THE EFFECT OF DIET ON THE PERFORMANCE OF NON-NUTRITIVE ORAL BEHAVIORS BY BEEF CATTLE

A Thesis

by

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ABSTRACT

Cattle display oral stereotypic behavior in the form of non-nutritive oral behaviors (NNOB). Stereotypic NNOBs, hypothesized to be caused by dietary challenges, include tongue rolling, bar licking, and ground licking. The purpose of this research was to determine the impact of dietary factors (roughage inclusion and rumen modifier supplementation) on NNOB performance by beef cattle housed in feedyards. Upon the performance of a systematic review on the current state of research regarding the diet-NNOB relationship, literature indicated that experiments that manipulated the level of dietary roughage inclusion provided conclusive evidence that roughage level influences NNOB performance. Diets that altered other dietary factors (e.g. particle size, total feed amount, mineral addition, or ingredient type) did not conclusively elicit changes in NNOB performance. To further investigate roughage inclusion and NNOB performance, a study was performed on beef steers (n = 54) fed increasing levels of corn stalks (5%, 10% or 15%). Corn stalk inclusion did not alter NNOB performance nor was NNOB performance associated with production metrics; however, tongue rolling increased as duration of time spent ruminating decreased ($P < 0.01$) and activity, or movement, increased with tongue rolling and bar licking ($P < 0.01$). A second study evaluated the effect of live yeast supplementation during wheat substitution on tongue rolling and bar licking by beef steers (n = 24). Live focal observations and a Growsafe system were used to collect NNOB performance and feeding behavior data. Cattle not fed live yeast when consuming a high-concentrate diet performed tongue rolling more frequently that all other treatments ($P = 0.05$) and individuals, irrespective of treatment, with smaller meal sizes, lower daily feed intakes, and shorter duration feeding bouts all more frequently performed of tongue rolling ($P = 0.05$, $P = 0.03$, $P = 0.05$,

respectively). Both studies showed that NNOB performance is variable over time. Results from the studies suggest NNOB performance may occur to compensate with the unfulfilled behavioral need ruminate and that live yeast may mitigate NNOB performance by cattle consuming high-concentrate diets.

DEDICATION

I dedicate this thesis to my loving husband, Grayson, and my parents, Ken and Lori, for their endless love, financial contributions and continuous support throughout my graduate school career.

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This work was supervised by a thesis committee consisting of Dr. Courtney Daigle (chair), Dr. Gordon Carstens of the Department of Animal Science and Dr. Tryon Wickersham of the Department of Nutrition and Department of Animal Science.

Study population and production data for Chapter 2 were provided by Dr. Jenny Jennings and video recordings were provided by Rachel Park. Study population and GrowSafe data for Chapter 3 were provided by Dr. Gordon Carstens and Lydia Forehand.

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NOMENCLATURE

NNOB	Non-nutritive oral behaviors
ADG	Average daily gain
DMI	Dry matter intake
G:F	Gain to feed ratio
kg	Kilogram
d	Day
h	Hour
m	Meter
NR	Not recorded

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CHAPTER I

INTRODUCTION

Stereotypic behaviors are repetitive actions performed by animals in response to frustration from being unable to fulfill a behavioral need (Mason, 1991). While they appear to lack any direct biological function, multiple hypotheses have suggested that oral stereotypic behaviors performed by cattle are in response to the diets fed in confinement (Bergeron et al., 2006). Shorter duration of time engaged in rumination, decreased time dedicated to feeding, and the onset of gastrointestinal discomfort caused by bunk feeding and the composition of the diet fed to beef cattle in feedyards cause both behavioral (Mathias and Daigle, 2018) and physiological (Loerch and Fluharty, 1999) changes that cattle must cope with upon transition into a confined feeding environment. Confined ungulates perform oral stereotypies in the form of non-nutritive oral behaviors (NNOB) to compensate for the shortened duration of time needed to ruminate and acquire nutrients when they transition from a forage-based diet to a concentrate-based diet (Baxter and Plowman, 2001). Both rumination and nutrient acquisition (e.g., grazing, feeding) are behaviors that undergo extreme time-budget alterations when roughage is limited and grazing is not possible. While the relationship between diet and NNOB performance has been evaluated in dairy cattle (Redbo et al., 1996; Redbo and Nordblad, 1997), the factors that influence the frequency of NNOB have yet to be thoroughly investigated in beef cattle.

Non-nutritive oral behaviors consist of tongue rolling, object licking, ground licking and cross sucking. While not stereotypic in nature, allogrooming and self-grooming are also non-nutritive and are commonly evaluated in conjunction with oral stereotypies. Tongue rolling has been primarily considered to be coping mechanism cattle adopt to compensate for a lack of grazing, as tongue rolling mimics the actions of the tongue when grazing on pasture (Sambrus, 1985). While NNOB may still occur while grazing, NNOB performance has been observed to be greater in cattle housed in a feedyard-setting than those on pasture (Ishiwata et al., 2007). Similarly, NNOB performance may be performed to compensate for a lack of mouth movements associated with shortened durations of time spent ruminating. Diets that lack roughages have been observed to decrease the duration of rumination (Gentry et al, 2016). This occurs because feedyard diets, in addition to containing low levels of forages, are primarily comprised of small particle sized grains, which contain low levels of fiber and ferment rapidly, thus limiting the amount of substrate available for mastication (Krawczel, 2016). However, it has been observed that when cattle have access to adequate roughages, NNOB performance is reduced (Redbo et al., 1996). Furthermore, the diet composition of feedyard diets elicits changes within the rumen, increasing risk of acidosis or rumenitis, which can cause discomfort. Cattle have been hypothesized to alleviate with this discomfort using extraneous mouth movements like NNOBs to increase salivary buffer in effort to return the rumen to a comfortable pH (Bergeron et al., 2006)

To better understand the current state of research of the NNOB-diet relationship, a systematic review was performed to evaluate the current literature examining which aspects of the diet may be influencing NNOB performance. In addition, two studies were performed, the first to evaluate the effect roughage inclusion and rumination behavior have on NNOB performance in beef cattle. The second study investigated the effect of a rumen modifier in the form of dietary live yeast on NNOB performance when fed during wheat substation in drylot-housed beef steers.

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CHAPTER II

EFFECT OF DIET ON NON-NUTRITIVE ORAL BEHAVIOR PERFORMANCE BY CATTLE: A SYSTEMATIC REVIEW

Introduction

Modern modes of agriculture require livestock to be housed and fed in environments that have the potential to restrict the performance of some natural behaviors. Although some environments may allow animals to perform their entire repertoire of behaviors, they may limit the duration of time an animal spends engaging in these behaviors – thus altering their overall time budget. Restriction in the duration and frequency of a specific behavior can result in unfulfilled behavioral needs, and these unfulfilled needs can catalyze the manifestation of stereotypic behavior (Mason, 1991). While stereotypic behaviors come in many forms, cattle tend to engage in orally motived stereotypies in the form of non-nutritive oral behaviors (NNOB; Redbo, 1998). Multiple hypotheses have been proposed suggesting that dietary-based or housing-based factors stimulate NNOB performance in both dairy and beef cattle housed in confinement.

Dietary-based contributors of NNOB performance center around three main hypotheses. Summarized by Bergeron et al. (2006), high-grain diets fed in confinement stimulate NNOB performance because said diets reduce rumination time, prohibit the animal from grazing, and potentially cause gastrointestinal discomfort. Cattle housed in confinement must adjust to eating feed in less frequent meals, which shortens the duration of time required to consume feed and can induce rumen microbiome changes (Swartzkophf-Genswein et al., 2003). While grazing cattle have been observed to ruminate for up to 10.2 h/d (Kilgour, 2012), cattle housed in confinement spent 3.8 ± 9. 4 hr/d ruminating (Wolfger et al., 2015). Cattle experiencing these multiple and simultaneous dietary challenges may perform NNOBs in an effort to cope.

Duration of time cattle spend ruminating is shorter when they consume diets that consist of small particle sizes, provide low gut fill, and ferment rapidly. Thus, the low roughage diets provided to cattle in confinement are associated with the reduction in time spent ruminating (Abijaoude et al, 2000). Reduction in time spent engaged in rumination is a hypothesized cause of NNOB performance in confinement. Additionally, gastrointestinal discomfort may catalyze the performance of NNOB. The rumen undergoes a rapid physiological shift when cattle begin to consume high grain diets. Cattle may then be managing this discomfort by performing more mouth behaviors to increase buffer availability to the rumen (Abijaoude et al, 2000).

While most feedyard diets will continue to be high-grain and low-roughage, it is worthwhile to determine how diet characteristics affect NNOB performance. Bergeron et al. (2006) offers a comprehensive summary covering oral stereotypies in captive ungulates; however, no systematic review of the NNOB literature has been conducted. The purpose of this systematic review is to determine which specific dietary components may alter NNOB performance. For this systematic review, the effects of dietary treatment tongue rolling, bar licking, ground licking, and object licking, in addition to self-grooming and allogrooming, were evaluated. Understanding the relationship between management and NNOB performance may provide animal mangers with a behavioral proxy to gauge cattle’s welfare state.

Materials and methods

Eligibility criteria

The population of articles searched in this systematic review of NNOB included beef and dairy calves, cows, heifers, steers, and bulls. Veal calves were included, but only if their diet consisted of primarily of plant-based feed and not milk replacer. No breed restrictions or housing-style restrictions were imposed; however, in each study breed and housing had to be consistent across dietary treatment groups. The activity of interest was the performance of NNOB. Non-nutritive oral behaviors were identified as either specific oral behaviors (e.g. bar licking, tongue rolling, ground licking, object licking, cross sucking, allogrooming, or self grooming) or as a collective of behaviors classified as NNOB or oral stereotypies. Self-grooming and allogrooming are not oral stereotypies, yet they are non-nutritive in nature and are often evaluated in conjunction with oral stereotypies. While the experiments were permitted to evaluate other parameters (i.e. weight gain, feeding behaviors), NNOB observation must have been recorded in relation to the imposed dietary treatment. Type of dietary treatments implemented was not restricted.

Given the small amount of research, all types of experimental designs were used, in addition to a multiple sample sizes and varying geographical locations. Studies had to be published in English and after 1970 in an effort to keep the literature relevant to modern modes of production.

Search and study selection

Four large databases, CAB Abstracts, AGRIS (OVID), Searchable Proceedings of Animal Sciences Conferences (SPAC) and Scopus were used in this review. Keyword search terms utilized in databases are outline in Table 1. All database searches were completed prior to September 2018.

Articles collected from the databases were uploaded into Rayyan QRCI (Ouzzani et al., 2016) and were evaluated based on abstract content and article title for inclusion. Upon identifying studies that would potentially meet the selection criteria, those studies were uploaded to a bibliography managing program to evaluate the full text against the inclusion and exclusion criteria. One reviewer was responsible for the inclusion of all articles while another was responsible for all search procedures.

Additional keywords that were not used in the first search were used to perform a second search in CAB Abstracts and all studies were evaluated using the previously described procedures. All selected studies were then searched by title in Scopus for the citing literature.

Data extraction process

Data extraction was performed using a standardized data collection form. The purpose of the form was to extract all dietary treatment and behavioral data from the studies as well as experimental information including experimental design and population characteristics. Data that was extracted from these articles focused on the performance of NNOB. Any production level data (i.e. average daily gain, feed intake, blood parameters) or additional behavioral data (i.e. aggressive behaviors, daily time budgets) were not collected. Dietary induced changes to NNOB performance were not considered significant or reported on unless $P \leq 0.05$.

Risk of bias assessment was performed using Joanna Briggs Critical Appraisal Tools (The Joanna Briggs Institute, South Australia). Given the wide range of experimental designs utilized in the study, both the checklist for randomized controlled trials and the checklist for quasi-experimental (non-random) studies were used. Modifications were made for each tool to better fit to animal-based studies. Two reviewers performed the risk of bias assessment.

Results

Upon completing the systematic search and article sorting based on the inclusion and exclusion criteria, a total of 22 articles were selected (Figure 1). Of these articles, 3 (Falerio et al., Phillip et al., and Webb et al., (2)) reported on 2 different studies, each using different experimental designs or treatments. In total, the search resulted 22 articles that presented information on 25 independent studies. All calculations for study demographics are carried out based on these 25 studies and research outcomes are evaluated by article.

Study demographics

The population of experimental animals that were evaluated in the studies are summarized in Table 2. The majority (88%) of the studies were performed using dairy cattle while only three of the reports utilized beef breeds (12%). The studies used a wide range of housing types, with individual housing (36%) and group housing (36%) being the most prevalent. Five dairy cow studies used tie stall barns (20%) which was considered the most restrictive form of housing, as animals in tie stalls, except for the movements associated with milking events, are not able to turn around and can only stand up and lay down. Two studies (8%) did not describe the housing environment. Sample size also varied across all studies (63.79 ± 15.54, range: 4 to 300). The majority of studies were performed in Europe (76%). One study was performed in Iran, China, Chile, and the United States, respectively.

