Emerging Technologies for a More Sustainable and Resilient Beef Production System – The Irish Approach

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ABSTRACT
This paper provides an overview of the application of current and emerging technologies to deliver a more sustainable beef system. It focuses initially on technology-based initiatives undertaken by the Irish beef industry and wider stakeholders to support verification and improvement of the sustainability credentials of the Irish beef industry. It then identifies other relevant technologies at farm and processing level. Some of the challenges and complexities surrounding delivering a sustainable production system from a consumer and societal perspective are then outlined. The paper concludes by highlighting the importance of an effective knowledge and technology transfer process.

INTRODUCTION
The sustainability and resilience of the world’s food production is constantly under scrutiny. Nonetheless it is projected that a 60% increase in food will be required by 2050 to satisfy the demand of a larger, more affluent population of 9.3 billion. Given land constraints, much of this increase will need to come from our exiting arable land resource through more efficient production systems and the application of scientific knowledge. However increased production will require extra resources, and more intensive production is often associated with detrimental environmental consequence such as climate change. The role of the agri-food sector, and particularly the livestock sector, as a contributor to both the problem and the solution of climate change is being increasingly recognised (Gerber et al., 2013).

In addition to these concerns, there is growing awareness of the human health implications of excessive meat consumption, with the latest focus in the meat consumption debate being the World Health Organization’s classification of red meat as a “probable” carcinogen. Statistics around the world showed a decline in beef consumption by up to 1% since the report was released in 2014 with a concomitant sharp rise in consumption of poultry and pork meat. Furthermore while public health initiatives in the past have generally promoted meat consumption, dietary guidelines in some regions are now designed to reduce consumption (Henchion et al., 2017).

In last decade, meat consumption has become increasingly contested with the environmental impact of meat production becoming as important as the human health impact from a public policy perspective. A plethora of literature proposes numerous technologies which can improve the sustainability of current beef production systems from an economic, social and environmental perspective. Such literature however recognises that the adoption of a single technology will not be sufficient to provide a sustainable system that also provides food and nutritional security; rather it is the complementarities and synergies that can be realised by assembling these technologies that will result in a sustainable beef production model. The objective of this paper is to outline various current and emerging technologies that are available to provide a more resilient and sustainable beef production system from farm to fork.

A SUSTAINABLE APPROACH TO BEEF PRODUCTION IN IRELAND
Despite being a small country, Ireland is the 5th largest net exporter of beef in the world with up to 90% of beef exported annually. The EU is the most important market destination however exports to America recommenced recently with sales valued at €11 million in 2015. The Chinese market is of emerging importance. The sector is of significant importance to the Irish economy accounting for 21% of Ireland’s total food and drink exports. Ireland’s beef production predominantly comes from pasture-based systems with about 1.1 million cattle raised on 80,000

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family farms. Many of these farmers are part-time operators with off-farm employment. Where farming is a full-time occupation, the beef enterprise is often combined with another enterprise, e.g. dairy or tillage. Of the almost 1.2 million cattle slaughtered in 2015, steers comprised 41% of the kill followed by heifers (27%), cows (20%) young bulls (10%) and mature bulls (2%). Live exports to the EU and North Africa are of varying importance. Given its high level of export orientation and relatively small scale in global terms, offering a differentiated product is an important strategic objective of the industry.

In Ireland, many innovative and radical steps have been taken by the agri-food industry to embrace, endorse and promote the nation as a sustainable food producing country with verifiable “green” credentials. Its national sustainability plan “Origin Green”, developed in 2012, is the world’s first sustainability programme at a national level. It uses independently verified sustainability credentials to position Irish beef as the supplier of choice for key European retail accounts in particular (Henchion et al, 2014). Its alignment with the UN sustainable development goals are highlighted in Figure 1 below. Administered by Bord Bia (the Irish food marketing agency that operates under the aegis of the Department of Agriculture, Food and the Marine), it is an inclusive initiative involving the key stakeholders of Ireland’s food industry including government, producers, processors and state agencies. Origin Green comprises an independently verified scheme that requires its members all along the supply chain from farming manufacturing, retail and food service to undergo monitoring. For instance, on farms, energy, emissions, socio-economic factors, biodiversity, water, traceability, welfare, animal health and food safety are measured. This allows continuous improvement for each farm in terms of a number of sustainability metrics.

A key aspect of Origin Green is to identify targets for improvement and provide advice on what action farmers need to take to achieve targets. Thus Teagasc (the science-based Agriculture and Food Development Authority) and Bord Bia, devised an innovative technology known as the Carbon Navigator to achieve improvements in relation to the on-farm carbon footprint. The Carbon Navigator does not measure a carbon footprint as such; rather it looks at key efficiency measures including length of the grazing season, genetic and breeding indices, nitrogen usage, manure management, and energy inputs to help farmers to set individual targets and to make plans in conjunction with their farm advisors. The best practice, mitigation options and financial benefits from the Carbon Navigator are based on scientific evidence and Teagasc research that is collated in Teagasc’s Marginal Abatement Cost Curve. The Carbon Navigator has the potential to have a very significant impact on GHG emissions with estimates that bringing farmers that are performing below average to average would reduce emissions by 1.4M tonnes CO₂ equivalent per annum or over 7% in Ireland (Bord Bia, 2017).

A key aspect of the programme is to benchmark farmers with each other, taking care to compare “like with like”. This has had a significant impact in facilitating all farming stakeholders to engage in a conversation around climate-friendly farming and has mainstreamed the message that carbon efficiency is synonymous with economic efficiency. To date 45,000 Irish beef farms have been accredited accounting for 90% of the national beef production. The system includes also 20,000 dairy farms and is expanding to include elements such as pollinator levels and habitat mapping.

Origin Green is an excellent example of how science can underpin such systems and promote sustainability not only at farm level but also within the whole beef production system. The Carbon Navigator is a key support to this along with the technology and knowledge transfer provided by Teagasc to ensure that best practice is implemented at farm and factory level. Linkages with other stakeholders in addition to Teagasc, through bespoke ICT systems, in conducting the farm assessments is also central to the effectiveness of the programme as highlighted in Figure 1. These additional stakeholders are the Department of Agriculture Food and the Marine for access to the database they have on individual animal identification and movement, Irish Cattle Breeding Federation (ICBF) for data on animal performance and the Carbon Trust whose role is independent third party certification. Despite the success of Origin Green it is important to note that it is not the panacea to directly reduce GHG emissions but it is a major step in the right direction. Furthermore, it is noteworthy that the scheme was established to target retailers; efforts are underway to develop a programme to respond to consumer demands for sustainability however the complexity of the sustainability message as well as the
limited willingness of consumers to pay for sustainability credentials are challenges to be overcome. Ireland’s leadership ambitions in this area extend to involvement in key international initiatives including Teagasc’s election to Chair the FAO Livestock Environmental Assessment and Performance (LEAP) partnership and contributions to the Global Research Alliance and the EU Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI).

To realise resilience in sustainable beef production system the use of technology is paramount. The central issue is how new technologies can help increase ecological, economic and social sustainability of beef production. Hence, the ambivalence between available technologies and sustainability is yet to be established based on various qualitative and quantitative indicators as shown in Figure 2. Various technologies available from farm to fork are outlined in the following sections which have proven to be highly efficient, provide economic and social benefits.

INNOVATIVE TECHNOLOGIES AT FARM LEVEL

Making agriculture more efficient and climate resilient requires increasing crop and livestock yields, reducing losses of primary resources but also connecting the primary producer with the other food actors including the consumers to link offers with demands. The development and implementation of ICT technologies must be better adjusted to the overall beef system, better shared and easier accessible to all farmers. The challenge is to use digital technologies to ease the task of operators, to translate data into knowledge and to allow more precise management, thereby improving production efficiency and protection of natural capital. The aim is to collect data at multiple points, analyse it in combination with existing data and deliver decision support to the farmer. Digital technologies offer the opportunity for integration between the different parts of the beef chain, thereby allowing changes to production that will facilitate downstream processing of meat products.

In Ireland, precise management of production starts with soil and pasture. The first step is to understand the behavior of nutrients in the soil in response to different conditions. This can be achieved through a combination of on-farm probes and sensors, measurement of grass yield, existing soil maps, weather data and farm yield records.

The next step is to develop tools for monitoring and enhancing livestock performance and welfare. More precise measurement of feed intake, rumen function, emissions and meat production will provide an opportunity for an improved understanding of the relationship between these factors. In turn, this will allow for more precise management which would deliver improved performance, environmental efficiency and higher quality products.

On-going, automated, monitoring of animal health and reproduction using sensors, collars and cameras allows for early detection of illness and heat. In the case of illness this allows for early intervention, thereby reducing spread and limiting the administration of medication.

PRECISION AGRICULTURE

Precision Agriculture (PA) is a whole-farm management approach using information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimising returns on inputs whilst potentially reducing environmental impacts. The potential benefits of precision farming systems include increased efficiency, reduced costs, improved product quality, reduced environmental impact, and improved animal health and welfare, thereby facilitating a holistic approach to sustainable farming (i.e. economic, environmental, stakeholder perception, and food security). The use of various enabling technologies including geographic

![Figure 2. Indicators for sustainable beef production system](image-url)
positioning system (GPS) mapping, sensors, geographic information systems (GIS), RFID tagging and other advanced software and precision application equipment has led to a significant improvement in the management of agriculture resources. The use of an ICT tool to capture data automatically from a “rising plate meter” with global positioning system (GPS) technology and mapping capabilities which contains an ultrasonic sensor to accurately and precisely measure compressed grass height, with recorded GPS coordinates, and is integrated with the capacity to transfer generated data automatically to a SMART device and then to the internet cloud. This technology provides the advantage of not requiring any physical fencing components to contain animals in a specific area. In place of fencing, GPS localisation, wireless networking and motion planning are combined to create an invisible fence line.

In Ireland where pastoral agriculture dominates over arable agriculture the ability of PA to yield map pastures is relevant and provides a decision support tool for improved pasture management. Application of hyperspectral sensors for providing an improved method for assessing pasture quality parameters and as a decision tool for feed budgeting and strategic fertiliser applications has been demonstrated (Hedley, 2015). Application of hyperspectral sensors mounted on agricultural machinery for data collection during routine farming operations (e.g. pasture yield mapping) can be used as a real-time decision-support tool to overcome issues of spatial and temporal variability in pasture quality (Pullanagari et al., 2012b). The pasture quality indicators provide valuable information for feed budgeting, facilitating the correct energy and protein balance in feed (Pullanagari et al., 2012a), which is critical to feed to meat conversion and quality of beef.

SENSORS

Critical analysis of scientific literature on the application of sensors and sensing techniques indicates that many systems have been tested at laboratory scale. Non-invasive image analysis by vision technologies, sound analysis by sound technologies and sensors attached to the animal body at farm level has shown significant advantages. Vision and sound based technologies have the advantages of not being in direct contact with the animals while a limited number of camera’s or microphones can measure groups of animals in big spaces. These techniques can handle groups of animals, individuals in groups or individuals. For individual animals like cows sensors on the body are today further developed for use at farm level. Vision technologies based on low cost cameras, in combination with image analysis techniques, can be used to quantify animal behaviour (Leroy et al., 2004) or to estimate the size, shape and weight of farm animals. Video tracking techniques have also been used for quantification of behavioural stress responses. Kane et al. (2004) developed a video-based movement analysis system to measure variables such as animal velocity, distance travelled and space utilisation of fish in individual tanks. Vision techniques have also proven to have great potential to be used for continuous quantification of lameness in cows. Poursaberi et al. (2010) showed a positive linear relationship between cows’ track ways overlap captured by image analysis and locomotion scores by human visualisation. Sounds produced by animals can also be monitored and analysed in order to assess animal health status (Van Hirtum and Berckmans, 2004). Microphones and sound analysis were used for visualizing the spread of respiratory diseases and eventually contribute to the reduction of the use of antibiotics by means of selective and early treatment of infected animal. Other sensors available today include pedometers for monitoring oestrus behaviour in dairy cows (Brehme et al., 2004). Telemetry sensors for measuring heart rate, body temperature and activity have been developed (Exadaktylos et al., 2014). Sensors for quantifying milk conductivity and yield of individual cows are available and may be used to optimise production and provide early detection of poor welfare in individuals (Smith et al., 2015). Sensing systems can facilitate monitoring of feeding times, feed intake, animal health and behaviour as well as conventional performance parameters. The real-time mathematical modelling methods needed for monitoring and controlling livestock farming processes are available today. These modelling methods, in combination with the ever-growing possibilities of sensors and sensing systems should allow improving the management and production control on the farm.

TECHNOLOGIES IN BEEF PROCESSING

Application of robotics at various stages of animal handling, grading, carcass handling all the way to packaging holds the promise of reducing the processing costs by helping speed up processing lines, making production more efficient and reducing labour requirement. The meat industry including beef is one of the most hazardous and unpleasant industries in the food processing sector. The main reason for robotization is to reduce the difficulty and danger in working environments (Alric et al., 2014) and can lead to lower production costs. Automation can result in improved worker safety; it will also reduce repetitive strain injury. Performing the same motion work for prolonged periods in chilled environment causes fatigue and damage to joints and muscles of workers. Automation can also result in improved food hygiene, through reducing contamination from human operation.

Advanced technologies for carcass evaluation which do no harm animal performance are increasingly popular because they are non-destructive and have no impact on live animal performance. It can be employed for the selection of breeding stock and/or estimation of the market value of animals (Stanford et al., 1998). The use of advanced technologies for more accurate measure of carcass traits in live animals, has increased the rate of genetic improvement in body composition traits (Kvame and Vangen, 2006). Various nondestructive methods including ultrasound, X-ray computed tomography and nuclear magnetic resonance have
been proposed and tested for the prediction and evaluation of various compositional traits in live animals. Computer tomography and magnetic resonance image analysis are commonly used for in-vivo three dimensional structure images that can be reconstructed to obtain volumetric measurements of target area.

Ex-vivo compositional analysis is an essential part of carcass evaluation. Compositional analysis has traditionally been carried out by physical dissection of animals or carcass which is a destructive, time consuming and expensive (Stanford et al., 1998) for meat carcass quality evaluation. Post mortem compositional analysis is generally carried out on relatively small sample sizes in the laboratory. With advancements in analytical technologies several non-destructive methods has been proposed for compositional analysis including; total body electrical conductivity (TOBEC), Video image analysis (VIA) Dual-energy X-ray absorptiometry (DXA, previously DEXA) and optical probes.

While the majority of carcass evaluation techniques were originally developed for clinical applications, many have emerged as powerful non-destructive measurement techniques for the meat sector. Research to date has demonstrated that numerous opportunities exist for their potential application in the meat industry. Carcass evaluation techniques have been successfully proposed and undergone various degrees of development and application in predicting in-vivo and ex-vivo carcass quality traits and body composition in livestock. Some of the applications discussed have been successfully adopted by the industry while others of these are still at the experimental stages. Technology advances is resulting in more sensitive, reliable, user-friendly and cost effective solutions with greater focus on commercial yield.

KEY SUSTAINABILITY CHALLENGES

Sustainable resource management and gas emissions reductions are two immediate challenges facing the beef production. In the longer term, questions related to the effects of climate change on agriculture (both altered climate and higher CO$_2$ levels) will have to be addressed. Recent focus of Ireland, for sustainable beef section the focus is at various levels and initiatives taken are shown in Figure 4.

CONSUMER AND SOCIETAL PERSPECTIVES ON BEEF PRODUCTION AND CONSUMPTION

Despite further projected growth in meat consumption globally, production and consumption of meat has positive and negative connotations from a sustainability and broader health perspective. Currently negative associations appear to get prominence in the media however more recent research would argue for the need for a more balanced perspective. Recent Irish research, and publications by Irish authors are contributing to this debate.

On the environmental side, 12% of GHG emissions globally derive from livestock production and 30% of human-induced terrestrial biodiversity loss can be attributed to animal production(Westhoek et al., 2011). Land use is also a concern; two thirds of total agricultural area is used for livestock production in the EU and around 75% of protein-rich animal feed is imported from South America using large tracts of land there also. However ruminants in particular fulfil other roles in addition to food; they provide fertiliser and fibre and in developing countries they function as financial instruments and a route out of poverty. A particularly important benefit of ruminants from a food security perspective is their ability to convert biomass that cannot be digested by humans.
(predominantly grass) into food. This aspect needs to be considered to a greater extent in research and modelling exercises that examine the sustainability of beef. For example, recent research (Van Kernebeek et al., 2016, van Zanten et al., 2016) suggests that beef production not only should be, but needs to be, part of a sustainable future. Van Kernebeek et al. (2016), using a land use optimisation model, concluded that meat is better for the environment compared to a vegan and vegetarian diet and that large populations can only be sustained if animal protein is consumed. This contradicts previous life cycle assessment results, and conventional wisdom, because such research did not consider the unsuitability of marginal lands to grow crops nor the ability of animals to use biomass that is not edible to humans. In a comparison between the land use efficiency of various livestock and crop production systems, van Zanten et al. (2016) concluded that certain livestock systems can produce human digestible protein more efficiently than crops and that therefore livestock systems have a role in future food supply and contribute to food security. The link between GHG emissions and nutrition adds further complexity to any discussions around the sustainability of beef.

From a nutrition and perspective, it is well accepted that lean meat is a natural highly nutritious food source that is appreciated for its sensory properties including taste. It is a rich source of many high quality proteins and minerals including zinc, iron, selenium, phosphorus, magnesium, potassium and copper; noteworthy is the fact that minerals present in beef are more bioavailable compared to plant sources. Some concerns have been raised however with regards to beef consumption and a potential link to cancer; the International Agency for Research on Cancer (IARC) reported (Bouvard et al., 2015) that red meat is “probably carcinogenic” to humans with strong positive association with pancreatic and prostate cancer. Given the important role of meat as part of a nutritious diet, it is crucial that such widely reported information which influences consumer choice is informed by impartial scientific knowledge that stands up to scrutiny. The IARC report has been criticised in many areas. For instance, Klurfeld (2015) has recognised there are many limitations of such studies including an inability to accurately estimate intake, lack of pre-specified hypotheses, multiple comparisons, and confounding factors—including body weight, fruit/vegetable intake, physical activity, smoking, and alcohol—that correlate significantly either positively or negatively with meat intake and limit the reliability of conclusions from such studies.

