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Relationship between Animal Handling, Meat Quality, and Food Safety

Contents

1. Introduction

The association between animal handling and ultimate meat quality has been extensively studied over the past 30 to 40 years. Literally thousands of research studies have been conducted in the US and elsewhere and the results reported in peer-reviewed scientific journals, *Meat Science* and *Poultry Science* in particular. While the results are not in 100% agreement, there is strong evidence of a scientifically significant relationship between how animals are treated and the quality of the meat produced. The relationship between animal handling and food safety has received less attention and is less well understood.

2. Evidence of Adulterated (Poor Quality) Products in US Meat Supply

Pale, soft, and exudative (PSE) meat refers to meat that is pale in color, forms soft gels, and has poor water-holding ability. Most frequently found in pork, this defective meat is also being seen with increasing frequency in turkey and meat chicken processing plants. It has been estimated that PSE-type meat represents 5 to 40% of meat that is produced in the poultry industry. One study of PSE broiler meat found that 47% of fillets produced at three US chicken processing plants were pale in color and had the potential to have lower water-holding capabilities.

Bruising and “dark cutting” meat represents an equivalent meat quality defect seen in beef cattle and other ruminants. Dark cutting meat typically results from rough handling and extended transport to slaughter. The National Beef Quality Audit has calculated that 5% of the beef carcasses in the United States are dark cutters due to the stress of improper handling.

3. Link between Animal Handling and Poor Meat Quality

The causes of PSE pork and poultry are thought to be genetic, environmental, or a combination of both.

PSE meat is associated with antemortem stressors including transport length and conditions, heat or cold stress, and pre-slaughter handling practices including the length of holding periods.

Scientific research has demonstrated a relationship between meat quality and a number of animal handling practices, including the use of handling devices such as electric prods, the length of transport, stocking density during transport and in holding, temperatures and ventilation during transport and holding, and the length of holding periods. One analysis of the impact of transport on meat quality found that only 5% of the studies reviewed failed to find a significant effect of transport on carcass or meat quality.

A sample of scientific studies into the connection between animal handling, meat quality and food safety follows below in the section titled "Annotated Scientific Bibliography."

4. Evidence of Adulterated (Unsafe) Products in US Meat Supply

Consumer Reports has been regularly testing the safety of poultry products found in grocery stores across the United States since 1998. It has repeatedly documented the presence of potentially harmful pathogens in chicken and turkey products. In 2010, Campylobacter was found in 62 percent of the chickens, Salmonella was in 14 percent, and both bacteria were in 9 percent. In 2014, Consumer Reports' analysis of more than 300 raw chicken breasts found potentially harmful bacteria in almost all of the samples.

5. Link between Animal Handling and Unsafe Meat

According to the USDA, stressful conditions have a significant deleterious effect on food safety through different mechanisms affecting the susceptibility of farm animals to infections and the presence and shedding of pathogens. However, the exact mechanisms involved have not been fully explained, and more research is needed.

6. Meat Industry Acknowledges Link between Animal Handling and Meat Quality

The American Meat Institute's animal handling guidelines, which the AMS commodity program utilizes as the resource for its transportation and slaughter specifications, make numerous references to the association between animal handling and meat quality, including the following:

- Once livestock – cattle, pigs and sheep—arrive at packing plants, proper handling procedures are not only important for the animal's well-being, they can also mean the difference between profit and loss. Research clearly demonstrates that many **meat quality** benefits can be gained through careful, quiet animal handling. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 3)
- Managing the transportation of livestock involves many variables. Managing these variables may include careful temperature management, driving practices, trailer design and maintenance and the actual loading and unloading process result in enhanced livestock welfare and improved **meat quality**. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 5)

- Loading—Research shows that overloading livestock trucks can increase bruising, dead or injured animals and poor **meat quality**. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 5)
- While cattle and sheep are less sensitive than pigs to cold weather, it is still important to manage temperatures to protect animals and ensure **meat quality**. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 7)
- To improve **meat quality**, pigs should be rested two hours prior to stunning. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 9)
- Research also shows that excessive use of electric prods in the stunning chute increases tough meat in beef and lowers **meat quality** in pigs. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 13)
- Pigs and cattle should enter a restraint device easily with a minimum of balking. Correcting problems with animal restraint devices can also help reduce bruises and **meat quality** defects such as blood splash. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 17)
- Good stunning also promotes animal welfare and **meat quality**. When stunning is done correctly, the animal feels no pain and it becomes instantly unconscious. Stunning an animal correctly also results in better **meat quality**. When using electric stunning systems, improper stunning will cause blood spots in the meat and bone fractures. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, page 19)
- Research conducted in commercial pork slaughter plants where squealing was measured with a sound meter indicated that the intensity of pig squealing in the stunning chute area is correlated with physiological measures of stress and poorer **meat quality**. (*AMI Recommended Animal Handling Guidelines & Audit Guide*, July 2013 edition, pages 23-24)

The AMI animal handling guidelines were written by Dr. Temple Grandin, professor of animal science at Colorado State University. In addition to Dr. Grandin, several major animal agriculture publications—including Drovers Cattle Network and Meatingplace—have run news articles and/or editorials by animal agriculture experts making the case for a connection between animal handling and meat quality. Excerpts from a few of those articles follow:

E. Voogd, The unconventional humane handling audit, Meatingplace, August 8, 2016.

> Many animal handlers are not fully aware of how their behavior effects [*sic*] the ultimate quality of the meat being produced. By explaining the importance of gentle handling and how closely it is linked to animal welfare and meat quality, management can dramatically influence employee behavior. Once the handlers understand how calm animals produce higher quality meat, they are more aware of the outcomes associated with their actions.