The most frequently utilized study design was a randomized control trial (24%; Table 3). Other randomized design types included factorial (20%), block (16%) or Latin square (16%) designs. Non-randomized studies of various designs accounted for 32% of the studies. The number of treatments imposed (4.28 ± 0.57; range: 2 to 15) and the length of experimental period (125.91 ± 20.39 d; range: 9 to 399 d) varied across the selected studies. While some studies explicitly recorded the length of the experimental periods, some of the listed periods in Table 3 were approximations based on treatment length.

Behavioral recording methods

The studies employed a range of different behavioral recording methods and were unique in the behaviors that were measured (Table 4). The majority of studies examined the performance of object licking (80%), tongue rolling (88%) and bar licking (80%). Self grooming and allogrooming were recorded in 60% and 44% of reviewed studies, respectively. Ground licking and cross sucking were recorded in fewer studies (24% and 20%, respectively). One study recorded all 7 NNOBs, and all but one study recorded more than 3 types of NNOBs. Studies varied regarding whether they recorded each behavior individually or grouped all oral behaviors into a single behavioral category. Most studies utilized scan sampling to record their behavior data (88%). Both video recordings (48%) and live/direct observations (60%) were used to collect behavioral data.

Diet treatment types

Studies were categorized by the reviewer based on the type of diet treatment imposed on the animal subjects (Table 3). The two most prevalent dietary treatment categories included "roughage inclusion" (32%) and "total feed amount" (24%). Additional, less robust categories included "ingredient type" (12%), "mineral addition" (12%), "particle size" (8%), "feed presentation" (8%) and "rumen content" (4%). "Roughage inclusion" studies imposed treatments where the manipulated variable was the amount of roughage included in the diet, with the roughage type remaining constant. Studies evaluating "ingredient type" focused on feeding a wide array of feed stuffs, including roughages, concentrates, and by-products (e.g., dry distillers grains, sunflower meal). “Total feed amount” studies evaluated NNOB behavior through feeding differing amounts of rations, such as comparing *ad libitum* or restrictive feeding techniques, or by providing solid feed to animals that had previously only consumed milk replacer.

Results of selected studies

Treatment descriptions and treatment effects on NNOBs are summarized in Table 5. Results were grouped by treatment type and presented by article. All summarized results represent the statically significant changes ($P \leq 0.05$) in NNOB performance due to the imposed diet treatment. All behaviors were classified as NNOBs. Trends existed among the summarized results regarding the ability of treatments to cause, increase, or decrease NNOB performance. Overall, 14 of the articles (56%) illustrated that the diet treatment either positively or negatively affected NNOB performance. Of the 14 articles that reported an effect, 78% observed an increase in NNOB performance while 21% observed a decrease. From studies that increased NNOBs, 50% of them were due to restricting the amount of roughages that were fed. Inversely, studies that supplemented the subjects with more roughage or provided additional amounts of feed decreased NNOBs (29% of the 14 studies). Single studies observed increases in NNOB performance due to decreased feeder space per animal, lower levels of NaCl, smaller particle size, or low rumen content. Across all selected studies, 44% showed no effect of diet treatment on NNOB performance.

Risk of bias assessment revealed little risk of bias among the included studies (Figure 2). Randomized trials struggled on reporting observer blindness with only 5% reporting blindness. Majority of non-randomized control trials failed to disclose both pre- and post- intervention measurements (38% reported none with 38% being unclear). The majority of non-random articles could have used a random design but did not (63%), however, 100% of non-randomized studies succeeded in discussing proper cause and effect.

Discussion

Evaluation of results

Profitability of feedyard cattle operations is dependent upon animal productivity (efficiency in which feedstuffs are used) and animal health status. Therefore, cattle diets are designed to promote productivity during each stage of production (i.e., weight gain, gestation, milk production). In addition to promoting productivity, feedyard diets also have the potential to alter cattle behavior, including NNOB performance, by limiting rumination and prohibiting grazing, both of which can increase the risk of gastrointestinal discomfort. Studies evaluated in this systematic review quantified changes in NNOB performance with regard to the different diet treatments. Treatment types including ingredient type, particle size, feed presentation, mineral additional, and rumen content did not conclusively alter NNOB performance, as either none of the studies or only one study in each of those categories impacted NNOB performance. However, in the category of "roughage inclusion", all studies observed an effect of roughage amount (typically free access or restriction) on NNOB performance. Results from the studies suggested restricting roughage increased NNOB performance and providing additional roughage resulted in reduced NNOB performance. These results suggest that out of the all the type of diet treatments recorded, roughage inclusion may the most effective strategy to mitigate NNOB performance.

All 7 reports that evaluated roughage inclusion determined that the amount of roughage inclusion was capable of influencing (both positive and negatively) NNOB performance. Cattle provided any source of straw (Castell et al., 2012; Webb et al., 2013) or had straw reintroduced into their diet (Redbo et al., 1997) performed a fewer NNOB. Adjusting the roughage to concentrate ratio to include more straw also decreased NNOB performance (Webb et al., 2015). As predicted, removing roughage (Redbo et al., 1997) or providing no straw (Devant et al., 2016; Falerio et al., 2011) in the diet increased NNOB. High-grain diets, in conjunction with low-forage levels limit the amount of time cattle spend ingesting and ruminating. Rapid fermentation of grain feedstuffs reduces the re-masticated, therefore; decreasing the time of rumination and the amount of saliva produced (Moran, 2005). Bergeron et al. (2006) suggests that the lack of rumination causes increased NNOB performance, as cattle turn to behaviors such as tongue rolling and bar licking to cope with the lack of mouth movement required to be performed as part of rumination (e.g., mastication of the cud).

Non-forage ingredients and their level of inclusion had little effect on the performance of NNOB in the reviewed articles. Addition of sunflower meal, barley, corn or soybean meal had no effect on the performance of NNOB (Rotger et al., 2006). A similar lack of effect was seen when feeding different types of by-product feedstuffs. When straw, hulls (soybean and cottonseed) and beet pulp pellets were fed to beef steers, and none of the treatments increased or suppressed NNOB (Iraria, et al., 2012). These results suggest that NNOB performance is not significantly affected through changing the type of concentrates or by-products in a total mixed ration.

Total amount of feed fed to cattle does not conclusively alter NNOB performance. Restricting feed, by limit feeding (Redbo et al. 1996) or when feeding milk replacer without forage supplementation (Kooijman et al.,1991) increased NNOB performance. In contrast, Webb et al. (2012) observed increased NNOB's while feeding the highest total amount of feed at a rate of 27 g (vs. 0, 9, or 18 g). Three studies (Webb et al., 2013; Suarez-Mena et al., 2012; Morrisse et al., 1999) found that changing total feed amount did not elicit any effects on NNOB performance. The contradicting results of the studies highlights that total feed amount may have minimal effects on NNOB performance.

Feed particle size also appears to have the potential to effect NNOB performance. In the "particle size" category, one article observed an increase in NNOB performance when cattle were fed smaller particle forages (Montoro et al., 2013). Feeding forages with larger in particle size not only take up more space in the rumen, providing a greater level of fill, but larger particles have a longer passage time as they take longer for rumen microbes to degrade them. Thus, larger particles are kept in the rumen for a longer duration of time compared to than smaller particles of feed (Kammes et al., 2012). These findings suggest particle size may effect NNOB performance; however, another study reported that the length of forage cut had no effect on NNOB performance (Rahman et al., 2017). Cattle consuming forage at shorter lengths (over 50% of forage included in the total mixed ration was >19 mm) performed no more NNOB than those receiving long cut forage, suggesting that particle size has no effect on NNOB performance.

Feed presentation had variable on NNOB performance. Boga et al. (2009) examined cafeteria feeding (feeding all diet ingredients separately) versus total mixed rations and discovered that neither treatment effected NNOB performance. Verdu et al. (2015) concluded that bunk length (m/animal) and bunk depth (m) did affect NNOB performance. Cattle that consumed feed from single space feeders (lateral protections between animals and 0.15 m deep) or out of a bunk that was 0.6 m deep performed more NNOB than cattle consuming feed from a shallower bunk that was 0.15 m deep. Cattle consuming feed from a bunk feeder consume feed in meals, which causes changes in the rumen environment and behavioral patterns (Schwartzkopf-Genswein et al., 2003), which may include NNOB performance. Both the timing of feed delivery and the way feed is presented is different between pasture and confinement (mixed ration in a bunk system), thus these differences may contribute to the performance of NNOBs.

Similar to other result categories, “mineral addition” and NNOB performance presented inconclusive results. Huenchullan et al. (not recorded; NR) observed a decrease in NNOBs when providing cattle with tryptophan and tryptophan/vitamin E supplementation while adding mineral supplementation, 200g of NaCl/animal/d, increased NNOB performance (Phillips et al., 1999). These results provide little insight into if NNOB performance could be impacted by diet supplementation and more research is needed in this area.

Evaluation of studies

Irrespective of experimental results, the collected population data offers insight into the current state of research regarding the NNOB-diet relationship. Most importantly, this systematic review reveals the lack of research performed in beef cattle regarding NNOB performance. Among the articles collected, studies lacked continuity in housing type and animal age and failed to account for previous experiences, such as weaning strategy, when choosing a study population. Studies varied in sample size and experimental design; however, because so little research is done in NNOB performance, this was not a concern. All studies excelled in using sound methods to collected behavioral data and presenting behavioral results.

An area for improvement in NNOB research is to expand the research to include beef cattle. As dairy breeds and beef breeds differ behaviorally and received different diets in confinement, this likely results in different effects on NNOB performance. In addition to breed differences, housing varied across the studies. Not only are beef breeds housed differently than dairy, but the studies that used dairy breeds also se different housing. While some studies used group housing that allowed for social interactions, other studies used individual housing or tie-stalls that limited social and environmental interactions. For example, while Rebdo et al. (1996 and 1997) concluded that diet does effect NNOB performance, their population was housed in tie-stalls and that could have possibly contributed to onset of abnormal behaviors in addition to NNOB. Group size may also effect NNOBs. Previous research suggests that dairy calves housed in smaller groups display more tongue rolling behaviors than calves housed in groups greater than 10 (Leruste et al., 2014).

In addition to differences among breed and housing types, experiments varied in the weaning strategy or failed to disclose the weaning strategy used. Mason and Latham (2004) suggest that maternal depravation; either abrupt weaning, young age at weaning, early weaning or poor maternal care can influence the NNOB performance. Weaning at an early age across many species, including primates, rats and horses, induces a higher incidence of NNOB. Therefore, moving forward, accounting for weaning method should be included in the evaluation of NNOB performance.

Assessment of risk of bias suggests that the majority of studies present very little risk of bias. However, in the analysis of randomized trials, behavioral observers were not disclosed as trained, validated, or blinded to treatment. This is an area of concern as non-blinded observers may bias their observations toward treatment groups. Five studies used a non-randomized design when using a random design would have been more appropriate. It was likely that some of the studies assessed as non-random designs were in fact randomized, but without explicit statement of randomization; however, they cannot be considered random designs. Non-randomized studies also lacked clearly taking measurements pre- and post- intervention, signaling possible concern for the validity of the findings.

Evaluation of systematic review

This systematic review searched a wide range of databases to gather studies that evaluated the effects of diet on NNOB performance in cattle. Subgrouping the dietary treatments presented in the articles allowed for concise and straightforward evaluation of results. However, only 22 articles were evaluated. A weakness of this systematic review was the lack of reviewers. Only one researcher viewed all the articles and therefore, bias could be present regarding the inclusion of certain articles. A second researcher performed the searches and aided in composition of the systematic review and an additional reviewer aided in the risk of bias assessment. One reviewer determined the articles that were used.

Implications for future research and the cattle industry

Stereotypies, which includes oral stereotypies like NNOB, are thought to be performed in frustration or as a coping mechanism when the environment and/or management practice limits an animal's ability to meet behavioral needs (Mason, 1991). While NNOB performance has not been documented to be associated with productivity or physiologically important factors (e.g., weight gain or reproductive success) the performance of NNOBs is able to serve as a possible indicator of behavioral frustration by cattle housed in confinement. Animal welfare is typically evaluated on the basis of three factors including biological functioning, affective states, and natural behaviors (Fraser et al., 1997). To achieve optimal welfare, all factors must be considered and stereotypies, including NNOB performance, can be an indicator that animals are experiencing frustration from the inability to perform the natural behaviors.