**CONCLUSIONS**

For livestock production and meat processing industries to remain competitive and sustainable many technology interventions must be employed that are realistic and verifiable and integrated at farm and post-farm level. There is no one single answer as agricultural systems vary widely across the world and interventions will need to be made locally. As the meat sector continues to face adverse commentary with regard to GHG emissions and health concerns of its product, the need for science based solutions is even more urgent. With support from government, producers, processors and scientists much progress can be made. In Ireland under a Government strategy called Food Wise (DAFM, 2015) all stakeholders contribute to making our food system transparently and verifiably sustainable while underpinning progress through research and development. Much emphasis is placed on knowledge transfer and technology adaption at farm and firm level, as illustrated by the Carbon Navigator and the Origin Green programme in Ireland, allowing continuous improvements.
REFERENCE


INTRODUCTION
In 2014, we were asked to consider and address the fact that many people in Malawi, particularly women and children, are anemic and lack iron in their diets. One of the main reasons for the lack of iron in people's diet was lack of a sustainable and readily available source of protein. This led us to implement and assess a goat meat intervention for women and children in Malawi, Africa.

Malawi is the third poorest country in the world. According to the World Health Organization, the Malawian people have an average lifespan of 57/60 years (males/females) and the child mortality rate is 66% for children under the age of 5 years (WHO, 2015). Malawians face malaria, diarrhea, and many other diseases that are preventable or treatable in developing countries. Most Malawians also are malnourished and food insecure. Food insecurity is defined by the World Food Programme (2017) as lack of “availability and adequate access at all times to sufficient, safe, nutritious food to maintain a healthy and active life”. Although most Malawians in the villages throughout the country have access to nsima, a corn based product that helps their bodies to feel satiated, it offers little in the way of balanced nutrition. The most common protein sources are mice and fish, both of which are fairly scarce. Given these factors, the question became “how can we provide protein to the Malawi people in a sustainable way that does not take a food source from the people?”

Although in developing countries an iron supplement pill may help stop anemia, Malawians do not benefit from supplements because many of them have had malaria and other diseases that have compromised their body’s ability to absorb and benefit from iron in that form. So, a bioavailable source of iron was needed. This was the impetus for the goat feeding intervention.

THE GOAT FEEDING INTERVENTION
Our project involved feeding 4oz of bone in goat meat to 22 women and 22 young children (ages 2 – 5) for 5 days a week for a year. The goat meat was prepared by the staff at the Grace Center, which is operated by COHI. The Grace Center contains an orphanage, school, feeding program, and job training in the midst of several rural villages.

Baseline data on children’s development was assessed at the beginning of the feeding program and then every 3 months thereafter for a year. Data were collected in July, October, March, and July. The planned data collection for January was not completed due to the rainy season in Malawi and the inability of the locally trained data collectors to take time from their responsibilities to collect the data. However, the feeding program was not interrupted during this time. During the first July and October data collection periods, a group of faculty and graduate students from Texas Tech University trained Community Health Educators who work for COHI to complete the assessments.

The child development assessments were ones adapted from commonly used assessments in the United States. Children’s social development was assessed via an observer checklist of various social and play behaviors during children’s outside play time at school, as well as a teacher report of each child’s social skills. Emotional development was assessed by asking children to identify pictures of faces depicting the emotions of happy, sad, mad, and scared based on a well validated measure of emotion recognition. Pre-literacy skills were asked by presenting children with a book upside down and seeing how they orient and handle the book. Physical development was assessed by measuring children’s height and weight, as well as a finger prick to assess the hemoglobin level of their blood. We
also took children’s temperature and reported presence or absences of illnesses. We had children complete a series of physical tasks (e.g., jumping jacks, walking on a line, twirling a scarf) that are assess young children’s motor development. Additional cognitive tasks included counting objects and identifying colors.

RESULTS

At the beginning of our intervention we had a comparison group of children who had previously had access to some goat meat via the feeding programs at the Grace Center. We did an initial comparison between these children and those in our study. These initial comparisons showed that children who had already consumed at least some goat meat were rated as having significantly more positive social skills, physical skills, and were taller and heavier than their non-meat eating peers.

We found an increase in children’s peer skills, social skills, height, weight, and hemoglobin levels within the first 3 months of the project. As seen in Table 1, children’s peer relationship scores and social skills scores decreased across the year. The likely explanation is that as children gained more energy and the ability to engage with one another, they were rated by teachers as less socially skilled due to the novelty of this set of behaviors. The general observations of children’s behaviors showed an increase in children’s smiling with peers (F = 3.00, p = .035), which is an indicator of an increase in socially oriented behavior for preschoolers.

The most consistent benefit of goat meat consumption across the yearlong intervention was the increase in children’s height, weight, and hemoglobin levels, even when controlling for child age and the generally expected pattern that height and weight will increase with age. The average height of children in the study went from 38.1 inches to 40.17 inches across the year (see Table 1). The average weight changed from 33.9 pounds to 35.6 pounds. Heminoglobin levels changed from 7.47 g/DL to 11.06 g/DL (grams per deciliter) across the year. Average hemoglobin levels changed from 7.47 g/DL To 11.06 g/DL (grams per deciliter) across the year. Average hemoglobin levels changed from 7.47 g/DL To 11.06 g/DL (grams per deciliter) across the year. To sustain interactions with others. Between the first July and October data collection points, there was a noticeable difference in children’s ability to respond to us and to play and to sit in their classrooms and learn.

Although it is not novel that increasing a person’s health increases their behavior and ability to learn, what is novel about this intervention is the holistic approach we took to this intervention. Instead of simply providing a meat source to feed the people, we also trained Malawians to raise and harvest the goat meat so that the access to goat meat is sustainable. In addition, we focused on the social benefits, as well as the health benefits, of the goat meat intervention. Young children’s social skills and peer interactions increased throughout the year. Meeting the basic needs of these children by providing a sustainable protein source helped them to be healthier and show positive developmental gains across all domains of development.

Reports from Mothers: Mothers also reported benefitting from the goat meat intervention. For example, mothers reported having more energy, being able to walk 2 miles farther to get water for their families, and overall felt better at the end of the intervention. They also noted that their children were more energetic and alert.
Reports from Teachers: Anecdotally, teachers reported the children in the intervention were more talkative, more active, and more interactive. Teachers did not have a script for teaching to children who were as engaged and interactive. They noted the increased levels of aggression and they did not know how to respond to these behavioral changes in the children. The prevalence of malnourishment is so great in their communities that they did not have experience teaching children who were awake, curious, talkative, and interactive.

Increase in Demand for Goat Meat: A year after our intervention, we travelled into a village away from the Grace Center. Some villagers became quite happy to see the Texas Tech logos on our shirts and referred to us as the “goat people.” Even those who did not participate in the study saw the changes in the woman and children who did participate and were eager to also have access to goat meat for themselves and their children.

Training to Raise and Harvest Goats: Simultaneously with the goat feeding, Malawians were trained on raising and harvesting goats. The loss of animal raising and harvesting capacity and knowledge due to the AIDS pandemic created a severe limitation in the teaching of production and harvest practices. The teaching of the basic concepts for the needs for the goats for grazing, feed and water as well as for their health care for the animals was often a slow, long process but it had great rewards. This was a crucial aspect to our focus on a sustainable intervention.

CHALLENGES
As you can imagine, there were many challenges and lessons to be learned by conducting research in another country, particularly a developing country.

Measuring Outcomes/Effectiveness: Conducting research in another country makes one question whether or not the way of assessing an outcome is culturally relevant or not. In terms of assessing the effect of goat meat consumption on children’s development, the measures were adapted from those reliably used in the U.S. Without having previously visited Malawi and the lack of developmental data and assessments from that country, adapting familiar measures was the approach I used. It turned out that all measures seemed to work, except the emotion recognition measure. Facial expressions, even when presented by Malawians to match the expressions in our standard photographs, were not useful for adults or children in identifying one’s emotions.

Language Barrier: Chichewa is the language spoken by Malawians in the area where we work. Malawians who have had the opportunity to complete an education do speak and write English. All of our assessments were translated into Chichewa by a bilingual Malawian to ensure that meanings were not lost in translation. Most of our training of the researchers was done with the aid of an interpreter, even though the Community Health Educators spoke at least some English.

Lack of Familiarity with Research: As you may imagine, people living in villages in Malawi are not familiar with the research process or being a research participant. This challenge was clear in how long it took to explain the project prior to requesting consent, as well as how long it took to train Malawians to assist in data collection.

Trust/Importance of Partnerships: Our work with the Malawian people would not be possible without the partnership with the NGO Circle of Hope International. Not only did COHI afford us access to woman and children to participate, but they provide the bridge between us and the Malawian people. The endorsement of the leadership of COHI made it possible for us to build relationships and rapport with the Malawian people.

Funding: Although federal funding is available for some types of international research/intervention most of the opportunities lack a focus on animals and especially meat as a intervention. This project was funded by local entities, including Rotary International, College of Human Sciences, Texas Tech University Horn Professor Endowment, The Circle of Hope International, Igo Farms, Ebeling Farms, San Antonio Livestock Show and Rodeo Chair endowment, San Antonio Stock Show and Rodeo gift for food quality, security and safety, State of Texas Research Incentive Program.

We did not have a large grant for this project. We relied on funding from these organizations, as well as donations from individuals to support the project. We accomplished a lot with a little and had a large impact.

Cultural Differences: We instantly found the Malawian people to be warm and welcoming and curious about our presence in their village. The receptiveness of the people made our project easier in many ways. We also learned much about the cultural differences between the U.S. and Malawi. One cultural difference is the view of time. While conducting research in the U.S., we are driven by deadlines and time schedules. Malawians are driven by a slower pace to the day. Our intervention and research did not happen in a linear fashion nor did it happen on the timetable we anticipated. This was not due to resistance, but simply a difference in the pace of life and the importance of spending time with each other and being with one another, rather than doing. Once we learned to be more Malawian, things went more smoothly.

CONCLUSION AND FUTURE DIRECTIONS
Having established the effectiveness of the goat meat intervention for children’s development and learning, we are now working on the next steps of how to combat food insecurity in Malawi. We are currently working on making the goat meat shelf stable since there is little access to refrigeration in the country. This summer goat meat powder will be tested as an additive to nsima. Then next summer we hope to train Malawians to create the power from the goat meat they have harvested so they have a food safe source of protein. We then want to replicate much of
our initial study with the goat meat added to the nsima to verify its effectiveness in supporting children’s growth and development.

We also hope to conduct a feeding intervention with pregnant mothers and assess their health and well-being through pregnancy and the first 4-5 years of their child’s life. We believe that this type of longitudinal study will not only be effective in illustrating the importance of good nutrition throughout pregnancy and in the first few years of a child’s life, but also that improving the health of mothers will improve long term outcomes for their children.

Throughout all of our work in Malawi, our goal is sustainable interventions that equip the people with knowledge, skills, and hope to work toward their own solutions to food insecurity. We hope that our approach can be used as a model throughout Malawi and other developing countries.
**FOOD SECURITY: A MEAT SCIENCE STORY**

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**Project SPAMMY® in Guatemala**

Kevin L. Myers, Ph.D.

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*Spammy*® is a fortified poultry product designed by Hormel Foods and named after the company’s iconic *SPAM*® family of products. *Spammy* was created to help address malnutrition in children.

*Spammy* was tailored to meet the specific micronutrient needs of children in Guatemala based on findings from earlier research conducted by Hormel Foods. The product is used as an ingredient and blends easily into customary diets. In a public/private partnership with the USDA McGovern-Dole program and Hormel Foods, this latest research demonstrated the benefits of supplementing traditional diets with high-quality protein and micronutrients. During the trial, more than 160 preschool-age children in Guatemala ate either a fortified or unfortified version of *Spammy* on school days over a 20-week period. The fortified version contained the addition of several micronutrients, such as vitamins D and B₁₂, which are important nutrients for children, but are deficient in this area of the world. Both versions were identical in protein, calories, and fat.

The study revealed:

- All participants showed greater-than-expected improvement in cognitive scores
- There was a 44 percent reduction in the number of school days missed due to illness
- Children receiving fortified *Spammy* showed statistical improvements in vitamin D and B₁₂ levels
- A positive correlation was found between increase in cognitive gain scores and vitamin D concentrations in the treatment group

**RESEARCH STUDY DETAILS:**

Millions of children throughout the world suffer from chronic malnutrition. Hormel Foods collaborative effort was built on the premise that changing lives occurs only through building sustainable solutions. The project focused on delivering proper nutrition through our expertise in protein and through partnerships. Together with the USDA, Food for The Poor and in-country partners Center for Study of Sensory Impairment, Aging and Metabolism (CeSSIAM) and Caritas, we implemented a feeding program to evaluate the benefits of *Spammy* for preschool-age children living in a low income area in Guatemala.

A total of 167 children at a daycare center located in Ciudad Peronia, a semi-rural city approximately eight miles outside of Guatemala City, Guatemala, completed the randomized, double blind trial. The control group received a daily meal containing unfortified *Spammy*, and a treatment group received a fortified version. The fortified product contained a vitamin and mineral blend that included, among other micronutrients, vitamin D, several B vitamins including vitamin B₁₂, iron, zinc and iodine.

Anthropometric measurements and blood draws were completed at both baseline and endline; a subset of 60 children completed cognitive tests before and after the 20-week trial.

Meals containing *Spammy* were prepared on-site and were served at the beginning of the school day. A 2-week rotating menu was created that incorporated *Spammy* into traditional foods such as doblada, tostada, chuchito, rice and black beans. Four women were hired from the community to monitor and record consumption and liking. The meals were well accepted among the children throughout the 20 week intervention.

Vitamins D and B₁₂ were low in many of the children at the beginning of the project. Overall 59 percent of the children had vitamin D values below 30 ng/mL and 19 percent had vitamin B₁₂ levels below 300 pg/mL.

Over the course of the program, school days missed due to illness decreased and teachers reported that children were better able to pay attention after eating the meal. Hemoglobin levels increased in both treatment and control groups. Vitamin D levels increased in the treatment group and decreased in the control group while levels of vitamin B₁₂ increased in the treatment group and remained steady in the control group.

The Bracken Basic Concept Scale - Receptive was administered to assess intellectual function at baseline and endline for a subset children. Both groups had higher
scores on the cognitive test at study completion and a positive relationship was found between vitamin D and cognitive gain among the treatment group.

Educational workshops were provided throughout the intervention. These included informational sessions for day care staff, parents and caregivers to increase community knowledge of nutrition and food safety. Workshops covered the importance of micronutrients by life stage and food related hygiene. Local experts helped develop and present information in a culturally relevant format.

This latest research built on previous work conducted by Hormel Foods showing vitamins D and B\textsubscript{12} are of public health concern in this population in Guatemala. A 2011 survey of preschool-age children living in urban and rural locations in Guatemala illustrated that 36 percent and 77 percent had low vitamin B\textsubscript{12} and vitamin D values, respectively. In response to these results, Spammy was reformulated to address the documented nutritional needs of the region.

Hormel Foods has been working with partners in Guatemala since 2008 to provide Spammy fortified poultry product to malnourished children and has donated 2.5 million cans of the protein-based item in 2013.

Hormel Foods and its partners, Caritas and Food For The Poor, are also building opportunities for thousands of families by providing Spammy to 8,300 families with more than 30,000 children in Guatemala. Additionally, Project Spammy provides scholarships to eight high school-age students to attend the Villa de los Niños boarding school in Guatemala City.

Spammy has been a great example of public-private partnership, combining organizations in the U.S. and Guatemala to provide meaningful solutions to childhood malnutrition. Spammy is now on the USAID food aid list for use in hunger relief efforts under “Fortified Poultry-Based Spread”.
What Do Changes in Antibiotic Regulation and Use on the Farm and Ranch Mean for Health and Resistance?

Liz Wagstrom, DVM, MS, DACVPM

INTRODUCTION
January 1, 2017 marked the full implementation of FDA Guidances 209 and 213. Those documents state that it is injudicious for “medically important” antibiotics to be used for production purposes (growth promotion/improved nutritional efficiency), and all therapeutic uses of those antibiotics should be under veterinary oversight. Medically important antibiotics are listed in FDA Guidance #152, but can be described as antibiotics that are in classes that are used to treat humans. Many of the antibiotics used in animal health are medically important and were impacted.

As FDA worked with sponsors to change labels and revise rules, veterinary oversight became defined as requiring a prescription (antibiotics in water) or a veterinary feed directive (VFD) (antibiotics in feed). The existing VFD rule was revised in 2015 in anticipation of many more products requiring a VFD. By January 1, 2017 all medically antibiotics carried labels that listed indications only for therapeutic use (disease prevention, control and treatment) and requiring a prescription or VFD.

ANTICIPATED OUTCOMES
While it is uncertain exactly how antibiotic use and public or animal health will change in the United States, it may be instructive to look to European countries that have increasingly restricted antibiotic use on livestock farms.

DENMARK AS AN EXAMPLE
Denmark has a long history of increasingly restricting veterinary antibiotic uses. They also collect and publish very robust information on antibiotic use and resistance in animals, meat and humans (DanMap).

<table>
<thead>
<tr>
<th>Summary Of Changes In Antibiotic Regulation In Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995  Ban on use of Avoparcin</td>
</tr>
<tr>
<td>1998  “Voluntary” ban on growth promotion use in finishing pigs</td>
</tr>
<tr>
<td>No sale of antibiotics by veterinarians</td>
</tr>
<tr>
<td>1999  Ban on growth promotion use in weaners</td>
</tr>
<tr>
<td>2010  Implementation of the Yellow Card System</td>
</tr>
<tr>
<td>2010  Voluntary ban on the use of cephalosporins in pigs</td>
</tr>
<tr>
<td>2014  Group treatment only with farm visit and supporting laboratory data</td>
</tr>
<tr>
<td>2016  Ongoing reductions to allowable levels in the Yellow Card System</td>
</tr>
</tbody>
</table>

The weight of veterinary antibiotics prescribed has approximately halved since 1994. The initial ban in 1998-99 resulted in a reduction to levels lower than are currently observed. This was followed by increased therapeutic uses that by 2009 were higher than the weight of growth promotion prior to the ban, although lower than the previous combined growth promotion and therapeutic. With subsequent implementation of the Yellow Card system penalizing individual producers for “excessive” use, as well as increasing numbers of pigs being exported to other countries for finishing, weights prescribed have fallen. Antibiotic use expressed as numbers of Animal Daily Doses, a calculated metric which adjusts for potency as well as weight of the drug, demonstrates more variation in trends of use.

