**Postformula feeding strategies to reduce concentrate consumption and improve feed efficiency in bulls fed high-concentrate diets**

Thesis

Presented to the Animal and Food Science Department of Veterinary Faculty of Universitat Autònoma of Barcelona

In Partial Fulfillment of the Requirements for the Degree of

DOCTOR IN ANIMAL PRODUCTION

By

Marçal Verdú Piqué

Directed by

Maria Devant Guille

Bellaterra, December 2015

FACULTAT DE VETERINÀRIA

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**Certifiquen:**

Que la memòria titulada "**Postformula feeding strategies to reduce concentrate consumption and improve feed efficiency in bulls fed high-concentrate diets**", presentada per **Marçal Verdú Piqué** per optar al grau de Doctor en Producció Animal per la Universitat Autònoma de Barcelona, ha estat realitzada sota la direcció de la Dra. Maria Devant Guille i, considerant-la acabada, autoritzen la seva presentació per tal que sigui jutjada per la comissió corresponent.

I per tal que consti als efectes oportuns, signen el present certificat a Bellaterra, 19 de novembre de 2015.

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| **Directora** | **Tutor** |

# AGRAÏMENTS

En primer lloc, voldria agrair a la Maria la direcció d'aquesta tesi, tant des de la vessant més acadèmica i formativa com des de la més humana. Les meves sinceres gràcies Maria pels ensenyaments i coneixements que m'has transmès, per l'estimació rebuda, la confiança dipositada i, finalment, per brindar-me l'oportunitat d'exercir la professió de científic. Per a mi has esdevingut un referent de director de tesi i també científic, m'has transmès passió per la recerca.

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## ABSTRACT

In Mediterranean countries most of intensive beef cattle are fed high-concentrate diets with concentrate to straw ratio 90 to 10, both *ad libitum* in separate feeders. The concentrate cost (price of ingredients and total concentrate consumption) represents around 70-80% of total production costs. The price of the concentrate has become largely variable year-by-year. Thus, a reduction of total concentrate consumption, without losing performance, may lead to an improvement in feed efficiency and thereby in fattening profitability. This current thesis has focused on feeding strategies beyond the nutritional formula that could improve production costs and profitability in intensive beef production independently of concentrate price. Hence, two different postformula feeding strategies were chosen as the more appropriate approaches to be studied in our (Catalonia) intensive beef production (Holstein bulls, corn grain-based high-concentrate diets, concentrate *ad libitum* in self-feeders, and pellet as main physical feed presentation); the concentrate feeder design and physical form of concentrate (pellet quality).

A first study was conducted to evaluate the effect of two alternative concentrate feeder designs (a conventional feeder with less concentrate capacity and single-space feeder with lateral protections) on performance, eating and animal behavior, welfare, ruminal health, and carcass quality. Both alternative feeder designs were good strategies to reduce total concentrate consumption without impairing performance, rumen health, and animal welfare. However, feed efficiency was not improved. Furthermore, eating and drinking patterns and its relationship with feeder design, and its evolution with BW were analyzed in a second study. Animals fed on collective feeders exhibited an eating behavior more synchronized during the growing phase (from 130 to 320 kg of BW) compared with single-space feeder animals, whereas they adopted a more individualized behavior during the finishing phase (from 320 to 440 kg of BW) like single-space feeder animals.

Data from the first study suggested that animals fed single-space feeder with lateral barriers had adaptation problems. Then, a third study was designed to evaluated the effect of the adaptation strategy (single-space feeder without lateral protections for first 4 d and additional feeder where feed offer was gradually reduced for first 14 d) to single-space feeder design with lateral protections on performance, eating pattern, and animal behavior for first 6 wk upon arrival at fattening. The adaptation strategy to the single-space feeder was successful facilitating feed access; fact that was translated in an increase of concentrate intake and ADG during the first week after fattening arrival, and resulting in a greater BW 6 wk later.

Lastly, the fourth study analyzed the effect of physical form of concentrate on performance, eating pattern, and feed preference in finishing bulls, together with studying the evolution of physical pellet quality from pellet mill to the feeder. Feeding animals with good quality pellets had a positive economic impact on fattening profitability due to improve performance (increased intake and growth, and reduced feed wastage). The feed preference study demonstrated that animals showed a strong preference for good pellet quality. In addition, it was important to preserve parameters of pellet quality (durability and percentage of fines) from pellet mill to feeder to expect the beneficial effect of pellet quality (with good quality) on performance.

In conclusion, all postformula feeding strategies proposed (concentrate feeder design, adaptation strategy to concentrate feeder design, and physical form of concentrate) had a small impact on performance and economic profitability. However, the additive effects of small benefits of these different feeding approaches could contribute to a more competitive and less dependent of feed prices intensive beef production. Moreover, this thesis has also raised awareness to producers in management strategies that improve efficiency and profitability easy to implement.

## RESUM

Als països mediterranis la majoria de bestiar d'engreix s'alimenta amb dietes riques en concentrat amb una ràtio de pinso i palla de 90:10, ambdós *ad libitum*, en menjadores separades. El cost del pinso (preu dels ingredients i el total de consum de pinso) representa el 70-80% dels costos de producció totals. El preu del pinso és variable any rere any. Així doncs, una reducció del consum total de concentrat, sense perdre creixement, podria millorar l'eficiència alimentària i conseqüentment la rendibilitat de l'explotació. La present tesi s'ha centrat en estratègies alimentàries que van més enllà de la fórmula nutricional per tal de reduir els costos de producció i millorar la rendibilitat independentment del preu del pinso. Per tant, les dues estratègies alimentàries postfórmula més apropiades per aplicar en el nostre (Catalunya) sistema intensiu d'engreix (vedells Frisons, dietes basades en blat de moro i granulat com a forma de presentació) van ser el disseny de menjadora de pinso i la forma física del pinso (qualitat del granulat).

Un primer estudi avaluà l'efecte de dos dissenys de menjadora de pinso alternatius (una menjadora convencional amb menor capacitat de pinso i una menjadora uniboca amb proteccions laterals) sobre els paràmetres productius, la conducta animal i alimentària, el benestar i la salut ruminal. Ambdues menjadores foren bones estratègies per reduir el consum de pinso sense perjudicar el creixement, la salut ruminal i el benestar. Tanmateix, l'eficiència alimentària no millorà. A més, la conducta alimentària i la seva relació amb el disseny de menjadora, així com l'evolució amb el PV van ser analitzats en un segon estudi. Els animals alimentats amb menjadores col·lectives van exhibir un comportament més sincronitzat durant la fase de creixement (dels 130 als 320 kg PV) comparat amb els animals uniboca; mentre que aquests adoptaren una conducta més individualitzada durant la fase d'acabat (dels 320 als 440 kg PV) igual que els uniboca.

El primer estudi va permetre detectar problemes d'adaptació a la menjadora uniboca, fet que originà un tercer estudi per avaluar l'efecte de l'estratègia d'adaptació (uniboca sense proteccions laterals durant els primers 4 d i una menjadora addicional amb menjar que gradualment es reduïa durant els primers 14 d) al disseny uniboca amb proteccions laterals sobre el creixement, la conducta alimentària i animal durant les primeres 6 setmanes després de l'arribada a l'engreix. L'estratègia d'adaptació a la menjadora uniboca

va ser exitosa facilitant l'accés al menjar, fet que es va traduir en un increment del consum i del GMD durant la primera setmana i en un major PV al cap de 6 setmanes.

Finalment, el quart estudi analitzà l'efecte de la forma de presentació del pinso sobre els paràmetres productius, la conducta alimentària, i la preferència en vedells en fase d'acabat; també s'estudià l'evolució de la qualitat del grànul des de granuladora fins a menjadora. Alimentar els animals amb grànuls de bona qualitat va tenir un impacte positiu en la rendibilitat de l'explotació degut a l'increment d'ingesta i creixement, i la reducció de malbaratament. Els animals mostraren preferència pels grànuls de bona qualitat. A més, va ser important preservar la qualitat del grànul (durabilitat i percentatge de fins) des de granuladora fins menjadora per observar millores en els rendiments productius.

Concloent, totes les estratègies alimentàries postfórmula (disseny de menjadora, estratègia d'adaptació i forma de presentació del pinso) van tenir un lleu impacte sobre el creixement i la rendibilitat. Tanmateix, l'efecte additiu d'aquestes millores podria incrementar la competitivitat i disminuir la dependència als preus dels aliments en la producció intensiva d'engreix. També, aquesta tesi ha permès conscienciar a alguns productors en la implementació fàcil d'estratègies per reduir el consum de pinso.

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**Chapter III: Effect of concentrate feeder design on performance, eating and animal behavior, welfare, ruminal health, and carcass quality in Holstein bulls fed high-concentrate diets**

# CHAPTER I

# INTRODUCTION

# 1. INTRODUCTION

In Mediterranean countries most of fattening cattle are fed high-concentrate diets, where concentrate and forage are offered *ad libitum*, in separate feeders, with a concentrate to straw ratio 90 to 10 (Devant et al., 2000; Mach et al., 2009). Meal and pellet are the predominant concentrate presentations (Acedo-Rico, 2001), and cereal straw (wheat or barley, mainly) is usually used as forage source offered in bale form. This feeding system is very dependent on ingredients that mixed constitute the concentrate, and the cost of concentrate represents around 70-80% of total production costs (Boyles et al., 2001). The diet is composed of several ingredients in order to satisfy the nutritional cattle requirements of maintenance and growth. Logically, the feed price is subjected to different costs of ingredients, and price of each ingredient depends basically on its annual yield or stored stocks (offer) and demand, manufacture cost, and transport cost. The prices of grains are largely variable year-by-year, circumstance that influences strongly the profitability of intensive beef production system and forces producers' economy becomes more dependent on fluctuations of ingredients prices. As widely known, the total concentrate cost is determined by the price of diet and total concentrate consumption per animal and fattening cycle (days on feed), and thereby both variables are important to reduce the concentrate cost. For that reason, improving feed efficiency without losing performance could be a good strategy to reduce feed cost.

Feed efficiency in livestock production is important to preserve and optimize worldwide feed/food resources. Niemann et al. (2011) suggest that efficient use of domestic animals is essential to tackle the worldwide shortage of arable land, the environmental impact of farm animal production, and the ever increasing human population. In addition, the "feed vs. food" competition between animals and humans is becoming a considerable challenge in the next 50 years (CAST, 2013).

One possible approach to improve the feed efficiency and, subsequently, the profitability in beef production could be reducing the amount of feed per unit of production (Lancaster et al., 2009), as the provision of feed is the major expense producing intensive beef (around 65-70% by Liu et al., 2000; Arthur et al., 2004). However, the improvement of efficiency should succeed without losing performance to remain a viable and sustainable pathway for the producers.

## 2. STRATEGIES TO IMPROVE FEED EFFICIENCY

The feed efficiency is defined as the live weight gain resulting from the daily feed intake (Koch, 1963), and is formed by the main benefit output (growth) and the major cost input (feed) in intensive beef production. Herein, an improvement of feed efficiency can be usually led in one of two directions or both directions, either reducing the feed or maximizing the animal BW. This relationship determines the profitability of the production system, and, consequently, the economic benefits.

The improvements in feed efficiency can be achieved through both genetic and nongenetic means (Luiting, 1991). The genetic improvement of feed efficiency involves breed choice, crossbreeding and selection within breeds (Herd et al., 2003). However, the present work was not focused on this topic, as it was based on the current breeds present in the market. Most animals raised in Catalonia are not born in this region; thus, at the moment, the industry can have little influence on the cattle breeding. However, this is an approach that should not be forgotten and, perhaps, it could be studied in the future.

On the other hand, there is a large list of nongenetic factors that could contribute to enhance the feed efficiency in intensive beef production: growth promoters, optimizing the slaughter weight (and in turn days on feed, which is influenced by feed and meat price fluctuations), feeding strategies, health, and management. Hormones and antibiotics used as growth promoters are banned in Europe since 1996 and 2006, respectively, circumstance that contrasts to their legal use in the USA or Canada among other countries. To optimize the slaughter weight is necessary to know the growth and intake evolution, and depends also on feed and carcass prices. This strategy is used by beef producers that have these data updated, and periodically they can estimate the optimum slaughter weight. One limitation of this strategy is that resulting optimum slaughter weight (carcass weight) must fit with commercial needs. Obviously, health and management (housing, animal grouping, etc.) should be taken into account because they could have a tremendous influence on feed efficiency. Health and management are multifactorial strategies and difficult to study; in the present work they will not be analyzed, even though they should not be forgotten for future studies.

## 3. FEEDING STRATEGIES TO IMPROVE FEED EFFICIENCY

There are several feeding strategies that can be applied for enhancing feed efficiency such as dietary composition of formula (ingredients and nutrient content), factors regarding feed/grain processing and physical form of concentrate (pellet or mash), forage provision (level, particle length, quality, and total mixed ration), feeding management (regime, time of day and frequency), and concentrate feeder design (feeder space, animal to feeding space ratio, and feeder adjustment).

Working on ingredients and nutrients selection to formulate the low-cost diet with the objective of meeting maintenance and growth requirements has been widely studied. Under the premise of least-price-inclusion of ingredients, there is not a big scope for action. Furthermore, there are circumstantial factors associated to geographic location that limit the inclusion of certain ingredients; the production system and its grade of intensification (intensive beef production), the type of diet and feeding practice (high-concentrate diets *ad libitum*), the main cereal source yielded (corn), the common grain processing (pelleting), even commercial preferences (type of meat demanded by consumer). Therefore, for that reasons, the current work is focused on feeding strategies beyond the nutritional formula (postformula) to explore deeply their potential effects on feed efficiency independently of price, quality, and availability of ingredients.

Lastly, it is important to highlight that feed intake is influenced by eating behavior (Grant and Albright, 1995). In addition, factors relative to housing, management, and environment can influence the eating pattern, and therefore the study of eating behavior is one means of understanding the way in which feeding strategies beyond the formula affect feed efficiency.

## 4. POSTFORMULA FEEDING STRATEGIES TO IMPROVE FEED EFFICIENCY

Hereafter, all feeding strategies applied beyond nutritional formula are presented, concretely, which range from the feed mill (grain processing) to the feeder (feeding system management, feeder design, forage provision, etc.).

### *4.1. GRAIN PROCESSING, PHYSICAL FORM OF CONCENTRATE, AND PELLET QUALITY*

Several grain processing methods have been evaluated in feed industry with the objective to optimize the nutrient utilization by cattle and, thereby, improving the efficiency of production (Theurer, 1986). Thus, most beef producers or nutritionists decide to include in the diet one or another cereal source according to the grain cost together with proper grain processing (Owens et al., 1997). Although, most of the processing methods vary in cost and effectiveness, all of them attempt to maximize the starch (energy) availability of grain source. Hale and Theurer (1972) have reported until 18 different grain processing methods applied in ruminants. In turn, the term processing defines the physical form of feed or grain presentation depending on processing method used (Nocek and Tamminga, 1991).

The effects of grain processing on starch utilization in ruminants have been reviewed extensively by Hale (1973) and Theurer (1986), which have indicated that efficiency of starch use improved by appropriate processing method, especially for corn and sorghum grains. These results are agreement with Hale (1980), who reviewed the effect of various processing methods on performance and feed conversion in beef cattle. This study showed that not all grain sources and processing methods are equal effective in improving feed conversion; for instance, processing methods used in corn or sorghum grain-based diets are more effective improving feed utilization compared with wheat or barley. Therefore, corn and sorghum have a greater potential of improvement when a processing method is applied than other grain sources (wheat or barley), as these first have a lower susceptibility of ruminal degradation and the grain processing increases to a large extent the ruminal digestibility (Guada, 1993).

The predominant grain processing methods used in Spanish beef industry are grinding and pelleting (Acedo-Rico, 2001), and this situation can be also generalized to Catalonia beef industry. In the Western Catalonia region, where corn is the main crop, the most of beef fattening farms use corn-based diets; besides, to our knowledge, pelleting is a quite widespread grain processing practice around this territory. The most common implemented combination of cereal source and processing method to improve feed efficiency is corn and pelleting.

According to definition from California Pellet Mill Co., the pellet feed can be considered as agglomerated feed formed by extruding mixtures by compacting and forcing through die opening by any mechanical process (pelleting). The extruding method means the combination of moisture (17-18%), heat (80-90ºC) and pressure (1.4 atm) on feed ingredients allowing a certain degree of starch gelatinization.

When contrasting both predominant grains processing methods in our beef fattening farms, animals fed pellet exhibited a better performance (growth) and feed conversion compared with those fed meal (Castillo et al., 2006; Solanas et al., 2008). Nevertheless, these studies are ones of the few studies that have investigated the effect of physical form of concentrate in cattle. For that reason, to contrast the beneficial effects of feed processing on performance and feed conversion in animal production it has to turn to the extensive literature in swine (Vanschouboek et al., 1971; Pond and Maner, 1984) and poultry (Calet, 1965; Quemere et al., 1988; Moran, 1989). Accordingly with Behnke (1994), the advantages of pellet over meal can be mostly attributed to (a) the feedstuffs are more digestible and, particularly, the gelatinization of starches could improve starch degradation; (b) pellet presentation helps to ensure a well-balanced diet, reducing ingredients sorting and their segregation; (c) decreases feed wastage during the eating process. Moreover, other benefits of pelleting related to the increase of feed consumption are (d) that animals devote less time and effort for prehension; and, (e) that palatability is improved and content of fines is reduced (McEllhiney, 1986; Nir, 1991).

Other advantages attributed to pelleting over mash is a greater feed hygiene that minimizes the presence of pathogenic organisms; pellet over the mash form has better flow and handling characteristics, avoiding the segregation of ingredients in a mixing, handling or feeding processes (Capdevila, 1993). Also, bulk density is increased enhancing storage capabilities of most bulk facilities (truck, silo, etc.) and reducing the transportation cost. Lastly, pelleting allows increasing flexibility of nutrient formulation (Mateos and Grobas, 1993). However, pelleting represents an estimated extra cost in feed manufacturing on the order of 1 €/t compared with mash presentation (Capdevila, 1993), as the main inconvenience. Another drawback of pelleting is a potential destabilizing effect on some micro-ingredients like vitamins, enzymes, antibiotics, etc., the availability and nutritional value of which in the diet could be compromised (Mateos and Grobas, 1993).