Conclusion

Through the systematic review of 22 articles, dietary treatment of "roughage inclusion" was the only dietary-based treatment observed to conclusively impact NNOB performance in cattle. This finding is well supported, as feedlot diets typically contain low levels of roughage and high levels of grain, which reduces the amount of rumination performed by cattle. All other dietary treatments (feed particle size, mineral addition, total feed mount, rumen content, ingredient type, feed presentation) evaluated in this review did not conclusively alter NNOB performance, suggesting one of two conclusions. Firstly, roughage inclusion is the only treatment able to effect NNOB performance and changing other aspects of the diet may not affect the level of NNOB performance in cattle or secondly, that NNOB performance is motivated by factors other than just diet alone, like social structure, housing environment, or previous animal experiences. Further research must be conducted on the NNOB perfomance in cattle to determine the true cause of these seemingly extraneous oral behaviors. Additionally, the questions must be posed to the industry as to whether NNOB performance should be mitigated or used as a behavioral proxy for determining if cattle have an unfulfilled dietary or environmental need.

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CHAPTER III

IMPACT OF DIETARY CORN STALK INCLUSION ON THE PERFORMANCE OF NON-NUTRITIVE ORAL BEHAVIORS BY DRYLOT-HOUSED BEEF STEERS

Introduction

Ungulates housed in confinement may develop stereotypic oral behaviors. These behaviors typically manifest as a response to high levels of animal frustration associated with being unable to fulfill a behavioral need (Mason, 1991). Non-nutritive oral behaviors (NNOB) are often classified as oral stereotypies because they are characterized by repetitive movements using the mouth, lips or tongue and appear to lack a direct biological function (Bergeron et al., 2006). However, a limited amount of research has been dedicated to investigating the dietary based motivators behind NNOB performance by cattle housed in confinement. High-concentrate, low-forage diets fed to cattle in confinement change the ruminal environment (Schwartzkopf-Genswein et al., 2004) and limit the duration of time cattle spend ruminating and acquiring food (Salfer et al., 2018). Due to the changes in the duration of time spent using their mouth or the internal changes in response to dietary changes, cattle may be engaging in NNOB to either cope with the unfulfilled need to use their mouth or to alleviate gastrointestinal discomfort.

While grazing on forages, cattle will consume feed for up to 9 h per day (Mason and Rushen, 2006). Cattle housed in feedyards are unable to graze and are fed in bunks at specific times. This management strategy reduces the duration of time spent eating and the frequency of meals eaten per day when compared to when cattle are housed on pasture (Redbo et al., 1996). In addition to adapting to meal feeding, cattle must adapt to a high-concentrate diet when they enter a confined feeding environment. High-concentrate, low-roughage diets increase ruminal fermentation rate and the diets contain primarily small particle sized grains, both factors that stimulate a decrease in rumen pH (Schwartzkopf-Genswein et al., 2003). As a result, the time spent ruminating and chewing that is required to digest the feedstuffs decreases, resulting in a reduction in saliva production (Abijaoude et al., 2000).

Saliva is a buffer that contains bicarbonates and phosphates that neutralize the acidic rumen pH when swallowed (Sauvant et al., 1999). Due to the shortened duration of chewing and ruminating as a result of consuming high grain diets, saliva production decreases (Hibbard et al, 1995). Limited forage in the rumen coupled with a lack of salivary buffer can potentially cause gastrointestinal discomfort that could impair animal welfare. For example, rumenitis, the inflammation of the rumen caused by low rumen pH, can create long term health issues through the development of gut lesions and rumen bacteria infecting organs (i.e. lungs, liver) (Nocek, 1997). Further, rumenitis is a hypothetical contributing factor to the development of liver abscesses, a major health and economical issue in beef cattle feedyards.

The objective of this study was to evaluate the impact of roughage content on the performance of rumination and NNOBs (tongue rolling and bar licking) in beef steers. The hypothesis was that cattle that are fed diets higher in roughage content will perform fewer NNOBs and ruminate more, since higher roughage contents will cause cattle to spend more time ruminating and fulfilling that behavioral need.

Materials and methods

All procedures completed during this study were approved by the West Texas A&M University Cooperative Research, Education and Extension Animal Care and Use Committee (approval # 01-19-17). The study lasted from November 2017 to July 2018. All behavioral observations and data for this portion of the study were collected between d 0 to d 66.

Animals and environment

Continental crossbred steers (n = 54) were shipped to Texas A&M Agrilife Research feedyard in Bushland, Texas and were weighed upon arrival. Cattle were then blocked by body weight into light (284 ± 13.75 kg) and heavy (321 ± 12.97 kg) groups and randomly assigned to one of three dietary treatments within block. Cattle were housed in 6 pens, each equipped with 9 Calan gates (American Calan, 1997). Each pen was 25.5 × 7 m (19.83m^2 per animal) with dirt flooring. Shade was provide over the Calan gates with a partial roof covering (5 × 7 m; 5m^2 per animal). Cattle were provided *ad libitum* access to water. Cattle were checked daily by caretakers for any signs of compromised health; however, no cattle were treated for illness throughout the duration of the study.

Prior to the implementation of the diets, cattle were trained to use the Calan gate system for 50 d. Three diet treatments differing in corn stalk inclusion (Table 6) were fed in all 6 pens. Cattle were fed once daily by hand between 0800 and 1100.

Behavioral observations

Cattle behavior was decoded from video recordings on d 0, 1, 2, 3, 4, 6, 10, 18, 34, and 66 relative to diet treatment implementation, using a 9 camera video recording system with digital video recorder (model SDH-C85100BF; Samsung, Ridgefield Park, New Jersey). Cameras were placed to ensure no blind spots occurred and cattle behaviors were recorded from 0800 to 1730 on all observations days for all pens. Behavioral data collection was performed by 23 trainer observers. The same individual trained all observers and the inter-rater reliability between observer, the trainer, and other observers was no less than 95% accuracy. The BORIS System (Version 6.1.; Friard and Gamba, 2016) was used to view video recordings and decode the frequency and duration of tongue rolling and bar licking bouts for individual animals.

Tongue rolling was described as an animal having "an open mouth with extended tongue repeatedly moving in and out and/or side-to-side". Tongue rolling was also characterized by repetitive side-to-side head motion. Bar licking was described as the steer having "direct contact to the bars of the pen" with its mouth.

Rumination and activity duration was collected using rumination collars (HR Tag; SCR Dairy, Netanya, Israel) applied to each individual. Rumination was detected by the passage of feed boluses though the esophagus and activity was detected by the animal moving.

Statistical analysis

All statistical analysis was performed using SAS v.9.4 (SAS Institute, Cary, NC). Bar licking and tongue rolling frequency and duration were square root transformed for normality. The relationship between diet, day, behavior frequency, and behavior duration was analyzed using a Generalized Linear Mixed Model (PROC GLIMMIX) with a Bonferroni's adjustment. The model accounted for the random effects of pen, diet, and individual animal with the fixed effect of dietary treatment. Orthogonal contrasts were used to analyze the linear and quadratic effects of corn stalk inclusion on rumination duration and activity duration. The relationship between NNOB performance and rumination and activity duration was evaluated using a linear regression (PROC REG). Correlations (PROC CORR) were performed to determine the association between average daily gain (ADG), dry matter intake (DMI), gain to feed ratio (G:F), and NNOB duration and frequency.

One steer was removed from the study prior to diet implementation and two additional steers were removed due to rumination collar malfunctions. Those individuals were not included in the data analysis.

Results

Percentage of corn stalk inclusion (5, 10, or 15%) did not affect (*P* = 0.13) the duration or frequency of tongue rolling or bar licking bouts (Table 7). Neither linear (P = 0.27) nor quadratic (P = 0.16) effects of corn stalk inclusion were detected for rumination or activity duration. Rumination and activity time did not differ by diet treatment during the observation period (Table 7). There was no interaction between experimental day and treatment for bar licking and tongue rolling duration (*P* = 0.37 and *P* = 0.97, respectively) or bar licking and tongue rolling frequency (*P* = 0.65 and *P* = 0.99, respectively). However, duration and frequency of tongue rolling and bar licking bouts were affected by experimental day (*P* < 0.01), in which tongue rolling frequency and duration increased and bar licking frequency and duration decreased over time (Figure 3).

As the duration of time spent ruminating increased, the duration of time engaging in tongue rolling decreased (β = -2.22, *P* < 0.001; Figure 4). Duration of time engaged in bar licking was unchanged. As the duration of time recorded as active by the activity sensor increased, the time engaged in bar licking and tongue rolling increased (β = 1.03, *P* < 0.01 and β = 0.96, *P* < 0.01, respectively; Figure 5).

Mean ADG (kg), DMI (kg) and G:F across all individuals for the observation period were 1.17, 6.9 and 6.00, respectively. Individual animal tone rolling or bar licking frequency were not associated with ADG (*P* = 0.39, *P* = 0.85), DMI (*P* = 0.13, *P* = 0.90) and G:F (*P* = 0.67, *P* = 0.56).

Discussion

Provision of corn stalk in the diet as the roughage source did not affect the frequency or duration of tongue rolling, suggesting that while previous research states that NNOB performance is impacted by roughage inclusion (treatments provided free access or restricted roughage access; Redbo et al., 1996), this study did not produce similar results. Production measures (ADG, DMI and G:F) were not associated with NNOB performance, but NNOB performance may be affected by the duration of time cattle spend ruminating and their level of physical activity. Rumination displayed a negative relationship with tongue rolling while activity displayed a positive relationship with both bar licking and tongue rolling. Duration and frequency of tongue rolling and bar licking changed across the observation period, with tongue rolling increasing as cattle moved through the feeding period.

Contrary to a previous study (Gentry et al., 2016), rumination was not impacted by roughage level during the observation period. The range in roughage level was realtivtly small (5-15%) dietary treatments in this study and there may have not been a large enough difference in roughage content to elicit changes to NNOB performance by diet. Previous research that studied the concept of providing straw or no straw when feeding a high grain diet suggests that altering roughage levels affects NNOB performance (Redbo and Nordblad, 1997). Similarly, limited roughage affects NNOB, as cattle who consumed diets comprised of pasture forages engaged in less oral stereotypic behaviors than their confined housing counterparts (Ishiwata et al., 2007). Diets that contain large amounts of high-energy concentrate that offer low levels of fiber and small particle size are rapidly digested (Owens and Basalan, 2016). The low fiber content in the grains of feedyard diets decrease the amount of time animals need to masticate (Krawczel, 2016). Increasing the roughage (or fiber) content of a diet increases rumination time

(Gentry et al., 2016) and supplying *ad libitum* or increased levels of roughage in dairy cattle diets reduced NNOB performance (Rebdo et al., 1996).

Lack of rumination is a key hypothesis for the cause of NNOB performance in captive ruminants (Bergeron et al., 2006). Compared to grazing counterparts, cattle housed in a feedyard environment spend less time ruminating, as less time is required for cattle to re-masticate ingesta because the standard feedyard diet composition differs from pasture. While cattle on pasture spend up 12.7 h/d grazing (Arnold, 1984) and up to 10.2 h/d ruminating (Kilgour, 2012), cattle housed in feedyards change their time budgets resulting in spending an average of 4.32 ± 10.23 h/d eating and 3.8 ± 9.36 h/d ruminating (Wolfger et al., 2015). Similarly, cattle in this study spent an average of hours ruminating. Animals may perform stereotypic behaviors to alleviate frustration from an unfulfilled behavioral need from not being able to perform behaviors that they are motivated to perform (Mason, 1991), such as ruminating in cattle (e.g., masticating the cud, repeated chewing motions with the mouth). Cattle have been observed to perform behaviors like tongue rolling to fulfill their behavioral need to use their mouths (Van Os et al., 2018). Irrespective of diet, individual animals in this study that engaged in rumination less spent more time engaged in tongue rolling, further supporting that a reduction in rumination time is counterbalanced with NNOB performance.

A positive relationship was observed between the duration of time engaged in activity as reported from the sensors and the duration of time engaged in NNOB performance. Non-nutritive oral behaviors have also been hypothesized to be a behavior that feedlot cattle engage in to fill the time they would spend roaming and ruminating if they were housed on pasture (Ishiwata et al., 2007), suggesting that activity levels and NNOB performance have an inverse relationship. Contrary to expectations, this relationship was not observed in this study; rather, animals that were physically active were more orally active as well. No previous research on the NNOB-activity relationship has been reported using the automatic detection of activity levels with collar technology. Previous research suggests that collar-based activity monitors are less accurate in detecting certain behaviors (e.g., lying) and calculating the duration of time spent walking compared to sensors attached to the leg (Elischer et al., 2013). Performance of tongue rolling and bar licking may incorporate physical movements that are similar to the movements the sensor is trained to recognize as activity and classifies those behaviors as activity, which could have contributed to the positive relationship between activity level and NNOB performance. The activity monitors were located on the neck, and both tongue rolling and bar licking are characterized by head movements, therefore NNOB performance may have been artificially inflated the actual activity levels reported by the sensors.