When Denmark first banned growth promotion, their leading scientists declared that these changes were designed to decrease resistance in human foodborne illness. Two charts in DanMap 2015 demonstrate the difficulty in
anticipating such relationships. *Salmonella typhimurium* in Danish pigs, pork and humans shows that there has been a steady increase of resistance in isolates from Danish pigs, a less linear but still upward trend in isolates from Danish pork and a much more confusing picture from isolates of human origin with current resistance similar to that in 2002, but with notable rises and falls during that period (Figure 1). In contrast, the chart of *Enterococcus faecalis* (Figure 2) shows steady but high levels of resistance in pig isolates, steady but low levels of resistance in pork isolates, and steady, low levels in human isolates with the exception of tetracycline resistance which is much higher than seen in pork isolates.

Of note, has been the emergence of the livestock associated Methicillin Resistant *Staph. aureus* (LA-MRSA). Since 2008 human isolates of LA-MRSA has increased greatly, however testing of farmers and others with livestock exposure has also been increased. Since the LA-MRSA isolates are uniformly resistant to tetracycline there has been an outcry in the press to further reduce the use of tetracycline in pigs. This outcry continues even though the public health authorities report that LA-MRSA foodborne transmission is an unlikely contributor to the increase, and that human-to-human transmission is limited.

Information on animal health impacts are more limited. Following the initial ban there was reported increases in post-weaning diarrhea followed by a rise in therapeutic antibiotics. Over time, production practices have adapted and alternative products (e.g. zinc oxide) have been utilized. These strategies are not without their challenges. For example, it was hypothesized resistance to zinc may be a driving force in the emergence of LA-MRSA. Additionally, environmental concerns of therapeutic levels of zinc in diets lead to a recent European Commission decision to phase out those uses.

**NETHERLANDS AS AN EXAMPLE**

The history of antibiotic restrictions in the Netherlands is a bit more compressed than in Denmark. The Netherlands
has historically been a country with very low antibiotic use in human medicine, low prevalence of resistance in important human pathogens, and high levels of use of veterinary antibiotics. The Netherlands banned the use of antibiotics as growth promoters as part of the EU wide ban in 2006. With the initial identification of LA-MRSA pork production faced intense scrutiny. There have been mandated reductions in weight of veterinary antibiotics. Significant reduction was achieved when feed mills stopped mixing medicated feeds while subsequent decreases have been more modest. They have demonstrated a decrease in resistance in *E. coli* isolates from pigs, however there has not been a demonstrable impact on resistance in human pathogens.

**UNITED STATES IMPACTS**

The changes in antibiotic labeling and availability in the U.S. are likely to disproportionately impact small farmers. This is due to increased requirements for veterinary oversight being spread relatively fewer animals, as well as the potential for medicated feed being less available in small quantities.

As FDA continues to evaluate prevention uses of antibiotics, there are some consistently repeating indications (e.g. post-weaning scours, ileitis) for which prevention labels may be at risk. Additional potential animal health impacts are likely due to lack of resource commitment by animal health sponsors in development of either new formulations or new molecule development in an uncertain regulatory (and customer acceptance) environment.

Considering the examples from Europe, as well as numerous peer-reviewed risk assessments on the risk to public health from antibiotic use in food animal production, this author anticipates that current and future antibiotic restrictions in the United States will contribute to the consolidation of animal production on larger farms, may have some slight negative impacts on animal health, and is unlikely to positively impact public health.

Figure 2. Resistance (%) in *Enterococcus faecalis* from pigs and pork, Denmark
INTRODUCTION
The global demand for an increased protein diet is expected to increase the need for meat, milk and eggs by nearly 60% (FAO 2011) in 2050. Population growth is expected to increase to 9 billion people by 2050, while the middle class alone is expected to grow by 3 billion people by 2020 (Kharas, 2010 and United Nations 2015). The projected population growth and demand for protein is daunting, as we face new concerns and regulations regarding antibiotic use and the associated effect on food security. Global agriculture will need to produce more food on fewer acres of land and with reduced inputs to assure secure food production that is sustainable for the future.

Antibiotics have been used to improve livestock growth performance for more than 50 years. Moore et al. (1946) and Jukes et al. (1950) reported the improvement in growth and feed conversion by feeding broilers and swine sub-therapeutic levels of antibiotics. Concerns surfaced as early as 1951 (Starr and Reynolds) that continual use of growth promoting antibiotics may result in bacterial resistance to the compound which may lead to a reduced response to the practice. In 2017, the Veterinary Feed Directive from the US Food and Drug Administration came into effect, indicating that shared class antibiotics between human and animal medicine now must be administered through a veterinarian:client relationship to assure the judicious use of antibiotics to treat disease and maintain animal health. This begs the question, how will technology evolve to fill the ever changing demand for efficient meat production that meets end consumer demands for abundant, safe and affordable product? Innovation is paramount to continue to fill the gaps in production, assuring that the food supply is safe and abundant for an ever growing population.

SOURCE OF PERFORMANCE GAPS
Since the introduction of antibiotics as growth enhancers (Moore et al., 1946; Jukes et al., 1950), production standards have changed dramatically. Genetics, nutrition, feed milling, health, and production management improvements now make it possible to process beef, pork and poultry at heavier weights with superior efficiency. Data from MetaFarms (Feedstuffs, 2017; Table 1) illustrates reduction in swine grow/finish mortality rates even though feed conversion did not tend to improve. The reduction in mortality shows that management is continually improving in the pork production systems, but does the lack of improvement in growth and feed conversion signal a gap in achieving full performance potential? To answer this question, production management and the technical community must understand the underlying principles that can cause the performance gaps so that innovation can be targeted towards improvement.

Table 1. Fourth Quarter 2016 Production Index

<table>
<thead>
<tr>
<th>Nursery</th>
<th>2015</th>
<th>2016 % change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average start weigh, lb</td>
<td>12.98</td>
<td>12.99</td>
</tr>
<tr>
<td>Mortality, %</td>
<td>2.80</td>
<td>2.81</td>
</tr>
<tr>
<td>Average out weight, lb</td>
<td>56.4</td>
<td>55.9</td>
</tr>
<tr>
<td>Feed per head, lb</td>
<td>69.3</td>
<td>68.9</td>
</tr>
<tr>
<td>ADG, lb/day</td>
<td>0.88</td>
<td>0.87</td>
</tr>
<tr>
<td>Feed conversion ratio, lb feed/lb gain</td>
<td>1.31</td>
<td>1.62</td>
</tr>
<tr>
<td>Average daily feed intake, lb</td>
<td>1.42</td>
<td>1.40</td>
</tr>
<tr>
<td>Average days on feed</td>
<td>48.8</td>
<td>49.1</td>
</tr>
<tr>
<td>Finishing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average start weigh, lb</td>
<td>53.07</td>
<td>55.00</td>
</tr>
<tr>
<td>Mortality, %</td>
<td>4.10</td>
<td>3.92</td>
</tr>
<tr>
<td>Average out weight, lb</td>
<td>280.5</td>
<td>278.7</td>
</tr>
<tr>
<td>Feed per head, lb</td>
<td>625.8</td>
<td>619.4</td>
</tr>
<tr>
<td>ADG, lb/day</td>
<td>1.90</td>
<td>1.91</td>
</tr>
<tr>
<td>Feed conversion ratio, lb feed/lb gain</td>
<td>2.78</td>
<td>2.80</td>
</tr>
<tr>
<td>Average daily feed intake, lb</td>
<td>5.29</td>
<td>5.35</td>
</tr>
<tr>
<td>Average days on feed</td>
<td>118.1</td>
<td>115.6</td>
</tr>
</tbody>
</table>

Adapted from MetaFarms Production Index, Feedstuffs March 2017.
Diagnosing the cause of performance issues is a key first step in determining how to enhance growth with new technology. Enteric pathogens continue to be a key target for technology in an effort to reduce the negative impacts low level pathogenic bacteria have on performance. The ability to understand the diversity of pathogens in the gastrointestinal tract (GIT) illustrates where the challenges are present and establishes a target for technology development (Davis et al., 2017). As production has shifted from antibiotic use, the ability to control enteric pathogens has a renewed interest. However, in many cases the performance drop is not from enteric bacteria alone or at all. Holtkamp et al. (2013) estimated that porcine reproductive and respiratory syndrome (PRRS) cost the US swine industry between $233.54 million and $1.104 billion dollars in an analysis of cost impact of PRRS in 2011. The data was comparable to a similar analysis conducted in 2005, suggesting that progress has been made in overcoming the negative impact of PRRS in growing pigs, however the impact in the sow herd has actually increased. Understanding the magnitude of effect a bacterial or viral challenge has on growth performance, gives insight into opportunity for new innovation ideas and the

**NEW INNOVATIONS**

The mode of action for growth enhancing antibiotics is generally believed to a result of positive impacts of the antibiotic to the gut microbiota (The Poultry Site, 2014). The Poultry Science Association (2007) suggested that antibiotics reduced subclinical infection, decreased production of microbial products that have toxic effects, decreased competition for nutrients and enhanced absorption. New technologies will need to address specific modes of action to overcome the stress associated with environmental or disease stressors. Hostetler (2017) overviewed an approach initiated by the National Pork Board to evaluate currently available growth-promoting compounds as a response to a lack of reliable data surrounding alternative growth-promoting technologies. In the first phase of this project, the literature was reviewed and technologies were characterized as: probiotics, prebiotics, oligosaccharides, organic acids, botanicals yeast, starch/fiber, zinc/copper, or lysozyme. Schweer and Gabler (2017) further indicated that feed conversion was not impacted in 33 to 76% of the swine trials summarized (n=2034), depending upon the technology used. The failure rate of these technologies is indicative of the need for new innovation in growth enhancement.

Song et al., (2014) indicated that a proprietary yeast blend improved growth rate and feed conversion in nursery pigs. Body weights for pigs fed the proprietary yeast blend were 3.7 to 10.0% heavier than control pigs at the end of each study, respectively. By focusing on specific combinations of products and designing a blend targeted for swine growth, the authors illustrate the ability to create consistent, positive improvements in growth that improves the cost effectiveness of pork production. Yeast has been shown to enhance the immune response (Broadway et al., 2015) in all livestock, thus reducing the negative impacts of sub-clinical bacteria on growth rate and feed conversion. The improved performance results from Song et al., (2014) taken in conjunction with the immune system results from Broadway et al., (2015) illustrate the ability to formulate a product that can consistently improve performance. In this specific example weaned pigs were the focus of formulated yeast technology, thus it was designed with the challenges of weaning in mind and specific needs of the young pig, rather than using a randomly selected yeast source.

The conditions for success is an extremely important component for discovering new technologies to enhance growth performance. As Hostetler (2017) pointed out in the National Pork Board project, developing standard testing procedures and understanding the health conditions of each study is important to interpreting the responses to alternative technologies. This is not unlike antibiotic research that has been conducted over the years. Clinical research requires close attention to health status, genetics, nutrition, and gender effects to name a few. Each of these factors has to be accounted for in trial design and studies are replicated over multiple study sites to gain ample replication as well as to demonstrate efficacy under varying field conditions to assure that a product is truly efficacious. Small studies that are poorly replicated, few numbers or under abnormal health conditions (positive or negative) will lead to misinterpretation of the results. Ultimately, technology will be implemented that does not deliver a positive value proposition, or technology will be discarded too early that has promise, but the difference could not be found due to improper study design.

**RISING TO THE CHALLENGE**

The protein producing industries are in one of the most dynamic moments in recent history. Consumer demands on how meat is produced is changing the landscape of how protein is produced and which practices are embraced. At the same time, the rapid rise in the global population indicates that the demand for protein will more than double in the foreseeable future. Our industries must respond swiftly, but technically sound. The specific challenges are different than past leaders have been faced with, but the need to respond to challenge is nothing new to agriculture. Improving growth performance with new classes of technology is really the same question with new constraints, so how do we answer the question?

Trudeau et al. (2017) suggest to define the mode of action for a given technology and then establish standard testing procedures for evaluating the technology. From an enteric challenge, the authors suggest a need to understand the microflora profile, the serum metabolite profile and the intestinal gene profile to establish a comprehensive mode of action for the technology. They go on to indicate 20 classes (Table 2) of alternative products are available, how-
Table 2. Dietary products and feed additives for improvement in pig health and performance.

<table>
<thead>
<tr>
<th>Functional Feed Ingredients/Nutrients</th>
<th>Diet Formulation Strategies</th>
<th>Feed Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray-dried plasma</td>
<td>Low-protein diets</td>
<td>Organic acids</td>
</tr>
<tr>
<td>Alternative fibers</td>
<td>Limit feeding</td>
<td>Inorganic acids</td>
</tr>
<tr>
<td>Conventional egg products</td>
<td>Fermented liquid feed</td>
<td>Mannan oligosaccharides</td>
</tr>
<tr>
<td>Immune egg products</td>
<td>Minimal diet buffering capacity</td>
<td>Fructo-oligosaccharides</td>
</tr>
<tr>
<td>Milk protein products</td>
<td>Minimal anti-nutritional factors</td>
<td>Supra-nutritional levels of Zn</td>
</tr>
<tr>
<td>Lactose</td>
<td></td>
<td>Supra-nutritional levels of Cu</td>
</tr>
<tr>
<td>Polyamines</td>
<td></td>
<td>Omega-3 fatty acids</td>
</tr>
<tr>
<td>Fermented soy products</td>
<td></td>
<td>Direct-fed microbials (probiotics)</td>
</tr>
<tr>
<td>Butyric acid</td>
<td></td>
<td>Prebiotics</td>
</tr>
<tr>
<td>Lactic acid</td>
<td></td>
<td>Yeast and yeast products</td>
</tr>
<tr>
<td>Glutamine</td>
<td></td>
<td>Bacteriocins</td>
</tr>
<tr>
<td>Threonine</td>
<td></td>
<td>Bacteriophages</td>
</tr>
<tr>
<td>Cysteine</td>
<td></td>
<td>Antimicrobial peptides</td>
</tr>
<tr>
<td>Nucleotides</td>
<td></td>
<td>Conventional &amp; recombinant enzymes</td>
</tr>
<tr>
<td>Medium-chain fatty acids</td>
<td></td>
<td>Lysozymes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Egg yolk antibodies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Essential oils</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Botanical herbs and spices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay minerals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rare earth elements</td>
</tr>
</tbody>
</table>

Adapted from de Lang et al., 2010; Liu et al., 2014

However, there is limited knowledge on the effectiveness and mode of action for all of the products. Earlier, the work from Song et al., (2014) indicated that a formulated approach to developing yeast can be successful for promoting growth in nursery pigs. This challenge gets greater as the pig or broiler matures and feed intake increases. However, understanding the conditions needed for success and production system limitations can help define which substances to focus on and how to properly design a program to understand the usefulness of such products.

It becomes critical then to understand the conditions for success to properly evaluate a technology, verses assuming that a broad spectrum product will work in a broad spectrum approach. Disease challenges are one consideration, but optimizing the use of alternative feed ingredients that could be limited in use due to fiber, anti-nutritional factors, or fat composition to name a few offers a fertile area for development. Thus, defining the desired outcomes become a critical step to testing alternative technologies for protein production.

SUMMARY

The need for new innovations for growth enhancement has never been more important as it is today. Market pressure from consumer demands to an increased need based on population growth both indicate the need to innovate technology to improve the rate and efficiency of growth in livestock and poultry. It will be key to understand the performance gaps, define the mechanism of action, and determine the conditions for success as a means to develop an understanding of innovation potential and ultimately establish a value proposition for the end user that both delivers on its promise and appeals to the final consumer need.

REFERENCES


Poultry Science Association. 2007. Newly proposed mechanism for the action of antimicrobial growth promoters (AGPs) may open the door to the development of new non-antibiotic alternatives to AGPs. Press release.


INTRODUCTION

The issues with antibiotics

The use of antibiotics in livestock production can take several forms. Treatment of animals when ill (therapeutic) or treatment of a batch of animals when one is ill (metaphylaxis) and prophylactic treatment to prevent disease. On top of that subtherapeutic doses are mixed into feed to improve feed conversion. This practice was banned in Europe in 2006 and the 2015 FDA Veterinary Feed Directive aimed at ending antibiotic use for purposes other than prevention, therapy and control of disease in the US by 2017. In 2011 Europe voted to ban preventive use of antibiotics in livestock. These moves come over growing concerns about the spread of antibiotic resistance.

While it has not been proven conclusively for the use of antibiotics in animals clear evidence shows that the use in humans to be correlated to the rise and dissemination of antibiotic resistance. It stands to reason that the same will hold true for livestock and pets. In this light the regulatory developments sound reasonable but especially the prohibition of preventive use of antibiotics can have serious consequences for farmers and animal health. For instance, in the Netherlands calves (mainly bull calves from dairy farms) are gathered from all over Europe to be raised on farms. These two-week old animals have sometimes traveled for days prior to arriving at the farm. In the past the animals were administered antibiotics to prevent diarrheal disease to which they are vulnerable under these circumstances. While in themselves not often fatal, these diseases leave the animals weakened and prone to more serious infections, mostly of the lungs. Since prophylactic antibiotics use was banned mortality of calves has risen. Similarly, an increase in mortality is seen in chicken hatchlings which until received a combination of Marek's vaccine with antibiotics to kill E. coli. Bacteriophages may offer an alternative to some of these antibiotic uses.

Bacteriophages

Bacteriophages or phages for short are bacterial viruses. They are obligatory intracellular parasites without their own metabolism, strictly relying on the host cell machinery to propagate. Outnumbering their bacterial hosts by a factor of 10 phages are the most abundant microorganisms on earth, with total phage numbers estimated at $10^{31}$. Seawater can contain up to a billion phage particles per milliliter and phages are highly abundant in the mammalian gut as well as terrestrial ecosystems.