C. Miles, Humane practices lead to better meat, researcher says, Drovers Cattle Network, August 28, 2014.

> Temple Grandin, livestock welfare researcher and Colorado State University professor, told food industry officials on Tuesday that humane practices lead to improved meat quality, which is helping contribute to historic high meat prices. Grandin said that humane treatment provides benefits at the slaughter plant, as well as the ranch and feedlot. Grandin told a conference of about 200 Performance Food Group employees at the National Cattlemen's Beef Association headquarters that an animal that gets agitated at the slaughterhouse in the last five minutes of its life will have tougher meat than those that do not get agitated. She said that stress from poor handling practices causes cattle to produce cortisol, which slows desired weight gain and makes meat less tender. Although the link between stress-induced hormones and meat quality has been studied for quite some time, it takes on new importance now as consumers become pickier about their purchases.

W. Hibbard, The case for low-stress livestock handling, Drovers Cattle Network, August 2014.

> Numerous scientific studies have illustrated that indices of animal performance (e.g., weight gain, conception rates, milk yield, immune function and carcass quality) are positively correlated with good handling practices and negatively correlated with coercive handling practices.

W. Schilling, How animal care affects meat quality, Meatingplace, April 21, 2014.

> [B]oth farmers and meat processors know that animal welfare is crucial to all stages of production for the good of the animal, to produce the best quality meat and to minimize production cost…. The industry needs to be able to scientifically explain how animal welfare is important for the good of the animal, economical success of a company, and the production of safe, wholesome meat without quality defects…. The higher the corticosterone or cortisol level, the greater the stress level, which indicates steps in the production process in which welfare may be improved and meat quality may be enhanced….
>
> Optimizing welfare conditions during catching, transport, holding, unloading, stunning and slaughter is crucial to the poultry industry for the good of the bird and because stress between loading on the farm and slaughter contributes to decreased meat quality…. Optimizing animal welfare improves yields, tenderness, juiciness and production efficiency and decreases the incidence of bruises, bloodsplash, PSE meat, dark cutter beef and broken wings and legs in chickens. The most efficient and highest quality animal welfare conditions provided for animals means enhanced profits for the producer/processor and ultimately lower costs for the consumer.

K. Vogel, Scientific and physiological aspects of animal welfare, Meatingplace, March 24, 2014.

> The accurate assessment of meat quality requires the consideration of multiple variables that define the characteristics of the specimen…. Considering the numerous attributes that must be included to accurately define meat quality, it is not surprising that a single, all-encompassing

variable that is capable of quantifying meat quality has not been discovered…. Animal welfare can directly and indirectly affect the quality of meat. [The column goes on to describe a study of the factors that produce dark-cutting beef. Article was taken from "The Science of Animal Welfare: Why a Multifaceted Approach is Necessary," a presentation at the 2013 Reciprocal Meat Conference in Auburn, Alabama.]

E. Voogd, Does animal welfare affect food safety, Food Safety Magazine, February/March 2009.

Does the welfare and humane treatment of food animals really affect the safety of the product? You bet! From the moment of conception until the meal is served, producers and processors can provide the care, husbandry and attention to welfare that will assure the meat we eat is safe and nutritious, as well as accepted and appreciated by the consumer…. The quality and safety of the meat is greatly influenced by management of the stresses associated with production, transport and harvest. Minimizing pain, fear and injuries requires calm, quiet handling and can improve meat-related issues.

7. Annotated Scientific Bibliography

Poultry

Adzitey, F., 2011, Effect of pre-slaughter animal handling on carcass and meat quality. International food Research Journal 18, 485-491.

Animal handling is a growing issue of concern in many countries around the world. Developed countries in particular show keen interest in the way animals are handled throughout production to processing. In such countries animal welfare is increasingly becoming a primary matter in the process of keeping animals either as pets or for food and at homes or on farms. Not only are they protecting the rights of these animals but poor animal handling has adverse effects on the animal, carcass and meat quality. Poor quality animal and meat will have poor processing properties, functional quality, eating quality, and more likely to be unaccepted by consumers. Lesser attention has been paid by most developing countries on this issue.
Quote: "Non ruminants (poultry and pigs) are more susceptible to stress compared to ruminants (sheep, cattle and goat). Thus poultry meat and pork are more prone to meat quality defects compared to mutton or beef."
Quote: "Carcass damages such as bruising, haemorrhages, skin blemishes, bloodsplash and broken bones (particularly in poultry) are common occurrences found on carcasses due to improper handling conditions. In a bruise, haemorrhage, skin blemish and/or bloodsplash the skin of the animal and the blood vessels may accumulate excessive blood which has to be trimmed off during processing. Trimming part of the carcass off will reduce meat yield and value, expensive and increase processing time. Untrimmed parts have poor appearance and can serve as substrates for microbial growth causing the meat to spoil earlier than the normal. Broken bones may cause bone splinters in meat and this will be dangerous to the consumer if not detected after deboning."