The relationship among NNOB performance and productivity measures (i.e. ADG, DMI, G:F) have not been previously evaluated in beef cattle. Quantifying the direct impact of NNOB performance without considering factors such as diet and feeding behavior is difficult, as they greatly impact productivity measures, irrespective of NNOB performance. Diets formulated for growth in feedyards are typically high-grain and low-forage diets to achieve optimal ADG. Low-forage diets may induce oral stereotypies, and therefore, ADG and oral stereotypies would be expected to display a negative inverse relationship. However, that was not observed in this study.

Non-nutritive oral behavior performance was influenced by day and tongue rolling increased over time. The daily pattern of NNOB performance is diurnal with the highest incident of NNOB performance occurring around time of feeding (Ishiwata et al., 2007; Redbo, 1990). However, less is understood regarding NNOB performance over time. Non-nutritive oral behavior performance has not been observed to change over a long span of time (e.g., from spring to autumn; Rebdo, 1990), yet animal-environmental interaction (e.g., bar licking and ground licking) have been observed to decrease over a 5-week period after arrival at a feedyard (Daigle et al., 2018). No consideration has been given to if beef cattle housed confinement may perform different levels and types of NNOB as they habituate to their housing environment and diet. Results from this study show that tongue rolling increased over time, signaling a challenge to homeostasis, potentially caused by frustration associated with the inability to meet behavioral needs. Bar licking did not show any pattern over time (with the exception of a large drop on d6, of which the cause is unknown), suggesting that bar licking may not be an indicator of environmental or dietary frustration. Bar licking has been observed to be altered more by the provision of environmental enrichment than diet (Park et al., 2019), and thus may have a different motivation (e.g., boredom vs. frustration).

Conclusion

The duration of time engaged in NNOB performance is influenced by the duration of time spent ruminating and performing physical activity and the performance of NNOBs was variable across the feeding period. Rumination and NNOB performance displayed an inverse relationship, suggesting that cattle are performing to NNOB to cope with the shortened duration of time spent ruminating as a result of diet. Activity was positively related to NNOB performance, suggesting that either individual cattle that perform NNOB are also the most active in the pen, or that the rumination collar technology was interpreting NNOB performance as activity. Study findings suggest that NNOB performance is not impacted by diet nor are NNOBs associated with productivity within the context of a relatively small treatment difference in roughage content. Previous research concluded that NNOB performance was effected by dietary roughage levels; however, this study did not support those results, as dietary treatments in this study may not be different enough to elicit a behavioral response. Additional research is needed on long-term NNOB performance pattern by cattle housed in confinement to better quantify the cause of NNOBs and to determine the impact of NNOB performance on cattle welfare. Although no production gains were associated with NNOB performance, both researchers and producers should consider NNOB performance as a possible positive coping mechanism signaling that animals are adapting with the transition to from pasture to confinement.

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CHAPTER IV

EFFECT OF LIVE YEAST AND WHEAT SUBSTITUTION ON THE PERFORMANCE OF NON-NUTRITIVE ORAL BEHAVIORS BY DRYLOT-HOUSED BEEF STEERS

Introduction

Adding live yeast to feeder cattle diets is a growing trend in the beef industry. Previous research suggests that live yeast may regulate an acidic rumen, mitigate harmful rumen conditions, and provide extra energy to cellulolytic rumen bacteria (Swyers et al., 2014; Magrin et al. 2018; Wiedmeier, et al., 1987). Much of the research performed on live yeast supplementation presents inconclusive results regarding production effects and the relationship between dietary live yeast and behavior remains unelucidated. Previous evaluation of the yeast-behavior relationship suggests that yeast shortens the duration of time spent eating, decreases meal size, and lengthens the duration of time spent ruminating (DeVries and Chevaux, 2014). In contrast, Ovinge et al., (2018) observed that steers fed live yeast did not change their ruminating, eating, drinking, resting or chewing activities. Dietary live yeast has been observed to affect behaviors other than feeding, including grooming behaviors and lying postures (Magrin et al., 2018).

Live yeast has the potential to effect the performance of rumination and feeding behaviors, yet little is known regarding the effect of live yeast supplementation on other orally centered behaviors, such as non-nutritive oral behaviors (NNOB). Bergeron et al., (2006) suggests NNOB performance is a stereotypic coping mechanism cattle develop in response to changes in feeding mode (e.g. grazing vs. eating), duration of time spent acquiring nutrients and ruminating (e.g. longer duration on pasture), and diet composition. The aim of this study was to quantify the effect of live yeast supplementation on NNOB performance in beef cattle being fed a diet high in rapidly fermentable grains.

Materials and methods

Animal and housing

Forty-eight Angus crossbred steers were shipped to Texas A&M AgriLife Beef Cattle Systems in College Station, Texas. Upon arrival, all animals were randomly assigned to 1 of 4 groups and fitted with a visual ear tag and electronic ID tag. Within each group, 6 animals were randomly selected to be fitted with a unique colored identification collar. Steers fitted with a collar (n = 24) served as the sample population for behavioral observations. Cattle were weighed upon arrival (333 ± 12.6 kg) and body weight and exit velocity were recorded weekly across the duration of the study. The entire experiment period, from arrival to the last day of behavioral observations, lasted 107 days. All experimental procedures were approved by Texas A&M AgriLife Research Animal Care and Use Committee (AUP 2018-018A).

Each group was housed in 1 of 4 pens. Each pen was equipped with 3 Growsafe System bunks (Growsafe Systems Ltd, Calgary, Alberta) and provided 22.3 m^2 of dirt flooring and 6.1 m^2 of shade/animal. An automatic water trough provided *ad libitum* access to water. Cattle were rotated weekly among the four pens to minimize the potential for environment being a confounding factor.

Diet treatments

Cattle were fed three times daily at 0800, 1100 and 1600. Each day, the amount of feed was adjusted for previous daily intake levels. High forage, grower diets were initially provided on d -98 and the percentage of grain slowly increased over time by decreasing the levels of a high-forage diet and increasing the amount of a high-grain diet (Table 8). Cattle were on a full high grain, finishing diet three weeks prior to implementing the wheat substitution diet treatments; therefore, all observations occurred while the cattle where on a finishing diet.

Each group was randomly assigned to 1 of 4 dietary treatments in a 2 × 2 factorial-repeated measures design. Factor one was the feeding of a high-concentrate diet with live yeast (YE; *Saccharomyces cerevisiae* strain I-1077 at 8×10^{10} cfu/d; Lallemand Animal Nutrition, Levucell, SC) or without live yeast (NY). The second factor was the substitution of wheat into the diet, where either wheat replaced 20% of the steam flaked corn (WHT) or the diet remained unchanged (NOWHT). Therefore, the 4 diet treatments were 1) YE-WHT, 2) YE-NOWHT, 3) NY-WHT and 4) NY-NOWHT. Cattle receiving wheat substitution also experienced an induced disruption in intake pattern by being fed alternations of 120% and 80% of their previous daily intake. Yeast supplementation was provided to cattle in the yeast treatments beginning on d-98 through the end of the study while wheat substitution commenced on day 0 of the study and continued until day 7. Starting on day 8, cattle returned to consuming a diet without wheat substitution while still receiving yeast supplementation.

The GrowSafe system recorded feeding frequency, feeding duration, amount of feed consumed per feeding bout (meal size) and total intake per day for each individual animal for each day throughout the experimental period.

Behavioral recording

Live focal observations were conducted from 0800 to 1030 and 1430 to 1700 on day -19, -15, 1, 2, 3, 5, 6, 8 and 9 relative to wheat substitution. Each observer watched 2 pens at alternating 10-min intervals, thus, each pen was observed for 120 min/d. Observers viewed the pens from a raised platform that was located across an alley at the back of the pen. Live observations had been conducted on these animals for 6 d prior to study commencement;

therefore, the cattle were habituated to observer presence. All observers (n = 9) were trained and validated by a single individual. All behaviors (Table 9) were recorded for duration and frequency.

Statistical analysis

Summary statistics for behavioral and feeding data were recorded (Table 10). All analyses were completed using SAS v9.4 (SAS Institute Inc, Cary, NC).

Frequency of tongue rolling, bar licking and ground licking bouts per day were evaluated throughout the entire experimental period were evaluated by treatment using a non-parametric chi-square test. The impact of experimental day on the performance of all NNOBs (sum of ground licking, bar licking and tongue rolling) by treatment was also evaluated using a chi-square test (PROC FREQ). Individual behavior bouts, ground licking, bar licking and tongue rolling, were evaluated for effect of experimental day, regardless of treatment, using a PROC FREQ chi-square test followed by a post-hoc pairwise comparisons being evaluated using PROC GENMOD with a Poisson distribution utilizing Bonferroni's adjustment.

The relationship between GrowSafe feeding behaviors (bunk visit frequency, feeding duration, amount of feed consumed per feeding bout and total dry matter intake) and NNOB bouts per animal per day were evaluated using a linear regression (PROC REG).

Results

Frequency of bar licking or ground licking was not significantly effected by diet treatment ($P = 0.93$ and $P = 0.13$, respectively). However, the inclusion of live yeast in wheat-based the diet impacted frequency of tongue rolling (Figure 6). Cattle fed the NY-WHT diet performed tongue rolling more frequently than cattle fed YE-NOWHT, YE-WHT or NY-NOWHT diets ($P = 0.05$).

At the individual animal level, regardless of dietary treatment, feeding frequency, did not affect the performance of tongue rolling, bar licking or ground licking (Figure 7). Amount of feed consumed per feeding bout decreased as the frequency of tongue rolling bouts increased (P = 0.05; Figure 8a). Daily intake (Figure 8d) and feeding duration (Figure 7d) decreased as the frequency of tongue rolling bouts increased (P = 0.03 and P = 0.05, respectively). Amount of feed consumed per feeding bout, total daily intake, and feeding duration were not associated with bar licking or ground licking.

Treatments differed numerically in the total number of NNOB bouts performed of across the different experimental days (Figure 9). Irrespective of treatment, tongue rolling, bar licking and ground licking differed by day (P = 0.02, P = 0.03 and P = 0.04, respectively) with bar licking decreasing over time (Figure 10).

Discussion

Effects of dietary live yeast supplementation on productivity are inconclusive, although benefits such as increased immunity, lessening the effects of heat stress, and improving the composition of the rumen microbiome have all been identified as benefits to live yeast supplementation (Broadway et al., 2015). This study highlighted the potential for live yeast supplementation to alter tongue rolling performance in beef cattle. Cattle receiving no yeast and wheat substitution performed more tongue rolling on average than cattle who received YE-WHT, YE-NOWHT and NY-NOWHT when fed wheat across the entire experimental period, suggesting yeast may play a role in NNOB performance. Results also showed the NNOB performance may be performed in relation to intake levels, consumption patterns, dietary changes or dietary-based time budgets (e.g., duration of time spent eating, grazing, ruminating on pasture compared to in a feedlot) our results show that as cattle decreased feeding bout duration and daily intakes decreased, tongue rolling increased.

Non-nutritive oral behaviors have been classified as a form of stereotypic behavior in captive ungulates, which rely on grazing or browsing as a key element of their natural behavioral repertoire. While stereotypic behaviors are deemed to have no direct impact on biological functioning, previous research suggest stereotypic behavior can be a behavioral indicator of sub-optimal environments or high levels of frustration, as animals across all taxa may use various stereotypic behaviors to cope with housing and dietary based challenges (Mason, 1991). Current hypotheses suggest cattle may perform to oral stereotypies, or NNOB performance, to cope with sub-optimal conditions including restrictive housing (e.g., tie stalls; Redbo, 1992), weaning methods (Mason and Latham, 2004), diets that are devoid of adequate forages (Bergeron, 2006), or limited duration of time spent eating (Redbo and Nordblad, 1997). Standard high-grain diets fed to feedlot cattle results in less time ruminating and grazing compared to pasture environment (Abijaoude et al., 2000). This reduction in time needed to acquire and process nutrients leave cattle with an unfulfilled temporal motivation to use their mouth (e.g., they are motivated to use their mouths for longer than is needed to consume their diet). Feedyard diets also challenge the ruminal environment (i.e. lowering ruminal pH, increasing fermentation rates in the rumen; Schwartzkopf-Genswein et al., 2003) which has the potential to cause gastrointestinal discomfort. Cattle may begin performing NNOB to cope with these physiological discomforts (Lambton and Mason, 2006) as the movement of the mouth produced saliva that acts as a buffer in the rumen (Maekawa et al., 2001). While NNOB performance has been hypothesized to be a coping mechanism for the changes in time and effort required to acquire and process nutrients, rumen modifiers, such as live yeast, are designed to help cattle cope with these challenges. Diet based strategies such as increasing roughage levels (Redbo et al., 1996), increasing particle size (Monotro et al., 2013) and changing bunk size (Verdu et al., 2015) have all been used in attempt to decrease NNOB performance.