They are highly specific, mostly infecting certain strains of a bacterial species but some phages have relatively broad host ranges infecting most strains of a given species and some phages are genus-specific, infecting several species within a genus. The specificity is on the cell-recognition level. Phages have co-evolved with their bacterial hosts and compatibility on the genetic level is required for phage replication. To make sure they infect the correct host, phages recognize receptor molecules specific to their own host cells. Most bacteriophages appear very different to other viruses in that they have a head containing double-stranded DNA and a tail (Fig 1). The tail structure is a device that allows the phage to penetrate the host cell envelope to inject its DNA. Once the linear DNA is injected it is circularized and the early genes are transcribed. The early genes function is to reprogram the bacterial cell. Almost the first bacterial system to be shut down is cell division, allowing the cell to grow but no longer divide. Even if the entire cycle is disrupted by some means, without generating progeny phage, the cell cannot recover from this event, resulting in cell death. The middle genes regulate phage genome propagation and the late genes code for the structural proteins of the phage particle and the two enzymes requires to break down the cell wall.
allowing progeny to escape and to infect new cells. This is known as the lytic cycle.

Many phages do not have an alternative to this lifestyle. They are known as virulent or strictly lytic phages. They are potentially useful for biocontrol purposes. Other phages, known as temperate phages have an alternative strategy to propagate themselves. Most infections by temperate phages result in the lytic cycle but in a small number of infections the phage DNA is integrated into a specific place of the host genome by phage encoded enzymes. The phage is now called a prophage and will replicate with the host cell as it divides resulting in two cells carrying phage DNA. The process is reversible and the prophage can re-enter the lytic cycle, which is triggered by distress signals in the host cell, i.e. when bacterial DNA is damaged and the cell is likely to die. These phages are not useful for bio-control purposes. Part of the cells would survive and the integration process renders them immune to this and closely related phages. They would not be effective. The two types of lifestyle can easily be distinguished by genetic analysis. Temperate phages have a distinct region known as the lysogeny control region.

Strictly lytic phages however, are useful tools in biocontrol of unwanted bacteria. Since their discovery, to this day they are employed in human therapy in what was the Soviet Union and its satellite states. The Western world stopped phage therapy research with the advent of antibiotics but the recent emergence of widespread antibiotic resistance has changed this. The advantages of phages over antibiotics are manifold. Their specificity ensures that there is no collateral damage to desirable microorganisms. This also means no withdrawal period would be necessary before treated animals could be slaughtered or milk and eggs consumed. Phages are adaptable, and able to change if its host changes. They are non-toxic and can easily be produced in large numbers.

Phages may not be the answer to all bacterial infections, for example intracellular infection can not be reached by phages. They are too large to migrate across the cell membrane but they may be a suitable treatment for a number of important bacterial diseases. Veterinary phage applications have also been the subject of scientific investigation. The results of these experiments were reviewed by Atterbury in 2009. Currently commercial phage products are available to the food industry and agriculture. Here we present the use of a Salmonella phage cocktail to improve calf health at 2 weeks old.

**PhageGuard S**

PhageGuard S contains phages S16 and FO1a. S16 is related to the well-studied E. coli phage T4 and FO1a is related to FelixO1 (Marti et al., Marti et al.). Both feature extremely broad host ranges, forming plaques (successfully replicating) on 85% of all Salmonella strains (with significant overlap). Both recognize different receptors: the outer membrane protein OmpC and an N-acetylgly-

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Fig. 1: Schematic representation of a tailed phage, showing head, tail and tail fibers which recognize the specific receptor molecules on the bacterial surface.

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cosamine moiety at the end of the invariable outer core of the lipopolysaccharide molecules. Therefore both phages infect all serovars of Salmonella. As mentioned previously, failure to complete the lytic cycle does not mean the infected bacteria will survive and no strain has been found to be resistant to both of the phages.

**Calf Experiments**

In the first two trials farms with barns allowing separate milk formula distribution to two halves were chosen. Milk formula was prepared as usual and PhageGuard S was added to the milk intended for 1 part of the calves and a placebo (peptone buffer) was added to the other half. PhageGuard S and placebos was added for 10 days after arrival of the calves on the farm at every feeding. The dose consisted of $10^{10}$ phages per animal per day. In the ongoing trial it was decided to treat all animals on each farm either with phages or the placebo.

Criteria for monitoring in the first trial were feces scores, antibiotic use over the six month rearing period and mortality. The second, larger trial did not take into account feces scores because of the scope of the trial and this is true for the ongoing, even larger, trial.

**Results**

Results are summarized in table 1 further on. The first trial conducted from 2012-2014 included a total of 1851 animals. Overall, feces scores were improved in the phage-treated group and antibiotics use was reduced by 75% compared to the placebo group. Antibiotic type able to successfully treat sick animals in the phage-treated group included fewer medicines also used for treatment of humans. Mortality was reduced by 60% (6.2% compared to 15.6% in the control group). The second, double blind trial was conducted from 2014-2015. 5685 calves were given phage or placebo treated milk. A 10 % reduction in antibiotic use in the phage treated group was observed and a 30% reduction in mortality compared to the control. Results of the ongoing trial involving 120,000 calves are pending.
**Micreos pipeline products/applications**

We are currently developing a *Campylobacter* phage cocktail for *in vivo*, pre-slaughter use in poultry. Previous *in vivo* experiments have demonstrated that phage can significantly reduce *Campylobacter* numbers in colonized chickens (Wagenaar et al. 2005, Loc-Carillo et al. 2005). While not causing disease in poultry it is zoonotic. Campylobacteriosis is the most common cause of bacterial gastroenteritis in Europe followed by salmonellosis. In the US salmonellosis cases outnumber campylobacteriosis cases. The 1-3 log reduction of *Campylobacter* numbers observed in the animal studies would result in fewer cases of illness according to a risk analysis (Wagenaar et al. 2005). Moreover, it would allow an intervention at a point where no current method is available. Decontamination of carcasses with harsh chemicals is possible but that does not work in live birds, and an additional hurdle at the farm level might make it easier for producers to comply with performance standards. This holds true for *Salmonella* as well and we are currently starting experiments to determine the efficacy of *Salmonella* reduction *in vivo* using PhageGuard S.

The reservoir for *E. coli* STEC bacteria is ruminants making cattle the biggest risk for STEC infection from a public health standpoint. In theory *in vivo* phage biocontrol of STECs is possible. However, the site of STEC colonization in cattle is the recto-anal junction, almost at the very end of the digestive tract. We surmise that administering phage orally to survive the ruminants complicated digestive tract intact is, at this moment, a challenge too great. Nonetheless, we are developing a phage cocktail to target STECs for use as a hide-wash or for use as decontaminant of carcasses or trimmings.

**DISCUSSION AND CONCLUSIONS**

If used correctly, phages can be an extremely valuable tool for effective bio-control of pathogenic bacteria. They are the natural enemy of bacteria and regulate bacterial proliferation on a global scale. Advances in the scientific understanding of these organisms finally allows us to harness their power to specifically eliminate undesirable organisms without damaging commensal organisms and without using toxic chemicals. While phages may not be able to address every single type of infection or contamination they can provide additional intervention strategies in many areas. From pre-slaughter interventions in animal husbandry, to bio-control in food and agriculture and eventually in human and animal infection therapy.

**REFERENCES**


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**Table 1. Effect of Phageguard S administration for 10 days in two week old calves**

<table>
<thead>
<tr>
<th>Nr. of animals</th>
<th>Feces score</th>
<th>Antibiotic use</th>
<th>Mortality reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>1851</td>
<td>Improved in phage-treated group</td>
<td>-75% in phage-treated group</td>
</tr>
<tr>
<td>Trial 2</td>
<td>5685</td>
<td>-</td>
<td>-10% in phage-treated group</td>
</tr>
<tr>
<td>Trial 3</td>
<td>120.000</td>
<td>-</td>
<td>Pending</td>
</tr>
</tbody>
</table>

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*American Meat Science Association*
WHERE HAVE WE BEEN, WHERE ARE WE GOING IN THE MEAT INDUSTRY

The U.S. Meat Industry: The 115 Year Path

H. Russell Cross, Ph.D.

INTRODUCTION

Meat packing was launched soon after the east coast began to be settled. William Pynchon was our first meat packer in 1662, packing pork in barrels with salt to ship to the colonies (Texas Tech, 2017). The Brighton Market in Boston (1742) was the first slaughter center. This paper focuses on events beginning in the early 1900s and progresses to modern times to illustrate how these events impact our production of food from animals. Specific decades highlight significance to the meat industry. I conclude by briefly tracing the evolution of Meat Science in the U.S., and Table 1 provides a brief timeline of key events.

MOST IMPACTFUL DECADES

Decades 1900 – 1930

• In the late 1800s, refrigeration burst onto the scene. The use of ice gave way to mechanical refrigeration, which greatly increased efficiency and shelf-life in the dressed beef trade and pork packing. Large companies in Chicago began to build branch plants in Omaha, Kansas City, Sioux City, Oklahoma City, St. Paul, and St. Louis. The big three had their own refrigerated rail cars (Philip Armour, Gustavus Smith and Nelson Morris) and were able to influence the market throughout the Midwest.
• 1904 – Upton Sinclair’s “The Jungle” focuses on poor conditions remaining in the meat packing industry, prompting meat inspection regulations.
• 1904 – Union leads a long, bitter strike for wage increases (n=50,000 protestors). President Roosevelt establishes the Federal Arbitration Process (wage increases and eight-hour day).
• 1906 – Meat Inspection Act passes, and predecessors to AMI/NAMI and NCBA are formed.
• 1921 – Packers and Stockyards Act passes.
• 1922 – National Livestock and Meat Board is founded.
• 1927 – Federal Meat Grading Service is established.

Decade – 1960s: Through the Eyes of Rosemary (Bjerklie, 2015a)

• On the verge of huge change (perhaps because Rosemary arrived from Scotland)
• IBP just coming on scene in Denison, Iowa. Boxed beef introduced (Andy Anderson & Currier Holman).
• Boxed beef is possible only because of vacuum packaging. Huge earthquake for the meat industry.
• Tyson is a small, regional poultry company.
• American Meat Institute still headquartered in Chicago.
• Food safety is not on the beef industry’s radar.
• Big issue is labor contracts.
• Begin shift to boxed beef (IBP and Monfort).

Decade – 1970s (Ogle, 2015; Bowling, 2017)

• Decade of turmoil.
• Famine has potential in many parts of the world.
• U.S. sells most of its grain harvest to highest bidder.
• U.S. food prices go through the roof. Consumers protest. Meat boycotts.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1662</td>
<td>William Pynchon first packages meat</td>
</tr>
<tr>
<td>1742</td>
<td>Boston becomes first slaughter center</td>
</tr>
<tr>
<td>1773</td>
<td>First Meat Scientist is Benjamin Franklin; he proposes a more “compassionate” slaughter method – adopted 200 years later</td>
</tr>
<tr>
<td>1818</td>
<td>First meat packing plant – Cincinnati “Porkopolis”; saws not yet used</td>
</tr>
<tr>
<td>1821</td>
<td>First commercial meat canning in Boston</td>
</tr>
<tr>
<td>1836</td>
<td>Steam power used in packing houses; allows production of meat-type animals instead of draft-type</td>
</tr>
<tr>
<td>1852-65</td>
<td>Railroads come to Chicago; reduces labor                                                                __________________________________________</td>
</tr>
<tr>
<td>1862-69</td>
<td>Chicago is the lead meat packing city and Texas the lead cattle state</td>
</tr>
<tr>
<td>1862</td>
<td>USDA and the Land Grant College System are created</td>
</tr>
<tr>
<td>1868</td>
<td>Refrigerator railroad car patented</td>
</tr>
<tr>
<td>1870-90</td>
<td>Westward expansion of meat packing – Oklahoma City, Kansas City, Omaha, Sioux City, St. Paul, St. Louis, Chicago</td>
</tr>
<tr>
<td>1880-89</td>
<td>Mechanical innovation - refrigerator, mixers, stuffers and choppers</td>
</tr>
<tr>
<td>1888</td>
<td>Refrigerated boxcars make first long-haul shipments of produce and meat</td>
</tr>
<tr>
<td>1893</td>
<td>First icemaker</td>
</tr>
<tr>
<td>1899</td>
<td>Invention of smokehouse trees; move meat on rails to smokehouse</td>
</tr>
<tr>
<td>1900</td>
<td>Development of cure pumps, slicing machines and “converyer-ized” tables</td>
</tr>
<tr>
<td>1901</td>
<td>Chicago Stock Yards established</td>
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<tr>
<td>1904</td>
<td>Upton Sinclair’s “The Jungle” prompted meat inspection legislation</td>
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<tr>
<td>1906</td>
<td>Predecessors to AMI/NAMI and NCA/NCBA are formed</td>
</tr>
<tr>
<td>1906</td>
<td>Pure Food and Drug Act passes</td>
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<tr>
<td>1917</td>
<td>U.S. enters World War I</td>
</tr>
<tr>
<td>1918</td>
<td>First meat delivery truck</td>
</tr>
<tr>
<td>1920</td>
<td>First cattle-skinning beds</td>
</tr>
<tr>
<td>1920</td>
<td>First “Monster” meat grinder</td>
</tr>
<tr>
<td>1920</td>
<td>First bandsaw for cutting meat</td>
</tr>
<tr>
<td>1921</td>
<td>Packers and Stockyards Act passes</td>
</tr>
<tr>
<td>1922</td>
<td>Founding of the National Livestock and Meat Board; cooperative effort by producers and packers to promote meat</td>
</tr>
<tr>
<td>1924</td>
<td>First refrigerated truck</td>
</tr>
<tr>
<td>1925</td>
<td>First appearance of pork carcass fab lines on wood tables</td>
</tr>
<tr>
<td>1927</td>
<td>Growth of chain stores and major packers begin use of brand names</td>
</tr>
<tr>
<td>1927</td>
<td>Federal meat grading service created</td>
</tr>
<tr>
<td>1941</td>
<td>U.S. enters World War II</td>
</tr>
<tr>
<td>1950-59</td>
<td>Many technological developments – power carcass-splitting saws, injection of bacons, continuous wiener processing, skinless sausages, lactic acid starter cultures, self-service supermarkets</td>
</tr>
<tr>
<td>1960-69</td>
<td>Slaughter facilities move to feedlot areas</td>
</tr>
<tr>
<td>1960-69</td>
<td>Retail grocery-central cutting facilities; impact of boxed beef</td>
</tr>
<tr>
<td>1960</td>
<td>Major shift from railways to truck transport of meat</td>
</tr>
<tr>
<td>1967-68</td>
<td>Wholesome Meat Act and Wholesome Poultry Act passed</td>
</tr>
<tr>
<td>1970-79</td>
<td>Computer accounting, sausage formulation, yield tracking</td>
</tr>
<tr>
<td>1971</td>
<td>Chicago Stock Yards closes</td>
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<tr>
<td>1971</td>
<td>DES banned</td>
</tr>
<tr>
<td>1977</td>
<td>Beef quality grade changes</td>
</tr>
<tr>
<td>1980-89</td>
<td>Consumer activists target red meat industry</td>
</tr>
<tr>
<td>1980</td>
<td>First vacuum-packaging machine; used for luncheon meats</td>
</tr>
<tr>
<td>1980-89</td>
<td>New meat fab equipment developed</td>
</tr>
</tbody>
</table>

Sources: Meischen, H. 2017, P.C.  
• U.S. exports drop due to competition from Europe. 
  Unemployment and interest rates increase.
• Inflation hammers all.
• Early to mid-70s – new breed of independent packers 
  is emerging. Feedlots move to corn, and packing plants 
  follow led by Monfort, IBP, Cargill and National Beef.
• Boxed beef at 8%.
• Early 70s – big central market packing plants in metro-
  politan areas begin to fade.
• The new breed of packers could divide and conquer.
• Soaring corn prices and unhappy consumers cause 
  many producers to shift from animals to corn.
• Along comes the chicken.
• Nation's broiler industry was born and forced to grow 
  up fast.
• Rapid technology and structural change.
• Case ready chicken (1977).
• Cargill buys Excel (1979).
• Huge export market – cheap food.
• Poultry moves into fast food market and then retail.
• Congress denounces “meat” as unhealthy and urges 
  alternative proteins – “other white meat.” McGovern 
  Senate Select Committee on Nutrition resulted in “Di-
  etary Goals for the United States.”
• Obesity begins increase from 10% to present day 38%.
• A decade to forget!

Decade – 1980s (Bowling, 2017, P.C., Meischen, 
2017, P.C.)
• 1982 – McDonald’s had first E. coli O157:H7 positive 
  at restaurants in Oregon and Michigan. The outbreak 
  is small and quickly contained. CDC immediately begins 
  working on methods to detect and identify O157:H7.
• At the same time, USDA initiates an effort to modern-
  ize carcass inspection, with the intent to minimize fe-
  cal contamination and pathogens.
• From that effort, Monfort and National Beef work with 
  USDA on the Streamlined Inspection System program, 
  which becomes the first on-the-slaughter-line HACCP 
  program in packing plants.
• Still one-inch fat trim at retail.
• Late 80s – vacuum packaging becomes commonplace 
  in beef fabrication and ground beef units, and course 
  ground trim is packaged in chubs, creating the need 
  for bacterial control all the way through the trim.
• Bone-in boxed beef at 85%.
• Shift to ¼ inch trim on retail cuts (1985).
• First Walmart Supercenter (1985).

SUMMARY
The beef industry witnessed the beginnings of change in 
the 1980s that were not fully evident until the 1990s. The 
face of the industry changed as metropolitan plants closed 
and new plants opened near corn and feedlots. A new 
pathogen made its appearance, as did the beginnings of 
HACCP to control fecal contamination and pathogens. 
With the advent of vacuum packaging, routine use of beef 
trim to meet fat targets, and packaging ground product in 
chubs, pathogen control began to receive the focus that 
led to current practices and regulations.

Decade – 1990s (Bejerklie, 2015b)
• 1980s revealed poultry as the nation’s most popular 
  protein; significant industry consolidation and the be-
  ginning of natural and organic trends.
• 1990s – get ready!
• Most have never heard of E. coli O157:H7.
• Few have heard of HACCP.
• Few are aware of Temple Grandin.
• November 1992 – eleven lots of ground beef contami-
  nated with E. coli O157:H7 are distributed to Jack in 
  the Box eateries in Washington, Oregon, California 
  and Nevada.
• By January 1993, more than 600 people in Washing-
  ton report symptoms of H.U.S. – 144 are hospitalized, 
  30 develop H.U.S. and four children die in two states.
• First topic of President Clinton's initial cabinet meeting.
• Industry terrified.
• New Secretary asks Administrator Cross how many of 
  USDA federally-inspected plants are voluntarily imple-
  menting HACCP. Answer – less than 300 out of 7,000. 
  Cross recommends that HACCP be mandated.
• Major food safety regulatory changes – pathogen re-
  duction and HACCP. (Mega Reg)
• International HACCP Alliance formed and remains en-
  gaged (Dr. Kerri Gehring, current CEO).
• E. coli O157:H7 becomes an adulterant (Michael Tay-
  ler)!
• Industry pays attention and commits to producing safe 
  foods.

