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Contents lists available at SciVerse ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Preface

Plant bioactive compounds in ruminant agriculture – Impacts and opportunities[☆]

ARTICLE INFO

Keywords:

Rumen fermentation
Enteric
Methane
Helminths

ABSTRACT

This preface outlines the reasons for undertaking the special issue, comments on the review process and provides a brief summary of the papers included. It also discusses some of the currently used, and potential, plant based bioactive compounds in ruminant agriculture and their applications in promoting animal growth, mitigating enteric methane emissions as well as possible applications as antiparasite agents. The final section provides a brief comment on future perspectives for use of plant based bioactive compounds in ruminant agriculture.

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1. Introduction

Plants, plant products, and other plant based bioactive compounds have recently been re-considered as natural feed additives with the potential to enhance efficiency of rumen fermentation (e.g., by enhancing beneficial aspects of N metabolism, by decreasing CH₄ production, by reducing nutritional stress caused by bloat or acidosis) thereby contributing to animal welfare and improving animal health and productivity.

In the last decade there has been renewed and increasing interest in plant products and bioactive compounds as rumen modifiers, with most experiments primarily focused on changes in rumen fermentation, mainly *in vitro* 'rumen' fermentation. Some of these products and compounds affect CH₄ production and stimulate microbial metabolism thereby increasing the extent of feed degradation in the rumen as well as the efficiency and yield of rumen microbial biomass. However, the effectiveness of these natural additives has varied based upon source, type and level of the active substance responsible for the effect.

The overall objective of this Special Issue (SI) of Animal Feed Science and Technology (AFST) was to allow researchers to publish research which established factors which could affect the useful influence of plant products, and other bioactive compounds included as feed additives in ruminant diets, on ruminal fermentation activities, such as mitigation of CH₄ emissions, enhancement of diet digestibility or ruminal fermentation efficiency, enhancement of animal health and welfare, in order to stimulate animal performance. These responses are often assumed to be primarily related to the active substance causing the effect, but effects may also be modulated by dietary (e.g., diet type, forage to concentrate ratio, feedstuffs used as diet ingredients, level of intake) and animal (e.g., physiological, production level) factors.

2. The review process for this issue

The papers in this issue tend to focus on one of the topics mentioned in the objectives above, but all have in common the use of plant bioactives to favorably modify rumen fermentation and/or animal welfare and/or animal performance and health.

Abbreviations: AFST, Animal Feed Science and Technology; SI, Special Issue.

[☆] This paper is part of the special issue entitled: Plant Bioactive Compounds in Ruminant Agriculture – Impacts and Opportunities, Guest Edited by A.Z.M. Salem and S. López, and Editor for Animal Feed Science and Technology, P.H. Robinson.

An open invitation was published in AFST and the Guest Editors (*i.e.*, Dr.'s A.Z.M. Salem and S. López) also contacted many potential authors directly. Of the 50 abstracts received and assessed, 32 were invited to submit full papers and 27 papers were actually received. All papers were reviewed by two primary reviewers chosen for their expertise in use of plant bioactives in ruminants, one of the two Guest Editors and finally by the Co-Editor-in-Chief of AFST responsible for this SI (*i.e.*, Dr. P.H. Robinson). All papers were improved as a result of the reviewers' comments, indeed some were very extensively revised, and some were rejected. A major reason for rejection was inadequacy of biological statistical replication as outlined in the AFST editorial entitled "Use of replicates in statistical analyses in papers submitted for publication in Animal Feed Science and Technology" (AFST, 171: 1–5). This particularly impacted *in vitro* studies. The resulting SI is a collection of 22 papers which, if not comprehensive in their coverage of the originally targeted topics, certainly cover a representative range of the topics.

Included in these 22 papers are five invited reviews which were also subject to the same scientific evaluation and revision process, and provide synopses of the current information on most of the topics covered in the SI.

3. Comments on the papers

3.1. Factors affecting on the effectiveness of bioactives

Two topics which have not received much attention by animal nutritionists are the chemical characterization of the compounds ultimately responsible for their effects, such as tannins, saponins, essential oils or other phytochemicals, and identification of factors determining their concentration in plants, as well as their biological activity. Most papers in the SI used plant material or plant extracts without chemical characterization of the active substances, likely due to limited opportunities to create research partnerships between animal scientists and specialized phytochemists. Nevertheless, some papers (Hutton et al. and Sun et al.) made a concerted effort to identify the chemically active substances and, in some studies, the phytochemicals themselves were tested (Carrasco et al., Geraci et al. and Zhou et al.).

When using plant material or extracts, it is important to consider that the type, concentration and activity of bioactives are likely to be affected by a number of factors. These can be classified as plant-related (*e.g.*, plant species, variety, eco- and chemo-type, the anatomical part of the plants, the phenology (growth and life cycle) and stage of maturity of the plant), environmental abiotic factors (influence of season and climate, temperature, humidity, duration of daylight, radiation, wind, geographic and geological location, altitude, soil fertility), agronomic factors (conditions of cultivation and harvesting, irrigation, fertilization and methods of harvest), as well as post-harvest processing factors such as storage and preservation, stability, as well as procedures for extraction. Most of these factors are extensively reviewed by Pavarini et al. to provide insights for animal scientists. A comprehensive analysis of factors affecting levels of condensed tannins in plants is in Jin et al., whereas Cieslak et al. compared effects of different types of tannins.