Barbut, S., 2009, Pale, soft and exudative poultry meat—Reviewing ways to manage at the processing plant. Poultry Science 88, 1506-1512.

This review focuses on ways the industry can currently deal with pale, soft, and exudative (PSE) poultry meat. Overall, the rapid increase in poultry meat consumption and the move toward selling more cut-up parts have resulted in some complaints associated with meat quality. Because no genetic marker related to PSE in poultry used by breeders has yet been identified, processors can employ several pre- and post-rigor strategies to minimize the magnitude of the problem. They include reducing stress before slaughter (e.g., during catching, transportation, waiting period, unloading) and during stunning (gas vs. electrical).

Benincasa, N.C., Sakamoto, K. S., Silva, I.J.O., and Lobos, C.M.V., 2020, Animal welfare: impacts of pre-slaughter operations on the current poultry industry, Journal of animal behaviour and biometeorology 8(2), 104-110.

The pre-slaughter operations are characterized by all the steps after the phase of raising at the farm until hanging of birds on the slaughter line, and this period is relatively faster than the farm phase. Nevertheless, this phase can cause acute stress in broilers, due to the direct handling of the birds at catching and by offering unknown stressful stimuli to the birds during transportation, lairage and hanging on the slaughter line. Other stressful factors such as handling the bird, crating density, impacts on live load, distance and duration of transport between farm and slaughterhouse, and microclimatic conditions in transport and lairage affect the welfare and, consequently, the meat quality of broiler chickens. The effects of these losses will be felt by all sectors of poultry farming. For all these factors, it is important that the poultry production chain be aligned in the near future to meet the external and internal consumers' requirements regarding animal welfare.

Bianchi, M., et al, 2006, The influence of genotype, market live weight, transportation and holding conditions prior to slaughter on broiler breast meat color, Poultry Science 85, 123–128.

A study was conducted to determine the influence of genotype, market live weight, transportation time, holding time, and temperature on broiler breast fillet color under commercial processing conditions. Holding time and temperature were found to exert the largest effect on broiler breast meat color. However, other factors, such as genotype, live weight, and transportation, may influence breast meat color.

Consumer Reports, January 2010, How safe is that chicken? Most tested broilers were contaminated. (https://www.consumerreports.org/cro/2012/05/how-safe-is-that-chicken/index.htm)

Consumer Reports has been measuring contamination in store-bought chickens since 1998. For this analysis, it had an outside lab test 382 chickens bought from more than 100 supermarkets, gourmet- and natural-food stores, and mass merchandisers in 22 states. CR tested three top brands—Foster Farms, Perdue, and Tyson—as well as 30 nonorganic store brands, nine organic store brands, and nine organic name brands. Campylobacter was found in 62 percent of the chickens, Salmonella was in 14 percent, and both bacteria were in 9 percent. Only 34 percent of

the birds were clear of both pathogens. Among all brands and types of broilers tested, 68 percent of the Salmonella and 60 percent of the Campylobacter organisms analyzed showed resistance to one or more antibiotics.

Consumer Reports, January 2014, Dangerous contaminated.
*(*https://www.consumerreports.org/cro/magazine/2014/02/the-high-cost-of-cheap-chicken/index.htm)

Consumer Reports' analysis of more than 300 raw chicken breasts purchased at stores across the US found potentially harmful bacteria lurking in almost all of the chicken, including organic brands. In fact, Consumer Reports was conducting its research when news of the national Salmonella outbreak linked to three Foster Farms chicken plants became public. In that case 389 people were infected, and 40 percent of them were hospitalized, double the usual percentage in most outbreaks linked to Salmonella….CR tests showed that resistant bacteria are commonly found in chicken at local grocery stores. CR collected samples in July 2013, months before the Foster Farms Salmonella outbreak drew a public-health alert from the Department of Agriculture. It turned out that CR had purchased a package of the tainted chicken and that its tests found a strain of Salmonella (known as Heidelberg) that matched one of those linked to the outbreak.

Dadgar, S., et al., 2010, Effect of microclimate temperature during transportation of broiler chickens on quality of the pectoralis major muscle, Poultry Science 89, 1033-1041.

This study investigated the effect of microclimate temperature during pre-slaughter transportation on chicken meat quality. Ninety broilers per load of 2,900 were monitored individually during 3 to 4 hours of pre-slaughter transport in an actively ventilated trailer. Birds were slaughtered in a commercial facility and meat quality of the chilled carcasses was evaluated by determination of pH, color, drip loss, thaw loss, cook loss, shear force, water-binding capacity, and pellet cook yield of the pectoralis major muscle. Exposure to temperatures below 0°C increased the incidence of dark, firm, and dry breast meat. These results demonstrate that pre-slaughter transport may influence breast meat quality characteristics of broiler chicken.

Dadgar, S., et al., 2011, Effect of acute cold exposure, age, sex and lairage on broiler breast meat quality, Poultry Science 90, 444-457.

The effect of acute cold exposure on bird physiology, muscle metabolites, and meat quality was assessed in 360 male and female broilers at 5 and 6 weeks of age, exposed for 3 hours to temperature ranges of −18° to −4 C and a control of +20°C, by using a simulated transport system followed by 0 or 2 hours of lairage. The 2-hour lairage resulted in darker breast meat with higher pH at exposure temperatures below −14°C. Also, a high incidence of dark, firm, and dry breast meat was observed at temperatures below −14°C. A 2-hour lairage resulted in an additional 20% increase in the incidence of dark, firm, and dry meat at temperatures below −8°C. The study concluded that it would be beneficial to limit the length of lairage before processing after exposure to acute cold to improve bird welfare and reduce meat quality defects.