Decade – 2000s (Kay, 2015)
• Cautious optimism. Recovered from E coli O157:H7. 
  Industry spent billions.
• Reasonable corn prices.
• Then came the cow that stole Christmas! December 
  2003 – BSE cow positive (came from Canada).
• Cost industry more than $16B (lost exports, etc.).
• Government’s support of ethanol production. Food vs. fuel debate (the debate continues).
• Shift to boneless boxed beef.
• Mergers and acquisitions
  ○ Tyson acquires IBP
  ○ JBS buys Swift and the Smithfield beef group, plus majority share of Pilgrims.
  ○ AgriBeef purchases Washington Beef
  ○ Cargill buys Beef Packers in Fresno

The Past Decade
• Severe drought unquestionably had a major impact on the beef industry, resulting in reduced cattle numbers, higher beef prices, greater use of beta agonists, larger carcasses, closing feedlots and packing plants.
• The past decade has seen a rise in social media, and the amount of “fake news” (to borrow the current term of the day), undercover videos, alleged problems with items such as “pink slime,” have greatly impacted the beef industry. Today, fears surrounding immigration could impact the labor force.
• Salmonella (shifting behavior and serotypes, changing virulence, presence in lymph glands, etc.), validation requirements, AMR, and many others - all major game changers.
• Increased focus on animal welfare issues. Even though there was not a specific event that occurred like the Jack in the Box incident, McDonald’s suing the folks in England at the McLibel trial triggered the animal welfare emphasis in which the industry has been involved for the past 20 years.
• Potential impact of Presidential election on trade (TPP, NAFTA, etc.).
• Impact of over-regulation on trade.
• Dietary guidelines’ potential impact on meat and obesity (past 30 years).
• Implementation of beef instrument grading.
• Ethanol mandate driving up beef prices.
• Global Food Safety Initiative (GFSI).
  ○ BSE epidemic of the mid-1980s in Europe caused global concern about the safety of food purchased at foodservice and retail establishments. In 2000, the Consumer Goods Forum in the United Kingdom created the Global Food Safety Initiative (GFSI) with the mission, “To provide continuous improvement in food safety management systems to ensure confidence in the delivery of safe food to consumers worldwide.” GFSI brought together three key elements of food production: (a) The Food Safety Management System (based on ISO 22000); (b) Good Agricultural Practices, Good Manufacturing Practices and Good Distribution Practices; and (c) A Hazard Analysis Critical Control Point system. GFSI approved two Primary Production Schemes (e.g., Global GAP), two Primary & Manufacturing Schemes (e.g., Safety Quality Food Code) and six Manufacturing Schemes (e.g., British Retail Consortium, Safe Quality Food, Food Safety System Certification) as avenues through which food companies could achieve certification to GFSI standards. In 2006, H-E-B Supermarkets adopted Safe Quality Foods (SQF) certification as a requirement of their suppliers; in 2007, seven major retailers in the EU committed to requiring supplier certification to GFSI-approved schemes; and in 2008, Walmart adopted GFSI certification for all of their food suppliers. Since that time, essentially the entire food manufacturing industry in the U.S. has adopted GFSI certification as a pillar of food purchase specifications. In the U.S., British Retail Consortium (BRC) and SQF are the GFSI-approved certification standards complied with most often by those in the meat industry.

Brief History of Meat Science
Bray (1997) and Beermann (2009) both provide excellent overviews on this topic. Briefly:
• Morrill Act (1862) led to the early creation of Departments of Animal Husbandry.
• Little evidence of the teaching of meat courses or meats research before 1900.
• First college meats course offered at the University of Minnesota in 1893 by Andrew Boss.
• First university meat laboratory built on University of Minnesota campus around 1900.
• The University of Illinois offered a meats course in 1902; Michigan State in 1907; Penn State in 1912; Ohio State in 1913; Cornell in 1915; Kentucky, Iowa and Colorado State in 1919. These programs were called “significant twenties,” in which ten other states began meats programs.
• Strong leaders with influential vision, including Thomas Wilson, who led formation of the National Livestock and Meat Board in 1922, and R.C. Pollock, the first general manager of the Meat Board.
• Cooperative Meat Investigations led by R.C. Pollock in 1924.
• R.C. Pollock pushed for intercollegiate meat judging contests – first contest in 1927 at the International Livestock Exposition in Chicago.
• “Meats Men” became “Meats Scientists” during the 50s and 60s.
• Interest in beef and pork grading post World War II led to carcass contests at county, state and national shows.
In the 1940s, there were fewer than six “meat” scientists with PhDs; the 50s and 60s saw a dramatic increase with focus on many of the basic sciences (Bray, 1997).

Many third and fourth generation meat scientists were called “muscle biologists.”

Microbiology of meat received little attention in the early days. Meat microbiology research saw significant expansion in the 70s and 80s.

With the *E. coli* O157:H7 outbreaks of the 90s, HACCP entered the classroom, and food safety research exploded.

Food engineering became a new and critical component of food/meat science.

Since the 1970s, the focus on nutrition and the role of meat in the diet have increased dramatically, as has the focus in meat science.

Meat scientists have truly evolved, from the first Reciprocal Meat Conference in 1947 to where we are today at the 70th RMC. This journey began as a partnership with the National Livestock and Meat Board and, today, involves so many valued industry and government organizations.

**REFERENCES**


Application Of Metabolomics To Understand Flavor And Flavor Stability: A Case Study In Beer

Adam L. Heuberger, Ph.D.

OVERVIEW
The application of omics technologies is a novel approach to understand the influence of raw materials on the chemistry and sensory properties of their food products. Metabolomics is a fast and sensitive biochemical profiling method that provides a comprehensive overview of the small molecules. Metabolomics can be applied to various biological systems, and recent studies have used metabolomics to investigate aspects of food science, specifically for a high-throughput comparison of the type and quantity of small molecules in food products.

THE METABOLIC WORKFLOW
Metabolomics is performed as a workflow comprised of the following steps: (i) experimental design (ii) extraction (iii) detection (iv) data processing and (v) data analysis methods. The experimental design includes understanding sources of biological, extraction, and analytical variation that can be observed. Metabolomics extractions are designed to maintain sample complexities while minimizing steps within a procedure to reduce extraction variation. Following extraction, samples are typically detected using chromatography coupled to mass spectrometry, which is a sensitive and robust technique for metabolomics. Following metabolite detection, mass spectrometry files are processed using algorithms that align large datasets, and the resulting data matrix of metabolites and metabolite quantities can be analyzed using univariate, multivariate, and networking methods.

APPLICATION OF METABOLIC TO FLAVOR AND FLAVOR STABILITY
Metabolomics is well-suited for investigations of flavor and flavor stability. Flavor encompasses taste, aroma, and mouthfeel, and is thought of as an integration (i.e. ‘profile’) of many small molecules. Flavor stability, the ability to maintain a chemical profile over time, can also be evaluated by conducting metabolomics on food products over a time-course. The end results of flavor or flavor stability metabolomics include a better understanding of the mechanisms behind flavor and the identification of small molecule markers to predict flavor and flavor stability without the need for sensory panels.

The Case Study: An example of applying metabolomics to understand chemical variation in beer flavor and flavor stability.

Here, metabolomics was applied to understand chemical variation important to the brewing industry. Chemical variation was evaluated among barley genotypes, the resulting malt, different maltsters, and the finished beer. The chemical data was integrated with metrics for malt quality, beer flavor and flavor stability. Metabolites were evaluated as aqueous/methanol extracts, and experiments were performed on UHPLC-MS (reverse phase and HILIC), GC-MS, ICP-MS (for metals) and HS/GC-MS platforms. The data was processed using XCMS and analyzed using ANOVA and principal component analysis, and the chemical and quality/sensory data was using the O2PLS method.

The data demonstrated significant metabolite variation in barley associated with variety, growing location, and genotype by location interactions. The genetic variation in the barley and malt raw materials was associated with changes to sensory attributes of the beer. The O2PLS modeling identified metabolites that co-varied with sensory traits, indicating a mechanistic basis for how variation in raw materials influenced sensory traits. Further, independent metabolomics experiments on beer reveal new information about metabolites associated with aging and flavor stability.
SUMMARY
In summary, these data provide new information about the extent of chemical variation in barley and the association to malting quality, beer flavor and flavor stability. The report serves as an example for how metabolomics can be applied to raw materials and foods to predict flavor properties of the finished food product. The technique can be readily applied evaluate volatiles and non-volatiles in meat products to understand flavor, evaluate processing and cooking methods, estimate nutrition, and to identify biomarkers in raw materials that can predict flavor and flavor stability of the finished food.
Using VOC Signatures to Characterize Lamb Flavor

Dale R. Woerner¹, Adam Heuberger², Jessica Prenni³, Jennifer N. Martin¹, Terry E. Engle¹, Robert J. Delmore⁴, and Keith E. Belk¹

A proof of concept was demonstrated for differentiating sheep meat flavor attributes using mass spectrometry (MS; Maneotis, 2016). Thus, the opportunity exists to identify and instrument technology that demonstrates the capacity to perform the task of reducing the incidence of consumers in the production environment. Rapid Evaporative Ionization Mass Spectrometry (REIMS) is a relatively new technology that is emerging in many areas of science, including in human medicine and biological sciences. At this time, REIMS is the only technology that is operational at this point in time that shows great promise for successfully classifying the flavor of sheep meat in the production setting. REIMS-based tissue analysis generally takes only a few seconds and can provide histological tissue identification with 90–98% correct classification performance (Balog et al., 2013). Using time-of-flight (TOF) mass spectrometry, REIMS profiling provides in situ, real-time molecularly-resolved information by ionizing biological samples in real-time without any sample preparation. Waters Corp. (Wilmslow, UK) has developed this technology as REIMS with “iKnife” coupled to a Xevo G2-S quadrupole time-of-flight mass spectrometer (Waters Corp., Wilmslow, UK). This simple system utilizes a handheld sampling device and can perform analysis of tissue in 2 seconds. A demonstration video of this technology can be viewed at: https://www.youtube.com/watch?v=Z9yVeMbaOmo. The primary advantage of this technology is that is requires no sample preparation or chromatography to achieve broad molecular profiling of tissue samples. With respect to the sheep industry, for the first time, this technology would allow for meat quality attributes such as flavor profile to be predicted and characterized in real time from carcass assessment. We hypothesize that this technology could be further developed and packaged as an online system in the processing environment to enable meaningful sorting of sheep meat products into categories reflecting tangible differences in eating satisfaction.

Multiple studies have shown that GC-MS approaches can effectively be used to profile volatile signatures from raw meat that can be correlated with human sensory data of cooked product. However, GC-MS analysis requires the use of sampling approaches to collect and concentrate volatile compounds (e.g. SPME) and are limited to a narrow window of compounds in the range of 33-500 m/z. Additionally, the GC-MS and SPME approach does not enable real-time sampling desirable in commercial food packaging applications, and significant sample preparation is required. Conversely, REIMS does not require any sample preparation or special sampling and can profile organic compounds over a much broader size spectrum from (150 -1,500 m/z), which allows for detection of lipids, fatty acids, sugars, peptides, and amino acids from a single molecular signature.

Recent research (funded internally) at Colorado State University demonstrated that REIMS (“iKnife”; Xevo G2-S quadrupole TOF-MSA, Waters Corp., Wilmslow, UK) effectively segregated sheep meat samples based on flavor intensity (unpublished data; Figure 1.). In this experiment, fat and lean tissue from the exterior of individual lamb legs determined to have “mild” or “bold” lamb flavor by a trained sensory panel (samples from Maneotis), were evaluated using iKnife technology. In a blind analysis, the technology segregated mild and bold lamb samples with 100 % accuracy.

In addition to meat-related research, it recently was demonstrated that REIMS spectrum of bacterial colonies, obtained by using standard bipolar electrosurgical tools as an ion source, shows excellent taxonomical specificity,
allowing also the differentiation of strains at subspecies (e.g., serotype) level (Strittmatter et al., 2014). On the basis of these observations, REIMS technology is expected to find its application niche in the field of food security, with special emphasis on food authenticity and food microbiology applications. Balog et al. (2016) recently published work aimed at exploring capabilities of REIMS profiling with regard to species- and breed-level differentiation of raw meat products. Balog et al. (2016) developed and tested a multivariate statistical algorithm that was to identify animal tissue of differing anatomical origin, breed, and species with 100% accuracy at the species, and 97% accuracy at breed, levels of prediction. Balog et al. (2016) reported a 97.48% correct classification rate for breed-type in beef cattle (Aberdeen Angus beef, 30 Blonde cross beef, 60 Hereford cross, 60 Limousin cross).

REIMS has potential to be developed to characterize and differentiate flavor and identify off-flavors in meat, as well as provide information about production history, age, color, and even breed-type of the animal.

REFERENCES
**Post-Mortem Handling and Beef Flavor Chemistry**

**Jerrad F. Legako, Jacqueline Ponce, and J. Chance Brooks**

**POST-MORTEM AGING**

Recent research conducted by Kirby et al. (2016) showed extended aging of certain beef cuts can have profoundly negative impacts on beef flavor. Beef muscles traditionally characterized as susceptible to oxidation were especially impacted by extended (42 d) aging. Principal component analysis further revealed specific relationships between lipid oxidation products and Maillard reaction products with consumer liking (Figure 1). The Maillard reaction products were more highly related with consumer flavor liking. However, the lipid oxidation products were not positively related with consumer flavor liking scores. Thus, this data indicates post-mortem storage can have a profound effect on beef flavor. Furthermore, extended aging was detrimental to consumer flavor liking for muscles which had greater lipid oxidation (TBARS). These results would indicate that the chemical stability of beef muscles is not equal and greater care should be taken when considering extended for specific beef muscles.

**POST-MORTEM PACKAGING ENVIRONMENT**

Consumer purchase decisions at retail are determined by meat color with little to no regard as to how the product may actually taste (Killinger et al. 2004). Thus, beef consumers are conditioned to purchase beef that is bright, cherry-red in color and free of discoloration or blemish. To provide consumers with this desired bright, cherry-red beef; various packaging systems are used to expose the lean surface to oxygen or carbon monoxide to obtain the desired color. However, the amount of time meat will retain this color is limited because exposure to oxygen and intense lighting prompts an oxidative and enzymatic degradation of beef which ultimately causes discoloration (Gray et al. 1996). The oxidative and enzymatic processes initiated by the meat package systems and display conditions are also responsible for the development of off odors and flavors in cooked beef products (Gray et al. 1994). Based on these results and the results of Kirby et al a second study was conducted to explore the impacts of packaging environment on beef flavor.

Paired strip loins and top sirloin butts were collected from USDA Choice, “A” maturity beef carcasses (n = 10) from a commercial processing facility in the Texas panhandle. All subprimals were packaged under vacuum, stored in dark storage at 0-4°C and aged for 14d. After initial aging, all top butts and strip loins were fabricated and sliced to produce 2.54cm Gluteus medius (GM) and Longissimus dorsi (LD) steaks, respectively. At 14d, steaks from each muscle group were randomly assigned to 1 of 5 package types: high-oxygen modified atmosphere lidded trays (80 % O2/20 % CO2, HIOX), carbon monoxide modified atmosphere lidded trays (0.4 % CO/30 % CO2/69.6%N2, CO), rollstock ROLL, vacuum packaging without retail display (VAC), and traditional overwrap (OW). The OW packages remained under vacuum prior to being placed on foam trays and sealed with polyvinyl chloride (PVC) film and displayed in retail cases on d 21 postmortem. All package types were placed in dark storage at 0-4°C for an additional 7d prior to display. At 21d postmortem, HIOX, OW, CO, and ROLL packages were removed from dark storage and displayed in coffin-style retail cases (0-2°C) for 48hrs under continuous fluorescent lighting, while VAC steaks remained in dark storage. All steaks were rotated every 12 hrs during display to ensure all packages were held to similar temperatures and lighting throughout the case. Following storage steaks were individual vacuum packaged and frozen until analysis. Steaks were evaluated by untrained consumers, a trained descriptive panel, and volatile flavor compounds were measured.

Principle component analysis was conducted to explore the relationship between volatile flavor compounds and muscle × packaging type combinations (Figure 2). The plot displayed a separation of GM HIOX and all other muscle and packaging type combinations. This separation is attributed to the increased quantities of lipid oxidation products, in addition to a decrease in Maillard products. Principle component 1 revealed a separation in
all muscle × packaging types similar to LS means differences determined in sensory data; vacuum packaging was more associated with positive consumer sensory scores than high oxygen packaging environments. Additionally, PC2 showed a separation between muscles on the basis of increased Strecker aldehydes and pyrazines in the LD and increased sulfur compounds associated with the GM. The flavor attributes that are more closely related to these sulfur compounds and the GM include liver-like and sourness, whereas sweetness and saltiness were more related to the LD.

Considering the combination of all these results it is evident that packaging environment impacts beef flavor. Package types which have greater levels of oxygen were detrimental to flavor. Furthermore, this detrimental impact on flavor was magnified in muscles which have lower chemical stability.

