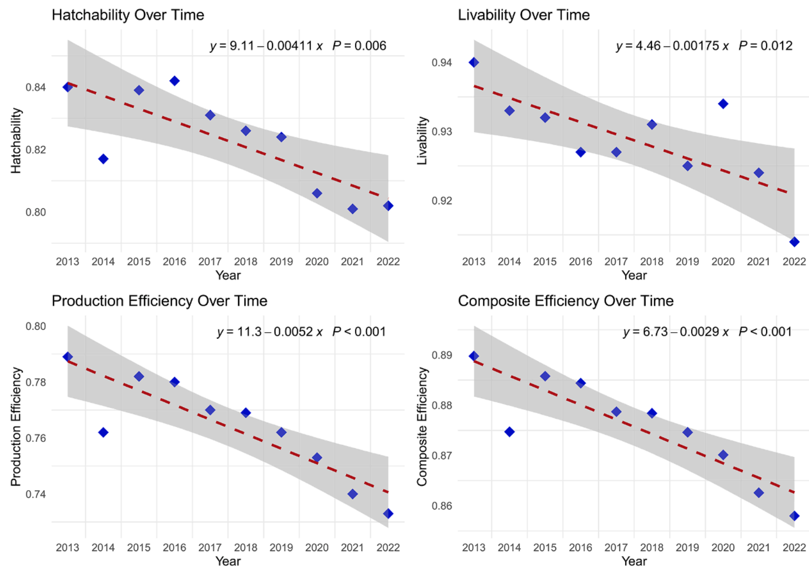

Fig. 1.. Results from a statistical analysis of the trends in key broiler production parameters between 2013-2022. The x-axis shows the time span, and the y-axis shows the observed values expressed as a proportion. Linear regressions that were fit to trends in hatchability (top left), Livability (top right), production efficiency (bottom left), and composite efficiency (bottom right). All four observed and calculated parameters showed statistically significant negative trends over time.

3. Combination: The composite index was then computed by aggregating the weighted standardized scores of each variable, yielding the BBPI. This index serves as a singular performance indicator, streamlining the analysis and interpretation of multidimensional data.

In addition to the base model described above, we developed an alternative BBPI model that incorporated three metrics from broiler production: market weight at 47 days of age, mortality rate, and per capita consumption for the same period (2013-2022). The data was obtained from the National Chicken Council (https://www.nationalchickencouncil.org). Increasing consumption and mortality can elevate the pressure on production, while higher market weight can reduce that pressure. Therefore, these metrics are sensitive to changes in fertility.

In developing the BBPI, we employed normally distributed priors for the regression coefficients and the intercept, a conventional choice without strong prior knowledge suggesting alternative distributions. We also modeled Cauchy distributions for the priors to account for the possibility of alternative distributions. The Cauchy distribution is characterized by its thicker tail, which includes a greater likelihood of extreme values, accommodating the potential for larger effects and, therefore, a more conservative treatment of prior knowledge.

With this approach, we could evaluate the sensitivity of our predictions to the underlying assumptions of the model specification. Through comparative analysis of these models, we aimed to assess the robustness of our predictions to variations in model assumptions and the sensitivity of our forecasts to changes in the prior distribution. This comparative framework explored robustness (stability of predictions against modifications) and sensitivity (the impact of altering the prior distribution on forecast outcomes).

Results

First, the NASS data trends show that fertility represented by hatchability (eggs hatched/eggs set) has declined over the last decade between 2013-2022 (Fig. 1). Furthermore, we see this pattern even as the total eggs set and broilers raised have increased in response to demand. The linear regression for each of the primary parameters (hatchability, livability) and two calculated parameters (production efficiency, composite efficiency) showed a significant negative correlation between the parameter values and time, showing that each of these parameters declined significantly over the preceding decade (Fig. 1).

Hatchability showed a significant negative relation with time (R^2 = 0.62, *b* = -0.004, P = 0.006). Livability (R^2 = 0.56, b = -0.017, P = 0.012) and production efficiency (R^2 = 0.76, b = -0.052, P = 0.0010) also showed significant negative changes. Similarly, the composite efficiency declined significantly over time (R^2 = 0.76, b = -0029, P = 0.0009).

We also calculated the effect size of the observed change in composite efficiency. Composite efficiency declined from 0.8898 (2013) to 0.8580 (2022), with a mean value of 0.8757 over that period (SD = 0.10). This decline had an effect size of -3.16 (Cohen's *d*), which presents a significant large effect.