A key nutritional factor which determines the efficacy of bioactives added to the diet is the nature of that diet. This is a key issue for many nutritionists, and has been addressed in Blanco et al., Castro-Montoya et al. and Klevenhusen et al. while, in Yousef-Elahi et al., an animal factor (*i.e.*, breed of goat) was examined.

3.2. Effects of bioactives on ruminal fermentation

Most papers in the SI deal with effects of plant products and bioactive compounds on ruminal fermentation. The subject is introduced by the reviews of Bodas et al. and Flachowsky and Lebzién. In Bodas et al. the topic is thoroughly reviewed and presents the most relevant information reported in the last ~20 years in order to summarize effects of bioactives on the ruminal microbial microbiome, fermentation processes and CH₄ production. Flachowsky and Lebzién provide a comprehensive and very exhaustive strategy to evaluate any bioactive as a potential candidate to be used as a feed additive to enhance ruminal fermentation.

As was the aim in the call for papers, there is a balance between primarily *in vitro* (6) and primarily *in vivo* (7) studies, and all the *in vitro* studies are connected to *in vivo*. The main end-points potentially affected by plant bioactives, as studied in the SI papers, are ruminal fermentation end products (Blanco et al., Carrasco et al., Castro-Montoya et al., Cieslak et al., García-González et al., Geraci et al., Klevenhusen et al. and Zhou et al.), extent of degradation of feedstuffs in the rumen from substrate disappearance or gas production kinetics (Guerrero et al., Salem and Yousef-Elahi et al.) as well as CH₄ production (Blanco et al., Briceño-Poot et al., Castro-Montoya et al., Cieslak et al., García-González et al., Klevenhusen et al. and Sun et al.). As expected, changes in CH₄ production by using phytochemicals was one of the key evaluators of its efficacy. From the information presented in all manuscripts, we suggest that there are a number of issues deserving attention in future research, among them characterization of the active agents responsible for the anti-methanogenic effect, discernment of whether anti-methanogenic effects are due to a general inhibitory effect on ruminal fermentation or specific selective action on methanogens, or methanogenesis, and confirmation of anti-methanogenic effects *in vivo*. Most of the *in vivo* studies in the SI estimated *in vivo* CH₄ production indirectly (Briceño-Poot et al., Cieslak et al., García-González et al. and Sun et al.), with no manuscripts in which CH₄ outputs were measured directly. However as the methodology for direct *in vivo* measurements is becoming more accessible, it is expected that papers presenting results from studies in which CH₄ emissions were measured directly will be available in the near future.

3.3. Effects on animal health, welfare and performance

Considering the likely effects of plant bioactives on ruminal fermentation and animal health and welfare, beneficial effects could also be expected on animal performance. Reducing ruminal CH₄ production should decrease loss of digestible energy in eructated gas, thereby enhancing efficiency of utilization of diets. Some bioactives may have antimicrobial and antioxidant activities, thereby enhancing the immune response or the gut integrity and function, and/or improving animal tolerance to oxidative or heat stress. Ingestion of feeds containing plant bioactives may increase feed intake and/or digestibility, thereby providing the potential to improve animal performance. Some of the *in vivo* papers addressed effects of plant bioactives on feed intake and whole tract digestibility (Briceño-Poot et al., Cieslak et al., Garcia-Aguilar et al., Garcia-Gonzalez et al., Geraci et al., Mendez-Ortiz et al., Sun et al. and Zhou et al.). However, there was little reported on this effect on animal performance (only Carrasco et al. and Geraci et al.), and further *in vivo* research aimed at validating the bioactivity of plant secondary compounds with animal performance traits as the target end points is required in order to demonstrate efficiency of these compounds as commercially viable feed additives. A related issue yet to be addressed is the point when use of plant secondary compounds as feed additives is safe for the target animal species, its human consumer and the environment. While it has often been assumed (especially by the general public) that as “natural” compounds, use of plant based bioactives in animal nutrition should not pose any risk, this must be demonstrated if the compounds are to be legally authorized for commercial use as feed additives.

3.4. Plant bioactives and parasite control

Use of plants containing bioactive compounds to control helminths in the gastrointestinal tract, either as phytotherapeutics or nutraceuticals, has been a growing research area in recent years. Strategies to identify viable candidate compounds with *in vitro* and *in vivo* anthelmintic properties, as well as factors which influence *in vitro* and *in vivo* results and the difficulties of translating *in vitro* results to *in vivo* conditions, have often used small ruminants such as sheep and goats. As reviewed in Sandoval-Castro et al., who summarize results of several plant bioactive materials against helminth parasites in the gastrointestinal tract of cattle, deer, rabbits, pigs and poultry, many plant materials have resulted in promising results in farm animal species besides sheep and goats and these bioactive materials have potential to be used as a part of sustainable helminth control strategies. Papers which discussed impacts of bioactive compounds of *Havardia albicans*, which is rich in tannins, supplemented to sheep on control of the parasite species *Haemonchus contortus* in sheep (Galicia-Aguilar et al. and Méndez-Ortíz et al.) concluded that use of this tropical tannin rich foliage could bring nutritional and anti-parasitic benefits to the ruminants which consume them.