Debut, M., et al., 2003, Variation of chicken technological meat quality in relation to genotype and pre-slaughter stress conditions, Poultry Science 82, 1829-1838.

> The present study was aimed at estimating the genetic variability between lines of breast and thigh meat quality (pH decline, color, drip loss, and curing cooking yield) by comparing a slow-growing French label- type line (SGL) and a fast-growing standard line (FGL) of chickens exposed to different pre-slaughter stress conditions. Thigh meat characteristics were influenced by pre-slaughter stresses. The main effect of heat stress in thigh meat was a decrease of the ultimate pH and led to paler color and lower curing-cooking yield. Breast meat was much more sensitive to physical activity of birds on the shackle line. Longer durations of wing flapping on the shackle line gave more rapid initial pH decline, which could be detrimental to the quality of breast meat.

Fletcher, D.L., 1999, Color variation in commercially packaged broiler breast fillets, Journal of Applied Poultry Research 8, 67-69.

> A survey of broiler breast fillet packages displayed in grocery stores in Georgia was conducted by The University of Georgia to determine the extent of discolored packages. It has been established in numerous commodities, including whole birds, that skin color uniformity is often considered a major quality issue. Numerous factors that affect poultry meat color have been identified, including live production, handling, and processing factors. Of the 997 packages examined in this survey, 71, or 7.1%, were identified as defective based on the presence of at least one fillet noticeably different in color from the other fillets in that package….The incidence of defects by retail outlet ranged from 0 to 25%.

Lara, L.J. and Rostagno, M.H., 2013, Impact of heat stress on poultry production, Animals 3, 356-369.

> There is increasing evidence to demonstrate that stress can have a significant deleterious effect on food safety through a variety of potential mechanisms. However, while there is evidence linking stress with pathogen carriage and shedding in farm animals, the mechanisms underlying this effect have not been fully elucidated. Environmental stress has been shown to be a factor that can lead to colonization of farm animals by pathogens, increased fecal shedding and horizontal transmission, and consequently, increased contamination risk of animal products….It is reasonable to speculate that high environmental temperature would not only affect the bacterial levels in the feces of birds, but also the duration and level of contamination in the environment where feces are deposited, potentially leading to increased dissemination. However, heat stress did not result in higher levels or longer survival of Salmonella shed in feces in a small study. Nevertheless, several epidemiological studies have reported seasonal effects on the occurrence of Salmonella and Campylobacter in flocks of broilers and laying hens, as well as in retail poultry products.

McKee, S.R. and Sams, A.R., 1997, The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey meat, Poultry Science 76, 1616-1620.

> Heat stress is one of the prominent antemortem stressors that elicits pale, soft, and exudative meat characteristics in stress-susceptible pigs. Industry reports of exudative turkey meat

increase in the early summer with the onset of prolonged high temperatures. To study the effect of seasonal heat exposure on turkeys, 122 17-wk-old Nicholas tom turkeys were subjected in January either to growth temperatures of 16°/24°C (night/day) (control) or to elevated temperatures of 32°/38°C (night/day) (heat-stressed, HS). The meat from HS birds was paler in color and exhibited increased drip loss and cook loss when compared to controls. In addition, the HS birds had a higher frequency of abnormal birds than controls when birds were grouped as normal or abnormal.

Nijdam, E., et al., 2004, Factors influencing bruises and mortality of broilers during catching, transport and lairage, Poultry Science 83, 1610-1615.

A multilevel analysis was performed to identify and quantify risk factors associated with mortality and bruises occurring between catching and slaughter of broiler flocks. The effect of each factor in the final model was expressed as an odds ratio. Data included 1,907 Dutch and German broiler flocks slaughtered in 2000 and 2001 at a Dutch processing plant. The mean dead on arrival (DOA) percentage was 0.46. Factors associated with DOA percentage were ambient temperature, moment of transport, catching company, breed, flock size, mean BW, mean compartment stocking density, transport time, lairage time, and the interaction term transport time × ambient temperature. The most important factors that influence DOA percentage, and which can be reduced relatively easily, were compartment stocking density, transport time, and lairage time. Reducing or removing these factors will reduce DOA percentage. Consequently, profitability and animal welfare will increase.

Northcutt, J. and Buhr, R., 2000, Chapter 2: Preslaughter factors affecting poultry meat quality, In Poultry Meat Processing.

Quote: "During the short time between production and processing, there are a number of factors, and opportunities for events to occur, that could potentially affect poultry meat quality and yield. Processing is not just a "stand-alone" operation but rather can be significantly influenced by poultry production factors that have an impact on the chemical, physical, and structural changes that occur in the muscle as it is converted to meat."

Owens, C.M., et al., 2009, Research developments in pale, soft, and exudative turkey meat in North America, Poultry Science 88, 1513-1517.