Pellet quality is critical to achieve all before mentioned advantages of pelleting on feed efficiency (Behnke, 2001). Pellet quality is defined by durability and hardness. Both parameters measure the resistance to rigors of transportation and handling, and thereby they can be also used to evaluate the physical pellet quality (Thomas and van der Poel, 1996; Boac et al., 2008). Hardness is the force necessary to crush a pellet or a series of pellets at a time (Thomas and van der Poel, 1996). Durability is a simple test in which the pelleted feed is tumbled in a mixer for a defined period of time that simulates the transfer and handling of feed (Fairfield, 1994).

Under cattle fattening conditions, handling by auger conveying and automated feeding distribution can produce excessive dust and fines (Walker, 1999) by either fragmentation or abrasive stresses. Reference values of durability, percentage of fines or hardness in cattle are scarce. Capdevila (1993) reported a durability of 96% and a maximum of 5% of fines as the main parameters of pellet quality for cattle; moreover, Bacha and Villamide (2010) recommended that pellet durability should be above 98%, highlighting that ruminants refuse fines, and hardness should be below 15 kg. However, in beef industry, each manufacturer establishes its own quality standard for durability and hardness. In addition, the origin of the samples (pellet mill, feeder, etc.) to measure pellet quality is crucial. Feeder should not be obviated as a sampling place to determine pellet quality because it is the feed destination and pellets have already undergone the rigors of transportation and handling. Lastly, whereas a minimum value of durability is important to avoid the presence of fines at the feeder in pelleting for intensively fed beef cattle, there is no reference value for hardness in beef. Nevertheless, hardness is not critical in beef. Thus, pellet quality parameters, mainly the durability, may play a role with feed preference in cattle, as it seems crucial to stimulate prehension allowing animals to eat as fast as possible (Baumont, 1996).

There are several factors that influence the pellet quality (Behnke, 2001). The formulation, concretely, the ingredients like cereal grain used and its dietary proportion can have a great influence due to their physico-chemical properties; or fats or oils above 1%, etc. Furthermore, the conditions from pelleting process which involve the conditioning, pelleting and cooling have also an impact on pellet quality.

Extensive research, mostly in non-ruminants, has demonstrated that a good pellet quality improves feed efficiency compared with other feed presentations characterized with poor pellet quality such as reground pellets or pellets with a high percentage of fines (Jensen and Becker, 1965; Trevis, 1979; Jones, 1985; Zatari et al., 1990; Stark et al., 1994). In all previous cited studies the hypothesis that explains the improvement of pelleting vs. reground or bad pelleting in feed efficiency is that pellet quality affects the feed wastage. When animals were fed bad pellet quality, greater feed consumptions were recorded without improving the growth; thus, these impaired performances may be attributed to an increase in feed wastage due to feed presentation (reground pellets) and/or greater content of fines in the feeder. Contrarily, to our knowledge, there are no published studies in ruminants and beef cattle that evaluate the effect of pellet quality on performance and feed efficiency. There is one study conducted to analyze the influence of grain processing on acid-base balance in feedlot steers (Castillo et al., 2006), which observed a greater numerical feed:gain ratio in pelleted-fed animals compared with ground-fed animals. Besides, another study in lactating cows where the effect of feed physical form on eating rate was evaluated (Kertz et al., 1981), a faster eating rate in cows fed pelleted form was observed in contrast with coarse, crumble, and meal forms. These results may support the hypothesis, which have already previously been reported by Baumont (1996), that cattle generally prefer the physical form of feed that can be eaten faster, as the feed presentation influences ease of prehension and mastication.

### *4.2. FORAGE PROVISION*

Two different approaches focused on the forage (level, quality and particle length) or use of total mixed ration (TMR) feeding system will be described. The main objective of these practices is to guarantee rumen health and in turn improve feed efficiency.

#### 4.2.1. Forage

Forages added to high-concentrate diets (in low percentages) help to prevent digestive upsets and to maximize energy intake by beef cattle (Galyean and Defoor, 2003). The main purpose of forage provision is to maintain the rumen functionality and pH conditions (Calsamiglia, 1997), and both functions depend on amount, quality and particle length of forage. Therefore, the utilization of forage may have a positive impact on performance and/or feed efficiency whenever the level of forage does not limit the concentrate intake (filling effect of forage and/or insufficient energy density of diet) and, thereby, impairing growth (less starch income). Galyean and Defoor (2003) have indicated that feed consumption is influenced by level and source of forage; thus, both characteristics of forage (level and source) also ultimately affect performance and carcass (Allen, 1997). The dietary proportion of forage, together with its particle length and/or its quality, may also have an effect on the retention time in the rumen and, by extension, in the rumen digestibility (Colucci et al., 1982). Nevertheless, Galyean and Defoor (2003) reported that reasons for increased feed intake with dietary changes in forage level or source are not understood clearly; these authors hypothesized that forage addition may have an energy dilution effect increasing finally feed consumption with subsequent improvement in performance. Contrarily, other authors (Madruga et al., 2015) have not observed an increased feed consumption when dietary forage source was changed from low-quality (barley straw) to high-quality (alfalfa hay) forage.

Adding forage helps to prevent digestive upsets, especially the risk of ruminal acidosis due to huge amounts of readily fermented carbohydrate consumed. Increasing dietary forage decreases eating rate and meal size, together with an increase of chewing/rumination time and saliva production to neutralize the acids produced during ruminal fermentation (Owens et al., 1998), as forage provides physical texture to ruminal content and has a slowly fermentation with low acid production (Bach and Calsamiglia, 2006). Although remaining unclear the relationship between salivary secretion and incidence of subclinical acidosis (Schwartzkopf-Genswein et al., 2003), it is extensively known that acidosis can reduce feed intake and in consequence impairs growth (Koers et al. 1976; Owens et al., 1998). Nevertheless, there are recent studies (Devant et al., 2000, 2001; Rotger et al., 2005) that have not observed signs compatible with ruminal acidosis in cattle fed high-concentrate diets when straw is also offered *ad libitum*.

In addition, a drastic approach to reduce productive costs could be removing the forage from diet in feeding systems where it can be an expensive ingredient (Bartle and Preston, 1991) or reducing labor costs. However, the usual purchase price of forage in our intensive beef production supposes one of the most inexpensive inputs of production system. Although performance can be improved (Wise et al., 1968) or not affected (Faleiro et al., 2011) in a non-forage diet, the higher incidence of ruminal acidosis and alteration of animal behavior (less rumination and increased stereotypic activity; Faleiro et al., 2011; Devant et al., 2015a) that compromise animal welfare does not justify this feeding alternative to forage use. Furthermore, Devant et al. (2015b) reported that the effect of straw provision also depends on physical form of concentrate (mash vs. pellet). Then, whereas bulls fed pellet without straw exhibited a decrease in intake and growth, and feed efficiency was impaired; in those fed mash, the lack of straw provision did not affect consumption and performance.

Under commercial conditions, animals are fed continuously straw *ad libitum*, which in addition is usually used for bedding. If the case that no straw is available (Faleiro et al., 2011) or is not in good conditions (accessibility, cleanness, etc.), it may decrease rumination and subsequent increase the risk of suffering acidosis (Faleiro et al., 2011; Devant et al., 2015b).

The other focus of attention is the length of forage included in the diet, which could also have an impact on pH and rate in the rumen, and salivary secretion. Nevertheless, Shain et al. (1999) reported that different forage length (0.95, 7.6 and 12.7 cm) had no effect on performance and feed efficiency, and ruminal metabolism in beef cattle.

Another feeding system option regarding forage to capitalize feed efficiency or profitability is the utilization of nonforage sources as an alternative method to provide fiber in cattle. The ingredients suggested as nonforage fiber can be byproducts from processing industry (Iraira et al., 2013). A priori, the main advantage of byproducts is their low cost; however, their physical characteristics (Grant, 1997) and chemical composition (NRC, 2000) can widely differ questioning their benefits in promoting chewing activity and ruminal buffering capacity (Iraira et al., 2013). Most studies that evaluated the benefits of nonforage sources have been conducted with TMR (Löest et al., 2001; Cranston et al., 2006; Iraira et al., 2013). The use of byproducts can have a positive impact on economic and environmental benefits, but no improvements in both performance (growth) and feed efficiency have been observed using soybean hulls and whole cottonseed, respectively (Löest et al., 2001; Cranston et al., 2006). On the other side, the improvement in promoting rumination and total chewing time when feeding byproducts was similar to the ones observed with conventional forages use (Iraira et al., 2013). In consequence, it questions the benefits of these byproducts and its implementation.

Then, after analyzing these published studies, when forage and concentrate are both provided *ad libitum*, any investment or extra cost relative to forage feeding management (machine to chop the forage, a better quality of forage, etc.) is justified in terms of economic profitability. However, it should not be forgotten the potential of forage provision in cases where forage management is problematic or deficient.

Lastly, assuming that increasing of dietary forage inclusion could be a strategy to improve the feed efficiency, this strategy is limited because the common feeding system results in a concentrate:forage ratio of 90 to 10. Then, the total mixed ration (TMR) feeding method could be a proper way to increase the forage consumption. TMR is based on mixing concentrate and forage offer to be feed them simultaneously. Hence, consumption of concentrate and forage is synchronized, and may have beneficial effects on performance and rumen health.

#### 4.2.2. Total mixed ration (TMR)

Total mixed ration (TMR) could be suggested as an alternative feeding system to capitalize performance and profitability when high proportion of grain and low amounts of forage are consumed in beef cattle fed high-concentrate diets (Moya et al., 2011; Iraira et al., 2012). This TMR can be wet or dry depending on the ingredients; wet TMR uses liquid or silage ingredients as a main difference (high-moisture corn, beetroot pulp, etc.). Often these liquid or water-rich ingredients are byproducts and, thereby, they have a more competitive price (cheaper than conventional raw materials) whenever the cost of transport is not very high. Basically, in wet and dry TMR, the rationale is to reach a more stable rumen pH and fermentation pattern (Kaufmann, 1976) and, subsequently, to mitigate the risk of rumen acidosis. The TMR feeding practice consists in chopping and pre-mixing feed components (cereals, forages, and nutritional supplements) prior feeding cattle, obtaining a mixed diet which may promote a more uniform feed consumption reducing the risk of rumen acidosis (Hernandez-Urdaneta et al., 1976), as one of the most benefits. Accordingly, this feeding system has another advantage, it minimizes feed sorting of the individual diet components by cattle due to feed processing (Coppock et al., 1981). In fact, TMR method has been suggested as an alternative approach to encourage a greater forage intake in beef cattle (Iraira et al., 2012; Madruga et al., 2015) than a conventional feeding scheme where concentrate and forage are offered *ad libitum* in separate feeders.

Then, the hypothesis that could explain an improvement in feed efficiency is based on the fact that cattle consume larger amounts of forage when is mixed with concentrate using TMR. Hence, the increase of physically effective fiber provided by forage stimulates the rumination that could reduce the risk of acidosis and would contribute positively in rumen health. However, no improvements in feed to gain ratio have been found in studies that evaluated the effect of TMR on performance in intensive reared cattle (Moya et al. 2011; Iraira et al., 2012). Even, Iraira et al. (2012) reported greater intakes and growth in heifers offered diet in separate feeders than those fed TMR. While Cooke et al. (2004) reported improvements on feed efficiency with TMR in finishing heifers in contrast to discrete feeding, another study with finishing steers no effect of TMR on performance was observed (Caplis et al., 2005). Thus, animal production advantages to a TMR in intensive beef fattening are not sufficiently evident to propose this feeding system as an alternative to enhance the feed efficiency. Nevertheless, a benefit from TMR is the stimulation of rumination, which may contribute to maintain a healthy ruminal environment, but this fact does not translate in positive effects on performance (Moya et al. 2011; Iraira et al., 2012).

Moreover, it is important to indicate that TMR can be a feeding system more expensive than conventional practices, as it has a greater grade of mechanization, requires specialized equipment, and more energy. All of these factors involve a higher production cost, fact that should be included in the economic analysis when implementing the use of this feeding system. In addition, one of the main limitations of wet TMR is the geographical proximity of the ingredients; then, if it needs to transport water-rich ingredients along big distances the price will be not attractive. Another critical point is the fluctuating nutrient content of some ingredients that could unbalance the diet. A last weakness is the maintenance and conservation of silage, and storage and transport conditions of byproducts that could alter their chemical and physical properties and in consequence their nutrient composition. In fact, this last aspect could impair the rumen environment and lead to digestive disorders (acidosis). In summary, the use of wet TMR could be an alternative economically attractive whenever the ingredients come from a proximate area; also, if the labor plus machines cost are well estimated and allow a competitive final feed price.

### *4.3. FEEDING MANAGEMENT*

Feeding or feeder management is a concept relative to control feed consumption in beef production (Galyean, 1999), which determines the amount, time of day, and daily frequency of feed deliveries offered to cattle. One of the purposes of managing feed intake is the control of metabolic disorders (Pritchard and Bruns, 2003), and especially preventing overconsumption of grain that can lead to clinical acidosis. Beef nutritionists and producers usually have associated subclinical acidosis with abnormal or erratic feeding behavior in cattle (Schwartzkopf-Genswein et al., 2004). Thus, from the point of view of feed intake control, the feeding system management can also be used as a practice to capitalize on improved feed efficiency due to optimization of concentrate consumption according to productive targets (growth rate desired).

#### 4.3.1. Feeding regime: limit-fed, restricted or programmed feeding

The response to maximize daily feed consumption, premise under which working clean-bunk or *ad libitum* feeding regimes, may not always return the maximum economic benefits by cattle (Peters, 1995). Then, alternative cattle feeding managements have been evaluated in order to improve the feed efficiency and profitability optimizing the amount of feed provided.

All of these alternative feeding methods consist in an intentional and substantial reduction of feed intake relative to expected *ad libitum* feed consumption. Nevertheless, these feeding regimes differ in magnitude of intake restriction (limited vs. restricted and programmed) and, also, the way in which the feed restriction is established (restricted vs. programmed). Thereby, whereas restricted and programmed feeding systems involve less feed restrictions that range from 5 to 10% compared with expected feed intake (Pritchard and Bruns, 2003), the limited feeding practice offers feed at 75 to 80% of predictable feed intake to feed cattle (Loerch and Fluharty, 1998). In addition, while restricted feeding means any method to control the feed intake in which consumption is restricted relative to actual or anticipated *ad libitum* intake, programmed feeding is based on the net energy equations to calculate the amount of feed required to achieve a specific rate of gain for maintenance and growth (Galyean, 1999).

The main purpose of these feeding regimes is to lower feed cost by a restriction of feed deliveries avoiding the overfeeding. Other benefits of restricted intake reported by Lake (1986) are increased diet digestibility, decreased manure and feed wastage.

Although some studies have reported that restrictions in feed consumption can lead to improvements in feed efficiency, the restricting intake also tends to reduce rate of gain (Plegge, 1987; Hicks et al., 1990). However, Murphy and Loerch (1994) observed no improvement in feed conversion even decreased daily gains. In summary, from research findings in finishing cattle, when intake is restricted (from 5 to 15% than *ad libitum* feeding) improvements in feed efficiency with decreasing growth have been observed (Galyean, 1999). Results of these feeding regimes are controversial and their implementation is not always easy. Moreover, in commercial farms all animals consume feed from the same feeder; when feed is restricted, dominant animal may eat more feed than expected limiting the remaining pen mates, and consequently increasing CV of BW.

Rate of gain and subsequent carcass weight, and carcass quality are very important in beef cattle production from economic point of view. Restricting intake increases carcass leanness and can decrease marbling scores (Plegge, 1987; Hicks et al., 1990; Murphy and Loerch, 1994). These aspects may be deeply affected by restricted intake and could be perceived as weaknesses. Although animals are able to undergo compensatory growth after a feed restriction period, this restriction increases the number of days on feed (Reinhardt et al., 1998). Thus, an economic analysis is necessary to determine if restricted feeding is beneficial. Although with an automatic feeding labor cost should be not very high, the feeding programs should be carefully supervised by nutritionists in order to avoid as much as possible an undesired reduction in animal growth. Thus, these last inconvenient make that this strategy is not very attractive for our production system.

### 4.3.2. Feeding Time and Frequency

Another interesting aspect relative to feeder management in intensive beef cattle can be the time of daily feed delivery or frequency of feeding for the purpose of reducing the variability in feed intake and subsequently mitigating metabolic disorders (ruminal acidosis, mainly). Several studies have indicated that feed consumption fluctuations may cause digestive disturbances (Fulton et al., 1979; Britton and Stock, 1987) and decrease performance (Galyean et al., 1992; Stock et al., 1995; Devant et al., 2010) in cattle fed high-concentrate diets. Thus, these strategies in feeding time of daily and frequency of feed delivery are basically designed to control and minimize the risk of ruminal acidosis reducing the starch income to rumen per meal by a more frequent feed allocation throughout the day in order to promote a more stable ruminal environment (Robles et al., 2007). Therefore, as acidosis can decrease the feed intake with a subsequent decrease in performance (Koers et al. 1976; Stock et al., 1990; Owens et al., 1998), these methods in feeding time and frequency can also be considered strategies to improve consumption, performance and gain to feed ratio. Nevertheless, the relationship between variation in feed consumption and the incidence of acidosis and, its effect on performance and feed efficiency have aroused reasonable doubts and controversies from contradictory results. On one hand, some studies have observed that large variation in feed intake did not impair performance (Copper et al., 1999; Schwartzkopf-Genswein et al., 2004), even increasing the risk of subclinical acidosis. Additionally, other studies have found that animals with greater fluctuation in feed consumption exhibited better growths and feed efficiencies (Zinn, 1994; Schwartzkopf-Genswein et al., 2011).

Regarding the effect of time of daily feed provision, a couple of studies reported improvements in ADG and feed efficiency for cattle fed in the afternoon or evening hours compared with those fed in the morning (Reinhardt and Brandt, 1994; Pritchard and Knutsen, 1995). Conversely, other studies have observed that both time and frequency of feeding did not affect performance in limit-fed steers (Soto-Navarro et al., 2000a) and *ad libitum* heifers (Robles et al., 2007); however, these same studies have hypothesized that an increase in feeding frequency (twice a day) may be beneficial to stabilize the ruminal environment (Soto-Navarro et al., 2000b; Robles et al., 2007).

An increase of feeding frequency (twice or more times per day) implies a more laborious and accurate feeding management (available fresh feed), increasing labor factor. Furthermore, feed deliveries can be achieved by an automated programmed feeding system, increasing the mechanization of production system (with slightly increased economic cost due to the investment and maintenance, and energy to run it), or employing somebody to take responsibility for that task. Usually, this feeding approach (feeding time and frequency) is conducted by total mixed ration (TMR) feeding method under a noncompetitive feeding situation because there is enough feeder space.