The effect of live yeast supplementation on feeding and rumination behaviors has yielded mixed results. Dairy cows fed diets supplemented with live yeast consumed shorter, and more frequent meals and ruminated more than control cows (DeVries and Chevaux, 2014; Dias et al., 2017), suggesting yeast stabilized the rumen environment and has the potential to mitigate gastrointestinal discomfort. However, live yeast supplementation did not change rumination or eating behaviors of Angus steers (Ovinge et al., 2018). An additional study observed that when dairy cows were fed high or low-starch diets in conjunction with live yeast , live yeast did not alter the total duration of eating (Dias et la., 2017). Margin et al. (2018) observed a similar lack in effect of live yeast on time eating and ruminating; however, beef bulls fed live yeast did spend a longer amount of time lying, drinking and engaged in licking the pen structure less than control bulls. Live yeast, when combined with an acidogenic diet or a grazing diet, did not alter rumination time (Ambriz-Vilchis et al., 2017). Therefore, it can be concluded, that while well researched, the impact of live yeast supplementation on the feeding, rumination and oral behaviors of cattle is has not been fully determined.

Cattle consuming the NY-WHT diet performed more tongue rolling bouts, suggesting that the absence of yeast while feeding wheat may have influenced the performance of tongue rolling. Dietary wheat inclusion can cause digestive upset as wheat provides a higher risk for acidosis and requires more time for ruminal adaptation compared to other grains as wheat starch is more rapidly fermented than corn starch (Kniffen and Comerford, 2014). Wheat grain has a small particle size and is typically fed in conjunction with low forages. Previous research has observed that consuming small particle-sized feeds limits the duration of ruminating (Wolfger et al., 2015). Diets with a higher proportion of wheat can potentially increase digestibility, causing rapid fermentation, and lowering the minimum rumen pH compared to corn based diets (Liu et la., 2016). Rapid fermentation rate and instability of rumen pH associated with feeding small grains can lead to a disruption of feeding patterns and rumen stability, all which may have contributed to higher NNOB performance as a coping mechanism in the absence of yeast while experiencing wheat substitution.

Irrespective of diet, the performance of tongue rolling, bar licking and ground licking varied across the experimental days. Large fluctuations in the performance of bar licking and ground licking may have been attributed to weather events, as rain occurred on day 5, which coincided with the lowest performance of bar licking. Furthermore, tongue rolling remained consistent regardless of weather events, suggesting that the performance tongue rolling may be in response to internal motivation while the performance of bar licking and ground licking are more responsive external factors. Dietary treatments did not differ on any particular experimental day. This is unlike the oral behavior patterns observed by Redbo et al. (1996), in which NNOB performance varied greatly between different roughage level treatments during differing experimental periods. Daily circadian behavioral patterns were not evaluated in this study, as behavioral observations were classified as “morning” or “evening”, not by hour.

Relationships among NNOB performance and electronically captured feeding behaviors were characterized in this study. Cattle are highly motivated to use their mouths (Van Os et al., 2018) and the diets and mode of feeding in confinement limit the amount of time animals spend consuming feed. In turn, cattle increase the amount of time engaged in oral stereotypies to cope with this unfulfilled behavioral need (Van Os et al., 2018). Irrespective of diet treatment, cattle that spent less time consuming feed performed tongue rolling more frequently. Cattle that consumed smaller meals performed more tongue rolling, suggesting that cattle may be using tongue rolling to compensate for the shortened duration of time spent associated with active engagement in foraging and grazing behaviors. A similar negative relationship has been observed between feeding time budgets and tongue rolling in other studies, in which cattle that ate more frequently did not perform any tongue rolling (Ishiwata et al., 2008). At the individual animal level, there was a negative association between average daily intake and tongue rolling frequency where cattle that ate more tongue rolled less frequently. These results provide further support the hypothesis that gut fill impacts NNOB performance (Bergeron et al., 2006), and, suggests that the reduction in time cattle spend consuming feed in confinement contributes to the performance of NNOBs to fill a behavioral need.

Conclusion

Live yeast supplementation was able to induce a behavioral response by beef cattle, but only upon wheat substitution. Cattle experiencing a 20% wheat substitution while receiving no yeast in the diet performed higher frequencies of tongue rolling than cattle that were provided yeast or did not undergo a 20% wheat substitution to their diet. Experimental day, irrespective of diet, did impact the amount of tongue rolling, bar licking, and ground licking performed by cattle, where each day was highly variable in NNOB performance. Tongue rolling also exhibited a negative relationship with some feeding behaviors regardless of diet. It was observed that as individual feeding duration and daily intake increased, tongue rolling decreased. Similarly, a negative relationship was shown with meal size, where individuals that consumed smaller meals performed more tongue rolling bouts. Previous research on the behavioral impact of live yeast supplementation of beef cattle has yielded inconclusive results, however, this study may support the hypothesis that yeast can decrease NNOB performance when fed during a dietary change. Further investigation into the behavioral impact of yeast on cattle, the relationship between NNOB performance and feeding behavior and the changes in NNOB performance across time is needed to solidify these findings.

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CHAPTER V

CONCLUSION

The performance of NNOBs in beef cattle may have multiple dietary-based motivators. Standard feedyard diets consumed by beef cattle require relatively shorted durations of time to consume and ruminate and can potentially alter the rumen environment. Cattle may perform NNOBs to compensate with their unfulfilled behavioral needs or to alleviate any gastrointestinal discomfort experienced. Providing adequate dietary roughage to cattle has the ability to mitigate NNOB performance. Despite the lack of differences in NNOBs performed by cattle consuming different levels of dietary stalk inclusion, feed additives such as live yeast may mitigate NNOBs in cattle that are consuming high grain diets. Cattle engaging in higher levels of rumination perform less NNOBs, suggesting that NNOB performance may occur in the absence of adequate time spent ruminating. Furthermore, NNOB performance may also increase in response to changes in feeding behavior, as cattle were observed to perform higher levels of NNOBs when spending less time eating and consuming less feed per meal. While activity was observed to increase with NNOB performance, however, further validation of collar technology is needed to better understand this relationship. While NNOB performance tended to increase over the experimental period, more research is needed to quantify the long-term performance of NNOBs in beef cattle. In conclusion, as more concern grows around the welfare state of beef cattle in confinement, both producers and research should consider observing NNOB performance as an indicator of if the diet and environment in feedyards are meeting the behavioral needs of cattle.

APPENDIX A
CHAPTER II TABLES AND FIGURES

Table 1. Search details for Cab Abstracts and SPAC

CAB Abstract search terms	SPAC search terms
(tongue adj2 roll*).ti,ab.	(cow* or cattle* or bull*)
(bar adj2 (chew* or gnaw*)).ti,ab.	(feed* or diet* or nutrition*)
(nonnutritive adj2 (mouth* or tongue)).ti,ab.	(tongue roll or bar chew* or bar gnaw* or crosslicking or interlicking or intersucking or licking or Allogrooming or stereotypies)
(self adj1 suck*).ti,ab.	
(crosslicking or interlicking or intersucking or licking).ti,ab.	
Allogrooming or stereotypies).ti,ab.	
(cow* or cattle or bull*).ti,ab.	
(feed* or diet* or nutrition*).ti,ab.	
Calves.ti,ab.	
(nonnutritive adj2 (oral* or mouth*) adj2 behav*).ti,ab.	
Limited to 1970-current and English	

Table 2. Population, location and animal type used in all studies

Author (year)	Cattle Type	Housing type (#/pen if group housed)	Sample Size	Geographical location
Dairy Cattle				
Boga, et al. (2009)	Calf	Individually housed	20	Turkey
Castells, et al. (2012)	Calf	Individually housed	179	Spain
Devant, et al. (2016)	Bull	Individually housed	24	Spain
Falerio, et al. (a) (2011)	Heifer	Individually housed	8	Spain
Falerio, et al. (b) (2011)	Calf	Group housed (6)	48	Spain
Kooijman, et al. (1991)	Calf	Group housed (6)	90	Netherlands
Lindstrom, et al. (2000)	Cow	NR (not recorded)	12	NR
Mirzaei, et al. (2016)	Calf	NR	60	Iran
Montoro, et al. (2013)	Calf	Individually housed	20	Canada
Morrisse, et al. (1999)	Calf	Individually housed	63	France
Phillips, et al. (a) (1999)	Calf	Individually housed	16	Estonia
Phillips, et al. (b) (1999)	Cow	Tie stall	36	Estonia
Redbo, et al (1) (1996)	Cow	Tie stall	37	Sweden
Redbo, et al (2) (1997)	Heifer	Tie stall	48	Sweden
Rotger, et al. (2006)	Heifer	Tie stall	4	Spain
Suarez-Mena, et al. (2012)	Heifer	Tie stall	8	USA
Verdu, et al. (2015)	Calf	Pair housed	240	Spain
Webb, et al. (1) (2012)	Calf	Group housed (3)	48	Netherlands
Webb, et al. (2-a) (2015)	Calf	Group housed (5)	160	Netherlands
Webb, et al. (2-b) (2015)	Calf	Group housed (5)	40	Netherlands
Webb, et al. (3) (2017)	Calf	Individual and group	48	Netherlands
Webb, et al. (2013)	Calf	Group housed (3)	300	Netherlands
Beef Cattle				
Huenchullan, et al. (NR)	Steer	Pair housed	NR	Chile
Iraira, et al. (2012)	Heifer	Individually housed	8	Spain
Rahman, et al. (2017)	Calf	Individually housed	14	China

Table 3. Experimental design, number of treatments, experimental period and designated treatment type for each study

Author (year)	Experimental design	# of treatments	Experimental period	Treatment type
Dairy Cattle				
Boga, et al. (2009)	Non-randomized no-control trial	2	56	Feed presentation
Castells, et al. (2012)	Randomized control trial	7	57	Roughage inclusion
Devant, et al. (2016)	Randomized factorial	4	64	Roughage inclusion
Falerio, et al. (a) (2011)	Non-randomized repeated measures	2	168	Roughage inclusion
Falerio, et al. (b) (2011)	Non-randomized repeated measures	2	252	Roughage inclusion
Kooijman, et al. (1991)	Non-randomized control trial	5	399	Total feed amount
Lindstrom, et al. (2000)	Randomized Latin square	4	NR	Rumen content
Mirzaei, et al. (2016)	Randomized factorial	6	63	Ingredient type
Montoro, et al. (2013)	Randomized no-control trial	2	56	Particle size
Morrisse, et al. (1999)	Non-randomized control trial	3	140	Total feed amount
Phillips, et al. (a) (1999)	Randomized control trial	2	42	Mineral addition
Phillips, et al. (b) (1999)	Randomized control trial	3	84	Mineral addition
Redbo, et al (1) (1996)	Randomized control trial	3	161	Total feed amount
Redbo, et al (2) (1997)	One group case study	2	56	Roughage inclusion
Rotger, et al. (2006)	Randomized Latin square	4	114	Ingredient type
Suarez-Mena, et al. (2012)	Randomized Latin square	8	19	Total feed amount
Verdu, et al. (2015)	Randomized control trial	3	206	Feed presentation
Webb, et al. (1) (2012)	Randomized Block	4	112	Total feed amount
Webb, et al. (2-a) (2015)	Randomized factorial	8	175	Roughage inclusion
Webb, et al. (2-b) (2015)	Randomized factorial	2	25	Roughage inclusion
Webb, et al. (3) (2017)	Randomized control trial	4	24	Total feed amount
Webb, et al. (2013)	Non-randomized factorial	15	365	Roughage inclusion
Beef Cattle				
Huenchullan, et al. (NR)	Randomized block	4	NR	Mineral addition
Iraira, et al. (2012)	Randomized Latin square	4	112	Ingredient type
Rahman, et al. (2017)	Non-randomized no-control trial	4	146	Particle size

Table 4. Type of non-nutritive oral behaviors recorded and the data collection method used for each study

	Non-nutritive oral behaviors recorded							
Author (year)	Tongue rolling	Allo-grooming	Self-grooming	Bar licking	Object licking	Ground licking	Cross sucking	Method of data collection
Dairy Cattle								
Boga, et al. (2009)		X	X		X			Video scans
Castells, et al. (2012)	X			X	X	X		Live scans
Devant, et al. (2016)	X		X	X				Live focal/scans
Falerio, et al. (a) (2011)	X	X	X	X	X			Video scans
Falerio, et al. (b) (2011)	X	X	X	X	X			Video scans
Kooijman, et al. (1991)	X			X	X	X		Live scans
Lindstrom, et al. (2000)	X					X		Video focal/scans
Mirzaei, et al. (2016)	X	X	X	X	X	X	X	Live focal
Montoro, et al. (2013)	X			X	X	X		Live scans
Morrisse, et al. (1999)	X		X	X	X			Live scans
Phillips, et al. (a) (1999)		X		X	X		X	NR, scans
Phillips, et al. (b) (1999)		X	X	X	X			Live focal
Redbo, et al (1) (1996)	X					X		Live scans
Redbo, et al (2) (1997)	X	X	X	X	X			Live scans
Rotger, et al. (2006)	X		X	X	X			Video scans
Suarez-Mena, et al. (2012)	X			X	X			Video scans
Verdu, et al. (2015)	X		X	X	X			Live/video, focal/scans
Webb, et al. (1) (2012)	X	X	X				X	Live focal and scans
Webb, et al. (2-a) (2015)	X		X	X	X		X	Live and video scans
Webb, et al. (2-b) (2015)	X	X	X	X			X	Live and video scans
Webb, et al. (3) (2017)	X				X			Live/video, focal/scans
Webb, et al. (2013)	X	X		X	X			Live scans
Beef cattle								
Huenchullan, et al. (NR)	X		X	X	X			Live scans
Iraira, et al. (2012)	X			X	X			Video focal
Rahman, et al. (2017)	X	X	X	X	X			Video scans

Table 5. Impact of diet on non-nutritive oral behavior for each study, categorized by treatment type. Only significant behavioral changes are recorded ($P \leq 0.05$).