The causes of pale, soft, and exudative (PSE) meat seem to be genetic, environmental, or a combination of both. Pale, soft, exudative meat is associated with antemortem and postmortem stressors including heat stress, pre-slaughter handling practices, and carcass chilling regimes. Birds enter the processing plant and are killed in an excited state with profound implications for the quality of their meat. They have an accelerated rate of metabolism, accelerating the decline in muscle pH that normally occurs with rigor mortis development. The abnormally low pH at an early postmortem time when the carcass is still warm causes the denaturation of the muscle proteins responsible for muscle color and the ability of the meat to hold water during cooking. It has been estimated that PSE-type meat represents 5 to 40% of meat that is produced in the poultry industry.

Petracci, M., Bianchi, M. and Cavani, C., 2019, Pre-slaughter handling and slaughtering factors influencing poultry product quality, World's Poultry Science Journal 66(1), 17-26.

> Over the past 15 years, the European processing industry has gradually increased the availability of poultry meat in a large variety of processed ready-meals, which follows recent trends in North America. The shift towards further processed products has underscored the necessity for higher quality standards in poultry meat to improve sensory characteristics and functional properties. Poultry meat quality is a complex and multivariate property, which is affected by multiple interacting factors including genetics, feeding, husbandry, pre-slaughter handling, stunning and slaughter procedures, chilling, processing and storage conditions. However it is likely that the effects exerted by *ante-mortem* handling (feed withdrawal, catching, crating, transport and lairage) and slaughter (hanging, stunning, killing, scalding, plucking, evisceration, chilling and processing) on final product quality may be greater than those attributable to variation in husbandry practices. Many problems may occur at these stages that potentially increase the rate of mortality, carcass downgrading and meat quality.

Rostagno, M., 2009, Can stress in farm animals increase food safety risks? Foodborne Pathogens and Disease 6, 767-776.

> All farm animals will experience some level of stress during their lives. Stress reduces the fitness of an animal, which can be expressed through failure to achieve production performance standards, or through disease and death. Stress in farm animals can also have detrimental effects on the quality of food products. However, although a common assumption of a potential effect of stress on food safety exists, little is actually known about how this interaction may occur. The aim of this review was to examine the current knowledge of the potential impact of stress in farm animals on food safety risk. Colonization of farm animals by enteric pathogens such as Escherichia coli O157:H7, Salmonella, and Campylobacter, and their subsequent dissemination into the human food chain are a major public health and economic concern for the food industries. This review shows that there is increasing evidence to demonstrate that stress can have a significant deleterious effect on food safety through a variety of potential mechanisms. Understanding when pathogen loads on the farm are the highest or when animals are most susceptible to infection will help identifying times when intervention strategies for pathogen control may be most effective, and consequently, increase the safety of food of animal origin.

Rostagno, M., 2010, Stress in farm animals and food safety: Is there a connection? USDA-ARS, Livestock Behavior Research Unit, Food Safety Fact Sheet.

> Stress in farm animals has a significant deleterious effect on food safety through different potential mechanisms affecting the susceptibility of farm animals to infections as well as the carriage and shedding of foodborne pathogens. It is imperative that the issue receives more research attention in the interests of optimizing animal welfare and minimizing losses in product yield and quality, as well as food safety risks to consumers.

Smith, D.P. and Northcutt, J.K., 2003, Red coloration of fully cooked chicken products, Journal of Applied Poultry Research 12, 515-521.

> Sporadic occurrences of discoloration seem to be widespread within the industry, but no data are available to adequately assess the incidence or severity of this problem. Therefore, products typically available to the consumer either directly from the supermarket or indirectly through a wholesaler were evaluated by USDA researchers to determine the relative occurrence and severity of internal red discoloration….Overall, 11% of products sampled would likely generate consumer complaints or rejection, as 10.6 and 0.4% were scored as extensively or severely discolored, respectively. Of the remaining products, 60.5% had little or no discoloration, and 28.5% showed slight to moderate discoloration….Live birds may be mishandled during catching or hanging or may be stunned improperly, all of which would increase bruising and hemorrhaging.

Wesley, I.V., et al., 2009, Prevalence of Campylobacter jejuni and Campylobacter coli in market-weight turkeys on-farm and at slaughter, Journal of Food Protection 72, 43-48.

> To monitor the effects of feed withdrawal on the prevalence of Campylobacter, market-weight turkeys from six farms were examined before and after peri-marketing events (feed withdrawal, transport, and holding at the slaughterhouse). Prior to transport, birds (n = 30 per farm) were slaughtered on-farm, and viscera (crops, duodenum, jejunum, ileum, colon, ceca, gallbladder, and spleen) were removed on the premises. Within ca. 48 h, cohorts (n = 30 per farm) from the same flock were transported to a commercial abattoir, maintained in holding sheds, slaughtered, and the viscera were removed. After feed withdrawal, transport, and holding at the abattoir, there was an overall increase in Campylobacter spp. isolated from the gallbladder at the abattoir (14.7%) when compared with on-farm levels (0%, $P < 0.05$). When compared with on-farm levels (3%), the overall increase in Campylobacter spp. recovered from the crops of birds at the abattoir (24%) was significant ($P < 0.05$).

Woelfel, R.L., et al., 2002, The characterization and incidence of pale, soft, and exudative broiler meat in a commercial processing plant, Poultry Science 81, 579-584.