The Bayesian MCMC analysis showed that hatchability would continue declining from a starting (2022) value of 0.81 to a median value of 0.72 by 2050 (95 % credibility interval = 0.61-0.0.77, Fig. 2). As with hatchability, both livability and production efficiency show declining trends. Projected livability declined from a starting value of 0.91 to a median value of 0.87 (95 % CI = 0.91-0.83). Production efficiency declined from a starting 0.73 to a median value of 0.59 (95 % CI = 0.52-0.68). Overall, trends, medians, and 95 % credible intervals show a continuing decline in key broiler production parameters.

Broiler breeder performance index

The implementation and comparative evaluation of the BBPI models examined the predictive performance and estimated the posterior distribution of performance indicators. Fig. 4 shows the outcome of the projections from the BBPI models assuming Gaussian and Cauchy priors. Both models predict a decline in the BBPI leading up to 2050 (Fig. 3). The y-axis, expressed in standard deviation (SD) units, indicates the magnitude of decline relative to the baseline values (average over the last decade). The negative change signifies that the performance index is expected to decrease below the baseline. As the units are SD from the mean, the posterior estimates show the magnitude of the decline. For instance, in 2035, the BBPI median crosses -2, with a 95 % CI between -0.5 and -3.5 SD from the baseline (present value). These results suggest that the *best-case scenario* would be a decline in BBPI of -0.5 SD, representing five units of change from the baseline (2022 value).

Notably, while both models project a similar trend of decline, the

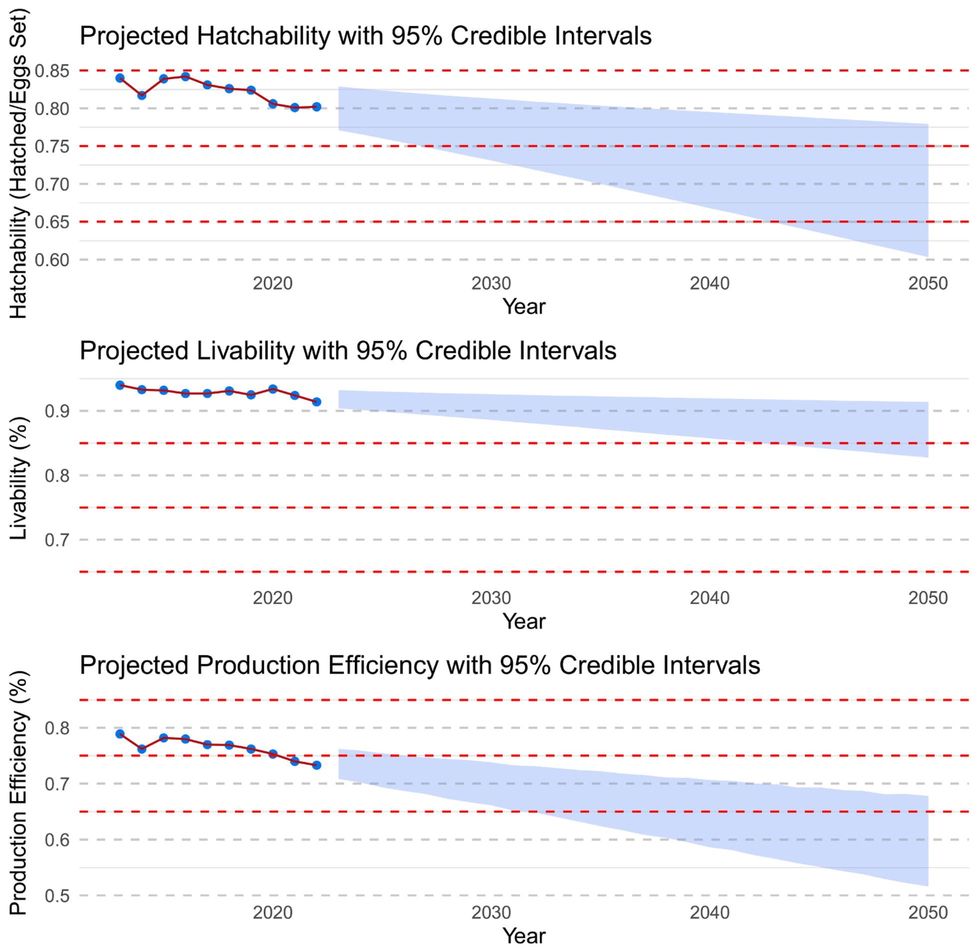

Fig. 2.. Bayesian Markov Chain Monte Carlo (MCMC) simulation results estimating the future broiler production parameters and their 95 % credible intervals. The x-axis shows the time spanning from 2013 to 2050, and the y-axis depicts the observed and projected parameter values. The shaded area shows the 95 % credible interval for each parameter. The three stacked panels show hatchability, livability, and production efficiency outcomes, respectively.