Author (year)	Treatment Description	Effect on NNOB performance ($P \leq 0.05$)		
		Increase	Decrease	None
	Roughage Inclusion			
Castells, et al. (2012)	Milk replacer alone vs. additional provision of alfalfa, ryegrass, oats, barley and corn or triticale silage		Providing alfalfa hay and ryegrass	
Devant, et al. (2016)	2x2 factorial of meal vs pellet feed and provision of straw	Providing no straw		
Falerio, et al. (a) (2011) Falerio, et al. (b) (2011)	Barley vs. no barley straw included in total mixed ration	Providing no barley straw		
Redbo, et al (2) (1997)	Transition from being provided straw, to no straw, back to straw	Removing straw	Reintroducing straw	
Webb, et al. (2013)	3x2x2 factorial of roughage source (wheat straw and 2 types of corn silage), roughage amount and roughage particle size		Providing wheat straw	
Webb, et al. (2-a) (2015) Webb, et al. (2-b) (2015)	4x2 factorial of solid feed amount and roughage: concentrate (20:80 or 50:50); plus one group receiving *ad-libitum* straw		More roughage (50:50) and providing straw	
	Ingredient Type			
Iraira, et al. (2012)	Providing barley straw (10% dry matter inclusion) vs. soybean hulls (17%) vs.			No effects

	beet pulp pellets (17%) vs. whole cottonseed (16%)			
Rotger, et al. (2006)	2x2 factorial of rapid (barley and sunflower meal) and slow (corn and soybean) fermenting ingredients			No effects
Mirzaei, et al. (2016)	3x2 factorial of supplement type (none, alfalfa hay or corn silage) and concentrate type (barley or corn grain)	Providing no forage		
Total Feed Amount				
Kooijman, et al. (1991)	2x2 factorial of feed presentation (pellet or hay) and *ad-libitum* or controlled amount vs. milk replacer only	Milk only		
Morrisse, et al. (1999)	No pellet control vs. 10 or 25 kg/calf of pellets provided			No effects
Suarez-Mena, et al. (2012)	2x2 factorial of high vs. low forage and inclusion of DDG (0, 7, 14, 21% DM)			No effects
Redbo, et al (1) (1996)	*Ad-libitum* with a temporary period of restrictive feeding (AL-R) vs. only restrictive feeding	Providing restricted feed amounts		
Webb, et al. (1) (2012)	Solid feed added to milk replacer in 0, 9, 18 or 27 kg amounts	Providing 27 kg of solid feed		
Webb, et al. (3) (2017)	Solid feed fed at 0, 9, 18, 27 g/d			No effects
Particle Size				

Montoro, et al. (2013)	Coarse vs. fine grass hay provisions	Providing fine grass hay		
Rahman, et al. (2017)	2x2 factorial of roughage amount and forage cut length			No effects
Feed Presentation				
Boga, et al. (2009)	Cafeteria feeding vs. total mixed ration			No effects
Verdu, et al. (2015)	Control bunk vs. less bunk capacity vs. single space feeders	Control and single space feeders (less space)		
Mineral Addition				
Huenchullan, et al. (NR)	Control vs. addition of tryptophan or vitamin E vs. Vit E and Tryptophan		Providing both tryptophan/Vitamin E or only tryptophan	
Phillips, et al. (a) (1999) Phillips, et al. (b) (1999)	NaCl addition vs no NaCl (control) 200g vs. 400 g vs. no NaCl	Providing 200g NaCl		
Rumen Content				
Lindstrom, et al. (2000)	2x2 factorial of rumen content (high and low) and duration of time eating (long and short)	Low rumen content with short duration of eating		

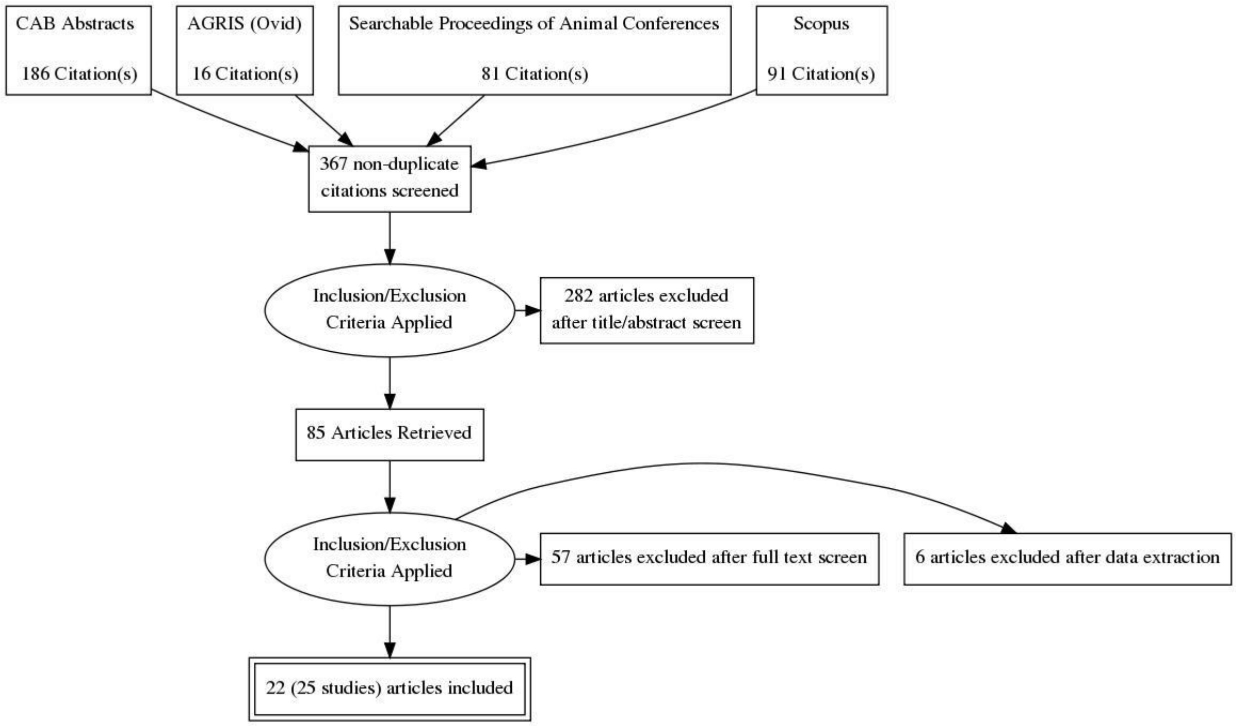

Figure 1. PRISMA flow chart outlining article selection

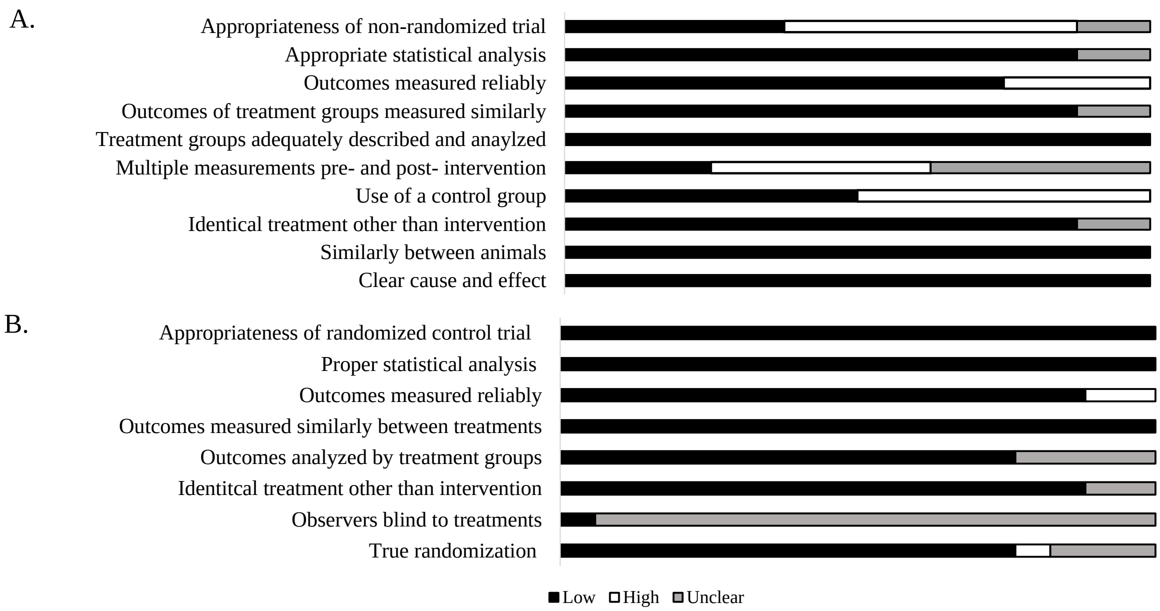

Figure 2. Risk of Bias Assessment Statement results for (A) non-randomized trials (n = 8) and (B) randomized trials (n = 17).

APPENDIX B
CHAPTER III TABLES AND FIGURES

Table 6. Diet composition and nutrient value for 5%, 10% and 15% corn stalk inclusion dietary treatments

Item (% DM basis)	Diet treatment (% corn stalk inclusion)		
	5%	10%	15%
Corn Stalks	5.0	10.0	15.0
Steam Flaked Corn	56.0	55.8	55.3
Wet corn gluten feed	30.0	25.0	20.2
Supplement premix	3.5	3.5	3.5
Urea	0.4	0.7	1
Limestone	1.5	1.2	0.9
Corn Oil	3.7	3.9	4.1
Calculated nutrient values			
DM, %	71.91	73.43	74.96
NDF, %	20.59	21.97	23.47
CP, %	14.53	14.22	13.93
Ca, %	0.79	0.73	0.67
P, %	0.58	0.53	0.47
S, %	0.21	0.19	0.17
ME, Mcal/kg	2.69	2.59	2.51
NE_m, Mcal/kg	1.77	1.68	1.61
NE_g, Mcal/kg	1.14	1.07	1.00

Table 7. Summary statistics of average non-nutritive oral behavior, rumination and activity duration per diet per day treatment across the observation period

	Diet treatment (% corn stalk inclusion)							
	5%		10%		15%			
Behavior	µ	Range	µ	Range	µ	Range	SEM	P-value
Bar licking bout	3.04	0 - 28	3.71	0 - 37	2.33	0 - 37	0.46	0.13
Bar licking (min)	1.90	0 – 24	2.43	0 – 30	1.76	0 – 22	0.35	0.44
Tongue rolling bout	9.48	0 - 58	10.15	0 - 68	11.09	0 - 100	1.29	0.79
Tongue rolling (min)	3.27	0 – 26	3.37	0 – 23	3.92	0 – 43	0.53	0.87
Rumination (min)	391.65	44 - 625	399.75	212 - 570	411.15	93 - 632	9.18	0.46
Activity (min)	517.06	422 - 740	505.88	329 - 768	486.60	365 - 621	5.47	0.20

