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Can novel ingredients replace soybeans and reduce the environmental burdens of European livestock systems in the future?

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ABSTRACT

Much of the protein in the diets of European livestock is sourced from imported soybeans produced in the Americas. This protein deficit in livestock production presents a risk to social, economic and environmental progress in Europe. In this study the impact of incorporating novel ingredients into future chicken diet formulations to serve as European sourced alternatives to imported soybeans was investigated. The novel ingredients considered were: microalgae, macroalgae, duckweed, yeast protein concentrate, bacterial protein meal, leaf protein concentrate and insects. Using horizon scanning and a modelling approach, the nutritional requirements of two potential meat-producing chicken lines were simulated. The two chicken lines were a fast-growing line based on the apparent maximum feed efficiency that could be achieved through further artificial selection, and a reduced growth rate for high welfare line. Diets were formulated to include the novel ingredients, whilst meeting the nutritional requirements of the birds. The effects of diet composition on indicators of environmental burdens, associated with feed production for the poultry industry, were then assessed. We found that soybean products can be completely replaced by novel feed ingredients, whilst reducing the greenhouse gas emissions and arable land requirements for feed provision relative to conventional diets formulated for both chicken lines. Switching from conventional diets to diets which incorporate novel ingredients was also shown to mitigate the increased environmental burdens associated with moving towards higher welfare livestock systems. Incorporation of novel ingredients in diet formulations offers a viable option for providing sustainable and nutritionally balanced livestock feed in the future and thus provides huge potential for facilitating bespoke feeding strategies and specific management choices for mitigating environmental impacts of chicken systems.

1. Introduction

Europe's reliance on imported protein, particularly soybeans, to feed livestock is inconsistent with sustainability objectives (de Boer et al., 2014; de Visser et al., 2014; Kebreab et al., 2016; Leinonen et al., 2012). The poultry industry (meat-producing chickens, egg laying hens, turkeys etc.) collectively consumes the most soybeans of any livestock sector in Europe (van Gelder et al., 2008). This protein requirement is set to increase further as the demand for chicken meat, in particular, continues to grow (Alexandratos and Bruinsma, 2012; FAO, 2016). In addition, the inclusion of valuable conventional protein sources of animal origin in livestock feed are either limited (e.g. fishmeal) or banned (e.g. meat and bone meal) in the EU (Brookes, 2001; European Commission, 2001), whilst growing soybeans in Europe is non-competitive with imports due to relatively low yields and a long growing season (van Krimpen et al., 2013). Thus, the poultry industry is presented with the challenge of providing an adequate and more sustainable supply of protein to feed meat-producing chickens in Europe.

In seeking a long-term solution to this protein deficit, the following second or third generation protein sources have been identified for future application in poultry diets: microalgae, macroalgae, duckweed, yeast protein concentrate (YPC), bacterial protein meal (BPM), leaf protein concentrate (LPC) and insect meal. All these novel ingredients are characterized by their potential to be cultivated in Europe and their low agricultural land use (ALU) requirement; each of the novel technologies that produce them is in a different phase of development. The novel ingredients were

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included individually (at a fixed inclusion level) and combined into mixtures of ingredients in alternative diet formulations.

The nutrient requirements of two future meat-producing chicken lines that are likely to arise from breeding strategies with different objectives were considered: a fast-growing and slow-growing line. The "fast-growing line" would be the result of the current, globally predominant selection strategy which is based on the continuation of artificial selection for increased energy efficiency. The performance and therefore the energy and nutritional intake of the fast-growing birds can be calculated based on evidence of current genetic trends and apparent biological limits in their underlying biology (Tallentire et al., 2016, 2018). The "slow-growing line" would have a reduced growth rate according to higher welfare standards (Tallentire et al., 2018), representing a market shift in response to growing societal concerns about animal welfare (Clark et al., 2016; Clark et al., 2017; EFSA Panel on Animal Health and Welfare, 2010).

Thus, the overall aim of our study was to assess the environmental implications of incorporating novel ingredients into the feeding strategy of future chicken meat production systems. The novel ingredient inventory was modelled in feeding scenarios, based on the nutritional requirements of future meat-producing chicken lines which were predicted in a previous study (Tallentire et al., 2018). Whilst the environmental impacts of some of these novel ingredients have been assessed in the past (e.g. Aitken et al., 2014; de Boer et al., 2014; Jorquera et al., 2010; Oonincx and de Boer, 2012), this is the first time the environmental burdens of all seven ingredients have been calculated systematically by applying a common methodology and reported in contrast to the use of imported soybeans as the main protein source in chicken feed. A sensitivity analysis developed in previous studies was also employed here to identify any substantial uncertainty in our projections (Mackenzie et al., 2015; Tallentire et al., 2017). This is the first study to demonstrate and compare the potential environmental trade-offs of incorporating novel ingredients into chicken meat production systems, whilst also accounting for the requirements of future genetic lines and their implications.