> Pale, soft, and exudative meat (PSE) is a growing problem in the poultry industry. Characteristics of PSE meat are paleness, low water-holding capacity, and formation of soft gels. This defective meat is the result of accelerated postmortem metabolism, which results in a rapid postmortem pH decline while carcass temperatures are still high. This combination can result in protein denaturation in the muscle that leads to paler meat color, decreased water-holding capacity, and softer texture. Poultry may be susceptible to the same types of antemortem and postmortem stressors as swine. These stressors include environmental temperatures, pre-slaughter handling practices, and stunning methods.

Zhang, L., et al., 2009, Transport stress in broilers: I. Blood metabolism, glycolyctic potential and meat quality, Poultry Science 88, 2033-2041.

> The effect of transport stress on blood metabolism, glycolytic potential, and meat quality in broilers was investigated. Arbor Acres chicks (n = 360, 1 day old, males) were randomly allotted

to 1 of 5 treatments: unstressed control, 45-min (short-term) transport with 45-min (short-term) recovery, 45-min transport with 3-h (long-term) recovery; 3-h (long-term) transport with 45-min recovery, and 3-h transport with 3-h recovery. Glucose concentration increased slightly during the first 45 min of transport and then decreased dramatically in the long-term transported broilers. These results suggested that transport induced the release of plasma CORT and glycopenia, which affected the contractive status of muscle fibers by changing their area and density, and enhanced glycolysis and even lipolysis. A long-term recovery after transport was beneficial in lowering plasma CORT levels and reducing muscle glycolysis, which might improve broiler meat quality.

Pigs

Correa, J.A., et al., 2010, Effects of different moving devices at loading on stress response and meat quality in pigs, Journal of Animal Science 88, 4086-4093.

Although there is increasing evidence regarding the negative welfare and meat quality implications of electric prod use for slaughter-weight pigs, this handling tool continues to be used. Therefore, the behavioral and physiological response and carcass and meat quality of 360 pigs being loaded onto a truck for transportation to slaughter according to 3 handling procedures were studied. The 3 handling procedures were 1) moving with an electric prod and board from the finishing pen to the truck (EP); 2) moving with a board and a paddle from the finishing pen to the truck (PAD); 3) moving with a board and a paddle from the finishing pen and using a compressed air prod in the ramp before going into the truck (CAP). Considering animal welfare, carcass bruising, and blood splashes standpoints, it was concluded that EP should be replaced with PAD or CAP.

Dalla Costa, O.A., et al., 2007, Effects of the season of the year, truck type and location on truck on skin bruises and meat quality in pigs, Livestock Science 107, 29-36.

The purpose of this study was to evaluate the effect of the season of the year (summer vs. winter), type of truck (A: single decker vs. B: double-decker) and pig location on the truck (front, middle, rear) on the incidence of skin bruising and pork quality variation. A higher number of bruises on the body at unloading and slaughter and a higher number of bruises on the carcass were observed in winter. At unloading a higher number of bruises on the body and on the carcass after slaughter was observed in pigs transported on Truck A. Higher paleness value was found in the longissimus and semimembranosus muscles in summer than in winter. Cold and heat stress have a negative influence on skin bruises and meat quality, respectively

Dokmanović, M., et al., 2014, The effects of lairage time and handling procedure prior to slaughter on stress and meat quality parameters in pigs, Meat Science 98, 220-226.

Lairage time (short — 8 min to 2.7 hours, n=28 vs. long — 14 to 21.5 hour, n=72) and pig handling (gentle— no use of stick or electric prod, pig not slipping, falling, nor emitting high-pitched vocalizations vs. rough — where any of these occurred) effects on pig stress and meat quality were measured. Lairage time significantly affected blood lactate, carcass rigor mortis,

skin damages, drip loss, color and meat quality. Handling procedure influenced blood lactate, pH60 min and T60 min. Rough handling was related to higher lactate and lower meat quality.

D'Souza, D.N., et al., 1998, The effect of handling pre-slaughter and carcass processing rate post-slaughter on pork quality, Meat Science 50, 429-437.

Forty-eight male crossbred pigs were used in a 2x2 factorial design to determine the effect of pre-slaughter handling (minimal and negative handling prior to slaughter) and the rate of carcass processing post-slaughter [normal rate (45 min) and delayed rate (70 min) from time of exsanguination to carcass entering the chiller] on muscle glycolysis and pork quality. Pigs negatively (using an electric goad) handled at the abattoir just prior to slaughter had lower muscle glycogen concentrations in the Longissimus thoracis (LT) and the Biceps femoris (BF) at all times post-slaughter and lower lactic acid at 5, 45 and 70 min post-slaughter compared to pigs minimally (no use of electric goads) handled prior to slaughter. Negative handling of pigs just prior to slaughter also resulted in pork which had higher surface exudate and a higher incidence of PSE compared with pigs minimally handled prior to slaughter. The results from this experiment have indicated that the use of electric goads to move pigs at the abattoir can have a detrimental influence on ultimate pork quality.

Edwards, L., et al., 2010, The relationship between exsanguination blood lactate concentration and carcass quality in slaughter pigs, Meat Science 85, 435-445.

Physiological changes associated with immediate pre-slaughter stresses, i.e. increased exsanguination blood lactate concentration, have been shown to have detrimental effects on pork quality causing increased drip loss and lighter color. The objective of these studies (one in the Midwestern US and one in Quebec, Canada) was to determine the relationship of pre-slaughter animal management, from the farm to the meat processing plant, on meat quality. Increased exsanguination lactate resulted in reduced pork quality. Lactate was highest following loading and at exsanguination, indicating areas of focus to improve animal handling during marketing.