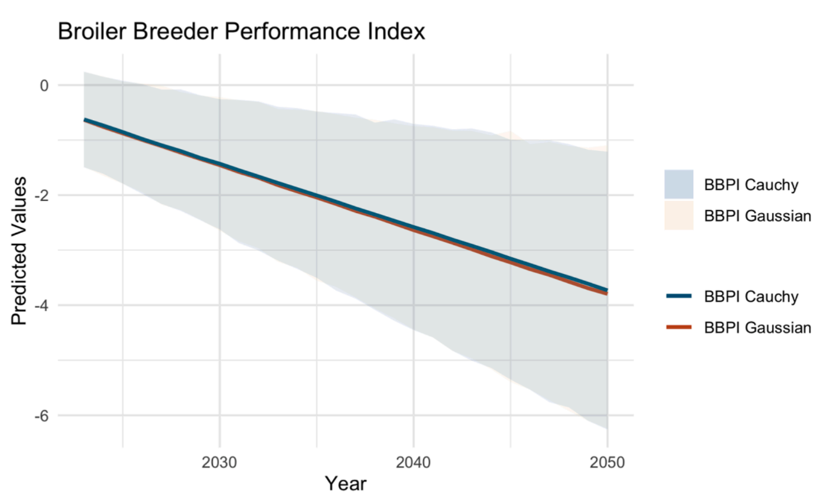

Fig. 3.. The results of the estimated Broiler Breeder Performance Index (BBPI) projected until the year 2050, based on the observed breeder fertility parameters from 2013-2022. The x-axis shows the time, whereas the y-axis shows the change in BBPI as standard deviation units.

Cauchy model showed slightly wider credible intervals, suggesting greater uncertainty in these predictions than the Gaussian model, but similar outcomes. These two models emphasize the importance of considering variable model assumptions in the predictive modeling of future scenarios.

The data for the alternative model including demand showed that overall poultry demand in the United States increased from 17.5 M metric tonnes in 2013 to 21 M in 2022. Per capita consumption of broiler meat increased from 37.4 Kg in 2013 to 45.72 Kg in 2022.Market weight of broilers increased from 2.69 Kg to 2.98 Kg in 2022. With these additional metrics included, the BBPI (with demand) showed a worse outlook than without the demand data (Fig. 4). For comparison, the median index estimates in 2035 cross -5, with a 95 % CI between -4.7 and -7.3 SD from the current baseline. These model outcomes suggest when the increasing demand and consumption trends are factored in, the index performed worse, highlighting the potential challenge of supplying demand in the face of fertility declines.

Discussion

Our study used a systematic approach to assess the trends in broiler production in the United States between 2013 and 2022. We then applied Bayesian and simulation-based statistical modeling to project future scenarios for broiler production parameters. Overall, our analyses showed (a) significant negative change over time in key broiler production parameters, specifically hatchability, livability, and efficiency, and (b) predicted continuing declines into the future that may threaten the ability to meet demand, if the causes are not identified and remedied. Our analysis showed that both pre- and post-hatch aspects of production are declining and that the combination of these two encapsulated in our composite efficiency and BBPI metrics suggest synergistic effects that could pose problems for supplying the national demand for broiler meat.

One of the main takeaways from our analysis is the clear sign of decline in breeder fertility over the past decade. While the decline is already widely acknowledged in the poultry community, we can make two important conclusions: 1) given the scale of the U.S. broiler production, over 9 billion birds per year, the observed trend over the past decade is representative of industry-wide trends across different integrated producer systems, and 2) the overall decline includes all broiler genetics used in U.S. broiler production and therefore, contributing to the observed trend. Whether the pattern observed is unique to the United State is difficult to evaluate due to lack or inadequacy of unified databases representing other large production regions. However, the models implemented in this study can be easily applied to other longitudinal datasets to examine if the United States is part of a larger trend.