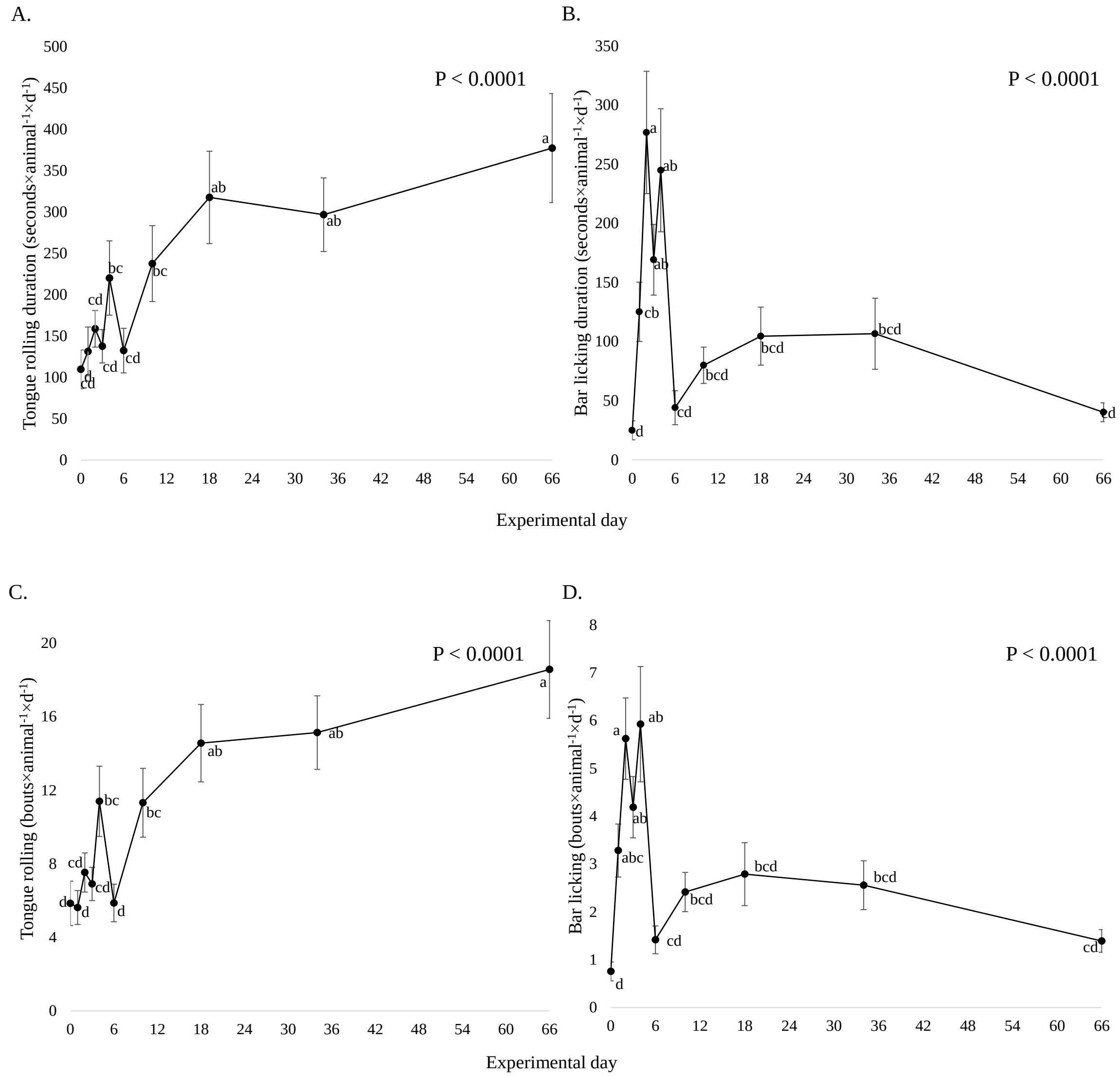

Figure 3. The average duration of time (seconds × animal^{-1} × d^{-1}) cattle where observed to spend (A) tongue rolling and (B) bar licking across experimental days. The average frequency (bouts × animal^{-1} × d^{-1})of (C) tongue rolling and (D) bar licking for each animal across experimental days, irrespective of dietary treatment

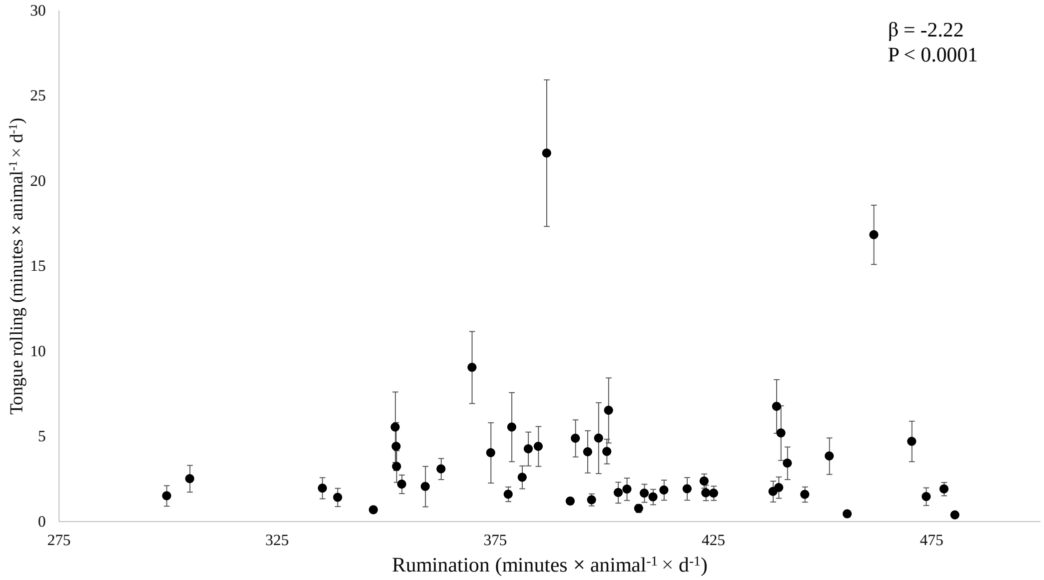

Figure 4. The relationship between average individual animal tongue rolling duration (minutes × animal^{-1} × d^{-1}) and average rumination duration (seconds × animal^{-1} × d^{-1}) during the entire experimental period, irrespective of dietary treatment

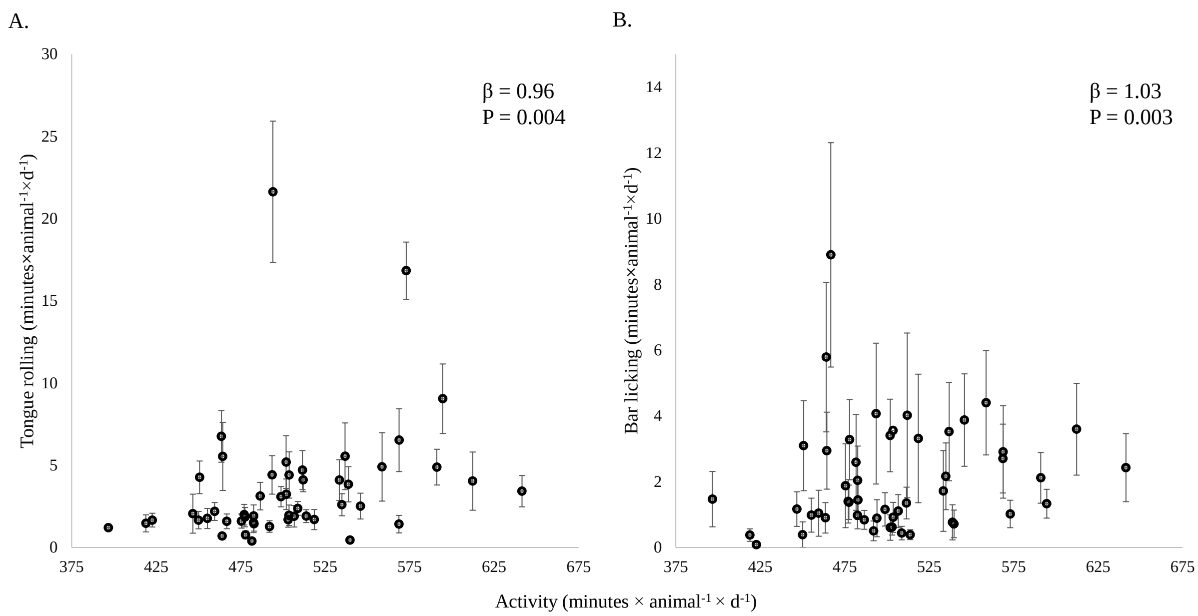

Figure 5. The relationship between the average duration of time (minutes × animal^{-1} × d^{-1}) spent active and the average duration of time (minutes × animal^{-1} × d^{-1}) performing (A) tongue rolling, and (B) bar licking during the entire experimental period, irrespective of dietary treatment

APPENDIX C
CHAPTER IV TABLES AND FIGURES

Table 8. Diet composition by ingredient and nutrient values of the grower, finisher and finisher with wheat substitution, irrespective of yeast supplementation

	Diet treatment (DM %)		
Item	Grower	Finisher	Finisher with wheat substitution
Ingredient, % DM			
Steam flaked corn grain	9.3	68.7	48.7
Dry distillers grains	10.4	16.4	16.4
Alfalfa hay	50.1	7.4	7.4
Molasses	4.2	4.4	4.4
Cottonseed hulls	2.9	-	-
Mineral supplement	23.2	3.0	3.0
Wheat grain	-	-	20.0
Calculated nutrient values			
DM, %	86.8	84.8	84.0
CP, %	12.8	10.9	12.4
NDF, %	51.9	17.4	17.2
Starch, %	6.3	55.0	52.9
Ca, %	1.2	0.5	0.9
P, %	0.4	0.5	0.5
NEm, (Mcal/kg)	0.2	0.4	0.4
NEg,(Mcal/kg)	0.1	0.3	0.3

Table 9. Ethogram of the non-nutritive oral behaviors recorded by live observation using continuous behavior sampling

Behavior	Description
Tongue Rolling	Mouth of steer is open with extended tongue repeatedly moving in and out and/or side to side. Characterized by repetitive side to side head motion
Bar Licking	Mouth of steer is in direct contact with bars of pen
Ground licking	Mouth of steer is in contact with the ground and tongue is extended or mouth is open and closing

Table 10. Summary statistics for non-nutritive oral behavior frequency and feeding behavior per animal per day within each dietary treatment (YE-NOWHT, yeast supplementation and wheat substitution; YE-NOWHT, yeast with no wheat substitution; NY-NOWHT, no live yeast with no wheat substitution; NY-WHT, no yeast with wheat substitution)

	Diet treatments								
	YE-NOWHT		YE-WHT		NY-NOWHT		NY-WHT		
Behavior	μ	Range	μ	Range	μ	Range	μ	Range	SEM
Tongue rolling bout	0.91	0 - 9	0.80	0 - 4	0.98	0 - 8	1.62	0 -11	0.21
Bar licking bout	0.31	0 - 9	0.23	0 - 4	0.35	0 - 6	0.32	0 - 6	0.10
Ground licking bout	0.31	0 - 6	0.16	0 - 3	0.18	0 - 3	0.20	0 - 4	0.08
Feeding frequency (bout)	17.10	3 -44	14.26	3 - 33	17.27	5 - 40	20.29	4 - 37	1.04
Feeding duration (sec)	156.00	26 - 721	149.55	22 - 410	107.76	22-288	109.73	25 - 337	10.12
Meal size (grams)	437.38	140-1240	389.23	124-1170	306.29	84-749	266.76	82 - 885	26.55
Daily intake (as fed, kg)	5.68	1 - 12	4.90	1 - 10	4.84	1 - 9	4.91	0.4 - 10	0.20

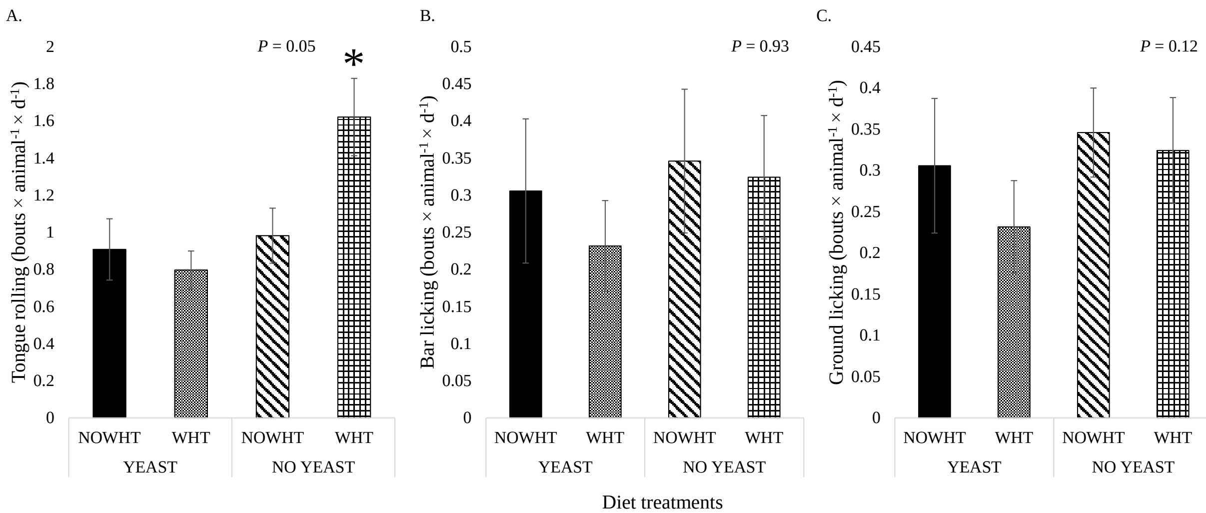

Figure 6. Average number of bouts per animal per day by diet treatment for the non-nutritive oral behaviors of (A) tongue rolling, (B) bar licking, and (C) ground licking. * $P \leq 0.05$