Hambrecht, E., et al., 2005, Negative effects of stress immediately before slaughter on pork quality are aggravated by suboptimal transport and lairage conditions, Journal of Animal Science 83, 440-448.

The objectives of the present experiment were 1) to study the effects of transport conditions and lairage duration on stress level, muscle glycolytic potential, and pork quality; and 2) to investigate whether the negative effects of high stress immediately pre-slaughter are affected by preceding handling factors (transport and lairage). High stress decreased muscle glycolytic potential, and increased plasma lactate, cortisol, muscle temperature, rate of pH decline, and ultimate pH. Water-holding properties (measured by electrical conductivity, filter paper moisture, and drip loss) were impaired by high stress. Comparisons with the "optimal" handling (short transport, long lairage, and minimal stress) revealed that, with regard to water-holding properties, the negative effects of high stress were aggravated by suboptimal transport and lairage conditions. High stress alone increased electrical conductivity by 56%, whereas high stress in combination with short lairage led to an 88% increase. However, high pre-slaughter stress contributed most and was the major factor responsible for reductions in pork quality.

Hambrecht, E., et al., 2005, Pre-slaughter handling effects on pork quality and glycolytic potential in two muscles differing in fiber type composition, Journal of Animal Science 83, 900-907.

The objective of the present experiment was to investigate the effects of transportation, lairage, and pre-slaughter stressor treatment on glycolytic potential and pork quality of the glycolytic longissimus and the oxidative supraspinatus or serratus ventralis muscles. It was concluded that, in glycolytic muscle types such as the longissimus, the high physical and psychological stress levels associated with stress in the immediate pre-slaughter period have a greater effect on the water-holding capacity of the meat and may promote PSE development. Conversely, oxidative muscle types tend to have higher ultimate pH values and produce DFD pork in response to intense physical activity and/or high psychological stress levels pre-slaughter.

Lammens, V., et al., 2007, A survey of pork quality in relation to pre-slaughter conditions, slaughterhouse facilities, and quality assurance, Meat Science, 75, 381-387.

A survey at five pig slaughterhouses was performed to investigate the effect of a quality assurance system, pre-slaughter conditions, and slaughterhouse facilities on pork quality. A total of 2,246 pigs were included over four transports per slaughterhouse, i.e. two transports were produced according to a quality assurance system and the other two were conventional pigs. Meat quality was measured on 446 pigs. Pigs managed according to a chain quality protocol showed an overall higher potential for improved meat quality. Influencing factors on pork quality seemed to be stocking density during transport, the handling during offloading the pigs from the truck, stocking density, and air temperature during lairage.

Mota-Rojas, D., et al, 2006, Effects of mid-summer transport duration on pre- and post-slaughter performance and pork quality in Mexico, Meat Science 73, 404-412.

Seven hundred and fourteen pigs were monitored during transport to slaughter in July in three treatments: 8, 16 and 24 transport hours; lairage time for the three groups was 8 hours. Transport to slaughter loss percentage was 2.7%, 4.3%, and 6.8%, respectively, for the three treatments. Animals transported under acute stress showed pale carcasses (high possibilities of transforming into PSE meat), while pigs transported for 24 hours had more dark red carcasses. The authors commented that transport from farm to the slaughterhouse should take no more than 16 hours in order to improve carcass quality and animals' welfare.

Warriss, P.D., et al., 1994, Relationships between subjective and objective assessments of stress at slaughter and meat quality in pigs, Meat Science 38, 229-340.

A study was carried out to relate subjective and objective measures of stress at slaughter and meat quality in pigs. Thirteen slaughter plants were visited. The systems used for handling the pigs pre-slaughter and the levels of stress experienced by the animals were subjectively assessed. The sound level immediately before stunning was also measured. Blood samples were collected at exsanguination, and meat quality was assessed. As the level of subjectively assessed stress experienced by the pigs increased, so did the average blood levels of lactate and creatine phosphokinase (CPK). There was also a progressive increase in the potential incidence of pale, soft, exudative (PSE) and dark, firm, dry (DFD) meat in the plants using more stressful handling systems.

Additionally, there were positive relationships between sound level and lactate and CPK, and sound level and indices of poorer meat quality. The overall conclusion was that subjective assessments of the stress suffered by pigs correlate well with objective measures and that higher stress levels are associated with poorer meat quality.

Ruminants

Ferguson, D.M. and Warner, R.D., 2008, Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? Meat Science 80, 12-19.

Stress is the inevitable consequence of the process of transferring animals from farm to slaughter. The effects of chronic stress on muscle glycogen depletion and the consequent dark cutting condition have been well documented. New evidence is emerging to show that non pH mediated effects on meat quality can occur through pre-slaughter stress in cattle and sheep. The article then examines the impacts of pre-slaughter stressors on ruminant carcass and meat quality and considers remedial strategies for remediating and preventing pre-slaughter stress. It is concluded that further quantification of the biological costs of pre-slaughter stress and the consequences to meat quality is required.

Gallo, C., et al., 2003, Effects of journey and lairage time on steers transported to slaughter in Chile, Veterinary Record, 152, 361-364.