Our analysis suggests that without immediate corrective actions, broiler fertility can be expected to decline further. A drop in production associated with declining fertility will challenge broiler production and threaten the supply of poultry meat in the U.S. and globally. Our study seeks to draw urgent attention to the fertility issues that are at the root of these declines, and highlight the food security issues that may emerge if the causative factors are not identified and remedied.

Potential factors driving fertility decline in broiler breeders

Many factors affect poultry fertility and reproductive success (King`ori, 2011). Some of these factors have been studied more extensively than others. The weight- and size-associated issues that restrict natural mating behaviors in turkey breeder production is not yet an issue broiler breeders, but excessive weight gain negatively affects fertility. Weight management is a well studied issue; Sex-specific feeding has become a common approach for maintaining the fertility of breeder flocks (Brillard, 2001). Feed restriction approaches are also implemented to limit the growth and body weight of breeders to prolong and improve the natural mating behaviors (Brillard, 2004). Some management practices also time photo-stimulation of sexual maturity to promote welfare (Bakst and Dymo, 2013; Bilcik et al., 2005). However, most approaches struggle to balance weight management, welfare, and fertility outcomes.

When it comes to the sex-specific factors influencing fertility and reproductive output, hens have fewer direct effects on the survivability of the embryos post-conception compared with other livestock species. Therefore, male and female physiological parameters at and pre-conception could play more of a role in hatchability than post-conception and oviposition factors. The main impact females have on fertility relates to the competitive selection of spermatozoa in the sperm storage tubules (Bakst et al., 1994; Brillard, 1993; Chai et al., 2024). However, sperm motility is the leading competitive factor affecting selection in these tubules (Takeda, 1974). The presence of sperm storage tubules removes the need to track the hormonal cyclicity for mating or semen depositions using artificial insemination (AI), as in other livestock species. The primary utility of AI in turkeys is to fill the sperm storage tubules of the hens since turkeys have lost the ability to mate naturally (Bramwell, 2021; Funk, 1950). However, due to the number of broiler breeders and the limited storage potential of avian semen, AI is not a viable option, except for small operations. Furthermore, the natural mating ability of broiler breeders is also a part of the solution, as natural breeding is significantly more efficient for fertilization than AI (Hughes, 1978).

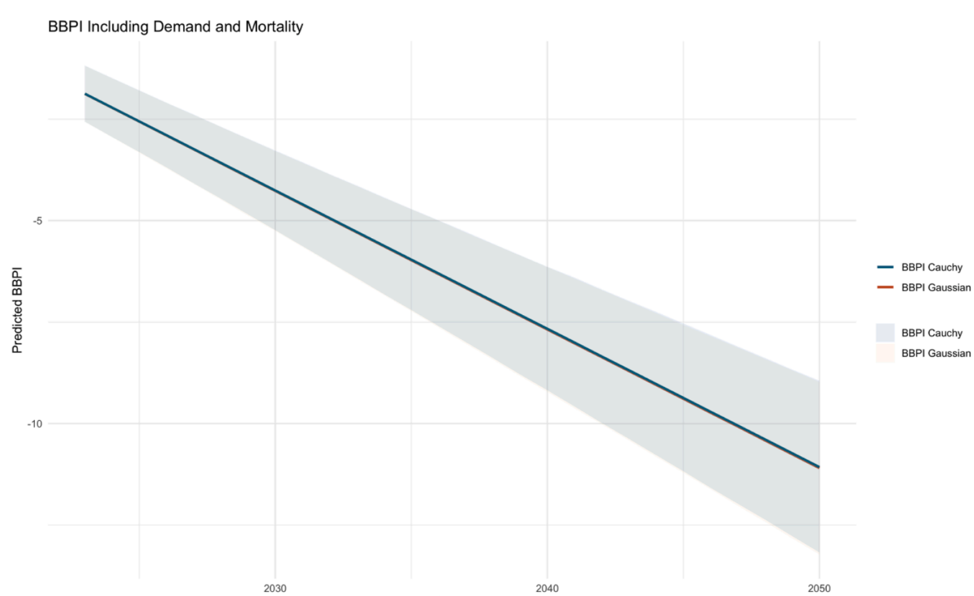

Fig. 4.. The results of the alternative BBP including demand and mortaility metrics from broiler. The x-axis shows the time, whereas the y-axis shows the change in BBPI as standard deviation units. This model showed that the inclusion of demand, market weight, and mortality data worsened the projected index performance.