Summarizing, although beneficial effects in rumen health are presumably attributed to an increase of the feeding frequency (twice a day), it does not translate an improvement in performance and feed efficiency. Thus, the implementation of this strategy is not justified, as it has questionable advantages.

### *4.4. FEEDER DESIGN*

The approach of feeder design as a strategy to increase the efficiency is the consequence of the coincidence of two circumstances. On one hand, a previous experience of adapting a commercial farm to research purposes, computerized feeders were required to measure individual intake and eating behavioral parameters (Devant et al., 2012). A technological problem with ear tags was detected; there were interferences among ear tags of each calf within a pen around the antenna, which is located at the feeder, and, subsequently, data registration was not adequate. To solve this limitation a chute (lateral barriers added to the feeder) was implemented. Thus, for that reason, animals were fed using a single-space feeder with lateral protections. At the beginning, a lot of drawbacks, fears and questions associated to this type of feeder design raised, some examples are listed below. Only one feeder space could be sufficient to feed twenty animals without altering the eating behavior taking into account that competition at the feeder would increase? In addition, this expected disrupted eating pattern should cause digestive disturbances, like acidosis e.g., related to irregular intakes due to impossibility to eat when animals would desire. If rumen health may compromise the intake, performance and feed efficiency of cattle could be impaired. Moreover, production targets could be threatened due to an increasing competition to feed access and/or a greater degree of difficulty to access to feed that would conduct a decreased feed intake. However, all of these mentioned problems were not observed in this farm in the last eight years with one and a half fattening cycle per year. In contrast, during that time, a notable reduction of total concentrate consumption was recorded obtaining similar performance compared with data from other similar commercial farms of the same beef producer, and, consequently, improving the feed efficiency. Thus, it was hypothesized that the feeder design could minimize the concentrate consumption reducing the feed wastage and new research topic started.

On the other hand, in swine production, there is an extensive research in feeder design to enhance performance traits and feed efficiency. This swine research has been a reference and source of inspiration for this research topic in beef cattle. For this reason, the knowledge in feeder design from swine has been used to evaluate the effects of feeder design in intensive beef production. Moreover, the eating swine behavior has been analyzed with different feeder designs, and, for example, it has been shown that eating pattern evolves as animal grows. Thus, in swine production the feeder design depends on animal BW or age and this approach is important to evaluate the efficiency of feeder design to feed animals.

Concentrate feeder design could become a feasible strategy to reduce the total concentrate consumption per animal throughout the fattening cycle reducing feed wastage without impairing animal growth. This approach would allow improving both the feed efficiency and the profitability of farm, as the feed cost was reduced per unit of production (Lancaster et al., 2009). As mentioned before, the feed cost in intensive beef production represents 65% of total production cost.

As Gonyou and Lou (2000) indicated, the economic efficiency of a feeder depends on feed wastage, among other items (cost, animal to feeding space ratio, etc.). However, there is a lack of research in cattle about the effect of feeder design on feed spillage. In fact, only a study in beef cows (Buskirk et al., 2003) has been published, which evaluated the effect of hay feeder design on feed spillage and eating behavior. Then, it is an opportunity to improve feed efficiency and to study the interrelation of feeder design and feed wastage, and the magnitude of feed savings.

There is a scarce information (Devant, 2006) regarding the types of concentrate feeder implemented in intensive beef farms (dimensions, the feeding space available per animal, the feeder capacity of contained feed, the manufacture material, the place of feeder within pen, etc.). Anyhow, the self-feeder design has pursued maximum consumption by ensuring continual availability of feed (Gibb and McAllister, 1999), *ad libitum* regime, usually with generous amount of concentrate into the feeder.

Contrary, an extensive research has been conducted in swine production recently; feeder models are used by industry according to the feeder space (single vs. multiple), the feeder adjustment, the size of pig (grower vs. finisher), and the type of feed (wet or dry), etc. There is a big amount of information and experience relative to the effects of different feeder designs on consumption, wastage, productivity, and eating behavior (Nielsen et al., 1996; Gonyou and Lou, 1997; Bergstrom et al., 2012a, 2012b; Myers et al., 2012), even recommendations in animal to feeder space ratio depending on feeder design (Gonyou, 1999; Gonyou and Lou, 2000).

Most of the intensive beef farms usually are not supplied of electricity and few short-term (minutes or few hours) activities that require energy are conducted by fuel generator. Depending on the presence or not of feed systems transferring from storage silo to feeder, the self-feeder management is different in terms of daily frequency of feed delivery. For instance, if the concentrate is delivered directly from silo a continual availability of feed is ensured as animals are eating, this system is called free-fall of concentrate because it falls under gravity action. Contrary, when concentrate is transferred by auger (screw conveyor) the frequency of feed delivery is established according to farmer attendance or automatic stopping system, but usually it is once or twice per day. A free-fall self-feeder (with big concentrate feeder capacity) together with a low daily feed delivery frequency results in feeding system where there is a huge amount of concentrate into the feeders when animals are eating. This circumstance contributes to increase the concentrate wastage due to eating behavior, mainly, and feed deterioration (out-of-condition). Commonly, beef intensive farms have implemented a large free-fall feeder that allows huge amounts of concentrate (100 to 200 kg) ensuring continuous access to feed for cattle.

The study of eating behavior related to feeder design gains importance to understand the way in which the final interface between animals and diets works (Gonyou and Lou, 2000). In swine production some recommendations or suggestions have been given as technical or practical considerations in order to implement these types of feeder designs. Wastage occurs while animals are eating, and there are some repetitive behaviors during the eating activity like lateral head movements, when animals back out of the feeder, pigs step in and out of the feeder, and during fights at the feeder (Gonyou, 1999). All of these eating behaviors contribute to a greater or lesser extent to generate feed spillage. Logically, this eating behavior analyzed in swine can be extrapolated in cattle to study the feed wastage generation.

Two aspects of feeder design can be modified to reduce feed spillage in swine; a reduction of available concentrate amount in the feeder, and a reduction of feeder space. In both strategies the feed accessibility may be compromised, as observed Gonyou and Lou (2000), which devoted more time at the feeder and did not eat expected feed amounts. There are some studies in swine related to feeder design (Bergstrom et al., 2012a; Myers et al., 2012), evaluating how feeder space and adjustment could affect feed intake and performance, and improve feed efficiency. This knowledge could be transferred and applied in intensive beef production changing the feeder designs.

### 4.4.1. Feeder space vs. animal to feeder space ratio

The feed intake and eating behavior can be modulated by feeding facilities, among other factors (Grant and Albright, 2001). In this way, feeder space (linear length of manger per animal for eating) and animal to feeder space ratio (number of concentrate feeding places per animal) can be used as a strategy to enhance the feed efficiency and/or farm profitability. Both concepts are related to the capacity/efficiency of feeder to feed animals under the feeding conditions established, but the first is more often used in dairy and second in beef cattle. Usually, feeder space involves a feeding system (like TMR) where the concentrate and forage are mixed and delivered once or twice daily in a linear length of manger that should allow that all animals could eat simultaneously with sufficient feed quantities ensuring *ad libitum* regime. Conversely, animal to feeder space ratio is relative to a feeding system in which concentrate and forage are provided continuously throughout the day in separate feeders but animals cannot eat all together at the same time.

#### *4.4.1.1. Feeder space, eating space or feed bunk length*

For instance, Olofsson (1999) suggested the possibility to reduce facilities costs in dairy farms limiting feeding space, whenever the feed accessibility was guaranteed by regulations or recommendations regarding feeding space. On the other hand, feeder space influences the eating behavior in a group, and, in turn, has a tremendous impact on feed consumption and subsequent fattening productivity. Thus, the purpose when designing length of feeder is to optimize the feeding space per animal required according to production targets to promote intense eating activity and maximum intake without impairing animal welfare (performance, intake, eating and animal behavior, and health). Lastly, feeder space allowance per animal is strongly influenced by cattle production system, feeding system/management, feeding facilities, trends and paradigms of cattle (dairy or beef) producers, etc.

Feeding space can become a critical factor in group feeding cattle when this is insufficient to allow all animals to feed at once, especially under restricted feeding regime. Then, a competitive eating situation inevitably occurs at the feed bunk when feeder space is limited. Herein, Grant and Albright (2001) specified that certain level of competition for feed at the manger depends on the group (pen) size, and the feed amount and availability (time) in the feeder defined by feeding program/system. These former authors also described several circumstances where a feed limitation can occur; inadequate amounts of feed daily provision, overcrowding bunk space, inadequate or poor maintenance of forage mangers, unstable feed, etc. Hence, a limited feeding situation can affect negatively cattle productivity and animal welfare. Likewise, several studies in beef cattle have reported a decreased growth rate and an increased feed conversion ratio when feeding space per animal was reduced (Keys et al., 1978; Lutz et al., 1982; Hanekamp et al., 1990). For instance, Hanekamp et al. (1990) reported a significantly improved daily gain and feed conversion rate when bulls were allowed 75 cm manger space compared to 55 cm. Furthermore, no effects of decreasing feed bunk length per animal on performance and feed efficiency have been observed in several studies (Zinn, 1989; Gunter et al., 1996; Longenbach et al., 1999).

However, the feeding space allowance (feeder space) can also have a positive influence on animal performance (intake and growth) and feed efficiency. Accordingly, some authors have postulated in dairy cattle that feed consumption and consequent milk yield are improved by provision of feed when cows need and want to eat (Schultz, 1992; Albright, 1993; Grant and Albright, 2001).

In North American context, a review from scientific literature reported by Grant and Albright (2001) showed the relationships among bunk space, eating behavior, and feed intake in dairy cows (Table 1).

**Table 1.** Bunk space and feed intake of dairy cows[1]

| Bunk space | Effect on feed intake |
|---|---|
| < 0.20 m | Reduced eating time and feed intake |
| 0.20 - 0.51 m | Increased competition with variable effect on feed intake |
| > 0.51 - 0.61 m | No measurable effect on feed intake |

[1]Data summarized from Albright (1993), Friend and Polan (1974), Friend et al. (1977), Manson and Appleby (1990), and Menzi and Chase (1994).

Few decades ago, the continuous access to the feed bunk became a popular feeding management in free stall housing dairy cattle (Friend et al., 1977). In addition, the trend in dairy farms was to expand herds, in which with existing facilities a competition problem at the feed bunk was expected (Keys et al., 1978). At that time, *ad libitum* feeding regime was still not extended following hypothesis to avoid feed wastage or prevent digestive disorders associated with excessive consumption of high-concentrate diets. Then, the space requirements for animals, together with the animal behavior and eating pattern became relevant factors in adequacy of this feeding system.

Grant and Albright (2001) suggested the recommendation of 0.61 m of linear feed bunk space per cow as a minimal length of feeder space needed for all cows to eat at one time. Although this measure of manger has been traditionally used for dairy industry as a reference of adequate amount space per lactating cow, the requirements in feeder space differs with herd (pen) size, and the amount and availability of feed (Grant and Albrigth, 2001).

Moreover, further research has been conducted in dairy cattle trying to understand why a certain level of competition at feed bunk was maintained even when increasing the feeding space. DeVries and Keyserlingk (2006) have suggested that other factors could be involved in this process, as studies in other domesticated species have found evidences that this feed competition can be affected by the feeding space configuration. The experience from swine reported by Gonyou (1999) indicates that feed trough partitions reduce aggressions and displacements at the feeder. In dairy cattle there is an extensive literature (Endres et al., 2005; DeVries and Keyserlingk, 2006) that reviews the effect of feed bunk space on eating behavior, performance (intake and milk yield), and animal competition (aggressions).

The feeding space for beef cattle should be designed depending on the weight (size) of animals and, also, the feeding program used. Hence, Table 2 summarizes European recommendations of feeding trough space for intensive reared cattle.

**Table 2.** Feeding trough space allowances for loose housed fattening cattle (m/animal) extracted from SCAHAW (2001)[1]

| Animal weight (kg) | Trough space (m) |
|---|---|
| > 400 | 0.60 |
| < 400 | 0.50 |
| > 350 | 0.55 - 0.70 |
| 250 - 350 | 0.45 - 0.55 |
| 130 - 250 | 0.30 - 0.45 |
| 500 | 0.60 |

[1]Data summarized from Jordbruksinformation (1999) and Hardy and Meadowcroft (1986).

However, a feed bunk length of 0.15 m/animal can be considered sufficient for optimal performance in beef cattle fed a total mixed ration at restricted feeding method, even though this length was considerably lower than space recommended (Albright, 1993). Anyhow, no improvements in performance were detected with a feeder bunk length above 0.15 m/animal; thus, it can be considered as a threshold (Zinn, 1989; Gunter et al., 1996; Longenbach et al., 1999).

Furthermore, Longenbach et al. (1999) established different feed bunk lengths per animal recommended at different ages based on growth responses and eating behavior in heifers fed a total mixed diet at restricted intakes at accelerated rates of gain. Other studies in field conditions (Graves and Heinrichs, 1984; Crowley et al., 1992) have revealed a large variation in the recommended feed bunk length across all ages of dairy heifers. All these findings indicate that feeder space requirements change as animals grow, which becomes a relevant factor to consider in feeder design housing cattle.

Lutz (1981) observed an increase of aggressive and mounting behavior, and, also, a reduction in lying time when feeder space at manger was reduced, as animals could not eat simultaneously. These findings are agreement with results obtained by Kongaard (1983) and Graf (1984), which indicated that reduced feeding space per animal at manger may negatively affect eating behavior such as increased frequency of feeder visits and reduced time spent eating. Different authors (Friend et al., 1977; Olofsson, 1999) have also observed that competition at the feed bunk, from limited feeding circumstance, can affect also eating behavior. Longenbach et al. (1999) observed that an increased the level of competition at the feeder altered the eating pattern, increasing the number of meals, decreasing the time spent eating and meal duration.

### *4.4.1.2. Feeding places or animal to feeder space ratio*

There are few studies (Andersen et al., 1997; González et al., 2008a; González et al., 2008b) that have focused on the effect of number of feeding spaces per pen (feeder places to animal ratio) on performance, eating and animal behavior, and welfare. For instance, Andersen et al. (1997) concluded that the effect of feeding space (1 to 5 animals per eating place) for truly *ad libitum* feed animals seems not to be significant in growth and feed efficiency. It is important to remember that other factors such as the design of the feed manger may also possibly influence performance (Bouissou and Signoret, 1971). Conversely, González et al. (2008a) showed a negative effect on performance when increasing social pressure at the concentrate feeder beyond the threshold of 4 animals per feeder space. Reducing feeding space at manger to less than one per animal seems to reduce performance (Ingvartsen and Andersen, 1993).

Anyhow, there are not recommendations in feeding spaces to animal ratio for intensive beef cattle nowadays.

### 4.4.2. Feeder adjustment and feed accessibility

To ensure feed accessibility may be more important than the amount of nutrients provided (Albright, 1993; Grant and Albright, 1995). On the other hand, feeder adjustment could be a strategy to reduce feed wastage but may difficult access to feed.

In swine, feeder adjustment affects the difficulty with pigs can access to the feed (Smith et al., 2004; Duttlinger, et al. 2009) and their feeding behavior. Thus, feeder adjustment has an impact on average daily feed intake, average daily gain, gain to feed ratio, and carcass back fat depth (Braude et al., 1959; Barber et al., 1972; Kanis, 1988). Moreover, differences in the amount of feed wasted can result from differences in feeder design, but decreases in feed intake and gain to feed ratio may also occur when pigs require more effort to obtain feed (Morrow and Walker, 1994a; Gonyou, 1998). In swine, adequate feeder adjustments (feeder gap) were effective to decrease feed wastage and, consequently, increase feed efficiency (Myers et al., 2012). In this before study, although no measurements of feed wastage had been registered, authors assumed or extrapolated that differences in gain to feed ratio may be attributed to feed spillage, as the remaining experimental conditions were the same.

However, not published cattle research has been found relative to the effect of feeder depth (lip to feed access) and lip height on performance, eating behavior, and feed efficiency.

### *4.5. STRAW FEEDER OR DRINKER DESIGN*

As concentrate feeder design affects the total concentrate consumption, by the extension, the straw feeder or drinker design could also have an effect in performance and fattening profitability. However, to our knowledge, no information relative to straw feeder and drinker design is available in the literature. Thus, a further research is necessary to know the impact of straw feeder or drinker design on concentrate intake, growth, and feed efficiency.

In summary, an overall assessment is presented (Table 1) to elucidate the best approaches for our intensive beef production system among several postformula feeding strategies reviewed previously.

**Table 1.** Overall assessment base on postformula feeding strategies reviewed to indicate the most appropriate approaches for our intensive beef production

| POSTFORMULA FEEDING STRATEGY | Literature supports that could improve | | Applicability to our intensive beef production (high-concentrate diets) | Expected economic benefits | Weakness or critical points | Overall evaluation |
|---|---|---|---|---|---|---|
| | feed efficiency[1] | growth | | | | |
| **Grain processing** | | | | | | |
| Physical form of concentrate (mash vs. pellet) | | | | | Transport and storage cost. | |
| Physical pellet quality (good vs. bad) | | | | | Pellet quality improvement cost. | |
| **Forage provision** | | | | | | |
| Amount, quality, and particle length, | | | | | Forage management (cleanness, accessibility). | |
| Nonforage sources | | | | | Variability in physical characteristics and chemical composition. | |
| Without forage | | | | | Risk of digestive disorders. Depending on physical form of concentrate. | |
| Total mixed ration (TMR) wet | | | | | Handling and labor. | |
| Total mixed ration (TMR) dry | | | | | Increase feeder space. | |
| **Feeding management** | | | | | | |
| Feeding regime (limit-fed, restricted or programmed) | | | | | Less kg and quality carcass. Risk of increasing pen BW heterogeneity. | |
| Feeding time morning vs. evening | | | | | Studies are based on TMR. | |
| Feeding frequency twice vs. once | | | | | | |
| **Feeder design** | | | | | | |
| Feeder space, feed bunk length | | | | | Studies are not based on *ad libitum* regime and using TMR. | |
| Animal to feeding places ratio | | | | | Optimal ratio. Risk of eating pattern altered and digestive disturbances. | |
| Feeder adjustment | | | | | To limit feed accessibility. | |

[1]The criterion of feed efficiency corresponds to concentrate efficiency which is the commercial criteria in our beef industry, with an exception of TMR.

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# CHAPTER II

# OBJECTIVES

## 1. OBJECTIVES

The main objective of the current thesis was to look for possible feeding strategies beyond the concentrate formula (postformula) to reduce the total concentrate consumption without impairing performance and animal welfare (animal and eating behaviors, rumen health) and, thereby, to improve the feed efficiency and/or the fattening profitability in Holstein bulls fed high-concentrate diets. To accomplish this latter aim two different approaches related to feeding system were chosen, the first was focused on features of concentrate feeder design (feeder depth and feeder space availability), and another on physical form of concentrate (physical pellet quality).