Steers representative of the most common type, weight and conformation slaughtered in Chile were transported for either 3 or 16 hours and held in lairage for 3, 6, 12 or 24 hours. Measurements of live weight, carcass weight, and the postmortem pH and color of muscle were made to assess the economic and welfare effects of the different transport and lairage times. Compared with the short journey, the longer journey was associated with a mean reduction in live weight of 8.5 (2.8) kg, and there was a further decrease of 0.42 (0.18) kg for every hour that the animals were kept in lairage after 16 hours of transport, an increase in final muscle pH, a decrease in muscle luminosity and an increase in the proportion of carcasses downgraded because they were classified as “dark cutting”. The carcass weights also tended to be lower after the longer journey and after longer periods in lairage.

Jeremiah, L.E., et al., 1988, The effects of castration, pre-slaughter stress and Zeranol implants on beef: Part 1 – The texture of loin steaks from bovine males, Meat Science 22, 83-101.

A total of 144 male crossbred calves were allocated to two pre-slaughter shipping treatments (minimum pre-slaughter stress with cattle shipped and slaughtered within 4 hour of leaving the feedlot pen; normal pre-slaughter stress with cattle mixed, trucked 160 km, and slaughtered up to 24 hour after leaving the feedlot pen). Results indicated that increases in pre-slaughter stress levels were detrimental to the eating quality of both intact males and castrated males.

Jones, S.D.M. and Tong, A.K.W., 1989, Factors influencing the commercial incidence of dark cutting beef, Canadian Journal of Animal Science 69, 649-654.

Data collected on 170,534 head of Saskatchewan cattle slaughtered over a period of 12

consecutive months were used to evaluate the importance of some factors influencing the incidence of dark cutting (DC) beef. The variables examined included carcass weight, gender of animal, daily temperature and precipitation, month of slaughter, distance from farm to abattoir, mixing of loads during transportation and slaughter plant. The incidence of DC beef increased as distance between farm and slaughter plant increased, and was higher in loads of cattle that were mixed during transportation than in those loads that originated from the same farm. It was concluded that the mixing of loads and location of the slaughter plant were the two most important predisposing factors for DC beef.

Maria, G.A., 2008, Meat quality. In: Long Distance Transport and Welfare of Farm Animals (eds. M.C. Appleby et al.), CAB International, Cambridge, MA, pp. 77-112.

The main problems caused by transport on cattle carcasses/meat quality are bruising and DFD meat. These two problems are directly associated with transport time. The longer the transport, the higher is the probability of bruising and DFD meat. The effect of transport on carcass/meat quality and welfare has been analyzed for the last 40 years. The detrimental effect of transport stress on meat and carcass quality has been demonstrated in several studies. Only 5% of the studies reviewed failed to find a significant effect of transport on carcass or meat quality.

Tarrant, P.V., et al., 1992, Long distance transportation of steers to slaughter: effect of stocking density on physiology, behavior and carcass quality, Livestock Production Science 30, 223-238.

Friesian steers were transported by road for 24 hours at low, medium, and high stocking densities to assess the welfare and economic effects of long journeys. Some animals laid down during transit at all stocking densities, but only at the high stocking density were animals trapped down and unable to rise. Carcass bruising and plasma activity of creatine kinase increased with stocking density. The results show that stocking densities above about 550 kg/m^2 are unacceptable for animals in this weight range on long journeys. At medium and low density, tile physiological data suggest that any increase in journey time or deterioration in transport conditions would be detrimental to welfare.

Warren, L.A., et al., 2010, Road transport conditions of slaughter cattle: Effects on the prevalence of dark, firm and dry beef, Canadian Journal of Animal Science 90, 471-482.

This is a benchmark study to investigate slaughter cattle transportation conditions in Canada. Data collected included: season; temperature variation; truck ventilation; transport conditions; length of time in transit; trucker training and experience hauling cattle; number of lots and whether lots were separated; sex and whether sexes were separated on mixed loads; cattle unloading gait score; cattle handling score; cattle weight; and number of dark cutters. Information was collected on approximately 50,000 animals transported by 1,363 trucks. The prevalence of dark cutters was highest in mixed loads, followed by heifers and steers. Mixed loads that were not separated (steers and heifers in the same compartment) had a greater prevalence of dark cutters than mixed loads that were separated. Province of origin, cattle unloading speed, driver training, truck ventilation, trucking experience, sex, origin (sale barn or

feedlot) and whether or not cattle were held in lairage overnight were all significant predictors for dark cutting beef.

Multiple Species

Schwartzkopf-Genswein, K.S., et al., 2012, Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: A review, Meat Science 92, 227-243.

This paper reviews the effects of road transport on the welfare, carcass and meat quality of cattle, swine and poultry in North America. The main effects of loading density, trailer microclimate, transport duration, animal size and condition, management factors including bedding, ventilation, handling, facilities, and vehicle design are summarized by species. The main effects listed above all have impacts on welfare (stress, health, injury, fatigue, dehydration, core body temperature, mortality and morbidity) and carcass and meat quality (shrink, bruising, pH, color defects and water losses) to varying degrees. It is clear that the effect of road transport is a multi-factorial problem where a combination of stressors rather than a single factor is responsible for the animal's well-being and meat quality post transport. Achieving optimal animal well-being, carcass and meat quality will entirely depend on the quality of the animal transport process.

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