**POST-MORTEM COOKING**

Recently it was determined that the development of volatile flavor compounds was influenced by multiple factors.
Specifically, volatile compounds interacted with product type (intact steaks or ground patties), quality grade, and degree-of-doneness. This 3-way interaction was most evident for Maillard reaction products. For example 2-ethyl-3,5-dimethyl-pyrazine was a representative compound for a common 3-way interaction (P < 0.001) of product type with quality grade and degree-of-doneness (Figure 3). Within this interaction there was clear segregation between quality grade at higher degrees-of-doneness within steaks. Patties, however, did not differentiate due to quality grade or degree-of-doneness. It is unclear what the root cause is for this observation. However, the cooking duration of patties was much shorter compared with steaks and there was little variation between different degrees-of-doneness. We have speculated that cooking duration greatly impacted the lower output of Maillard products among ground patties. Within steaks Prime was greater or equal to Low Choice at all cooked temperatures. Likewise, Prime and Low Choice both had greater concentrations of Maillard products at cooked temperatures compared with Standard. This influence of quality grade on concentration of Maillard compounds may be attributed to multiple factors. Again, cooking duration may contribute as Standard steaks required less cooking time in comparison with Low Choice and Prime steaks. Another possible contributor was the retention and delivery of volatile flavor compounds in lipid. Volatile compounds express some solubility in lipid. With Standard having considerably lower fat content there is less lipid to retain and deliver volatile compounds. A third scenario that may have contributed to these concentration differences with quality grade was a concentrating effect of precursor compounds. Maillard reaction compounds are the result of interactions between water-soluble amino acids and sugars. In higher fat beef there is less moisture. This may allow for a concentrating of water-soluble precursor compounds into the water fraction of higher fat beef and thus providing greater interactions between these compounds for flavor development. Further work is needed to determine the precise driver of volatile compound output between quality grades.

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INTRODUCTION
The browning of food is something that we, as consumers, enjoy everyday. Besides the visual appeal of bread, cookies, and bakery items to the sizzle of a nicely-browned steak, the process of browning also adds a host of flavors—both sweet and savory—that define the taste of these food products. We take for granted the complex process that creates these traits and simply just assume that by cooking something it will create the browning that we enjoy. We often forget the “browning” process can take place at room temperature in some foods and can be found in some jerky and fermented products that do not have a heat treatment. The process of browning in food is dependent on whether it is mediated by enzymes or not. While not necessarily mutually exclusive, it is generally accepted that browning of food during the cooking process (which is what we will concentrate on in this paper) takes place in the absence of enzymes, for most enzymes are inactivated at the temperatures at which cooking takes place. While a small amount of browning in meat takes place by the direct degradation of sugar (caramelization), most of the browning reaction in meat is the result of an initial step that occurs with the condensation of a reducing sugar and an amine group from an amino acid, peptide, or protein. This reaction is the beginning of what we now refer to as the Maillard reaction.

To understand browning during the cooking process in meat, it is helpful to understand the history of the browning process as we now understand it. Louis-Camille Maillard graduated with a degree in medicine from the University of Nancy in 1903, where he then joined the Chemical Division of the School of Medicine (Kawamura, 1983). He was interested in the synthesis of peptides which he hypothesized could be carried out under rather mild conditions using glycerol as a substrate. This led to the use of sugars as a type of poly-hydroxy compound to bring about the formation of these peptides and then to the discovery of reducing sugars that showed extra reactivity. He published numerous papers on the subject with his pivotal paper in 1912 (Maillard, 1912) which is cited widely as the origin of the reaction that bears his name. Nevertheless, it wasn’t until 1953 that Hodge published the schematic used today in various forms to describe the reactions that lead to the wide variety of compounds that result from numerous chemical reactions and ends with the production of melanoidins.

Hodge divided the Maillard reaction into three distinct stages. The initial stage includes sugar-amine condensation and Amadori rearrangement, resulting in products that are colorless, without light absorption in the ultraviolet range (~280 nm). The intermediate stage includes sugar dehydration, sugar fragmentation, and Strecker degradation. The products from this stage range from colorless to a light yellow with strong absorption in ultraviolet light. The final stage produces highly colored products and include aldol condensation and aldehyde-amine condensation in addition to the formation of heterocyclic nitrogen compounds.

While many factors influence the development of the Maillard reaction such as pH, water activity, and nutrient composition, time and temperature are two factors that we have the most influence to control in our preparation of meat. Model systems have been developed over time that combine specific substrates (amino acids and reducing sugars) in the lab to determine the rate and end products of time and temperature. More recent efforts have been to develop model systems using actual meat products like steaks, chops, and ground beef to measure the development of Maillard reaction products as a function of time and temperature.
MAILLARD REACTION

An abbreviated outline of the Maillard reaction is shown in Figure 1. It shows the complex interaction of numerous chemical reactions that are highly dependent on the conditions present during the reaction, some of which are outlined below. While this schematic is not exhaustive, it gives a good visual cue as to the complexity of the reactions and the origin of many of the classes of products that arise from the reaction.

Condensation

In the initial step of the reaction process, a sugar reacts with an amine group from a free amino acid, peptide, or protein to form an N-substituted glycosylamine. Processes of gluconeogenesis and glycolysis in meat result in the synthesis of glucose and glucose-6-phosphate, whereas degradation of ATP results in the formation of ribose and ribose-5-phosphate. It is worth noting that this reaction is reversible. From there an Amadori rearrangement product (ARP) is formed.

Amadori rearrangement products

From the condensation reaction, the Amadori rearrangement is not reversible and takes place spontaneously, even at temperatures as low as 25°C (Martins et al., 2001). The subsequent degradation of the ARP is dependent on the pH of the system. At a pH < 7 it undergoes 1,2 enolisation with the formation of furfural (when pentoses are involved) or hydroxy-methylfurfural (HMF; when hexoses are involved). When the system pH is > 7, the formation of numerous reductones as well as fission products are produced. All of these compounds are highly reactive and participate in further reactions. Naturally, the formation of HMF is preferred due to the pH of meat (~5.6), and the production of furans are very commonly a result of this reaction.

Strecker degradation

The development of various reaction products from the degradation of amino acids was first reported by Strecker in the 1860's and reviewed by Shönberg and Moubacher.
This is a reaction of α-amino acids which are oxidized to their corresponding aldehyde, releasing carbon dioxide in the process. Additionally, ammonia is transferred to other components of the system with very little of it being liberated intact. Dicarbonyl fragments react with the amine group of the amino acid, giving off an intermediate common to strecker aldehydes and pyrazines. Additionally, Strecker aldehydes can also represent the nitrogen-containing heterocyclic compounds such as pyrroles and pyrrolidines coming from the reaction of dicarbonyls with proline and hydroxyproline (Mottram, 1994).

**Schiff's base**

As Nursten (2005) described, proogression from the ARP and under acidic conditions, furfurals are produced. Glycine accelerates the conversion of xylose to furfural and glucose to HMF. This appears to be because the Amadori products dehydrate more readily than the original aldose or N-substituted glycosylamine, giving the Schiff's base of furfural which is then hydrolysed, re-liberating part of the amine. It is generally considered that HMF is of low browning potential and does not lie on the main pathway to melanoidins.

**Reducrones**

The reductones are products formed from sugars by the loss of only two molecules of water; whereas, the loss of three water molecules leads to furfurals (Nursten, 2005). The reductones help to explain the reducing power that develops during browning, but they take part in browning in the dehydro form. Therefore, the presence of oxygen is necessary in order to be converted into the reductone.

**Heterocyclization**

Numerous steps during the rearrangement of a sugar may result in the cyclization to form new classes of compounds. In the simplified Maillard scheme proposed by Jousse et al. (2002; and summarized here in Figure 1), the intermediate ARP can cyclize to form nitrogen-containing heterocyclic compounds, such as pyrroles or pyridines. It may also give a rearranged sugar – a new compound still containing the intact chain of the original sugar. The rearranged sugar may cyclize into oxygen-containing heterocyclic compounds, like furans, or may break up into dicarbonyl fragments which may then recombine to give furans.

**Melanoidins**

As Martins et al. (2001) indicates, we first “eat with our eyes”. The development of browning in processed foods is of obvious importance. The degree of browning, which can be measured by the absorbance of light at 420 nm, is often assessed to determine the extent to which the Maillard reaction has taken place in foods. In the final stage of the Maillard reaction process, colored intermediates and other reactive precursors condense and polymerize to form brown polymers. Some of the reported properties of these compounds are brown, high-molecular, furan ring-containing and nitrogen-containing polymers. As with the volatile aroma compounds, melanoidins have largely been studied in model systems, and further research is needed related to the development of these compounds in meat systems.

**Factors that affect development of Maillard products**

Numerous factors have an impact on, and add to the complexity of, the Maillard reaction (Dashdorj et al., 2015). Factors such as pH, water activity, time and temperature are perhaps the most influential in the development of the Maillard products. As already discussed, pH is influential in determining the initial pathways of the Maillard reaction (Figure 1), and because meat products have pH near 5.6, the development of the HMF pathway is clearly preferred. Portanguen et al. (2014) discussed at length the development of crust formation on the surface of meat as it impacts water activity, the importance of the depth of the crust, and temperature impacts on the development of Maillard products. They determined that the crust formed during the cooking process of meat is an extremely complex structure with very distinct areas. The crust formation begins when the liquid is replaced by a mixed liquid/vapor area, which leads to the evaporation front. Beyond this front, the liquid is replaced by vapor. The water content then decreases toward the surface, leading to a high-temperature area dominated by the formation of colored Maillard compounds and heterocyclic aromatic amines. Furthermore, the thickness of the crust increases linearly with time. They also indicated that when the water activity reaches 0.6 to 0.7 (compared to 0.99 in meat normally), Maillard reactions are intense. Moreover, it is when water activity finally drops to 0.2 at the crust surface where the melanoidins develop. It is also noted that temperature near the surface remains near 100°C as water continually transitions to vapor, building the vapor front. As a result, the surface of the meat has a complex temperature/time/water activity interaction that functions to influence the development of the Maillard products.

**PRODUCTS OF MAILLARD REACTION TIME/TEMPERATURE**

**Time/temperature**

Ames (1990) described mechanisms that control the Maillard reaction in food systems and indicated in her review that increasing temperature increases the rate of Maillard browning. The Maillard reaction has a relatively high temperature coefficient, as measured by $Q_{10}$ values ranging from 2 to 8. Temperature coefficients, or $Q_{10}$ values, are unitless and represent the factor by which the rate of a reaction increases for every 10°C rise in the temperature. If the rate of the reaction is completely temperature inde-
dependent, it will have a $Q_{10}$ value of 1.0. The more temperature dependent a process is the higher its $Q_{10}$ value.

**Kinetic modeling**

Table 1 (from Jousse et al., 2002) shows the independent rates in M/s for different Maillard reaction steps outlined in Figure 1. It is noteworthy that the rate increases with an increase in the temperature of the reaction and most notable is that the formation of Strecker intermediates is an extraordinarily fast reaction with orders of magnitude faster rates compared to other reactions in the table.

**Formation of temperature-dependent volatile compounds**

In work completed by our own lab, we have investigated the influence of grill temperature on the formation of volatile aroma compounds from beef. Figure 2 shows the increase in Maillard products as the grill temperature increases. Conversely, a concurrent reduction in lipid degradation products takes place as the grill temperature increases (data not shown). These data suggest that low grilling temperatures of 177°C (350°F) is insufficient to generate a significant amount of these Maillard reaction products – namely the pyrazines, which are formed later in the Maillard reaction.

Kerth (2016) reported various volatile aroma compounds could be predicted by measuring cooking parameters such as cook surface temperature, cooking time, steak surface temperature, and cook loss %. As an example, 51.5% of the variation in 2,5-dimethyl-pyrazine present could be attributed to the initial cook surface temperature, final steak surface temperature, and total cooking time, and as much as 65.6% of the variation in

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$20 , ^{\circ}C$</th>
<th>$100 , ^{\circ}C$</th>
<th>$180 , ^{\circ}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar/AA condensation to N-sub. glycosylamine</td>
<td>$7.9 \times 10^{-10}$</td>
<td>$6.7 \times 10^{-5}$</td>
<td>$1.0 \times 10^{-1}$</td>
</tr>
<tr>
<td>Formation of furans</td>
<td>$3.1 \times 10^{-9}$</td>
<td>$4.8 \times 10^{-5}$</td>
<td>$2.4 \times 10^{-2}$</td>
</tr>
<tr>
<td>Cyclization to pyrroles</td>
<td>$1.4 \times 10^{-7}$</td>
<td>$8.7 \times 10^{-5}$</td>
<td>$5.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>Formation of Strecker intermediates from AA</td>
<td>$5.9 \times 10^{-4}$</td>
<td>$3.8 \times 10^{0}$</td>
<td>$1.1 \times 10^{1}$</td>
</tr>
<tr>
<td>Formation of Strecker aldehydes</td>
<td>$3.1 \times 10^{-11}$</td>
<td>$7.7 \times 10^{-7}$</td>
<td>$5.4 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

![Figure 2. Levels of different Maillard volatile reaction products measured at 3 different grill temperatures for 1-inch-thick beef steaks.](image-url)
2,4-nonadienal present could be attributed to six different cooking temperature, time, and cook loss parameters. In the same paper, steaks were cut to different thicknesses in order to induce different cooking times at the same cooking temperatures and degree of doneness. We concluded steaks can be cut to different thicknesses and cooked with different surface temperatures to differentially create aroma volatiles characteristic of beef lexicon descriptors, and it appeared it may be possible to give specific cutting and cookery instructions in order to generate volatile aroma compounds that match consumers’ likes and dislikes.

CONCLUSION

The Maillard reaction is an extraordinarily complex reaction that has been under investigation for more than 100 years. Researchers have done an admirable job of delineating the multitude of pathways that exist in the reaction in addition to developing model systems that have ascertained the reaction rates for different reactions with the Maillard scheme. It is critical that these model systems be used to develop models in meat systems, so a practical model can be constructed for use in steaks, roasts, chops, and ground products with different compositions and quality traits. Current data is being generated by numerous meat flavor chemistry labs around the country, and we are making headway at developing recommendations for the industry that will allow the preparation of meat products to create very specific flavor profiles simply by using product specifications and cooking parameters.

LITERATURE CITED

INTRODUCTION

The world is changing, and every dimension of the food system will be reimagined. To feed the world sustainably into the future, the industry will need to explore new technologies, processes, and business models. This discussion will provide a future-focused perspective on where consumers and the food industry are headed in the next decade, including the primary challenges the industry faces to help address this future. Key areas of focus include: new distribution & access to food; advances in food science; new consumer food values; and the growing culture around food.

NEW DISTRIBUTION & ACCESS TO FOOD

As life becomes busier, individuals are looking for new ways to optimize their eating habits. The on-demand economy is well established with services like UberEats that provide efficiency but command premiums. The next frontier of anticipatory fulfillment will be contextual, sensitive, responsive, and anticipatory. By utilizing the user’s full environment through sensors, unobtrusive micro and nano tech, software agents, smart environments, and wireless infrastructures, interactions between the user and provider will be reinvented. This new paradigm will not only enable instances of unmediated gratification, it will also facilitate choice, reducing the problem of decision-fatigue by helping users navigate the decision making process. Algorithms filter options for users according to the given situation and provide a few personalized solutions in completely new interfaces that may be screenless or embedded in the environment.

ADVANCES IN FOOD SCIENCE

Technological innovations and data-based insights are breaking food into its constituent components, and enabling new interactions between form, function, and flavour. Where the results align with latent demands, experimenting with food forms can lead to the creation of new categories through packaging and technological innovation. These in turn create opportunities for new vending channels, as well as social and digital tie-ins. In addition, because society is increasingly becoming concerned about the sustainability of meat production, and in light of energy, water, and land constraints, and an imperative to limit carbon and methane emissions, synthetic biology may soon transform the way we farm and eat. Proponents believe synbio will be the key to meeting the world’s demand for food, feed, fuel, and materials, while reducing their environmental impact. As the tools, materials, and processes of synthetic biology become more accessible and intuitive, the walls of big bio are falling. Startups, outside of university lab and big pharma contexts, are exploiting emerging biotech to solve problems associated with animal agriculture by creating animal products made without animals.

NEW CONSUMER FOOD VALUES

Moral concern over food waste, stemming from awareness over environmental impact and imbalances in global food distribution, is increasing if not yet critical. Attitudes, behaviours, and perceptions around waste and its impurity are changing, enabling new models for companies looking to reclaim waste.

With all actors becoming more efficient, opportunities to partner with existing and new entrants are emerging. The right communications strategies will deepen alignment with consumer concerns around overconsumption and waste, create tie-ins to other impact narratives, and ultimately reduce the global food gap. As the amount of waste in the food value-chain undergoes increased scrutiny, small-scale entrepreneurs, high-tech innovators, and
local community initiatives are looking to leverage ubiquitous connectivity, alternative business models, and the human need for connection to address the issue.

Whether it's cultural shifts around what makes produce 'inedible,' to next-generation business models for biofuels, to the sharing of time-sensitive information around food about to go bad, waste is being transformed from an output without value to an input extending the cycle of value.

THE CULTURE OF FOOD
As food becomes central to contemporary culture, sitting alongside fashion, film, and music at the heart of the arts mix, the likelihood of consumers trading up to premium foods increases. While the truly high-end luxury food streams remain defined by Michelin-star restaurants, in packaged goods higher-margin categories like organic have grown steadily over the years, demonstrating opportunity for 'mass prestige' lines. And with increased general knowledge about nutrition and how food affects health, consumers are demanding products that provide some sort of additional benefit. Added with the increasingly diverse array of diets due to religious beliefs, health concerns, production values, food intolerance and allergies, dietary personalization is expected. For many, caffeine in various forms provides focus and alertness. Protein allows the athlete to restore energy and rebuild muscles. Health benefits are the primary concern for the aging population as they want to prevent disease and manage their wellbeing. Whether it's a simple drink or a specifically tailored diet, consumers expect companies to help them achieve their health and physical performance goals and improve holistic wellbeing.

RESOURCES
Fast Company (2015)
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The Role of Packaging in a Changing World

Shawn Harris

ABSTRACT FOR PRESENTATION

Approximately one-third of food produced for human consumption is wasted globally. While there is no single remedy to solving the problem of food waste, advanced packaging technologies play an important role in extending the shelf life of food, enabling retailers to better satisfy consumer demands and minimize food waste from farm to fork. In this session, Shawn Harris will delve into the role of packaging in a sustainable supply chain and the role it will play in enabling omni-channel distribution and marketing. Participants will gain insight into current consumer trends and preferences in packaging at the retail meat case and explore the latest packaging solutions and innovations to meet consumer demands.

As a leader in the food packaging industry, we recognize our responsibility in influencing food waste reduction for the future of our planet. It's estimated that 1 out of every 3 calories that is produced for human consumption is wasted—enough to feed three billion people. We're motivated to change this story.