2. Methods

2.1. Goal, scope and model structure

The goal of this study was to assess the environmental implications of replacing soybeans with novel ingredients in chicken feed formulations. From this analysis the most sustainable technologies were identified for use in livestock production; this information is crucial for nutritionists, livestock producers, breeders, policymakers and potential investors. The scope of the study was to propose potential diets, which incorporated novel protein sources, for future chicken meat production systems in Europe based on analysis of trends in recent genetic change and the apparent physical limits of the biological processes (Tallentire et al., 2018), i.e. energy (feed) intake, digestion, metabolic heat production and chemical energy partitioning. To achieve this a life cycle assessment (LCA) methodology with an integrated diet formulation tool, which was developed in a previous study, was used (Tallentire et al., 2017). The functional unit of this study was one bird grown to a live weight of 2.2 kg, the average slaughter weight of meat-producing chickens in the UK (Defra, 2014), raised in a standard European indoor system i.e. climate-controlled (e.g. fan-ventilated), artificially lit buildings.

The model inputs included: a detailed inventory of feed production (section 2.2.), the total feed intake and body composition of future chicken lines, their nutritional requirements and the nutrient content of all ingredients included within the feed formulation calculation. The model structure can be summarised as follows: all diets were formulated for a fixed set of minimum nutritional requirements for the different growth phases modelled, i.e. the starter, grower and finisher phases. Two meat-producing lines were considered. Since the nutritional requirement of each line was met in every diet formulated, it was presumed that bird growth rate per kg of feed consumed was unaffected between different diets. The methodology for calculating the nutritional requirements of these two future meat-producing chicken lines is discussed below (section 2.3). Maximum and minimum limits constrained the inclusion of each ingredient in each diet to ensure that issues of palatability, inhibition of digestibility or variability in specific ingredients did not adversely affect bird performance i.e. growth rate or carcass composition. The methodology also assumed meat quality would not be adversely affected. Although some of the novel ingredients have been shown to have a positive effect on bird health (Bovera et al., 2016; Pulz and Gross, 2004; Qureshi et al., 1996) and performance (Shanmugapriya and Saravana Babu, 2014), this was not included within the scope of this study. Environmental burden values were assigned to each ingredient, conventional and novel, in order to determine the environmental implications of formulating each diet for future chicken meat production. Finally, the environmentally important nutrients excreted by the bird were calculated based on mass balance.

2.2. Model inventory and system boundary

An inventory of conventional feed ingredients was compiled and used to build system processes in Simapro based mainly on the Agri-footprint database (Blonk Agri Footprint, 2015a,b; Durlinger et al., 2014; Vellinga et al., 2013) and previous studies (Tallentire et al., 2018, 2017). Inventory data for the processes involved in the production of a few minor ingredients were adapted from the Ecoinvent database, e.g. limestone (Swiss Centre for Life Cycle Inventories, 2007). An inventory was compiled for the novel ingredients using peer-reviewed sources and industry supplied primary data (Appendix A). All upstream system processes associated with the feed production were included within the boundary of the LCA analysis. All resource and energy inputs to fertilizer, herbicide and pesticide production and the various processing requirements of the ingredients (harvesting, separation, grinding and drying) were included in the analysis. The direct and indirect emissions that arise as a result of these system processes, including any land transformation associated with production, were all accounted for within the boundaries of the model (Blonk Agri Footprint, 2015a,b; Defra, 2015; FAOSTAT, 2015; Vellinga et al., 2013). The production of conventional ingredients was based on current practices (i.e. Conventional cropping systems), whilst novel ingredient production was based on potential upscaled processing scenarios based on novel technologies (Appendix A). It was expected that the housing conditions were maintained in such a way as to provide each chicken line with the optimum growing conditions for its genotype. However, with the exception of the feed, the resource and energy inputs to the birds' growing facility and beyond the farm gate were not included within the boundary of this study (Fig. 1). Finally, since the functional unit was only one bird raised to a live weight of 2.2 kg, the effects of bird mortality were not considered within the boundary of the model.

2.3. Future bird nutritional requirements

The nutritional specifications were based on two breeding scenarios that were presented in Tallentire et al. (2018) via horizon scanning which result in: 1) a fast-growing line based on the apparent maximum feed efficiency that could be achieved through