The widespread practice of spiking to improve fertility suggests that the causative factors may lie with broiler cockerels. An updated and modern understanding of male fertility parameters in poultry is relatively limited and, compared to mammalian livestock species, especially. Improved understanding of the complex regulation of reproductive factors in poultry, particularly male reproductive factors, is necessary for improving broiler breeder fertility (Cassina et al., 2015; Dohle et al., 2005; Irvine, 1998). Leveraging the latest knowledge and techniques from human and different livestock reproductive research will be critical for thoroughly evaluating the causative factors and finding solutions for poultry fertility declines.

Implications of fertility declines in poultry

Livestock production is a meticulous process with many implications for food security, economic success, and environmental sustainability. The most consumed animal protein sources are poultry, pork, and beef ("Global meat projections to 2050 - FAO – processed by Our World in Data.,"). As the global population continues to increase, the demand for animal protein production is also increasing. A substantial portion of the global population suffers from undernourishment and food insecurity despite improvements in food availability. Therefore, understanding the effects of fertility declines on poultry meat production for human consumption and environmental and economic sustainability is essential.

The 2022 Poultry and Egg Industry Economic Impact Study evaluates the collective economic influence of chicken, turkey, egg, and other poultry sectors, encompassing rendering, hatcheries, feed production, and secondary processing. This industry contributes significantly to the US economy, totaling $555.93 billion, equivalent to 2.20 % of the GDP. Its extensive production and distribution networks extend influence across over 520 sectors within the US economy. The workforce engaged in poultry and egg production, sales, primary processing, packaging, direct distribution, and value-added processing amounts to 498,492 employees (Dunham, 2022). Therefore, ongoing declines or major disruption in broiler production is likely to have a sizable impact on the economic and food security of Americans. Economic losses due to livestock infertility can be substantial; studies in cattle show that for a 100-head cattle cattle operations, the annual economic cost of infertility can range from $2,800 to $13,200, depending on the prevalence and economic impact per cow (Prevatt et al., 2018).

Besides the economic consequences, there are the environmental consequences to consider, which affects the overall sustainability of food production. At present, the environmental footprint of poultry production is lower than that of livestock sources, such as beef and pork ("You want to reduce the carbon footprint of your food? Focus on what you eat, not whether your food is local - Our World in Data,"). However, continued fertility declines may necessitate increasing the number of broiler breeders, to offset the shortfall in broiler output. Such an increase in breeder populations may require additional land to house broiler breeders, increased feed and water, and electricity. We already see this trend in the observed data, which showed that more eggs are set every year, while producing fewer broilers.

Poultry breeding is a complex process focused on achieving production goals. Pedigree animals are selected based on the economically valuable traits such as feed efficiency, weight at market age, leg strength, heart and lung fitness, and disease resistance. While these traits have showed quick gains under selection, other functional traits can be more difficult to improve. For traits such as fertility which typically have low heritabilities, improvement of fertility may need to be part of both short- and long-term strategies, as changes in breeding stock can take several years to affect commercial broilers. This forward-looking approach underscores the strategic planning required in poultry breeding decisions (Hiemstra and Napel, 2013). For targeted breeding strategies to improve fertility, there must first be focused efforts that can uncover the genetic and functional bases of factors affecting fertility. Combined with effective management strategies in the near term, selection for improved fertility-determining traits in the long-term will be crucial for averting the worst outcomes of continuing fertility declines. Our study underscores the importance of integrating reproductive traits more extensively into breeding goals to enhance the economic sustainability of animal agriculture production systems.

Conclusions

Our study highlights a concerning trend in broiler breeder fertility, with significant declines in key metrics such as hatchability, chick livability, and production efficiency over the last decade. These trends, if unaddressed, may severely impact the sustainability of poultry production, posing risks to food security and economic stability. The implementation and outcomes of the Broiler Breeder Performance Index underscores the challenges facing the industry, emphasizing the need for integrated approaches to address fertility issues. Immediate corrective actions are needed, including improved management practices and generation of new knowledge to enable genetic selection to mitigate further declines. Future research should prioritize understanding the underlying causes of fertility decline and exploring solutions to enhance reproductive performance. Addressing these challenges is critical for maintaining the sustainability of the broiler industry amid increasing global demand for poultry meat.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Cara Cash reports financial support was provided by Texas A&M University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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