One third of food produced is never eaten...enough to feed 3 billion people. Food waste is an intimidating challenge and one that processors, retailers, and consumers all play a part in tackling. For the U.S. food industry, implementing food waste prevention strategies could result in $1.9 billion in profits. For developed nations, the issue is wastefulness and what we, as consumers, waste. For many developing nations, food waste occurs even before the product reaches a processing facility, let alone the consumer. We know that in the United States, for example, food travels 1,500 miles on average from farm to consumer, so oftentimes food that is not properly packaged is spoiled before anyone can eat it. Even before food can reach consumers, an estimated 2.7 billion pounds of meat, poultry and fish—valued at nearly $9 billion—are thrown out by retailers each year. Using proper packaging and predictive technology, the industry can better track of production and operations, monitor for food waste and ensure processing practices, ultimately delivering the best possible product to the final consumer.

In addition to the food itself, the resources used to create and transport it are also lost. This presents a financial, environmental and transparency challenge for the industry. For example, did you know that the carbon footprint of one kilogram of beef is 370 times the carbon footprint of the bag used to package and protect it? Many people don’t realize that food packaging plays a vital role in reducing food waste and that the environmental impacts of food waste are greater than the environmental impacts of the use of packaging. It’s a top priority that the food we produce makes it to the consumer’s table before it spoils and packaging can help do that.

The right type of packaging can also provide portion control, helping prevent the over-purchasing or over-production of food by consumers and restaurants. Sixty-two percent of U.S. households have only one or two people, so we want to make food available in portions that give them more options for meal preparation. According to The Power of Meat study by the North American Meat Institute (NAMI), the Food Marketing Institute (FMI) and sponsored by Sealed Air, in which more than 2000 people were surveyed, about 50% responded that they “manage but are not experts at cooking” and that they generally “need help.” About 70% of those who responded that way were millennials. The industry needs to provide solutions to retailers who are looking to meet this growing needs of consumers who are looking for convenient, healthy, ready-meal solutions to fit their busy lifestyles.

The next Internet of Things era is already transforming the food and beverage industry from being reactive to proactive to predictive. Data from connected devices will increasingly provide broad insight into equipment, consumption and operations to achieve quantifiable value to customers, raising the overall qualitative standards,
yet lowering the total cost of food and beverage manufacturing. Almost all OEMs are collecting data now, but if you don’t know what to do with that technology, it is useless. Food and beverage processors must measure key performance indicators (KPIs) to be competitive, to meet changing environmental demands, and to be responsible brand stewards.

In the U.S., e-commerce continues to grow at a dramatic pace, putting pressure on traditional retail. According to the “Digitally Engaged Food Shopper” report from the Food Marketing Institute (FMI) and Nielsen, the share of online grocery spending could reach 20% by 2025, representing $100 billion in annual consumer sales, the study projected. To put that into context, that is the equivalent of 3,900 grocery stores based on store volume. While currently, 23% of American households are buying food online today, this upward trend will continue with more than 70 percent expected to engage with online food shopping by 2025. As retailers increasingly invest in their digital infrastructures, they must also take a holistic view of the consumer experience. In particular, it is important to consider the role of packaging, not just as a functional container offering protection, but as the first and potentially last impression of the company’s brand. Appropriate primary packaging is crucial to reducing product damages during delivery, extending shelf life, boosting the brand and offering the visual “wow effect”. Effective secondary packaging should reduce packaging waste through cube optimisation and reusability while also guaranteeing freshness and cooling. Both types of packaging must be easy for consumers to open, while still sufficiently protecting against contaminants. In the end, putting the consumer experience first can improve operational efficiency and significantly contribute to market growth. As perishable food e-commerce continues to grow and technology evolves, so will consumer expectations. Shoppers will expect shorter delivery times and more traceability of their orders. The focus on tracking products will extend throughout the supply chain with consumers increasingly interested in food miles and sourcing. Packaging technology has the potential to address these demands, providing real time information about location and even product condition.

The future of the food and beverage industry is in our hands. While it may not be possible to solve each issue overnight, investing in smart, sustainable food packaging is a great place to start.
“OMIC” APPROACHES TO SOLVE MEAT QUALITY ISSUES

Mass Spectrometry “Omics” Technologies and Their Potential for Meat Quality Research—A Tutorial

Jessica Prenni, Ph.D.

INTRODUCTION – MASS SPECTROMETRY “OMICS”

The term “omics” broadly describes an approach rather than a particular technique. While there are a variety of omics approaches, the two most suitably addressed by mass spectrometry are proteomics and metabolomics. Omics approaches enable global characterization of biological systems in a high-throughput manner and can be utilized to address a wide range of both basic and applied research questions. The goal of this tutorial is to present and overview of these technologies and provide examples how they can be applied to meat science research.

MASS SPECTROMETRY

As a first step, it is important to understand the basic premise of how a mass spectrometer works. A mass spectrometer measures the mass of molecules that have been converted to ions - in essence, a mass spectrometer is a “molecular scale”. The mass can be measured very accurately, within 1 ppm, depending on the type of mass spectrometer used; this output is called a mass spectrum (MS). With this level of accuracy, the molecular formula of a compound can be determined. However, even if we know the number of carbons, nitrogens, and hydrogens in a compound we do not know the order in which they are arranged and this is what gives the compound biological function. Fortunately, mass spectrometers can also selectively fragment compounds and then measure the mass of the resulting fragment ions; this output is called a tandem mass spectrum (MS/MS). The way that a compound fragments in a mass spectrometer is structure specific and thus a combination of the MS and the MS/MS spectra is required to characterize a detected compound.

PROTEOMICS

The proteome is the full complement of proteins expressed by a cell or tissue at any given time and/or environmental condition and “proteomics” is the study and/or identification of these proteins. While the genome identifies all of the potential proteins that can be expressed, the proteome is the composed of all proteins that are expressed, representing a “snapshot” of a biological system at a point in time. Furthermore, the actual proteome is much larger and more complex than what is predicted by the genome due to events such as alternative splicing and post-translational modifications.

Proteomics experiments typically involve digestion of proteins with an enzyme (e.g. trypsin) followed by liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of the resulting peptides. The MS/MS spectra for each peptide are queried against theoretical MS/MS spectra for all predicted proteins and the peptide identification is determined based on the best match. The protein identification is then inferred from the identified peptide sequences. Informatics tools are critical to this process and dependent on the availability of a well-annotated genome of the species under study (or a closely related species). Proteomics experiments are often comparative, where relative differences in protein expression under various conditions (e.g. diseased versus normal) are measured.

Example Application. Microorganism detection by MALDI-TOF mass spectrometry is an example of a powerful proteomics approach that does not actually require identification of specific proteins. In this approach, the mass spectrometer is used to generate a “fingerprint” of intact proteins on the surface of cells. This fingerprint is queried against a library generated from standards to enable easy and fast identification of the organism. This
technology is FDA approved and widely used for species identification in clinical diagnostic settings. We have recently demonstrated the potential utility of this technology for serotyping of salmonella isolates relevant to meat safety.

**METABOLOMICS**

The metabolome is the full complement of metabolites expressed by a cell or tissue at any given time and/or environmental condition. Metabolites represents the set of biological molecules that most closely reflects phenotype and thus are uniquely attractive as biomarkers for quality or environmental influences. Historically, metabolite analysis has been performed in a targeted manner focusing on a few known metabolites important to the biological question at hand. In such experiments, the biological hypothesis dictates the choice of metabolites targeted, and the analytical steps are optimized to detect those specific molecules. This approach results in sensitive quantitation for the molecules of interest and data interpretation and analysis is easy and transparent. However, the outcome of such experiments is limited to the molecules targeted in the assay. Conversely, a non-targeted metabolomics experiment involves a comprehensive and unbiased analysis of all metabolites. This approach is extremely powerful as it has the potential to enable novel discoveries. Nevertheless, disadvantages of a non-targeted approach include reduced sensitivity for any given specific metabolite due to competition from other compounds and more rigorous and complex data analysis including the necessity for spectral interpretation to characterize the mass spectra as a biological compound.

Metabolomics experiments typically involve extraction followed by liquid or gas chromatography mass spectrometry analysis (GC- or LC-MS). In a targeted metabolomics experiment, authentic standards are used to develop the assay and thus all peaks observed are “known”. Conversely, in a non-targeted metabolomics experiment every detected peak is an “unknown” until it is annotated. Unlike peptides, which fragment predictably, small molecule metabolites are structurally diverse, making their behavior in the mass spectrometer less predictable. This unpredictability has greatly inhibited the generation of theoretical spectral databases as used in proteomic applications. Empirical small-molecule spectral libraries are well developed for gas chromatography-mass spectrometry (GC-MS), but have been slower to develop for liquid chromatography-mass spectrometry (LC-MS). Given the complexity of the metabolome, its variation among biological species, and the variation in molecular fragmentation with different MS conditions, generating comprehensive spectral libraries through the analysis of authentic standards is a slow process and intractable when standards are unavailable. Thus, the process of molecular identification remains a significant bottleneck in non-targeted, LC-MS based metabolite profiling studies and represents an active field of research.

**Example Application.** Meat tenderness is an important quality metric that is difficult to characterize in a high-throughput manner. In a recent study, we applied both LC-MS and GC-MS non-targeted metabolomics to identify small molecule markers associated with meat tenderness and days post mortem (DPM). The study identified several hundred compounds of which many were clearly associated with either tenderness (as measured by SSF) and/or DPM. Meat tenderness was also evaluated using a new analytical approach - rapid evaporative ionization mass spectrometry (REIMS). With REIMS, sampling is performed under ambient conditions directly from the meat without any sample preparation and spectra is generated in real-time. The resulting spectra are dominated by fatty acid and lipid compounds, many of which were found in the non-targeted experiments to correlate with tenderness. Using predictive multivariate statistical modeling approaches we are able to classify “unknowns” in real-time as tender or tough.
INTRODUCTION
The fundamental understanding of muscle biochemistry is of great interest to human and animal science researchers. In recent years, a systems biology approach utilizing proteomics, transcriptomics, and metabolomics has been incorporated into basic meat science research to elucidate the mechanistic basis of meat quality. Since meat color is one of the most important quality attributes determining consumer purchasing decisions; several novel research approaches have been adopted in the last decade to examine this complex trait. Therefore, the focus of this review will be on the applications of metabolomics approaches in beef color research.

ROLE OF METABOLITES IN BEEF COLOR
Postmortem muscle metabolism switches from aerobic to anaerobic pathways due to limited oxygen supply. The cells attempt to maintain homeostasis through various protective mechanisms (Ouali et al., 2006). One of the significant changes occurring in skeletal muscles during the postmortem is the drop in pH from 7.4 to an ultimate pH around 5.6. Further, the temperature of the carcass also changes from the physiological body temperature to a lower temperature depending on the storage conditions. Moreover, the antioxidant systems in cells that helps to maintain oxidative stability is depleted postmortem. Thus, a combination of lower pH, drop in temperature, and less efficient antioxidant systems make postmortem muscle very susceptible to oxidative changes. In fact, a lower storage temperature, in part, can counteract the harmful effects of lower pH. Interestingly, biochemical reactions continue to take place, albeit at a slower rate.

Consumers prefer a bright cherry-red lean color for beef steaks. Oxygenation of myoglobin gives fresh beef its cherry-red color, whereas oxidation leads to accumulation of brown colored metmyoglobin (AMSA, 2012). Oxygen consumption (OC) and metmyoglobin reducing activity (MRA) are the two important biochemical processes that are critical for myoglobin redox stability and meat color (Figure 1).

Metmyoglobin reducing activity refers to the ability of postmortem muscle to reduce metmyoglobin to deoxymyoglobin, and this can occur by enzymatic, non-enzymatic, or electron-transport mediated pathways. Bekhit and Faustman (2005) reviewed in detail the factors and mechanisms influencing MRA in meat. To our current knowledge, NADH is a key reducing agent required for metmyoglobin reduction. NADH can donate an electron to metmyoglobin via electron carrier such as cytochrome C to form deoxy- or oxymyoglobin. During enzymatic metmyoglobin reduction, NADH-dependent enzymes are responsible for the transfer of electrons from NADH to ferric myoglobin via electron carrier (Hagler et al., 1979;
Faustman et al., 1988). However, in non-enzymatic met-myoglobin reduction compounds such as quinone, cytochrome C, or methylene blue transfer electrons from NADH to met-myoglobin (Elroy et al., 2015). In mitochondria-mediated met-myoglobin reduction, electrons available between complex III and IV are transferred to ferric myoglobin through cytochrome C (Tang et al., 2005a).

Oxygen consumption refers to the ability of the post-mortem muscle to consume oxygen. Various processes/organelles such as mitochondria, oxygen consuming enzymes, myoglobin, microorganisms, and lipid oxidation continuously utilize oxygen in tissue (Tang et al., 2005b; Ramanathan et al., 2010). Among these mitochondria and oxygen consuming enzymes in meat play a critical role in determining OC. Mitochondria and myoglobin compete for available oxygen in postmortem muscles. Oxymyoglobin is the predominant myoglobin redox form in a bloomed steak. When an oxygenated steak is vacuum packaged, oxymyoglobin is converted to deoxymyoglobin (purplish-red in color) via a two-step process. Oxymyoglobin is first converted to metmyoglobin and then to deoxymyoglobin (Figure 1; Mancini and Hunt, 2005; English et al., 2016a); hence this reaction is substantially dependent on the reducing activity and mitochondrial OC. From a practical standpoint, these reactions are critical in color of aged meat and also in vacuum packaged meat. When mitochondrial oxygen consumption is less efficient due to lack of mitochondrial substrates, complete removal of oxygen from the package may not be possible. Hence, myoglobin will be more prone to oxidation when oxygen partial pressure reaches 3 - 7 mm Hg (AMSA, 2012). Conversely, a greater OC can decrease bloom and results in a darker meat color (English et al., 2016b). This is evident in high pH meat where a greater pH enhances mitochondrial activity and limit oxygen diffusion into the meat. Both MRA and OC are interrelated processes. More specifically, the concentration of metabolites that can regenerate reducing equivalents such as NADH can affect MRA and OC.

Earlier work by Grant (1955) indicated that the post-mortem muscle is biochemically active. Carbohydrate metabolism in postmortem muscles can regenerate reducing equivalents such as NADH and FADH (flavin adenine dinucleotide reduced). Moreover, Saleh and Watts (1968) demonstrated that addition of various glycolytic intermediates helped in metmyoglobin reduction with the addition of NAD. However, the limiting factor in MRA is the depletion of metabolites in the postmortem period. To date, NADH and succinate are the two important reducing equivalents that can donate an electron for metmyoglobin reduction.

The introduction of case-ready packaging has allowed meat packers to enhance meat with various ingredients and modify gas compositions within packages to improve the shelf-life. Enhancing beef with lactate improved color stability of steaks (Knock et al., 2006). The research assessing the mechanisms of improved color stability in lactate-enriched loins indicated that addition of lactate can regenerate the NADH pool in meat, which can be used for both MRA and OC (Kim et al., 2006). Various researchers investigated the effects of other metabolites such as succinate, pyruvate, and malate on meat color (Ramanathan et al., 2011; Bjelanovic et al., 2016). Interestingly these metabolites exhibited a packaging-specific effect on meat color. For example, malate, succinate, and glutamate improved the color of (steaks/ground beef) in aerobic, high oxygen, and vacuum packaging while pyruvate discolored steaks/ground beef in vacuum packaging. However, the biochemical mechanism responsible for metabolite-induced color changes remains unclear.

The muscle fiber composition can also play a critical role in metabolite utilization. The concentration of blood capillaries and mitochondria varies between muscle types (Hunt and Hendricks, 1977). Psoas major (PM) has a greater proportion of red fibers while longissimus lumbarum (LL) has a greater percentage of white fibers. Psoas major has approximately 1.21-fold greater mitochondria than LL (Mohan et al., 2010). Hence, metabolite utilization will be different in each muscle type and this in turn can affect beef color in response to metabolite enhancement. Characterizing the metabolite use in muscles can enhance our understanding of metabolome changes in muscles. Traditional wet-laboratory techniques involve analysis of single metabolites at a time, which is challenging as well as time-consuming. Use of high-through put techniques will help to unravel metabolite changes in muscles during the postmortem period.

**APPLICATION OF METABOLOMICS IN FOOD SCIENCE**

Metabolomics is a systematic analysis of small molecules such as amino acids, tricarboxylic intermediates, and fatty acids in a biological system (Fiehn, 2002; Julian, 2004). It is a relatively new omic technique, and the methodology includes metabolite separation, detection, quantification, data analysis, and interpretation. Various studies have shown that quantification of metabolites provides a real-time snapshot of reactions in a biological system.

Metabolites play a critical role in macromolecular reactions through signal pathways or feedback inhibition. Metabome analysis helps to identify the ultimate phenotypical changes that happen to cells or tissue due to changes in environment or gene expression. There are two types of approaches in metabolomics: global metabolomics and targeted metabolomics (Kaddura-Daouk et al., 2008). In the global approach, the analyst tries to identify and characterize all the metabolites present in a biological sample; whereas in the targeted approach, only a specific number or class of metabolites are studied. Comprehensive analysis of metabolome using a single platform may be challenging (Villas-Bôas et al., 2005). The metabolomic analysis involves usage of either a single technique or a combination of techniques. The popular analytical tools
are gas chromatography-mass spectrometry (GC-MS), liquid chromatography – mass spectrometry (LC-MS), capillary electrophoresis – mass spectrometry (CE-MS), and nuclear magnetic resonance (NMR) (Baker et al., 2006).

Apart from human medicine, nutrition, and plant sciences, metabolomics has application in the field of food and agriculture. It can also be employed to study the effects of the environment on crops, effects of hazardous chemicals, and stress on organisms (Dixon et al., 2006). Targeted metabolomics can be used to assess the quality of agricultural produce and also to identify specific biomarkers in the case of diseases (Wishart, 2008). Metabolite predictive models have been developed to estimate sensory attributes of green tea, watermelon, and mushrooms. With the help of multiple sensory evaluations, the particular compound/metabolite which can improve consumer acceptance can be determined (Wishart, 2008).