The study of eating behavior throughout the present thesis has a predominant role because it can be considered as the result of the interaction between animals and feeding system (facilities, management, presentation form, etc.). Furthermore, it is extensively known that eating behavior has a tremendous impact on concentrate consumption, cattle productivity, animal well-being, herd health status, and profitability (Grant and Albright, 2001). For these reasons, the present thesis has made an effort to expand the knowledge in eating behavior according to the concentrate feeder design and physical form of concentrate.

The specific objectives derived from the principal purpose are framed within our experimental/productive context, which is characterized by the fattening of Holstein bulls fed high-concentrate diets, where concentrate and forage are offered *ad libitum*, in separate feeders, following a ratio of 90 to 10. Concentrate is presented in pellet form, and corn is the main ingredient included in the mixture that compounds the concentrate.

These specific objectives were:

1. To evaluate the effect of two alternative concentrate feeder designs (a feeder with less concentrate capacity and a single-space feeder with lateral protections) on concentrate consumption, growth rate, feed efficiency, eating pattern, animal behavior, welfare, rumen health, and carcass traits.

2. To assess the impact of an alternative concentrate feeder design (a collective feeder with less feeder depth and a single-space feeder with lateral protections) on eating and drinking behaviors, together with studying the evolution of these patterns with animal BW evolution according to concentrate feeder design.

3. To evaluate the effect of an adaptation strategy (single-space feeder without lateral protections for first 4 d and additional feeder where feed offer was gradually reduced for first 14 d) to a single-space feeder with lateral protections on performance, eating pattern, and animal behavior for first 6 wk upon arrival at the fattening.

4. To assess the effects of physical form of concentrate on performance, eating pattern, and feed preference in finishing bulls, together with studying the evolution of physical pellet quality from the pellet mill to the feeder.

To achieve all of these specific objectives, four studies were conducted:

**Study 1:** Effect of concentrate feeder design on performance, eating and animal behavior, welfare, ruminal health, and carcass quality in Holstein bulls fed high-concentrate diets.

**Study 2:** Effect of concentrate feeder design on eating and drinking behaviors, and their evolution with bodyweight in Holstein bulls fed high-concentrate diets.

**Study 3:** Effect of adaptation strategy to a single-space concentrate feeder design with lateral protections on performance, eating and animal behavior at entrance of fattening in Holstein calves fed high-concentrate diets.

**Study 4:** Effect of physical form of concentrate on performance, eating pattern, and feed preference in Holstein bulls fed a finishing high-concentrate diet.

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# CHAPTER III

## Effect of concentrate feeder design on performance, eating and animal behavior, welfare, ruminal health, and carcass quality in Holstein bulls fed high-concentrate diets

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## ABSTRACT

A total of 240 Holstein bulls (121 ± 2.0 kg initial BW; 99 ± 1.0 d of age), from 2 consecutive fattening cycles, were randomly allocated in 1 of 6 pens and assigned to 1 of the 3 treatments consisting of different concentrate feeder designs: a control feeder with 4 feeding spaces (CF), a feeder with less concentrate capacity (CFL), and a single-space feeder with lateral protections (SF). Each pen had a straw feeder and a drinker. All animals were fed a high-concentrate diet for ad libitum intake. Concentrate consumption was recorded daily using a computerized feeder, straw consumption was recorded weekly, and BW was recorded every 14 d. Animal behavior was registered on d 1, 3, 5, 8, and 14 and every 28 d by scan sampling. Eating behavior at concentrate feeders was filmed on d 12, 125, and 206. On d 7, 120, and 204, samples of rumen contents were collected for measurement of pH and VFA and blood samples were obtained to analyze NEFA, haptoglobin, glucose, and insulin. Animals were slaughtered after 223 d, and HCW and lesions of the rumen wall and liver were recorded. The accumulative concentrate consumption per animal tended ($P = 0.09$) to be greater with CF than with CFL and SF. Also, CV of concentrate consumption was greater ($P < 0.01$) for SF than for CF or CFL. However, feeder design did not influence the other performance and carcass data. Also, no differences among treatments in rumen wall evaluation and liver abscesses were observed. At 7 and 204 d of study, SF bulls had greater ($P < 0.05$) rumen pH compared with CF and CFL bulls. On d 7, the acetate to propionate ratio from SF was greater ($P < 0.05$) than for CFL or CF. At d 7, NEFA of SF were greater ($P < 0.05$) compared with CF and CFL. Bulls fed with CF have the greatest ($P < 0.01$) concentrate disappearance velocity followed by bulls fed with CFL and finally by bulls fed with SF, and this was associated with different feeding behaviors. Bulls on SF spent more time ($P < 0.05$) eating straw and exhibited fewer ($P < 0.05$) displacements at concentrate feeder than CF and CFL bulls. The CFL bulls exhibited ($P < 0.01$) more attempted mounts and tended ($P = 0.10$) to exhibit more completed mounts than CF bulls. In conclusion, both alternative feeder designs (CFL and SF) are good strategies to reduce total concentrate consumption without impairing performance, rumen health, or animal welfare in Holstein bulls fed high-concentrate diets. However, at the beginning, there was evidence that animals fed using SF had problems with adaptation.


**Key words:** beef, behavior, feeder design, performance, rumen pH

## 1. INTRODUCTION

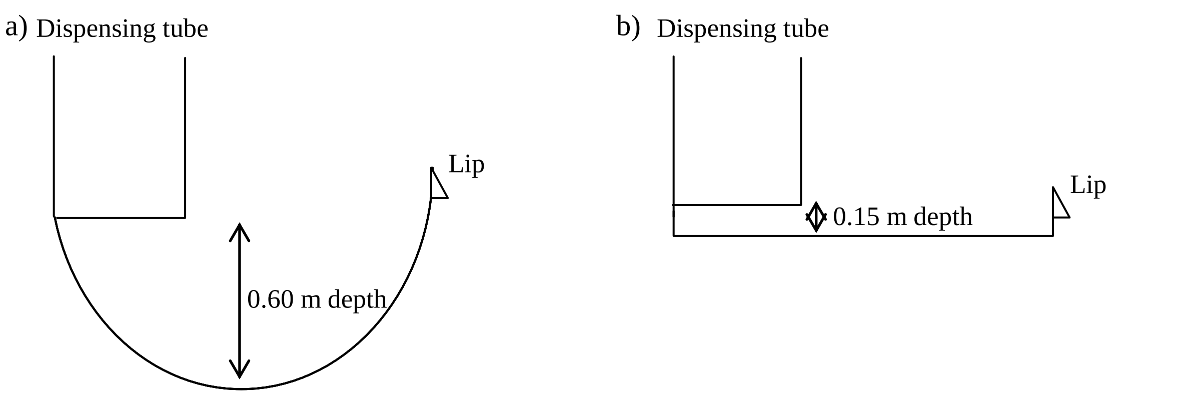
In Mediterranean countries in beef feeding systems, concentrate and straw are both fed for ad libitum intake in separate self-feeders resulting in a concentrate to straw ratio of 90 to 10 (Devant et al., 2000; Mach et al., 2009), differing from the most common world feeding systems, fence line bunk feeding with a total mixed ration. In recent years, prices of ingredients have increased drastically, a circumstance that has forced producers to look for alternatives beyond the formulation. A single-space feeder with lateral barriers has been used to record individual concentrate intakes for research purposes (Devant et al., 2012; Marti et al., 2013), and total concentrate consumed by the cattle was less than in previous studies (Mach et al., 2006; Devant et al., 2010) without impairing growth. So, it was hypothesized that the single-space feeder with lateral barriers could reduce feed consumption and feed costs compared with selffeeders with multiple feeding spaces. However, reducing the feeder space to animal ratio could increase effort to obtain feed and competition to access feed (Huzzey et al., 2006; González et al., 2008), and increased eating rate could negatively affect rumen health (Sauvant et al., 1999; González et al., 2008), as greater fluctuations in rumen pH and consumption can lead to rumen acidosis and liver abscesses (Fulton et al., 1979; Stock et al., 1987, 1990). Moreover, feed adjustment at the feeder (amount of feeder pan coverage) can affect time spent eating, competition at the feeder, and feed wastage (Gonyou, 1999) and, in turn, feed efficiency as observed in swine (Bergstrom et al., 2012; Myers et al., 2012). So another alternative to improve feed efficiency in beef would be the reduction of feeder depth. The present study evaluated the effect of feeder design on concentrate consumption, growth rate, feed efficiency, eating pattern, animal behavior, welfare, rumen health, and carcass traits in Holstein bulls fed high-concentrate diets.

## 2. MATERIALS AND METHODS

### *2.1. Cattle, Feeding, and Housing*

Animals were reared under commercial conditions in a farm owned by Agropecuaria Montgai SL (Lleida, Spain) and were managed following the principles and specific guidelines of the Institut de Recerca i Tecnologia Agroalimentàries Animal Care Committee. Two hundred forty male Holstein calves (121 ± 2.0 kg initial BW; 99 ± 1.0 d of age) in 2 consecutive fattening cycles (120 animals each cycle) were used in a replicated study, which was conducted in a commercial farm with 6 pens. Pens were totally covered and measured 12 by 6 m (72 $m^2$ per pen), with a space availability of 3.6 m2 per animal, and were deep bedded with straw. Each pen had 36 m2 of resting area and 36 m2 of feeding area in the front with the concentrate feeder, a separate straw feeder (3.00 m long by 1.12 m wide by 0.65 m deep; 7 feeding spaces), and a water bowl. Animals were randomly allocated in 1 of 6 pens and assigned to 1 of the 3 different concentrate feeder designs (20 animals per pen): 1) a control feeder with 4 feeding spaces (**CF**), a concentrate feeder capacity of 200 kg, and a feeder depth of 0.60 m (Fig. 1a); 2) a feeder (like CF) with less concentrate capacity (**CFL**; 45 kg) and a feeder depth of 0.15 m (Fig. 1b); and 3) a single-space feeder with lateral protections (**SF**), a concentrate feeder capacity of 10 kg, and a feeder depth of 0.15 m (Fig. 1b).

**Figure 1.** Schedule of a cross sectional cut of the control feeder (a) and the control feeder with limited concentrate level or the single feeder with lateral barriers (b). The trough depth is indicated



Concentrate feeders were manufactured in stainless steel, which were elevated at 0.80 m from the floor but had different features of design (dimensions of feeder): CF was 1.90 m long, 0.60 m wide, and 0.60 m deep, with a feeder capacity of 200 kg of concentrate and stanchions defining 4 feeding spaces (0.35 m inside distance; Fig. 2); CFL was 1.90 m long, 0.60 m wide, and 0.15 m deep, with a feeder capacity of 45 kg of concentrate and stanchions defining 4 feeding spaces (0.35 m inside distance; Fig. 3); and SF was 0.50 m long by 0.26 m wide by 0.15 m deep, with a feeder capacity of 10 kg of concentrate, protected by 2 lateral barriers (1.40 m long by 0.80 m high) forming a chute, the inside diameter of which could be regulated from 0.42 to 0.72 m wide (Fig. 4). Animals fed with SF were adapted for the first 4 d of the study by widening the chute to facilitate feeder access (adaptation period). After these first days, the width of the chute was adjusted 3 times during the study to adapt the entrance to the animal size providing sufficient space to eat comfortably. At d 5 of study, the width of chute was fixed at 0.42 m, at d 25 it was 0.55 m, and at d 120 it was widened to 0.72 m.

**Figure 2.** Control feeder. Concentrate feeder with 4 feeding spaces and 200 kg of trough capacity. (a) Top view and (b) front view

a)

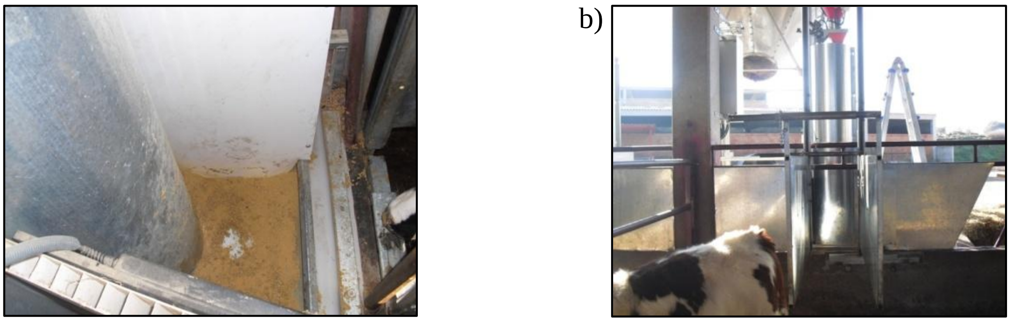
b)

**Figure 3.** Control feeder with limited feeder capacity. Concentrate feeder with 4 feeding spaces and 45 kg of trough capacity. (a) Top view and (b) front view

a) b)

**Figure 4.** Single feeder. single feeder with lateral protections and a trough capacity of 10 kg. (a) Top view and (b) front view

a) b)



### *2.2. Feed Consumption and Performance*

All animals were fed a commercial concentrate (Table 1), formulated according to the NRC (1996) recommendations. For the initial 130 d of the study, animals were fed the grower concentrate, and from 131 d of study to the end of the study, they were fed the finisher concentrate. Also, animals had ad libitum access to wheat straw (3.5% CP, 1.6% ether extract, 70.9% NDF, and 6.1% ash; DM basis) and fresh water. A sample from each concentrate batch was collected and was analyzed for DM, CP, NDF, ash, and ether extract.

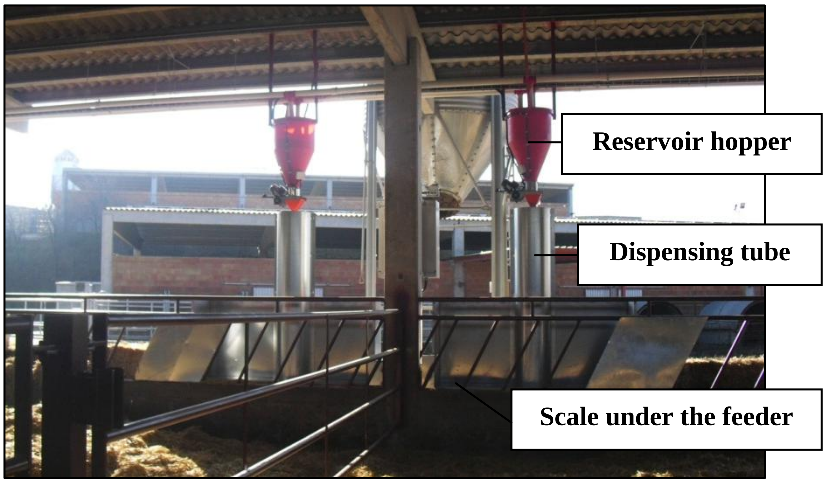
**Table 1.** Ingredients and nutrient composition of the experimental concentrates

| | Concentrate | | | |
|---|---|---|---|---|
| | Grower | | Finisher | |
| | Fattening cycle | | | |
| Item | First | Second | First | Second |
| Ingredients, % of DM | | | | |
| Corn | 43.0 | 40.7 | 33.4 | 48.5 |
| Soybeanhulls | 15.0 | | 17.0 | 3.0 |
| Soybeanmeal | | 4.3 | | 4.0 |
| Canolameal | | 3.0 | | |
| Corn dried distillers grains | 14.0 | 10.0 | 14.0 | 12.0 |
| Corngrits | | 17.0 | 15.0 | 17.0 |
| Lupinmeal | 13.3 | | | |
| Wheat middlings | 11.8 | 21.8 | 3.9 | 12.3 |
| Peameal | | | 9.4 | |
| Palm oil | 1.2 | 1.3 | 3.0 | 1.8 |
| Sunflower meal | | | 3.0 | |
| Calcium carbonate | 1.2 | 1.4 | 0.8 | 0.9 |
| White salt | 0.3 | 0.3 | 0.3 | 0.3 |
| Vitamin-mineral premix[1] | 0.2 | 0.2 | 0.2 | 0.2 |
| Nutrient composition, % of DM | | | | |
| Ash | 5.00 | 4.71 | 5.38 | 4.47 |
| CP | 16.33 | 15.15 | 15.58 | 14.38 |
| Ether extract | 6.73 | 9.09 | 7.05 | 7.88 |
| NDF | 28.21 | 27.45 | 21.61 | 20.42 |
| NFC[2] | 43.73 | 43.60 | 50.38 | 52.85 |
| ME, Mcal/kg | 2.88 | 2.88 | 3.01 | 3.00 |

[1]SinuvitTerneros Final (Sinual S.L., Sallent, Spain): vitamin and mineral premix containing, per kg of DM: 4,500 kIU of vitamin A, 1,000 kIU of vitamin $D_3$, 22.5 g of vitamin E, 0.5 g of vitamin $B_1$, 1 g of vitamin $B_2$, 5 mg of vitamin $B_{12}$, 2.5 g of vitamin $B_3$. 15 g of Mn, 3 g of Cu, 30 g of Zn, 0.5 g of Co, 0.5 g of I, 0.1 g of Se, 1 g of butylated hydroxytoluene, 1 kg of calcium carbonate as excipient.
[2]NFC = nonfiber carbohydrates [calculated as 100 – (CP + ash + NDF + ether extract)].

An automated system was used to register concentrate consumption by recording the feed disappearance within an interval of time. Each pen was equipped with a scale that consisted of 4 load cells (Utilcell, Barcelona, Spain) where the feeder was suspended. The scales were programmed to transmit the feed weight at 1-min intervals or when weight change was detected to a Programmable Logic Controller (Allen-Bradley model 1769-L35E; Rockwell Automation, Milwaukee, WI) and finally displayed by a personal computer with a software application (Voltec, Lleida, Spain). The computer recorded initial and final feed weight with its corresponding initial and final time. The negative values of concentrate consumption, which were usually caused by eating action belonging to animals (scratching) or when feed was added inside the feeder, were removed from the data set by computer filters. The scales were calibrated weekly. All feeders were designed to be refilled automatically to ensure continuous feed availability. The refilling system was common for all feeders (Fig. 5).