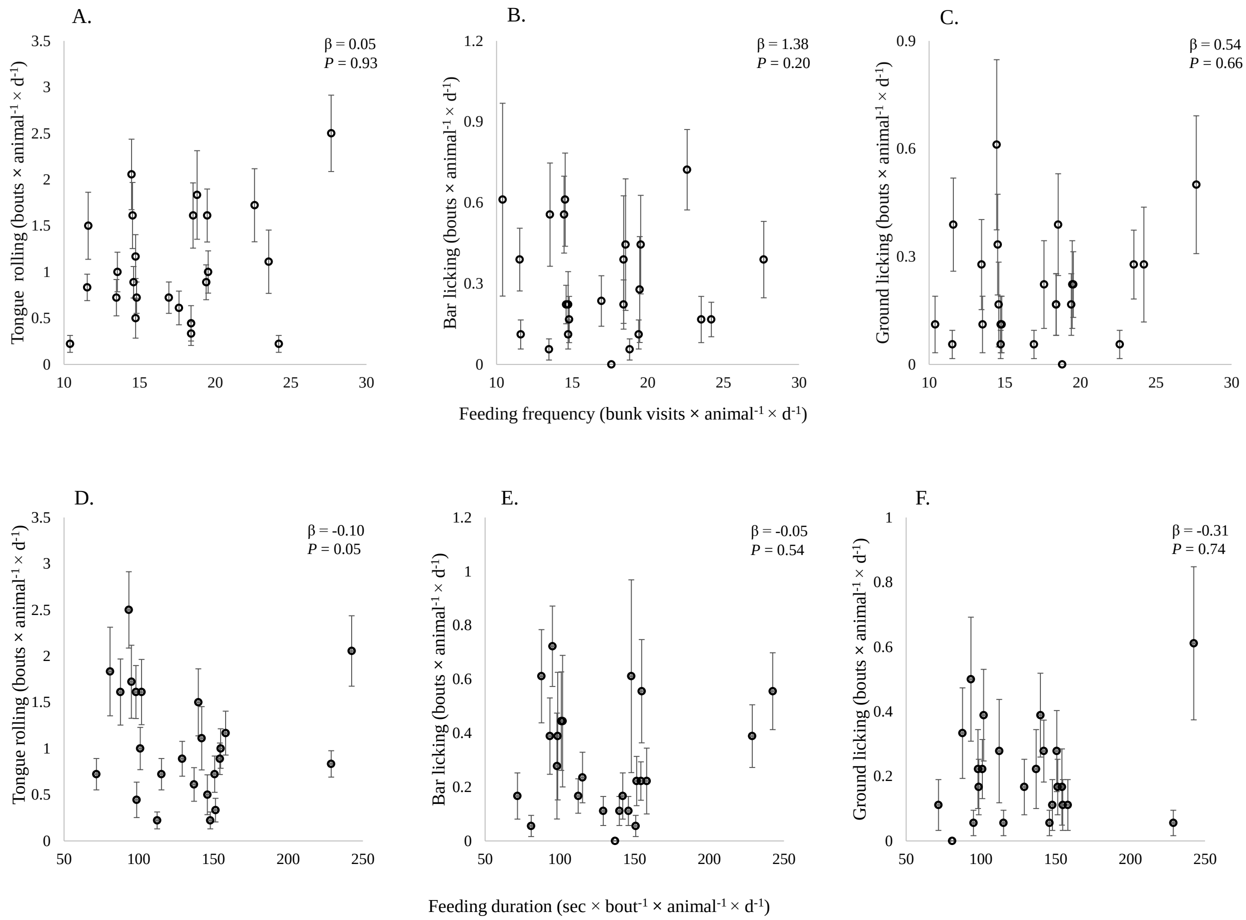

Figure 7. Relationships between average individual animal feeding frequency and (A) tongue rolling, (B) bar licking, and (C) ground licking (bunk visits/d) and the relationship between animal feeding duration and (D) tongue rolling, (E) bar licking and (F) ground licking (bouts/d) throughout the entire study.

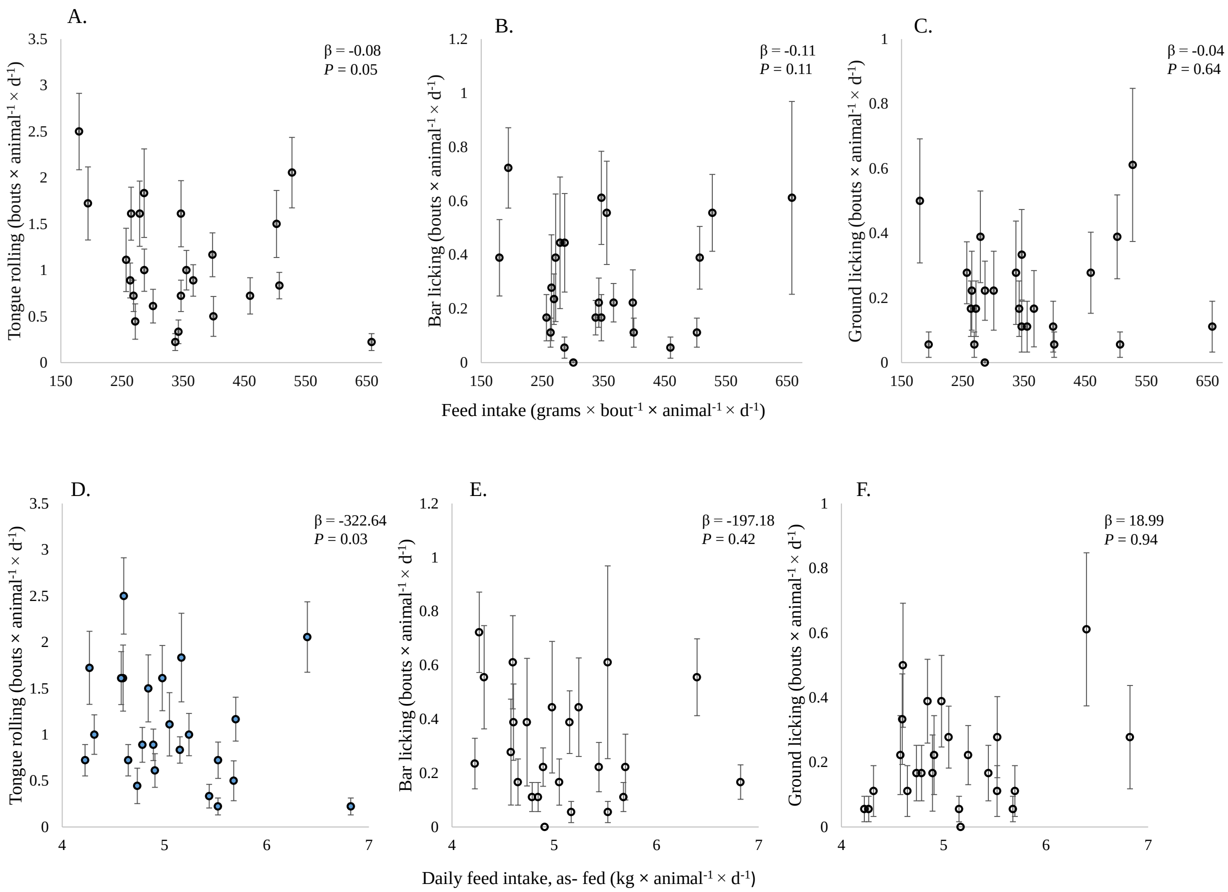

Figure 8. Relationship between average individual animal feed intake (meal size) and (A) tongue rolling, (B) bar licking and (C) ground licking (bouts/d) and the relationship between animal daily intake and (D) tongue rolling, (E) bar licking and (F) ground licking (bouts/d) throughout the entire study.

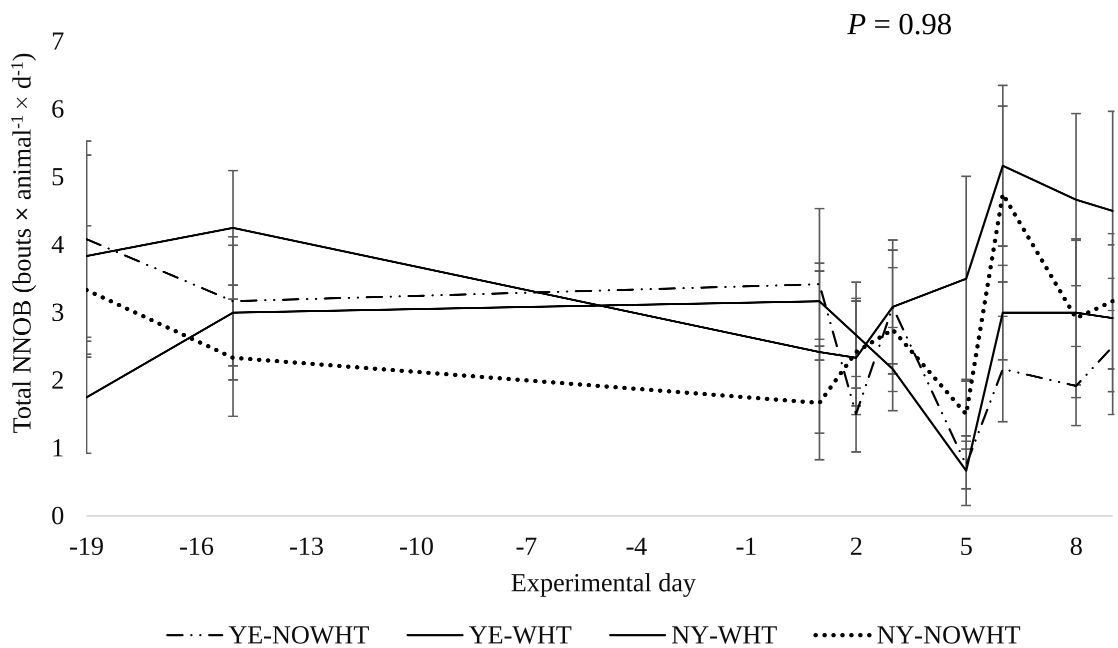

Figure 9. Total non-nutritive oral behavior performance (sum of tongue rolling, bar licking and ground licking) across time per diet treatment.

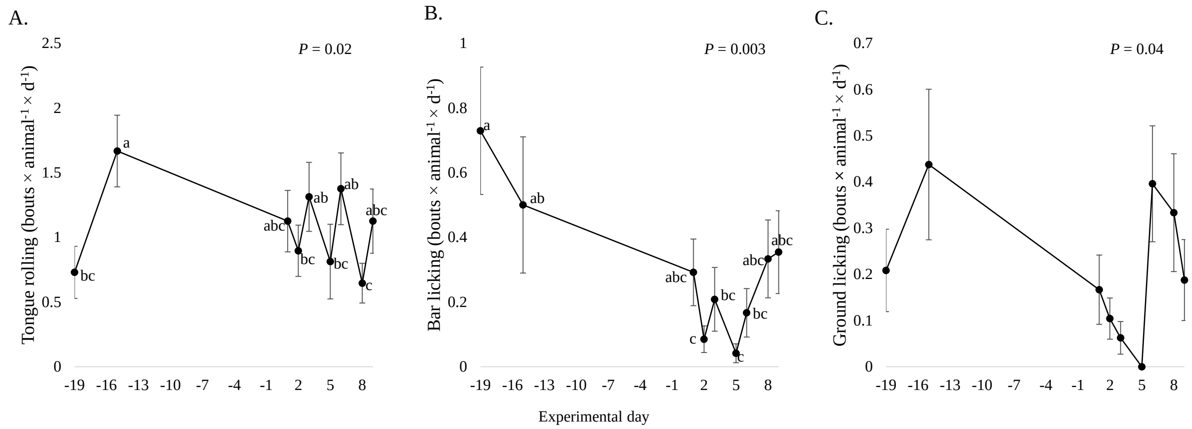

Figure 10. Performance of (A) tongue rolling, (B) bar licking, and (C) ground licking bouts (bouts × animal^{-1} × d^{-1}) across experimental period, irrespective of dietary treatment