**APPLICATION OF METABOLOMICS IN MEAT COLOR RESEARCH**

Limited peer-reviewed research is currently available on the application of metabolomics to characterize beef color. In a recent study, Abraham et al. (2017) compared the metabolite profiles of beef LL and PM; two muscles which demonstrate marked difference in their color stability during display. Beef short loins were collected 3 d postmortem (n = 10). Steaks were cut from each LL and PM muscle and displayed under retail conditions for 7 d. Surface color, MRA, OC, and metabolites were analyzed during retail storage. Gas chromatography-mass spectrometry was utilized to characterize the metabolites in LL and PM. As expected, PM decreased in redness (P < 0.05) by d 3 of the display compared with LL. A shorter color stability of PM was characterized by lower MRA and increased OC. Twenty-nine compounds were differently abundant (P < 0.05) after Benjamini-Hochberg multiple test correction. Of these, 19 compounds were found to have a fold change difference greater than 2 on a logarithmic scale. The principal component analysis scores plot (Figure 2) clearly displayed the separation of metabolites between LL and PM samples. Component 1 explains 55.75% variation in metabolite changes between samples (across muscles and display times) while component 2 explains 22.12% of the variation. Further, the PCA plot indicates LL metabolite separation among d 0, 3, and 7 for the component 2. However, for PM, d 3 and 7 had little separation compared to d 0 across component 2. Uracil, hypoxanthine, malic acid, carnitine, and dihydroxyacetone had positive loadings indicating their effect on PM; whereas fructose, glucose–6–phosphate, methionine, and succinic acid had negative loadings explaining their influence on LL. Glycolytic compounds (fructose, glucose–6–phosphate, and pyruvic acid) were more abundant in LL than PM. Citric acid was greater in PM on d 0 and 3 compared with LL. However, on d 7, citrate levels were greater in LL than PM. This can be attributed to the utilization of citrate in PM for mitochondrial activity. A previous study indicated that pyruvate dehydrogenase was overabundant in color stable muscles (Joseph et al., 2012). This suggests that in LL, pyruvate may be entering the Krebs cycle and thereby, increasing citrate levels. Further, PM has a higher mitochondrial aconitase (Joseph et al., 2012), which may be another reason for the lower level of citrate in PM. On d 3 and 7, succinate levels in PM were lower than LL. Hence, rapid discoloration in PM can be attributed to lower levels of succinate. Psoas major had greater carnitine compared to LL. This can be attributed to greater mitochondrial content in PM than LL. Hypotaurine, a metabolic breakdown product of cysteine and methionine metabolism, was lower in LL. Therefore, it is possible that PM and LL differ in cysteine-methionine metabolism. Joseph et al. (2012) reported greater levels of antioxidant protein peptide methionine sulfoxide reductase (PMSR) which can prevent the oxidation of methionine in the longissimus, and may be a possible reason for the increased levels of methionine in LL.

Figure 2. The PCA score plots of differentially abundant metabolites in longissimus and psoas muscle during 7 d display. LL = longissimus lumborum; PM = psoas major. Abraham et al., 2017, Meat and Muscle Biology, 1, 1-10.
Metabolomics research is supported by the proteomics study on LL and PM. For example, Joseph et al. (2012) reported heat shock proteins, antioxidant proteins β-enolase, and triose phosphate isomerase (glycolytic enzymes) were greater in color-stable LL than in color-labile PM. Further, the color-labile gluteus medius had a higher mitochondrial content and greater oxygen consumption rate compared to color-stable longissimus dorsi (McKenna et al., 2005). All this research indicated that the inherent alterations in muscle biochemistry can lead to a difference in color stability of muscles during retail display.

Subbaraj et al. (2016) utilized a hydrophilic interaction liquid chromatography–mass spectrometry (HILIC–MS) based metabolomics approach to study color stability of ovine meat. The HILIC–MS helps to quantify polar metabolites in tissue. There were significant differences in metabolites present in color-stable and color-labile longissimus muscles. Similarly, aging had an effect on type and concentration of metabolites as represented by different clusters in a PCA plot. NADH, malic acid, and guanosine levels were significantly greater in color-stable ovine muscles than color-labile muscles. However, methionine was lower in color-stable muscles than color-labile. Glutathione was greater in vacuum packaging than modified atmospheric packaging. Ma et al. (2015) also reported a decrease in NADH and glutathione in beef muscles with increasing aging time. These authors utilized high-performance liquid chromatography–electron spray ionization-mass spectrometry to differentiate non-polar metabolites.

APPLICATION OF METABOLOMICS IN MEAT QUALITY RESEARCH

Postmortem meat metabolism plays a major role in meat quality because it can affect various parameters such as pH, water holding capacity, tenderness, and flavor. However, limited research has utilized metabolomics techniques to study postmortem muscle metabolism. D’Alessandro et al. (2011) used metabolomic techniques to analyze pork quality traits of Casertana and Large White breeds. These authors employed HPLC-MS to analyze the effect of fat deposition on pH, water holding capacity, and color in pork. Castejón et al. (2015) utilized metabolomic analysis of beef exudates using NMR to characterize the chemical changes during storage and to classify beef samples according to postmortem aging time. Metabolomic approaches have also been used to detect incorporation of mechanically recovered meat in food products (Surowiec et al., 2011). Alessandro et al. (2012) utilized a combination of proteomics and metabolomics employing HPLC-ESI-MS to characterize the metabolites in relation to tenderness in Italian beef breed. The results indicated that the tender meat group was characterized by higher levels of non-phosphorylated glycolytic enzymes than tough meat. These authors reported that phosphoenolpyruvate, NADH, lactate, and NAD+ were greater in tender meat compared with tough meat.

FUTURE RESEARCH OPPORTUNITIES

Metabolomics helps to understand the importance of concentration and presence of metabolites in meat quality. A single platform such as gas chromatography–MS, liquid chromatography–MS or NMR cannot demonstrate all metabolites. Hence, depending on the objective of the research, appropriate selection of technique is critical. Furthermore, data analysis and interpretation remain a significant challenge. The commonly available software help in analyzing data, but the lack of consistency in various parameters can influence the outcome. Johanningsmeier et al. (2016) indicated that metabolomics and related omics disciplines are often referred to as hypothesis-generating as these technologies can demonstrate changes in several biomolecules at a particular set of conditions. A systematic analysis is critical to validate the results of metabolomics. A combination of all omics techniques will improve our understanding of postmortem changes and will help the processors to adopt strategies to improve meat quality.

REFERENCES


BACKGROUND

In the context of raising, producing, processing, and distributing a meat and poultry product for human consumption, challenging issues exist that engender controversy among government, industry, academic, and public entities. To encourage academic dialog among contemporary topics, an interactive roundtable was held. During the roundtable, four topics were presented then, rebutted as “yes” and “no” including:

1. Should there be a single food safety agency?
2. Should *Salmonella* be declared an adulterant in meat and poultry products?
3. Should animals only be treated when sick to be ethically responsible for the One Health initiative?
4. Should mandatory labeling be required for processing aides used in foods?

To evaluate public preference, an electronic pre-debate survey was conducted by registered RMC attendees to obtain a baseline of responses in favor of “yes” or “no” per topic. Results of the pre-debate survey found respondents to respond to the topics as:

1. Should there be a single food safety agency?
   - 63% responded “yes”; 37% responded “no”
2. Should *Salmonella* be declared an adulterant in meat and poultry products?
   - 23% responded “yes” and 77% responded “no”;
3. Should animals only be treated when sick to be ethically responsible for the One Health initiative?
   - 44% responded “yes” and 56% responded “no”,
4. Should mandatory labeling be required for processing aides used in foods?
   - 38% responded “yes” and 62% responded “no.”

During the session, two speakers presented either a “yes” or “no” position during a 7-minute presentation, and each presenter conducted a 3-minute rebuttal. Concluding the rebuttal, a 6-minute question and answer session was allowed for audience participation. Discussion among topics advanced audience knowledge on the subject matter and awareness of concerns presented by each speaker. An overview of the presented evidence per topic by “yes” then “no” is provided. It is important to note, the speakers views given in this session may not have been reflective of personal or professional positions as this was purely an academic discussion.

**TOPIC 1, SHOULD THERE BE A SINGLE FOOD SAFETY AGENCY?**

Presented evidence for “yes”:

The presentation eluded to the meaning of the One-Health initiative as human, animal, and ecosystem health being linked among practicing physicians, veterinarians, and scientific professionals. The vision statement for One Health is dedicated to improving the lives of species both human and animal through integration of the human medicine, veterinary medicine, and the environment. In the meat industry, the overlap between zoonotic diseases provides the greatest concern. Food safety efforts are conducted predominately (80%) by the U.S. Department of Agriculture’s Food Safety and Inspection Service (USDA-FSIS) to mitigate risks. Though, these regulatory agencies may have some challenges with authority given dynamics of other (20%) regulating bodies and the percentage of proteins and/or foods incorporated into a product. By having one single food safety agency, more expert collaboration and leadership can occur to improve efficiency and protection. To achieve the One Health initiative, incorporation with environmental agencies also needs to occur. Thereby, one food agency would be more cost effective, focused, create clear lines of responsibility, have greater compliance, enhance prevention, and respond more efficiently to outbreaks.
Presented evidence for “no”:

On the contrary, the “no” presentation eluded to the USDA-FSIS and Food and Drug Administration (FDA) mission statements. The USDA-FSIS is in charge of the inspection of meat and poultry products and cracked eggs whereas, the FDA regulates all other food products and pet foods. The One Health initiative argues that the FDA and USDA-FSIS goals and initiatives do not align yet, the goals of each agency is to ensure food safety. The USDA-FSIS mission is to prevent foodborne illness and emerging risks while, the FDA monitors compliance of science-based food safety and labeling standards to ensure safety and security for humans and animals. Therefore, both USDA-FSIS and FDA do coincide with their missions and goals; thus, these two agencies are working together. The proposed “Safe Food Act” of 2015 directed these agencies be formed under one system yet, a challenge arose in that the food safety aspects would be lost as inspectors and manpower became reduced. This brings forth the concern of less inspection, where today, USDA-FSIS is onsite every day during production whereas; the FDA may have less frequent visits depending upon the product in production. If these agencies would become one, there is a great risk of losing agency scrutiny during transition periods which could result in food safety negligence. Lastly, there would be added costs for this transition from two developed agencies into one agency.

Post-Debate Results

The live-polling post-rebuttal and after interactions with the audience changed results to 41% “yes” and 59% “no.” Therefore, the pre-debate poll response shifted as there were fewer “yes” responses and an increase in “no” responses by 22%. Overall, the majority of responses indicate that there should not be a single food safety agency.

TOPIC 2, SHOULD SALMONELLA BE DECLARED AN ADULTERANT IN MEAT AND POULTRY PRODUCTS?

Presented Evidence for “yes”:

According to the Federal Meat Inspection Act, the definition of adulteration is, “if it bears or contains any poisonous or deleterious substance which may render it injurious to health; but in case the substance is not an added substance, such article shall not be considered adulterated under this clause if the quantity of such substance in or on such article does not ordinarily render it injurious to health.” However, the Centers for Disease Control and Prevention (CDC) describes the abundance of Salmonella to be the second leading cause of foodborne illnesses and the first cause of hospitalizations of foodborne illness with 19,336 cases annually. Salmonella is the leading cause of death and hospitalizations due to foodborne illness. Multi-state outbreaks involving multiple strains of Salmonella in both poultry and beef have been documented to have multi-drug resistance. Annually, $77 billion is spent on foodborne illness, and the leading pathogen expense is Salmonella at $11.39 billion. This is much larger in comparison to non-O157:H7 Escherichia coli which is estimated that $63 million is spent annually due to foodborne illness. The school lunch program tests for Salmonella in their ground beef, illustrating incentives to reduce Salmonella for every human’s life thus; Salmonella should be declared an adulterant.

Presented Evidence for “no”:

There is no question that non-typhoidal Salmonella is the most abundant bacterial foodborne pathogen causing illness in the U.S. Therefore, reducing Salmonella prevalence should be a public health goal. It is easy to declare Salmonella as an adulterant, although it is important to consider that it differs from E. coli. Three reasons why Salmonella shouldn’t be declared as an adulterant are as follows:

1. The multi-hurdle approach and adoption of HACCP and antimicrobial interventions in beef, pork, and poultry facilities. All production systems have interventions as well, though current technology still cannot guarantee Salmonella-free beef, pork, or poultry.

2. The complex pathogen needs more than a simple declaration, as there are multiple strains that can affect humans differently and some humans may be more susceptible than others. Each Salmonella species has a different serotype and the most present strains occurring on meat products are not the most virulent to human health. If labeled as an adulterant, the majority of products would need to be cooked and value would be lost.

3. Addressing Salmonella from a quantitative approach versus a qualitative approach will provide more useful information, and protection from high microbial loads. Current USDA standards do not address the virulence of Salmonella for a positive test, which would result in wasteful losses. Perhaps setting hygiene process requirements based upon load presence would be more cost beneficial. The presence versus absence from declaring Salmonella as an adulterant is non-informative, and limits improvement among scientists and meat processors.

Post-Debate Results

The live-poll results post-rebuttal and audience interaction stayed fairly consistent with the pre-debate poll, 22% “yes” and 78% “no.” The live presentations resulted in a shift of the pre-debate poll by 1% towards “yes,” Salmonella should be declared an adulterant.
Presented Evidence for “yes”:
The meaning of the One Health initiative is, “a collaborative effort of multiple disciplines working locally, nationally, and globally to obtain sustainable optimal health for an ecosystem. The ecosystem is a biological community of living organisms, human, animal, plant, and microbes and their physical environment interacting as a system.” As meat and animal scientists, the decisions made to use antibiotics in production agriculture influence the ecosystem. There are many ways in which antibiotics can be appropriately used either as therapeutic, sub-therapeutic, or as a preventative measure. Though, there are two particular reasons the use of antibiotics should be reduced:

1. the concern of antibiotic resistance development from overuse of antibiotics and the likelihood of greater long-term resistance influencing the ecosystem; and
2. the opportunity to promote alternative natural antimicrobials and probiotics use, and greater genetic selection for improved disease prevention.

By reducing antibiotics, agriculturalists could become more cognizant of best management practices as the industry adapts to becoming better stewards of maintaining optimal animal health.

Presented Evidence for “no”:
In brief, the One Health concept is that the health of people is connected to the environment. The CDC assumes that resistance occurs without considering time and the withdrawal period. During antibiotic administration there is resistance that begins, increases, and is halted once the withdrawal period is met. In meat animal production, we prevent diseased animals from entering the food chain through the use of food safety hurdles such as the use of prebiotics, probiotics, vaccines, phages, washing, vacuums, steam pasteurizers, and organic acids to remove bacteria. The over simplification of antibiotic resistance assumes that contamination occurs at the farm though, other industries such as the hospital system need improvement. The use of metaphylaxis or, “the timely mass medication of a group of animals to eliminate or minimize an expected outbreak of disease…” from a feedlot entrance perspective is necessary. Use of this method prevents inadequacies in deciphering if an animal is really sick. Trying to determine if an animal is sick is challenging because animals are prey and they hide their illness from predators (humans). Without efficient and adequate treatment, fibrin tag adhesions can occur in the lobe of lungs, which can turn into large thick collagen connective tissue. This tissue solidifies and the animal breathing becomes more painful resulting in a loss of performance, reduced hot carcass weight, diminished muscling, and a less finished animal. For these reasons, antibiotics are used for bovine respiratory disease in 21% of feedlots in the U.S. for preventative measures. By pulling and treating, this greatly reduces current and future morbidity and mortality. Further, liver abscesses are another major reason why metaphylaxis is used. Tylosin, chlortetracycline, and virginiamycin, are some antibiotics used to prevent liver abscess and is used in 71% of fed cattle. In Holstein steers this is also very important, as 25% of Holstein steers experience abscesses. Therefore, metaphylaxis is important for optimal animal performance. When asked if animals should only be treated when sick to be ethically responsible to the One Health initiative, “no”, because that would be ethically irresponsible.

Post-Debate Results
The live-polling results post-rebuttal and audience interaction increased the pre-debate “no” response by 30% and the end result was 86% “no” and 14% “yes.” The presentations resulted in a majority of the public audience agreeing that use of metaphylaxis in the feedlot is important and that animals should not only be treated when identified as sick to be ethically responsible.

TOPIC 4, SHOULD MANDATORY LABELING BE REQUIRED FOR PROCESSING AIDES USED IN FOODS?

Presented Evidence for “yes”:
There should be mandatory labeling of processing aides that we use in food production. To demonstrate commitment to transparency; in a world where nothing can be hidden, you should have nothing to hide. There are two fundamental points:

1. disclosure of processing aides has the potential to build trust and transparency with consumers; and
2. a failure to disclose processing aides in and on foods will ultimately lead to distrust and an erosion of precious resources in industry.

Shifting to voluntary disclosure allows consumer issues to go away. Without a level of disclosure for technologies, ultimately each technology will be revealed, and an erosion of consumer trust will occur. Where there is disclosure, there is no story, but the lack of the willingness to be transparent of what is in and on foods is where the story is. It is not what is done to food that angers a consumer and causes distrust, it is what is done to food and consumers are not told about. By labeling processing aides this would allow for:
1. promotion of greater consumer trust through transparency, and
2. avoid extensive resources that are expended during a company’s defense to a consumer.

Making the commitment to label processing aides provides the first step that is needed to build consumer trust through transparency.

Presented Evidence for “no”:

How can we take all the products utilized in the meat industry and make those products available to consumers at a reduced price while, allowing consumers to see a lengthy ingredient list, which they will not understand? In doing so, this creates more consumer uncertainty and greater lack of trust. The incidental additive, or, the safe and suitable ingredient list is online but not utilized by the consuming public. Further, the average consumer across the U.S. has a 4th grade reading level. Therefore, labeling of ingredients will not improve trust level or enhance consumer trust. Though it will increase the cost of foods as small companies struggle to compete with changing labels. Ultimately, consumers will have greater confusion if all additive ingredients are disclosed such as chlorine or fluoride in water. There are too many additives available, and their use isn’t in secrecy because it is on the internet and provides the opportunity for consumers to learn. Processors can utilize safe and suitable ingredients that have been proven safe. Processors should not have to go through the needs of re-labeling processed items as this inflicts unnecessary costs. If the industry would like to do something, let’s educate consumers.

Post-Debate Results

The live-poll results post-rebuttal and audience interaction resulted in an audience poll of 34% “yes” and 66% “no” which, shows an increase in the “no” response by 4%. These results remained consistent with the pre-debate poll where the majority of participants believed that there should not be mandatory labeling required for processing aides used in foods.
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