**Figure 5.** The refilling system is common for all feeders. The dispensing tube capacity has the same dimensions in all feeders and the dispensing tube is always full. The scale under the feeder continuously registers the weight, when it detects that the dispensing tube (stainless steel half-tube, 2m long, and radium of 20.5 cm), is empty (by weight difference) the dispensing tube is automatically refilled with concentrate contained in the intermediate dispensing hoppers (in red), so the level of concentrate at the trough (limited by the lower end of the dispensing tube and the trough depth) is continuously maintained




The dispensing tube capacity had the same dimensions in all feeders and the dispensing tube was always full. The scale under the feeder continuously registered the weight, and when it detected that the dispensing tube was empty (by weight difference), the dispensing tube was automatically refilled with concentrate contained in the intermediate dispensing hoppers, so that the level of concentrate in the trough (trough depth) was continuously maintained. The amount of straw offered to each pen was recorded weekly to estimate the total amount of straw consumed; however, because straw was also used for bedding, these data are only guiding data. Animals were weighed every 14 d throughout study, and calculations used full BW data.

### *2.3. Animal Behavior*

To analyze the general activity (standing, lying, eating concentrate and straw, drinking, and ruminating) in the pen and social behavior (nonagonistic, agonistic, and sexual interactions) of animals, a scan sampling procedure was used. Records correspond to total counts of each activity in a pen (Mounier et al., 2005). Animal behavior was recorded on d 1, 3, 5, 8, 14, and 26 and every 28 d throughout the study from 0830 to 1100 h by scan sampling as described by Rotger et al. (2006), Robles et al. (2007), Mach et al. (2008), and Marti et al. (2010). The scan sampling method describes a behavior exhibited by an animal at a fixed time interval (Colgan, 1978). Two pens were observed at the same time, and whereas social behavior (Table 2) was scored during 2 continuous sampling periods of 15 min, general activities (Table 3) were scored using 2 scan samplings of 10 s at 5 min intervals (Mach et al., 2008). This recording procedure (15 min) was repeated twice during the morning.

**Table 2.** Description of the social behavioral categories recorded

| Item | Definition |
|---|---|
| Nonagonistic interactions | |
| Self-grooming | Defined as nonstereotypied licking of its own body or scratching with a hind limb or against the fixtures. |
| Social behavior | When a bull was licking or nosing a neighboring bull with the muzzle or horning. |
| Oral behavior | The act of licking or biting the fixtures. |
| Agonistic interactions | |
| Fighting | When bulls pushed vigorously head against head. |
| Butting | When 1 bull pushed vigorously its head against any part of another bull’s body. |
| Displacement | When 1 bull shoved itself between 2 other animals or between an animal and a wall or any equipment. |
| Chasing | When 1 bull made another animal flee by following fast or running behind it. |
| Chasing-up | When 1 bull used forceful physical contact against a resting animal that made the receiver rise. |
| Sexual interactions | |
| Flehmen | Upper lip reversed. |
| Attempted mounts | Head on the back of another animal. |
| Completed mounts | Forelimbs on the back of another animal. |
| Stereotypies | |
| Oral stereotypies | Tongue rolling, stereotyped licking or biting on certain bars or sites in the stall. |

### *2.4. Eating Behavior*

To study the effect of feeder design on eating behavior at the feeder, the feeding area was filmed for 24 h at the beginning (d 12), in the middle (d 125), and at the end (d 206) of the experiment using digital cameras (Sony CSM-BV420; Sony Corp., Barcelona, Spain) that filmed the feeding area of each pen. Videotapes were processed by continuous recording of the activities performed by animals at the concentrate feeders. Only 12 h of recordings (0600 to 1800 h) were used to create a data set, because the quality of the night recordings was not always acceptable. Activities recorded included eating concentrate, waiting time to access to the feeder, and displacements at the feeder. These activities were registered by simultaneously recording for each activity the time duration (min), the number of animals involved, and the frequency of activity.

**Table 3.** Description of the general activities recorded

| Item | Definition |
|---|---|
| Eating | Eating (concentrate or straw) was defined as when the animal had its head into the feeder and was engaged in chewing. An observation was defined as eating when the bull was eating from the feed bunk with its muzzle in the feed bunk or chewing or swallowing food with its head over the bunk. |
| Drinking | Drinking was recorded when the animal had its mouth in the water bowl. An observation was recorded as drinking when the bull was with its muzzle in the water bowl or swallowing the water. |
| Ruminating | Ruminating included the regurgitation, mastication, and swallowing of the bolus. |
| Lying | Lying was recorded as soon as the animal was not standing on its 4 legs, independently of any activity the animal might perform. |
| Standing | Standing was recorded when the animal was standing on its 4 legs, independently of any activity the animal might perform. |

### *2.5. Rumen Samples*

Samples of rumen contents (10 mL) from each animal were collected in the morning on d 7, 120, and 204 by rumenocentesis for pH and VFA determination. The order in which pens were sampled was random to avoid the effect sampling time on rumen data. Rumenocentesis was conducted with a 14-gauge, 140-mm needle (Abbocath-T; Hospira, Madrid, Spain) inserted into the ventral sac of the rumen approximately 15 to 20 cm caudal–ventral to the costocondral junction of the last rib. Rumen liquid pH was immediately measured with a portable pH meter (Crison pH25; Crison Instruments SA, Barcelona, Spain). Following Jounay (1982), a 4-mL rumen sample was mixed with 1 mL of a solution containing 0.2% (wt/wt) of mercuric chloride, 2% (wt/wt) orthophosphoric acid, and 0.2% (wt/wt) of 4-methylvaleric acid (internal standard) in distilled water and stored at –20°C until subsequent VFA analyses.

### *2.6. Blood Samples*

Blood samples for each animal were collected on d 7, 120, and 204 via tail or jugular venipuncture using Vacutainer tubes and 18 gauge needles. One blood sample (10 mL) was harvested into a Vacutainer tube with spray-dried clot activator (BD Vacutainer, Franklin Lakes, NJ) for insulin, NEFA, and haptoglobin concentration analysis; a second blood sample (4 mL) was collected into a Vacutainer tube with sodium fluoride and potassium oxalate (BD Vacutainer) for glucose analysis. All blood samples were centrifugedat 1,500 × *g* at 4°C for 15 min, and serum was decanted and stored at –20°C until further analyses.

### *2.7. Carcass Quality*

On d 217 of the study and onward, animals were randomly selected from each pen and transported to a commercial slaughterhouse (Mercabarna, Barcelona, Spain) by truck. Transport distance was less than 150 km and the waiting time until slaughter was less than 12 h. Animal transport was organized in 3 different loads without mixing animals from different treatments and pens. Before each loading, animal BW was recorded. Animals were stunned using a captive-bolt pistol and dressed according to commercial practices.

Immediately following slaughter, HCW was recorded, and the degree of carcass conformation and fatness were graded according to the (S)EUROP categories (EU Regulation No. 1208/81 and 1026/91) and into EU classification system into 1.2.3.4.5 (EU Regulation No. 1208/81), respectively. The conformation class designated by the letter ‘‘S” (superior) describes carcasses with all profiles extremely convex, and with exceptional muscle development (double-muscled carcass type), whereas the conformation classified as ‘‘E” (excellent) describes carcasses with all profiles convex to super-convex, and with exceptional muscle development, and the conformation classified as ‘‘U” (very good) describes carcasses with profiles on the whole convex, and with very good muscle development. The carcasses classified as “R” (good) present profiles, on the whole, straight and with good muscle development. Carcasses classified as “O” (fair) present profiles straight to concave and with average muscle development, and carcasses classified as “P”(poor) present all profiles concave to very concave with poor muscle development. In addition, the degree of fat cover describes the amount of fat on the outside of the carcass and in the thoracic cavity. The class of fat cover classified as 1 (low) describes none to low fat cover, and the class of fat cover classified as 5 (very high) describes an entire carcass covered with fat and with heavy fat deposits in the thoracic cavity. Dressing percentage was calculated dividing on HCW by BW before slaughter.

### *2.8. Rumen and Liver Macroscopic Evaluation*

Rumens were divided into areas according to Lesmeister et al. (2004) to examine the presence of ulcers and presence of clumped papillae (Nocek et al., 1984). Also, rumens were classified from 1 to 5 depending on the color, being “5” a black colored rumen and “1” a white colored rumen (González et al., 2001). Liver abscesses were classified according to Brown et al. (1975).

### *2.9. Chemical Analyses*

Feed samples were analyzed for DM (24 h at 103°C), ash (4 h at 550°C), CP by the Kjeldahl method (method 981.10; AOAC, 1995), NDF according to Van Soest et al. (1991) using sodium sulfite and α-amylase, and ether extract by Soxhlet with a previous acid hydrolysis (method 920.39; AOAC, 1995).

Rumen VFA concentration was analyzed with a semicapillary column (15 m by 0.53 mm i.d. and 0.5 μm film thickness; TRB-FFAP; Teknokroma, Barcelona, Spain) composed of 100% polyethylene glycol esterified with nitroterephtalic acid, bonded and cross-linked phase, using a CP-3800-GC (Varian, Inc., Walnut Creek, CA).

Plasma glucose concentration was determined following the hexokinase method (Tietz, 1995; intra-and interassay CV of 0.6 and 3.0%, respectively), and serum insulin concentration was determined using Porcine Insulin RIA (kit PI-12K; Millipore, Billerica, MA) with intra- and interassay CV of 4.8 and 5.8%, respectively. Plasma NEFA concentration was determined by the colorimetric enzymatic test ACS-ACOD-MEHA (acyl-CoA-synthetase/acyl-CoA-oxidase/3-methyl-N-ethyl-N-β-hydroxyethyl-aniline) method (NEFA C; Wako Chemicals, Neuss, Germany; with an intra- and interassay CV of 2.7 and 4.8%, respectively). Haptoglobin was determined by the hemoglobin binding method with the use of a commercial haptoglobin colorimetric assay (Assay Phase Range; Tridelta Development Limited, Maynooth, Ireland); the intra- and interassay CV were 4.1 and 11.2%, respectively.

### *2.10. Calculations and Statistical Analyses*

The frequency of each social behavior was observed by summing by day, pen, and scan, and they were transformed into the root of the sum of each activity plus 1 to achieve a normal distribution. The percentage of each general activity was averaged by day, pen, and scan, and it was transformed into natural logarithms to achieve a normal distribution. Serum metabolites and pH data were transformed into natural logarithms to achieve a normal distribution. The means presented in the tables correspond to backtransformed data, and SEM and *P*-values correspond to the ANOVA analyses of the transformed data. The occupancy time of concentrate feeder (min) and total waiting time to access to the feeder (min) were calculated as the sum of total time performing these activities per day and pen. The number of bulls eating concentrate and number of visits at concentrate feeder were averaged by pen and day. Number of displacements at the feeder were summed by pen and by hour and divided by total time analyzed to express as frequency of displacements per hour. Feeder occupancy and waiting time data were expressed as the percentage of time devoted to these activities from total daily time of video recording analyzed (12 h). All eating behavior data were corrected by the number of animals within the pen for each filming period.

The pen was considered the experimental unit for all statistical analysis ($n = 4$), with animals considered sampling units. Hence, a power analysis was conducted to check if 4 replicates per treatment would be sufficient to detect differences in feed consumption. The power analyses was conducted for the primary outcome variable (concentrate consumption) using the SD of this parameter between pens observed in previous studies under same experimental conditions (Devant et al., 2012; Marti et al., 2013), an $\alpha$ of 0.05, and a power of 0.80. The power analysis indicated at least that 3 replicates (pens) per treatment were necessary to detect expected differences among treatments. An expected 10% in total concentrate consumption difference among treatments was expected; this expectation was based on previous studies data (Devant et al., 2012; Marti et al., 2013). To the extent that individual measurements on animals were possible, animals were included in the analyses as sampling unit and not as experimental unit (like a repeated measure typically seen with several determinations on the same animal over time). This allowed the use of covariate measurements on the animals (sampling units). So the covariate adjustments were done on the individual animals.

Consumption, performance, and eating and animal behavior data were analyzed using a mixed-effects model with repeated measures (version 9.2; SAS Inst., Inc., Cary, NC). The model included initial full BW as a covariate; treatment, period (14 d for consumption and performance data; 3 times throughout the study for eating behavior data; weekly for first month and 28 d for the remaining of study for animal behavior data), and their interaction as fixed effects; and pen and fattening cycle as random effects. Period was considered a repeated factor, and pen nested within treatment was subjected to 3 variance–covariance structures: compound symmetry, autoregressive order 1, and unstructured. The covariance structure that yielded the smallest Schwarz's Bayesian information criterion was considered the most desirable analysis.

Rumen and serum metabolites were analyzed using mixed-effects ANOVA with repeated measures (version 9.2; SAS Inst., Inc.). The model was the same

as the previous one, but sampling time (time of the day when the animal was sampled) was also included as a covariate for pH and VFA data.

Initial full BW, age, final BW, and carcass data were analyzed using a mixed-effects model (version 9.2; SAS Inst., Inc.) including treatment as a fixed effect and pen and fattening cycle as random effects.

Carcass conformation and fatness, rumen wall macroscopic evaluation and liver lesions data, and animal health records were analyzed with the PROC FREQ of SAS with a $\chi^2$ distribution (version 9.2; SAS Inst., Inc.). Significance was established at $P < 0.05$, and trends were discussed as $P \leq 0.10$.

## 3. RESULTS

### *3.1. Animal Health Records*

Thirteen animals were removed from the study due to health problems (2 bulls from the CF treatment, 6 bulls from the CFL treatment, and 5 bulls from the SF treatment). During first month after entrance, 2 animals from the CF and CFL treatments died from unknown causes and 2 others from SF group were removed for inability to adapt to the feeding system. In the second month of the study, 1 bull from the CFL treatment died because of bloat. The remaining of animals were sent to the slaughterhouse before the end of study: 3 bulls from the CFL treatment due to weight loss, 4 animals as a result of chronic pneumonia (1 from the CF treatment, 1 from the CFL treatment, and 2 from the SF treatment), and 1 bull from the SF treatment due to chronic lameness. No differences ($P$ > 0.10) among fattening cycles and treatments were found in health problems.

### *3.2. Consumption, Performance, and Carcass Quality*

Daily concentrate consumption (6.2 ± 0.17 kg of DM/d) and straw consumption (0.7 ± 0.07 kg of DM/d) were not affected by feeder design (Table 4). However, cumulative concentrate consumption per animal throughout the study tended ($P$ = 0.09) to be greater in CF (1,322 ± 19.3 kg of DM) than in CFL (1,264 ± 19.3 kg of DM) and SF (1,234 ± 19.3 kg of DM). Also, feeder design did not influence ADG (1.51 ± 0.035 kg/d) and feed efficiency (0.25 ± 0.005 kg/kg). However, CV of concentrate consumption was greater ($P$ < 0.01) in SF bulls (8.7 ± 0.75%) than in CF (7.7 ± 0.75%) and CFL (7.3 ± 0.75%) bulls.

Carcass data are presented in Table 5. Feeder design did not affect slaughter BW (461 ± 10.3 kg), HCW (247 ± 4.7 kg), dressing percentage (53.6 ± 0.29%), carcass conformation (97.3% classified as “O”), and carcass fatness (65.6% classified as “2”).

**Table 4.** Performance and concentrate consumption of Holstein bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study

| | Treatment[1] | | | | *P*-value[2] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM | T | P | T x P |
| Days of study, d | 214.5 | 214.5 | 214.5 | 0.00 | 1.00 | | |
| Initial age, d | 98.9 | 99.3 | 99.3 | 8.23 | 0.96 | | |
| Initial BW, kg | 121.1 | 120.7 | 121.0 | 7.61 | 0.32 | | |
| Final BW, kg | 449.8 | 445.4 | 441.4 | 3.27 | 0.20 | | |
| Concentrate DM consumption | | | | | | | |
| Mean, kg/d | 6.4 | 6.2 | 6.0 | 0.17 | 0.15 | <0.01 | 0.84 |
| CV, % | 7.7[b] | 7.3[b] | 8.7[a] | 0.75 | 0.01 | <0.01 | 0.44 |
| Accumulative concentrate DM consumption after 214 d, kg | 1,322 | 1,264 | 1,234 | 19.3 | 0.09 | | |
| Straw DM consumption, kg/d | 0.7 | 0.7 | 0.7 | 0.07 | 0.80 | <0.01 | 0.28 |
| ADG, kg/d | 1.54 | 1.50 | 1.49 | 0.035 | 0.44 | <0.01 | 0.98 |
| Gain to concentrate ratio, kg/kg | 0.25 | 0.25 | 0.26 | 0.005 | 0.40 | <0.01 | 0.99 |

[a-c]Means within a row with different superscripts are differ (*P* < 0.05).
[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

**Table 5.** Carcass data of Holstein bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study

| | Treatment[1] | | | | |
|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM | *P*-value |
| No. | 76 | 72 | 72 | | |
| Days of study, d | 223.1 | 223.1 | 223.1 | 1.26 | 1.00 |
| Slaughter age, d | 322.2 | 322.5 | 321.9 | 6.55 | 0.93 |
| Slaughter BW, kg | 464.8 | 462.8 | 456.5 | 10.30 | 0.21 |
| HCW, kg | 249.7 | 247.9 | 244.1 | 4.70 | 0.15 |
| Dressing percentage, % | 53.7 | 53.6 | 53.5 | 0.29 | 0.78 |
| Conformation,[2] % | | | | | |
| R | 1.3 | 0.0 | 0.0 | | 0.67 |
| O | 97.4 | 97.2 | 97.2 | | |
| P | 1.3 | 2.8 | 2.8 | | |
| Fatness,[3] % | | | | | |
| 1 | 6.6 | 4.1 | 5.5 | | 0.84 |
| 2 | 60.5 | 68.1 | 68.1 | | |
| 3 | 32.9 | 27.8 | 26.4 | | |

[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]Graded according to the EU classification system into (S)EUROP categories (EU Regulation N0. 1208/81, 1026/91). The conformation class designated by the letter ''E" (excellent) describes carcasses with all profiles convex to super-convex, and with exceptional muscle development, whereas the conformation classified as ''U" (very good) describes carcasses with profiles on the whole convex, and with very good muscle development. The carcasses classified as ''R" (good) present profiles on the whole straight and good muscle development. Carcasses classified as ''O" (fair) present profiles straight to concave, and with average muscle development, whilst carcasses classified as ''P" (poor) present all profiles concave to very concave with poor muscle development. In addition, the degree of fat cover describes the amount of fat on the outside of the carcass and in the thoracic cavity.
[3]Graded according to the EU classification system into 1.2.3.4.5 (EU Regulation No. 1208/81).The carcass fat cover that classifies as 1 (low) describes none to low fat cover, the class of fat cover classified as 5 (very high) describes an entire carcass covered with fat and with heavy fat deposits in the thoracic cavity.