4. Future perspectives

Use of plant bioactive compounds by humans is probably as old as humans. While many plant bioactives were traditionally used as curatives of maladies of humans and their animals, plant bioactives were less used (at least intentionally) to prevent disease from occurring. Many of these traditional curatives were lost as human civilizations, especially in the past 200 years, grew more dependent upon bioactive compounds produced by other humans, generally marketed as drugs, and often seen to be representative of the relentless progress of human civilization. In tandem, reliance on ‘traditional’ curatives was often considered as akin to witch doctory by ‘enlightened’ societies and so their use declined and, in some cases, the knowledge may have been lost. However it has become evident that human produced bioactives can have unintended side effects, only some of which are likely known, such as being long lived in the environment, become so ubiquitous in the environment that they may have continuing impacts on humans (and other mammals) who live in that environment, create cross-reactivity with other bioactives, create human resistance to critical medical bioactives and may lose efficacy as microbial communities become resistant to them. All of these possibilities have led government regulatory authorities in many countries to re-visit use of human produced bioactives in non-critical situations, which has often included their use as additives to diets of our food animals. Hence the search for alternatives, since the need to produce more food with a lower net environmental impact for a burgeoning human population demands more efficient use of feeds by food animals, that is if food animals are to survive as a source of human food for more than a few more decades, at least for all but a privileged elite.

This SI of AFST has followed up on the 2011 AFST Greenhouse Gases in Animal Agriculture SI in the area of nutritional interventions to favorably impact rumen fermentation in order to improve efficiency of feed nutrient use by food animals and to reduce release of compounds to the environment which can degrade that environment. A major difference in papers published in the Greenhouse Gases in Animal Agriculture SI and the current SI is that the ratio of *in vivo* to *in vitro* papers is much higher in the current SI. While these important *in vivo* papers in this SI are still very low in numbers, and immediate impact, taken together they provide reason to believe that naturally occurring plant bioactives have the potential to favorably impact rumen fermentation and/or human health and/or efficiency of use of diet nutrients by food animals, and that they may play an important role in future food animal production systems. However it is also painfully clear that these are early days, arguably very early days, of this research area and that current research efforts to identify and evaluate plant based bioactives appears almost random in nature. But, based upon the papers in the SI, it is clear that there is more than hope.

However as research efforts in the area of plant based bioactives and their impacts on food animals accelerates, we should not lose sight of the reality that the long term objective is to use efficacious plant based bioactives on a large scale and, that

if these research efforts are successful, at least some of the issues identified as problems with 'human created' bioactives may also occur for 'natural' plant based bioactives used on a large scale in animal agriculture. Thus collateral impacts of these plant based bioactives on non-target systems must be researched simultaneously in order to be certain that benefits of plant based bioactives are not counteracted by harm in other areas. This may be the most critical long term issue since humans have a long track record of creating changes deemed to be positive in one area which are later determined to have serious negative impacts in others. Simply because a plant based bioactive is naturally occurring in our environment does not mean that it cannot be harmful if it is used as an animal feed additive, an event which will demand its creation at levels several orders of magnitude higher than it currently exists in naturally occurring plants.

Acknowledgements

The editors are very grateful for the time and commitment given by all the reviewers involved in the evaluation of the manuscripts submitted, and would like to acknowledge the excellent review efforts of: D. Alipour, B.N. Ametaj, M.A. Bamikole, T.N. Barry, Y. Bartley, Á. Belenguer, R. Bodas, J. L. Borquez, S. Calsamiglia, M.D. Carro, R. Casals, O.A. Castelán-Ortega, L. Castillejos, C. Castillo, V. Cechinel-Filho, M.A. Cerrillo-Soto, A.V. Chaves, D. Colombatto, N. Di Lorenzo, S. Duval, A. Ferret, M. Fondevilla, P. de Frutos, E. Ghisalberti, F.J. Giráldez, M. González-Ronquillo, M. Gralak, F. Klevenhusen, A. Kotze, J.-X. Liu, S. Liu, I. Martín, T.A. McAllister, M. Mellado-Bosque, G.D. Mendoza-Martínez, F. Mirzaei, D. Morgavi, I. Mueller-Harvey, T.G. Nagaraja, E.N. Odongo, Z.M. Parissi, A.K. Patra, M.J. Ranilla, C. Sandoval-Castro, A. Shimada, M. Spanghero, K.H. Südekum, X. Sun, A. Vega, D.M. Veira, P. Vercoe, G.C. Waghorn, R.J. Wallace, W. Yang, D.R. Yáñez-Ruiz, P. Yu, Q. Zebeli, C. Zhou and W.-Y. Zhu. If any reviewer was missed, please accept our most sincere apologies.

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