### *3.3. Animal Behavior*

***General Activities.*** During the 2.5-h observation period in the morning, the percentage of animals per pen standing (66.6 ± 0.06%), lying (33.4 ± 0.11%), drinking (1.9 ± 0.05%), and ruminating (11.3 ± 0.06) were not affected by feeder design and the interaction between day and treatment was not significant (Table 6). During this observation period in the morning, the percentage of animals eating concentrate tended ($P$ = 0.06) to be less for SF (5.7 ± 0.05%) than for CF and CFL (10.7 ± 0.05%) throughout the study. Exceptionally, for the first 3 d of the study, this interaction was not observed because chute was widened, and more than 1 animal was often recorded at the feeder. Also, in the morning and throughout the study, a greater ($P$ < 0.01) proportion of animals in SF pens were eating straw (12.8 ± 0.05%) compared with animals in CF and CFL pens (10.0 ± 0.05%).

**Table 6.** Percentage of general activities (%) from bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study recorded by scan sampling

| | Treatment[1] | | | | *P*-value[3] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM[2] | T | P | T x P |
| Standing | 63.9 | 67.1 | 68.7 | 0.06 | 0.22 | <0.01 | 0.14 |
| Lying | 36.1 | 32.9 | 31.3 | 0.11 | 0.29 | <0.01 | 0.31 |
| Eating concentrate | 10.8[a] | 10.6[a] | 5.7[b] | 0.05 | <0.01 | 0.15 | 0.06 |
| Eating straw | 10.0[b] | 9.9[b] | 12.8[a] | 0.05 | <0.01 | 0.02 | 0.33 |
| Drinking | 1.8 | 2.2 | 1.6 | 0.05 | 0.89 | 0.68 | 0.37 |
| Ruminating | 11.2 | 10.4 | 12.2 | 0.06 | 0.78 | <0.01 | 0.87 |

[a-c]Means within a row with different superscripts are differ ($P$ < 0.05).
[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]The values presented herein correspond to backtransformed means; however, SEM and *P*-values correspond to the ANOVA analyses using log-transformed data.
[3]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

***Social Behavior.*** During the 2.5-h observation period in the morning, behaviors related to nonagonistic interactions are presented in Table 7. Bulls in SF and CF treatments exhibited more ($P$ < 0.05) oral behavior (7.7 ± 0.12 and 6.9 ± 0.12 times/15 min, respectively) than bulls in the CFL treatment (6.1 ± 0.12 times/15 min). No differences in social behavior were found among treatments (10.4 ± 0.11 times/15 min). The frequency of selfgrooming behavior (18.9 ± 0.08 times/15 min) differed ($P$ < 0.05) among treatments depending on the day of sampling. Regarding agonistic behaviors, no differences in fighting (5.6 ± 0.29 times/15 min) and butting (4.1 ± 0.12 times/15 min) behaviors were found among treatments. However, the incidence of displacements was less ($P$ < 0.01) in SF pens (2.2 ± 0.20 times/15 min) in contrast to collective feeders (4.1 ± 0.20 times/15 min). Chasing and chasing-up behaviors differed among treatments over the study ($P$ < 0.05), but these behaviors were exhibited occasionally and their interpretation is difficult. For sexual interactions, no differences among treatments in flehmen (2.9 ± 0.08 times/15 min) were observed; however, CFL bulls exhibited ($P$ < 0.01) more attempted mounts (7.0 ± 0.27 times/15 min) and tended ($P$ = 0.10) to exhibit more completed mounts (3.4 ± 0.12 times/15 min) than CF bulls (4.7 ± 0.27 and 2.2 ± 0.12 times/15 min, respectively). Moreover, no stereotypies were observed throughout the experiment.

**Table 7.** Frequency of social interactions (times of behavior in the pen/15 min) from bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study recorded by scan sampling

| | Treatment[1] | | | | *P*-value[3] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM[2] | T | P | T x P |
| Nonagonistic interactions | | | | | | | |
| Self-grooming | 18.4 | 19.4 | 18.9 | 0.08 | 0.61 | <0.01 | 0.04 |
| Social behavior | 10.7 | 10.8 | 9.8 | 0.11 | 0.47 | <0.01 | 0.92 |
| Oral behavior | 6.9[ab] | 6.1[b] | 7.7[a] | 0.12 | 0.03 | <0.01 | 0.48 |
| Agonistic interactions | | | | | | | |
| Fighting | 5.6 | 5.6 | 5.6 | 0.29 | 1.00 | <0.01 | 0.88 |
| Butting | 4.2 | 4.7 | 3.5 | 0.12 | 0.13 | <0.01 | 0.47 |
| Displacements | 4.3[a] | 3.8[a] | 2.2[b] | 0.20 | <0.01 | <0.01 | 0.81 |
| Chasing | 0.7[b] | 1.6[a] | 1.4[a] | 0.06 | <0.01 | <0.01 | <0.01 |
| Chasing-up | 0.5[ab] | 0.3[b] | 0.5[a] | 0.08 | 0.08 | <0.01 | 0.02 |
| Sexual interactions | | | | | | | |
| Flehmen | 2.9 | 2.7 | 3.0 | 0.08 | 0.84 | <0.01 | 0.70 |
| Attempted mounts | 4.7[b] | 7.0[a] | 5.9[ab] | 0.27 | 0.01 | <0.01 | 0.52 |
| Completed mounts | 2.2[b] | 3.4[a] | 3.1[ab] | 0.12 | 0.10 | <0.01 | 0.12 |

[a-c]Means within a row with different superscripts are differ ($P$ < 0.05).
[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]The values presented herein correspond to backtransformed means; however, SEM and *P*-values correspond to the ANOVA analyses using arcsin+1-transformed data.
[3]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

### *3.4. Eating Behavior*

There was a statistically significant difference ($P$ < 0.01) among treatments in concentrate disappearance velocity recorded at the feeder (Table 8). Also, there was an interaction between treatment and period in occupancy time of feeder ($P$ < 0.05), number of bulls at the feeder ($P$ < 0.01), number of visits at the feeder ($P$ = 0.09), displacements at the feeder ($P$ < 0.01), and waiting time to access to the feeder ($P$ < 0.01). Animals fed with SF registered less ($P$ < 0.01) concentrate disappearance velocity (140.4 ± 8.35 g/min) than animals fed with CFL (168.9 ± 8.35 g/min) and CF (197.4 ± 8.35 g/min) throughout the study. In the first filming period (d 12), SF bulls recorded greater ($P$ < 0.05) occupancy time at the feeder (90.6 ± 2.58% of total time analyzed, which was 567 ± 19.95 min) compared with CF and CFL bulls (80.6 ± 2.58% of total time analyzed, which was 521 ± 19.95 min). Also, in second filming period (d 125), the occupancy time at the feeder was greater ($P$ < 0.01) in SF (80.9 ± 2.58% of total time analyzed, which was 528 ± 19.95 min) than CFL and CF (65.6 ± 2.58% of total time analyzed, which was 424 ± 19.95 min). However, in the last filming period (d 206), no differences were observed among treatments (62.6 ± 2.58% of total time analyzed, which was 406 ± 19.95 min). Animals in the SF treatment showed fewer ($P$ < 0.01) visits (23.8 ± 24.27 visits/d) than other treatments (137.3 ± 24.27 visits/d) during the first filming period. In the second period, the SF group exhibited less freqüent ($P$ < 0.05) feeder visits (44.8 ± 24.27 visits/d) than CF (128.9 ± 24.27 visits/d), whereas in the third period, no differences among treatments were observed (71.7 ± 24.27 visits/d). Whereas in the SF group always 1 animal was registered at the feeder over the study, the number of bulls for CF and CFL changed throughout the study, being 2 animals per feeder in the first filming period and the remaining of fattening the number of bulls decreased to 1.5 animals per feeder. However, the number of displacements registered in CFL and CF was greater in the first filming period (7.8 ± 0.83 and 4.9 ± 0.82, respectively), whereas for the remaining of fattening, the number of displacements reduced in both treatments (1.4 ± 0.82 for second period and 0.8 ± 0.82 for third period). No displacements at the feeder were recorded in SF throughout the study. Although SF animals spent more waiting time to access the concentrate feeder over the study compared with other treatments, this waiting time progressively declined throughout the filming periods (130.2 ± 11.24, 88.4 ± 11.24, and 32.4 ± 11.24 min for first, second, and third period, respectively, which represented 21.2 ± 2.02 %, 13.6 ± 2.02 %, and 5.1 ± 2.02 % of total time analyzed).

**Table 8.** Eating behavior at concentrate feeder on d 12, 125, and 206 of the study from bulls fed high-concentrate diets with different concentrate feeder designs, from recording videos (0600 to 1800 h)

| | Treatment[1] | | | | *P*-value[2] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM | T | P | T x P |
| Concentrate disappearance velocity, g/min | 197.4[a] | 168.9[b] | 140.4[c] | 8.35 | <0.01 | <0.01 | 0.26 |
| Occupancy time of feeder, min/d | 644.6 | 644.6 | 641.4 | 5.52 | 0.84 | 0.72 | 0.50 |
| Occupancy rate of feeder, % of time | 438.3 | 459.2 | 500.1 | 32.71 | 0.02 | <0.01 | 0.05 |
| Number of bulls at the feeder | 67.8 | 71.3 | 77.7 | 5.61 | <0.01 | <0.01 | 0.04 |
| Number of visits at the feeder | 1.8 | 1.6 | 1.0 | 0.12 | <0.01 | <0.01 | <0.01 |
| Displacements at the feeder, no./h | 112.5 | 102.6 | 41.0 | 16.7 | <0.01 | 0.18 | 0.09 |
| Waiting time to access to the feeder, min/day | 2.3 | 3.4 | 0.0 | 0.48 | <0.01 | <0.01 | 0.01 |
| Waiting time rate to access to the feeder, % of time | 4.1 | 2.5 | 83.7 | 9.57 | <0.01 | <0.01 | <0.01 |

[a-c]Means within a row with different superscripts are differ ($P < 0.05$).
[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

### *3.5. Rumen Liquid Determinations, Macroscopic Rumen Wall Evaluation, and Liver Abscesses*

An interaction between treatment and time ($P < 0.05$) was found in rumen pH and total VFA concentration (Table 9). At the beginning of the study (d 7), rumen pH of the SF (6.1 ± 0.01) was greater ($P < 0.01$) than CF and CFL (5.5 ± 0.01), whereas rumen VFA concentration in SF (96.3 ± 15.54 m*M*) was less ($P < 0.01$) than those found for CF and CFL (129.8 ± 15.53 m*M*). In the middle of the study (d 120), no statistical differences in average rumen pH (6.3 ± 0.01) and total VFA concentration (136.3 ± 15.51 m*M*) were observed among treatments. At the end of study (d 204), CF animals had lower ($P < 0.05$) rumen pH (5.8 ± 0.01) than CFL and SF (6.1 ± 0.01) animals, and opposite to rumen pH, total VFA concentration was greater (*P* = 0.10) in CF (138.9 ± 15.54 m*M*) compared with CFL and SF (113.9 ± 15.54 m*M*).

Treatment did not affect total rumen VFA concentration and rumen molar proportions of acetate, butyrate, and valerate (Table 9). However, for rumen proportion of propionate (*P* = 0.09), isobutyrate (*P* < 0.01), and isovalerate (*P* < 0.05) and acetate to propionate ratio (*P* = 0.06), the interaction between treatment and time tended to be or was significant. At the beginning of the study (d 7), for SF animals, rumen proportion of propionate tended (*P* = 0.08) to be less (38.0 ± 1.03%), isobutyrate percentage (0.9 ± 0.12%) was greater (*P* < 0.01), and isovalerate proportion (1.1 ± 0.13%) tended (*P* = 0.10) to be greater compared with other treatments (41.9 ± 1.03, 0.5 ± 0.12, and 0.7 ± 0.13%, respectively). Moreover, at the beginning of the study (d 7), acetate to propionate ratio from SF animals (1.5 ± 0.08) was greater (*P* < 0.05) compared with CFL and CF (1.2 ± 0.08).

No differences among treatments (data not shown) in rumen color (47% classified as "3" and 47% classified as "4"), presence of clumped papillae (21.6% of clumped papillae), or presence of ulcers (0% ulcers) were found. No liver abscesses were detected at slaughterhouse.

**Table 9.** Rumen pH, total VFA concentration, and VFA proportions from bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study

| | Treatment[1] | | | | *P*-value[3] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM[2] | T | P | T x P |
| pH | 5.9 | 6.0 | 6.2 | 0.01 | 0.13 | <0.01 | <0.01 |
| Total VFA, m*M* | 134.3 | 126.9 | 115.9 | 14.62 | 0.17 | 0.03 | 0.04 |
| VFA proportion, mol/100 mol | | | | | | | |
| Acetate | 49.3 | 49.8 | 50.3 | 0.69 | 0.57 | 0.01 | 0.22 |
| Propionate | 39.8 | 39.0 | 38.4 | 0.66 | 0.39 | 0.05 | 0.09 |
| Butyrate | 7.4 | 7.4 | 7.2 | 0.38 | 0.78 | 0.02 | 0.48 |
| Isobutyrate | 0.6 | 0.7 | 0.8 | 0.11 | 0.19 | <0.01 | <0.01 |
| Valerate | 1.9 | 2.0 | 2.1 | 0.34 | 0.54 | <0.01 | 0.56 |
| Isovalerate | 0.9 | 1.1 | 1.1 | 0.11 | 0.41 | <0.01 | 0.05 |
| Acetate:propionate | 1.3 | 1.3 | 1.4 | 0.05 | 0.12 | 0.27 | 0.06 |

[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]pH data presented herein correspond to backtransformed means; however, SEM and *P*-values correspond to the ANOVA analyses using log-transformed data.
[3]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

### *3.6. Serum Metabolites*

A treatment × time interaction was detected ($P < 0.05$) in serum NEFA and insulin concentrations (Table 10). Serum NEFA concentration was greater ($P < 0.05$) at the beginning of the study (d 7) in SF (0.20 ± 0.021 mmol/L) compared with CFL and CF (0.15 ± 0.021 mmol/L) animals. However, at the middle of the study (d 120), serum NEFA concentration was less ($P < 0.01$) for SF (0.16 ± 0.021 mmol/L) than CFL and CF (0.19 ± 0.021 mmol/L). However, at the end of the study (d 204), no differences among treatments in serum NEFA concentration were observed (0.16 ± 0.021 mmol/L). Serum insulin concentration did not differ among treatments at the beginning (d 7) and in the middle of the study (d 120); however, at the end of the study (d 204), serum insulin concentration tended ($P = 0.10$) to be greater for CF (1.06 ± 0.025 µg/L) compared with CFL and SF (0.82 ± 0.025 and 0.92 ± 0.025 µg/L, respectively). Plasma glucose, insulin to glucose ratio, and serum haptoglobin were not affected by feeder design.

**Table 10.** Serum physiological parameters from bulls fed high-concentrate diets with different concentrate feeder designs for 214 d of study

| | Treatment[1] | | | | *P*-value[3] | | |
|---|---|---|---|---|---|---|---|
| Item | CF | CFL | SF | SEM[2] | T | P | T x P |
| NEFA, mmol/L | 0.16 | 0.17 | 0.16 | 0.012 | 0.18 | 0.03 | 0.02 |
| Haptoglobin, mg/mL | 0.15 | 0.15 | 0.15 | 0.013 | 0.98 | 0.59 | 0.18 |
| Glucose, g/L | 0.87 | 0.87 | 0.86 | 0.006 | 0.66 | <0.01 | 0.87 |
| Insulin, µg/L | 0.71 | 0.67 | 0.66 | 0.016 | 0.47 | <0.01 | 0.02 |
| Insulin:glucose, µg/g | 0.82 | 0.77 | 0.77 | 0.020 | 0.65 | 0.01 | 0.34 |

[1]Treatments were different concentrate feeder design. CF = a control feeder with 4 feeding spaces; CFL = a feeder with less concentrate capacity; SF = a single-space feeder with lateral protections.
[2]The values presented herein correspond to backtransformed means; however, SEM and *P*-values correspond to the ANOVA analyses using log-transformed data.
[3]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).

## 4. DISCUSSION

### *4.1. A Control Feeder with 4 Feeding Spaces vs. a Feeder with Less Concentrate Capacity*

Reducing concentrate capacity due to less feeder depth tended to reduce cumulative concentrate consumption by 58 kg after 214 d, which corresponds to a 4.4% reduction. It could be expected that the reduced concentrate level at the feeder may have limited the concentrate availability and concentrate consumption and, in consequence, may have reduced animal growth. However, in the present study, no differences in G:F and ADG among treatments were observed. Furthermore, in the present study, no differences among CF and CFL in serum glucose and NEFA concentration were observed; only at the end of the study serum was insulin concentration less for CFL compared with CF. This decrease in serum insulin concentration could indicate that CFL bulls could be limited at the end of the study. Murphy et al. (1994) did not observe differences in serum glucose and insulin concentration when comparing steers fed high-concentrate diets ad libitum with steers submitted to an intake restriction of 30% during 14 d. However, Schoonmaker et al. (2003) reported a decrease in serum glucose and insulin concentration when steers were restricted to a 30% of total intake during 100 d. Moreover, at the end of our study, average daily concentrate DM consumption during this period was similar for both treatments (8.0 ± 0.24 kg/d). This concentrate consumption data, in addition to the serum NEFA concentration and ADG data, would refute the hypothesis that the reduction of the concentrate level restricted concentrate consumption. Therefore, the reduction in concentrate consumption for CFL compared with CF animals may be explained by greater concentrate wastage of the CF animals due to feeder design (Myers et al., 2012).

It could be expected that by decreasing the level of concentrate in the feeder, animal competition for eating could increase; in the present study, 2 indicators of the competition at the feeder were measured, concentrate disappearance velocity and displacements at the feeder. The concentrate disappearance velocity, as an indicator of eating rate, is often considered an indirect indicator of competition in the feeder (González et al., 2008). In the present study, in contrast to expectations, eating rate was decreased by 14.4% when concentrate level was reduced at the feeder. One explanation could be that eating rate or velocity of concentrate disappearance at the feeder in the present study was more related to feed spillage than to "real" eating rate; however, as no direct measurement of feed wastage was recorded, this hypothesis cannot be confirmed. Another indication that the disappearance velocity (or eating rate) of CF could be overestimated would be that mean eating rate of CF was around 200 g/min and with this eating rate animals should suffer subclinical acidosis (Sauvant et al., 1999). Sauvant et al. (1999) summarized different studies and observed that when the eating rate was above 200 g/min, rumen pH was below 5.6, the threshold pH value for rumen subclinical acidosis (Britton and Stock, 1989; Owens et al., 1998; DeVries et al., 2007) and, in consequence, animal growth could be impaired (Schwartzkopf- Genswein et al., 2003). However, no differences in ADG and rumen pH among CF and CFL animals were observed; therefore, the present study results do not support this argument. It is important to consider the rumen pH data of the present study with caution because rumen samples were collected at different times. However, other rumen acidosis indicators such as laminitis, bloat, erratic concentrate consumption, rumen wall lesions, liver abscesses, and ruminating data do not support that CF suffered more rumen acidosis than CFL animals. In summary, eating rate data of CF animals seem to be overestimated, probably because of feed wastage, explaining why it is not a good indicator of the competition at the feeder and why it was not related with rumen pH data.

As mentioned before, it was expected that by decreasing the level of concentrate in the feeder, animal competition for eating would increase; in contrast to eating rate data, the increase in number of displacements at the feeder when comparing CF with CFL could support this hypothesis. Also, CFL animals ex exhibited more sexual activity than CF. These behaviors, displacements and sexual activity, increased when the depth of feeder was decreased, which would, in theory, induce stress and impair growth. The increase of frequency in sexual behavior that was recorded by CFL bulls could lead to increased energy requirements impairing growth and G:F; but no differences in ADG were observed and the frequency of these behaviors was low. Therefore, in the present study, the impact of sexual behaviors on energy requirements was probably insignificant. Moreover, serum haptoglobin concentration did not differ between CF and CFL animals. Haptoglobin is an acute phase protein that increases in blood as a consequence of inflammation, tissue damage or injury, infection, and stress, so haptoglobin has been proposed to be a possible marker of stress in cattle (Alsemgeest et al., 1995; Arthington et al., 2003; Hickey et al., 2003). Hence, according to most of the stress indicators measured in the present study (haptoglobin, concentrate consumption, grow, etc.), the reduction of feed level at the feeder was not stressful to the animals in spite of the increase of competition at the feeder or greater sexual activity recorded. Moreover, greater frequency of oral behavior was recorded in the CF group than the CFL group. The reasons for these behavior differences among treatments are unknown, and it is difficult to find explanations related to feeder design.

In summary, behavior as well as rumen and serum metabolite data may indicate that when the feed level at the feeder was decreased, total feed consumption was reduced by 4%, probably because of the reduction in feed spillage. This reduction of the feed level at the feeder had no negative impact on performance, rumen health, or stress despite the increase of displacements at the feeder and sexual activity. Therefore, reducing concentrate level at the feeder could be a good strategy to reduce concentrate consumption and associated feed costs without negative effects on performance, stress, and rumen health.

### *4.2. A Control Feeder with 4 Feeding Spaces vs. a Single-Space Feeder with Lateral Protections*

A reduction in accumulative concentrate consumption (6.7%) was achieved when animals were in SF compared with CF without impairing ADG. Andersen et al. (1997) reported that the reduction of eating space did not affect ADG and G:F, whereas other reports (Keys et al., 1978) observe a negative effect of this concentrate consumption reduction in growth rate and feed efficiency. It could be expected that reducing the feeder space to a single feeder with lateral barriers compared with a multiple-space feeder could limit the animal access to the feeder and/or the concentrate consumption impairing animal growth. The greater serum NEFA concentration in SF during the first 2 wk of the study compared with CF may indicate that animals had adaptation problems and consumption was limited. In addition, waiting time at the feeder in the first period was greater compared to the CF indicate that animals had adaptation problems to SF. Moreover, 2 animals were removed due to inability to adapt to the SF design, as they were not able to go into chute. In addition, in spite of there not being statistically significant differences between treatments in proportion of standing animals, for the first 2 wk there were numerical differences among treatments: the SF pen had greater (64.8 ± 0.05%) percentage than the

CF and CFL pens (53.6 ± 0.05%). The greater proportion of standing animals during the adaptation period to single feeder design might suggest that animals need time to establish their hierarchy or internal order to feeder attendance, because after the adaptation period, these differences among treatments disappeared. This behavioral change has been also reported by other authors in similar circumstances as a waiting time for less competition at the feeder (Gonyou and Stricklin, 1981; Olofsson, 1999; Huzzey et al., 2006; González et al., 2008). Perhaps, in the present study, the strategy used to adapt animals (widen the chute for 4 first days) should be improved; a possible adaptation strategy could be to use a supplementary feeder or having more days the chute elevated to achieve easier and better adaptation. Despite serum NEFA concentrations and some behavior traits indicating that animals did not adapt well to the SF, overall performance was not impaired.

The greater CV in concentrate consumption exhibited for SF may indicate that animals may have suffered rumen acidosis, and this could affect negatively ADG (Galyean et al., 1992). One possible explanation of these great fluctuations in day-to-day concentrate consumption may be that rumen acidosis can lead a reduction of feed consumption (Britton and Stock, 1987) and, thereby, can cause erratic consumption patterns (Stock et al., 1995). In feedlot cattle, Brown et al. (2000) observed a high correlation coefficient ($r$ = 0.84) between the lowest daily ruminal pH and feed intake on the subsequent day. When ruminal pH is low, the animal's feed intake drops; this limits further production of fermentation acids and restores pH to more optimum conditions. Once the pH is restored, then the animal consumes feed and again this may lead to excessive production of acids and this cycle can be repeated. However, in the present study, rumen pH of SF animals was above 6.0. Also, records related with ruminal acidosis such as rumen wall lesions and/or liver abscesses support the hypothesis that these animals fed with the SF did not suffer rumen acidosis. In addition, as discussed previously, the eating rate average observed in SF animals (140.4 g/min) is within the range of eating rates values that would not be related with rumen acidosis (Sauvant et al., 1999; González et al., 2008). Moreover, previous research has yielded contradictory results in regards to the effects that the CV concentrate daily consumption have on performance and efficiency. Several studies have concluded that large variation in feed intake by cattle fed high-concentrate diets may cause digestive disturbances (Fulton et al., 1979; Britton and Stock, 1987) and decrease growth performance in feedlot cattle (Galyean et al., 1992; Stock et al., 1995; Devant et al., 2010) with this effect being greatest early in the feeding period (Krehbiel et al., 1995; Soto-Navarro et al., 2000). Golden et al. (2008) also reported a greater within-day variation in intake of inefficient steers than efficient steers regardless of the amount of roughage in the diet. In contrast, Cooper et al. (1999) reported that variation in intake did not increase acidosis or decrease performance in finishing steers fed ad libitum. Schwartzkopf-Genswein et al. (2004) also reported similar findings when they observed that ADG and G:F were not different between steers fed either a constant or a fluctuating amount of feed, and they concluded that daily intake fluctuations of 10% DMI or less do not alter overall intake by feedlot cattle and are unlikely to have any negative consequences on growth performance. Additionally, a study with steers fed barley-based diets indicated that the steers classified as having a high ADG and G:F showed the greatest CV of DMI (Schwartzkopf-Genswein et al., 2011). Therefore, even though concentrate CV was greater in SF animals than CF animals, it was not related to rumen acidosis and had no negative impact on performance.

In addition, it could be expected that when the animals were fed in a single feeder with lateral barriers, competition at the feeder would be greater compared with a CF, causing stress and impairing growth. González et al. (2008) reported that by increasing the animal to feeding spaces ratio, the number of displacements increased, leading to a potential increase in stress and risk to suffer rumen acidosis. In the present study, no displacements at the feeder and fewer agonistic interactions were recorded in the SF compared with the collective feeders, mainly due to lateral barriers of feeder design, which reduce significantly the aggressions and displacements at the feeder (Bouissou, 1970; Grant and Albright, 1995). Although some animal behaviors were affected by feeder design, such as number of animals eating straw or frequency of oral behaviors, no evidence of an associated negative effect were found on performance, welfare, or health. Moreover, SF had a greater proportion of animals eating straw compared with collective feeders throughout the study. The sustained hypothesis could be that SF bulls attended the straw feeder more often because the concentrate feeder was occupied and that animals redirected their concentrate appetite to spend more time at straw feeder (227.9 ± 7.00 min for SF vs. 185.9 ± 7.00 min for CF) while they waited to access the concentrate feeder (data not shown). However, this greater proportion of animals eating straw did not translate to an increase of straw consumption.

In addition, the single feeder design did not compromise natural cattle behavior such as feeding, resting, or rumination patterns (Friend, 1991). In the present study, resting and rumination behaviors were not affected by the feeder design. Furthermore, SF animals did not exhibit more oral behavior than CF animals. Although some authors associate oral behaviors with stereotypies (Redbo and Nordblad, 1997), others regard that is an intrinsic behavior of intensive production systems (Ishiwata et al., 2008) related with the lack of occurrence of feeding behavior. Moreover, no stereotypies were detected over the experiment. Some authors associated stereotypies as indicators of poor welfare related to restriction of movements (Redbo, 1992) and low roughage intake (Redbo and Nordblad, 1997) such as it was reported by Rotger et al. (2006). No differences in social behavior were found among treatments. Val-Laillet et al. (2009) reported that increasing competition does not disrupt the social behavior known as allogrooming behavior. The frequency of self-grooming behavior expressed was different depending on the period of fattening and treatment but without any clear pattern. Ishiwata et al. (2008) suggest that selfgrooming is another behavior to spend the spare time, instead of engaging in walking; however, other authors (Phillips, 2004) associate self-grooming as a well-being or satisfaction behavior. Related to agonistic interactions, behaviors associated with hierarchy establishment (Mounier et al., 2005), no differences were found among treatments. Most behavioral data (ruminating, resting, displacements, etc.) studied did not indicate that SF provoked welfare problems; however, the interpretation of other behaviors (oral behavior and time devoted to eat straw) could be ambiguous. As other welfare indicators such as performance, serum haptoglobin, and health did not differ among treatments, it can be concluded that SF did not seem to impair animal welfare.

In summary, both alternatives of feeder design, reduction of concentrate level at the feeder and a single-space feeder with lateral barriers, are good strategies to reduce total concentrate consumption without impairing performance, rumen health, and animal welfare in Holstein bulls fed high-concentrate diets and therefore may effectively contribute to the reduction of nutrition costs associated with beef production. However, at the beginning, there are evidences (NEFA and some behavior traits) that animals fed SF have adaptation problems without impairing overall performance, so further research focus on adaptation strategies is necessary.

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# CHAPTER IV

## Effect of concentrate feeder design on eating and drinking behaviors, and their evolution with animal BW in Holstein bulls fed high-concentrate diets

*Part of this information has been included in a paper submitted to Journal Animal Science*

## ABSTRACT

The objective of the current study was to assess the effect of an alternative concentrate feeder design on eating and drinking behaviors, and to analyze the evolution of these behaviors with animal BW in Holstein bulls fed high-concentrate diets and straw, both *ad libitum*, reared under commercial conditions. Two hundred and forty Holstein bulls (121 ± 2.0 kg of initial BW and 99 ± 1.0 d of age), from 2 consecutive fattening cycles (120 animals per fattening), were randomly housed in 1 of 6 pens (20 animals per pen), and each pen was assigned to 1 of the 3 different concentrate feeder designs (40 animals per treatment): a control collective feeder with 4 feeding spaces (CF), a collective feeder with less concentrate capacity (CFL), and a single-space feeder with lateral protections (SF). Each pen had a straw feeder and a drinker. Concentrate consumption was recorded daily using a computerized feeder, and was expressed as percentage of feed disappearance in four 6-h time periods within day. Eating and drinking behaviors were filmed for 24 h on d 12 (130 kg of BW), 125 (320 kg of BW), and 206 (440 kg of BW) of the study. The percentage of concentrate disappearance increased ($P< 0.01$) as bulls grew, and was affected ($P < 0.01$) by feeder design, being greater in collective feeders (CF and CFL) than in SF. During the growing phase (from 130 to 320 kg of BW), SF had a greater ($P < 0.05$) concentrate feeder occupancy time, but a lesser ($P < 0.05$) frequency of visits compared with CF and CFL. The number of bulls recorded at collective feeders was reduced ($P < 0.01$) as bulls grew. Although no displacements were registered in SF, the waiting time to access to the feeder was reduced ($P < 0.01$) as BW increased. The occupancy time of straw feeder was greater ($P < 0.01$) in SF than in collective feeders, and during the growing phase, a greater number of bulls tended ($P = 0.06$) to be recorded at straw feeder in SF than CF or CFL. During the growing phase, bulls in CF spent ($P < 0.01$) more time drinking, and more displacements at drinker were recorded ($P < 0.01$) than in CFL and SF. Thus, eating and drinking behaviors were affected by concentrate feeder design, and evolved differently with animal BW. Animals fed on collective feeders exhibited an eating behavior more synchronized during the growing phase, whereas they adopted a more individualized behavior during the finishing phase (from 320 to 440 kg of BW).


**Key words:** beef, drinking behavior, eating behavior, feeder design

## 1. INTRODUCTION

Previous research (Verdú et al., 2015) suggested that alternative designs to conventional concentrate collective feeders (a single-space feeder with lateral barriers, and a conventional collective feeder with less feeder depth with less concentrate availability) were effective strategies to decrease the total concentrate consumption in beef fed concentrate and straw, both *ad libitum*, in separate self-feeders without compromising performance. Research involving calves (González et al., 2008a), heifers (González et al., 2008b), and cows (DeVries et al., 2004; 2006) has analyzed the effect of feeding space to animal ratio and feeder design (feed stalls in cows) on eating behavior; however, the impact of a concentrate feeder design with lateral protections and less feeder depth have not been evaluated in beef. Moreover, concentrate feeder design not only could affect eating behavior at the concentrate feeder, it could also affect eating and drinking behaviors at straw feeder and drinker. Hence, one single feeder for 20 bulls could limit animal access to the feed; however, as eating rate increases with age (González et al., 2008b; Mialon et al., 2008), the occupancy time of feeder could be reduced. Similarly, when bulls are fed on conventional collective feeders with less concentrate capacity, the occupancy time could be more limiting at initial than at older ages. Understanding the eating and drinking behaviors at feeding zone for each concentrate feeder design could be useful to establish practical management and technical considerations throughout the fattening cycle. Therefore, the objectives of the present study were: 1) to assess the effect of an alternative concentrate feeder design (a single-space feeder with lateral barriers, and a collective feeder with less feeder depth) on eating and drinking behaviors; and 2) to describe the evolution of eating and drinking patterns in cattle fed on different feeder designs as animal BW increases.

## 2. MATERIALS AND METHODS

### *2.1. Cattle, Feeding, and Housing*

Animals were reared under commercial conditions (Agropecuaria Montgai SL, Lleida, Spain), and were managed following the principles and specific guidelines of IRTA Animal Care Committee. The corresponding data of the present study were collected in a former study that evaluated the effect of concentrate feeder design on performance, animal behavior, welfare, rumen health, and carcass characteristics in Holstein bulls fed high-concentrate diets (Verdú et al., 2015). Thus, the experimental design of treatments, animals, diets, feeding system, and housing facilities are described previously (Verdú et al., 2015). In short, a total of 240 Holstein male calves from 2 consecutive fattening cycles (n = 120 animals for each cycle), averaging 121 ± 2.0 kg of initial BW and 99 ± 1.0 d of initial age, were used in a replicated study. Animals were randomly allocated in 1 of 6 pens (20 animals per pen), and each pen was assigned to 1 of the 3 different concentrate feeder designs: 1) a control collective feeder with 4 feeding spaces, with a feeder capacity of 200 kg, and a feeder depth of 0.60 m (**CF**); 2) a collective feeder similar to CF with 4 feeding spaces, but with a reduced capacity of 45 kg, and a feeder depth of 0.15 m (**CFL**); and, 3) a single space feeder with a capacity of 10 kg, protected with lateral protections, and a feeder depth of 0.15 m (**SF**). All concentrate feeders were manufactured in stainless steel and were placed at 0.80 m high in front of the pen. Each feeder had different design features and dimensions: collective feeders were 1.90 m long, 0.60 m wide, and had 4 feeding spaces defined by stanchions (0.35 m inside distance); however, they differed in feeder depth and storage capacity of concentrate, as described above; lastly, SF was 0.50 m long by 0.26 m wide, with a less storage capacity and depth too, and protected by 2 lateral barriers (1.4 m long by 0.80 m high) forming a chute, the inside diameter of which could be regulated from 0.42 to 0.72 m wide. Animals fed on SF were adapted for the first 4 d of the study by widening the chute to facilitate feeder access. After this adaptation period to the lateral protections, the width of chute was adjusted to animal size 3 times throughout the study (0.42 m at d 5, 0.55 m at d 25, and 0.72 m at d 120). An automated system was used to register concentrate consumption recording the feed disappearance within an interval of time on a daily basis. Each concentrate feeder was suspended on a scale constituted by 4 load cells (Utilcell, Barcelona, Spain), which were programmed to transmit the feed weight, at 1-min intervals or when a weight change was detected, to a Programmable Logic Controller (Allen-Bradley model 1769-L35E; Rockwell Automation, Milwaukee, WI), and, lastly, displayed by a personal computer with a software application (Voltec, Lleida, Spain). The scales were calibrated weekly. All feeders were refilled automatically to ensure continuous feed availability at certain level in the trough by a dispensing tube. The scale under the feeder continuously registered the weight, and when it detected that the dispensing tube was empty, the system refilled automatically by intermediate dispensing hoppers.

Pens were totally covered and measured 12 x 6 m (72 $m^2$ per pen) with a space availability of 3.6 $m^2$ per animal, and were deep-bedded with straw. Each pen had a 36 $m^2$ of resting area, and a 36 $m^2$ of feeding area in the front with the concentrate feeder, a separated straw feeder (3 m long x 1.12 m wide x 0.65 m depth; 7 feeding spaces), and a water bowl (1 drinking space). The straw consumption was an estimate of actual total amount of straw consumed per pen because straw was also used for bedding. Animals were weighed every 14 d throughout study, and calculations used full BW data.

The effect of feeder design on concentrate consumption pattern throughout the day and fattening cycle was analyzed by dividing the day into four 6-h daily time periods (0000 to 0600 h, 0600 to 1200 h, 1200 to 1800 h, and 1800 to 2400 h), and expressing the daily feed disappearance as a percentage of concentrate disappearance for each time interval of day in relation to total daily concentrate intake. In addition, the fattening cycle was divided into fifteen 14-d periods corresponding to BW recording dates (15 fattening periods).

### *2.2. Eating and Drinking Behaviors*

To study the effect of feeder design on eating and drinking behaviors throughout the day and fattening cycle, the feeding area (including concentrate and straw feeders, and drinker) was filmed for 24 h at the beginning (d 12), in the middle (d 125), and at the end (d 206) of the experiment (3 filming periods) using digital cameras (Sony CSM-BV420; Sony Corp., Barcelona, Spain). Output from the cameras was recorded with a time-lapse video recorder (AVZ CSM-UTM824-500).Videotapes were processed by continuous recording of the activities performed by animals at concentrate and straw feeders, and at drinker. Only 12 h of recordings (0600 to 1800 h) were used to create a data set, because the quality of the recordings at night was not always acceptable. Two time periods of day were established, one from 0600 to 1200 h, and another from 1200 to 1800 h, to analyze the pattern of eating and drinking behaviors throughout the day. Moreover, data of feed disappearance rate presented later in the results section support the use of daily time interval to evaluate the eating behavior. Recorded activities (eating concentrate or straw, drinking, waiting time to access to the feeders or drinker, and displacements at feeders or drinker) were registered simultaneously recording the time (min), the number of animals involved, and frequency (the number by hour or time analyzed). Eating (concentrate or straw) was defined as when an animal having its head into the feeder, and an observation was defined as eating when the bull was eating from the feed bunk with its muzzle in the feed bunk or chewing with its head over the bunk. Drinking was recorded when an animal had its head in the water bowl, and an observation was recorded as drinking when the bull was with its muzzle in the water bowl. Waiting time to access to feeder or drinker was recorded when an animal was close to the feeder or drinker and had the intention to access, but this place was occupied by another animal and, also, the rest of feeding spaces (in case of collective feeders) were occupied. Displacements among animals from feeders (concentrate or straw) and drinker were recorded when one animal displaced a pen mate that was eating or drinking, and forced to displaced animal to remove completely its head from feeding space. Only displacements with physical contact were considered.

### *2.3. Calculations and Statistical Analyses*

The percentage of concentrate disappearance for each pen was averaged by time period of day and period of fattening, and was transformed into natural logarithms to achieve a normal distribution. Values presented in the tables herein correspond to non-transformed data, whereas SEM and *P*-values correspond to the ANOVA analyses of the transformed data.

The dataset from video recordings included the occupancy time of feeder or drinker (min), and the total waiting time to access to feeder or drinker (min),that were calculated as the sum of total time performing eating or drinking activities per pen and filming period. The number of bulls eating or drinking, and the number of visits recorded at the feeder or drinker was averaged by pen and filming period. Number of displacements registered at the feeder and drinker were summed by pen and filming period, and divided by total time analyzed to express it as frequency of displacements per hour for 12 h of recording. Displacements and waiting time data were root-squared to achieve a normal distribution. The means of these data presented in the tables correspond to back-transformed data, SEM and *P*-values to the transformed data. Feeder and drinker occupancy and waiting time were also expressed as the percentage of time devoted to these activities during the 12 h of video recording. All eating and drinking behavioral data were corrected by number of animals within the pen for each filming period, as some animals were removed from the study for health reasons (for details see Verdú et al., 2015). The rate of concentrate disappearance velocity (RCD) was obtained dividing concentrate consumption by occupancy time of the feeder, which was averaged by pen and filming period. For each corresponding filming period, the average of animal BW was calculated. Thus, the relationship between animal BW and filming periods was established as 130 kg of BW at the beginning (d 12), 320 kg of BW in the middle (d 125), and 440 kg of BW at the end of study (d 206). To simplify the discussion, these filming periods were summarized in two fattening phases: the growing phase (from 130 to 320 kg) and the finishing phase (from 320 to 440 kg).

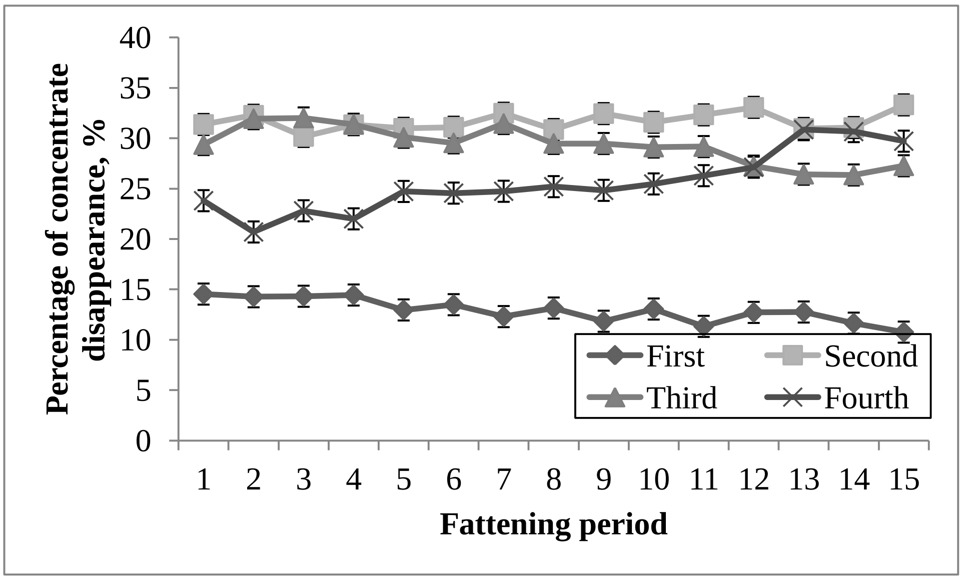
Pen was considered the experimental unit for all statistical analysis (n = 4).The RCD, eating and drinking behavioral data were analyzed using a mixed-effects model with repeated measures (Version 9.2, SAS Inst., Inc., Cary, NC). The model included initial BW as a covariate, treatment, period (period of fattening for percentage of concentrate disappearance, and filming period for eating and drinking behavioral data), and their interaction, as fixed effects, and included pen and fattening cycle as random effects. Period was considered a repeated factor, and pen nested within treatment was subjected to 3 variance-covariance structures: compound symmetry, autoregressive order one, and unstructured. The covariance structure that yielded the smallest Schwarz's Bayesian information criterion was considered the most desirable analysis. Significance was established at $P < 0.05$, and trends discussed as $P \leq 0.10$.

## 3. RESULTS

### *3.1. Evolution of Concentrate Consumption throughout the Day*

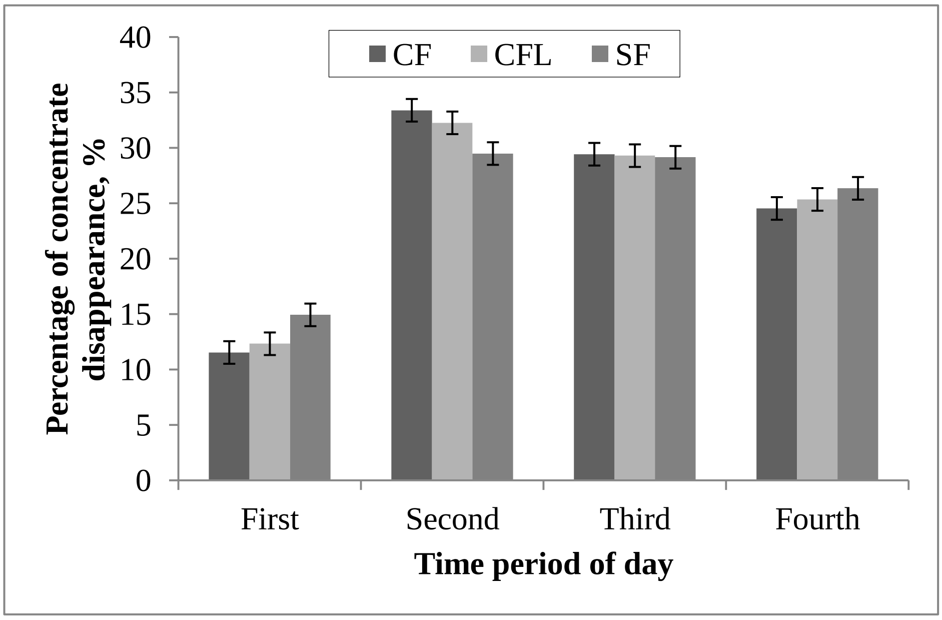
***By Animal BW.*** The percentage of concentrate disappearance evolved ($P < 0.01$) differently according to time period of day and animal BW (Figure 1). The proportion of concentrate disappearance recorded during the first time period of day was lesser compared with the others, despite this proportion decreased as animals grew. Contrary, the second and third time periods of day showed similar concentrate disappearance percentage until the eighth period of fattening, from which the percentage registered in second time period of day increased at the expense of third, describing opposed tendencies. Lastly, the percentage of concentrate disappearance recorded during the fourth time period of day increased as animals grew, especially during the last 3 periods of fattening reaching similar values to those observed during the second time period of day.

**Figure1.** The evolution of concentrate disappearance (as a proportion of total consumed) according to the time period of day as animals grew throughout the fattening periods




***By Concentrate Feeder design.*** An interaction ($P < 0.01$) between feeder design and time period of day in concentrate disappearance percentage was observed (Figure2). For the first time period of day, a greater concentrate disappearance percentage was recorded in SF (14.9 ± 0.01 %) compared with collective feeders (11.9 ± 0.01 %); contrary, during the second time period of day this percentage was greater in collective feeders (32.9 ± 0.01 %) than in SF (29.5 ± 0.01 %). Lastly, no differences among feeder designs were found for the remaining time periods of day (29.3 and 25.4 ± 0.01 % for third and fourth, respectively).

**Figure 2.**Concentrate disappearance (as a proportion of total consumed) throughout time periods of day according to concentrate feeder design in Holstein bulls fed a collective conventional feeder (CF), a collective conventional feeder with less concentrate capacity (CFL), and a single-space feeder with lateral protections (SF) for 214-d of study




### *3.2. Eating Behavior at the Concentrate Feeder*

Concentrate disappearance velocity was greatest ($P$ < 0.01) for CF (197.4 ± 8.35 g/min), followed by CFL (168.9 ± 8.35 g/min), and SF (140.4 ± 8.35 g/min) over the study (Table 1). Moreover, concentrate disappearance velocity increased ($P$ < 0.01) as animals grew; being 90.7, 188.9, and 227.2 ± 6.81 g/min when animal BW was 130, 320, and 440 kg, respectively.

There was an interaction between feeder design and animal BW for the number of bulls at the feeder ($P$ < 0.01), displacements at the feeder ($P$ < 0.01), and waiting time to feeder access ($P$ < 0.01). There was a tendency for occupancy time of feeder ($P$ = 0.05) and number of visits at the feeder ($P$ = 0.09) to also evolved differently with BW and feeder design.

When bulls BW was 130 and 320 kg, the occupancy time of SF (90.6 and 80.9 ± 2.57 % of total time analyzed) tended ($P$ = 0.05) to be greater compared with CF and CFL (80.6

and 65.6 ± 2.57 % of total time analyzed); however, when animals weighed 440 kg, no differences among treatments were observed (62.4 ± 2.57 % of total time analyzed).

In the SF design, the number of animals at the feeder was ($P < 0.01$) always one throughout the study. In contrast, the number of bulls observed at collective feeders (CF and CFL) changed ($P < 0.01$) throughout the study depending on animal BW: when animals weighed 130 kg an average of 2 animals per feeder were recorded, whereas at BW of 320 and 440 kg the number of bulls decreased to 1.5 animals per feeder, on average.

The number of visits recorded at the feeder was lesser ($P < 0.01$) in SF (23.8 ± 24.55 visits) compared with CF and CFL (137.3 ± 24.55 visits) when calves were 130 kg of BW. Moreover, a lesser ($P < 0.05$) feeder frequency of visits was registered in SF (44.8 ± 24.55 visits) than in CF (128.9 ± 24.55 visits) when animals weighed 320 kg of BW. No differences among treatments were found when bulls weighed 440 kg (71.7 ± 24.55 visits).

No displacements at the concentrate feeder were recorded ($P < 0.01$) in SF throughout the study. Nevertheless, although the number of displacements registered in CFL (7.6 ± 0.20 displacements/h) was greater ($P < 0.05$) than in CF (4.4 ± 0.20 displacements/h) when animals weighed 130 kg of BW, in the remaining fattening periods no differences between collective feeders were found, and the frequency of displacements was reduced from 1.4 to 0.7 ± 0.20 displacements/h between 320 and 440 kg of BW, respectively.

Although SF animals spent more ($P < 0.01$) time waiting to access the feeder over the study compared with insignificant times from collective feeders, this waiting time for SF design declined progressively as animals grew (20.4, 13.3, and 5.8 ± 0.29 % of total time analyzed for 130, 320, and 440 kg of BW, respectively).

### *3.3. Eating Behavior at the Straw Feeder*

The occupancy time of the feeder was greater (*P* < 0.01) in SF (71.1 ± 2.59 % of total time analyzed) than CFL and CF (58.6 ± 2.59 % of total time analyzed) throughout the study (Table 1). In addition, the occupancy time at the straw feeder tended (*P* = 0.07) to decrease with increasing animal BW: when calves weighed 130 kg of BW exhibited more occupancy time of the feeder (69.8 ± 4.60 % of total time analyzed) compared with the same animals with 440 kg of BW (53.9 ± 4.60 % of total time analyzed).

There was a tendency in the interaction (*P* = 0.06) between feeder design and animal BW in number of bulls recorded at the straw feeder. When calves weighed 130 kg of BW the number of bulls recorded at the straw feeder in SF pens was greater (3.1 ± 0.16 animals), followed by CF (2.4 ± 0.16 animals), and, lastly, for CFL (2.0 ± 0.16 animals).When bulls weighed 320 kg of BW, a greater number of bulls at the straw feeder was registered in SF (2.2 ± 0.16 animals) compared with CFL and CF (1.7 ± 0.16 animals).However, when animals weighed 440 kg, no differences among treatments were observed (1.6 ± 0.16 animals).

No differences among concentrate feeder designs were found in the number of visits at the straw feeder (122.2 ± 28.47 visits) throughout the study. However, the daily number of visits at straw feeder decreased (*P* < 0.01) as animals grew, exhibiting a greater frequency of visits at the feeder (173.9 ± 23.00 visits) when calves weighed 130 kg of BW than in the rest of fattening periods (96.3 ± 23.00 visits).

Frequency of displacements at the straw feeder did not differ among treatments (1.2 ± 2.84 displacements/h). However, the number of displacements recorded was greater (*P* < 0.01) when calves weighed 130 kg of BW (2.2 ± 2.84 displacements/h) in contrast to bulls with 320 and 440 kg of BW (0.6 ± 2.84displacements/h).

No differences among treatments were observed in waiting time to access the straw feeder (0.02 ± 0.08 % of total time analyzed).

**Table 1.** Eating and drinking behaviors at concentrate and straw feeders, and at drinker registered by video recordings (0600 to 1800 h) on d 12 (130 kg of BW), 125 (320 kg of BW), and 206 (440 kg of BW) of the study from bulls fed high-concentrate diets with different concentrate feeder designs

| Item | Treatment[1] | | | | | | | | | SEM[3] | *P*-value[2] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CF | CFL | SF | CF | CFL | SF | CF | CFL | SF | | T | P | T x P |
| | 130 kg of BW | | | 320 kg of BW | | | 440 kg of BW | | | | | | |
| **Concentrate feeder** | | | | | | | | | | | | | |
| Rate of concentrate disappearance, g/min | 104.4 | 100.1 | 67.5 | 228.8 | 182.5 | 155.4 | 259.1 | 224.3 | 198.3 | 11.80 | <0.01 | <0.01 | 0.26 |
| Occupancy time of feeder, min/d | 515.7 | 526.0 | 566.5 | 402.0 | 445.9 | 527.9 | 401.5 | 405.3 | 409.6 | 20.28 | 0.02 | <0.01 | 0.05 |
| Number of bulls at the feeder | 2.2 | 2.0 | 1.0 | 1.6 | 1.5 | 1.0 | 1.6 | 1.4 | 1.0 | 0.13 | <0.01 | <0.01 | <0.01 |
| Number of visits at the feeder | 129.8 | 144.8 | 23.8 | 128.9 | 81.1 | 44.8 | 78.7 | 81.8 | 54.5 | 24.55 | <0.01 | 0.18 | 0.09 |
| Displacements at the feeder/h | 4.4 | 7.6 | 0.0 | 1.2 | 1.6 | 0.0 | 0.8 | 0.6 | 0.0 | 0.20 | <0.01 | <0.01 | <0.01 |
| Waiting time to access the feeder, min/d | 4.6 | 0.2 | 126.6 | 3.5 | 0.8 | 86.7 | 1.5 | 3.6 | 37.8 | 0.70 | <0.01 | 0.03 | <0.01 |
| **Straw feeder** | | | | | | | | | | | | | |
| Occupancy time of feeder, min/d | 435.2 | 381.7 | 517.6 | 335.3 | 416.7 | 474.7 | 326.2 | 336.9 | 322.1 | 48.30 | <0.01 | 0.07 | 0.56 |
| Number of bulls at the feeder | 2.4 | 2.0 | 3.1 | 1.7 | 1.8 | 2.2 | 1.6 | 1.5 | 1.7 | 0.16 | <0.01 | <0.01 | 0.06 |
| Number of visits at the feeder | 143.7 | 169.5 | 208.5 | 129.7 | 99.9 | 84.7 | 93.3 | 89.6 | 80.6 | 28.47 | 0.94 | <0.01 | 0.19 |
| Displacements at the feeder/h | 1.1 | 2.4 | 3.4 | 0.6 | 0.6 | 0.4 | 0.8 | 0.7 | 0.7 | 2.84 | 0.16 | <0.01 | 0.23 |
| Waiting time to access the feeder, min/d | 0.2 | 0.0 | 2.5 | 0.1 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.41 | 0.60 | 0.32 | 0.14 |
| **Drinker** | | | | | | | | | | | | | |
| Occupancy time of drinker, min/d | 307.2 | 224.6 | 174.2 | 165.7 | 187.0 | 214.9 | 166.5 | 151.5 | 144.3 | 14.75 | 0.01 | <0.01 | <0.01 |
| Number of bulls at the drinker | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 1.0 | 0.02 | 0.42 | <0.01 | 0.41 |
| Number of visits at the drinker | 87.8 | 87.2 | 82.5 | 77.3 | 65.3 | 56.5 | 66.2 | 57.1 | 55.1 | 17.77 | 0.17 | <0.01 | 0.89 |
| Displacements at the drinker/h | 4.2 | 3.8 | 3.2 | 1.4 | 1.2 | 1.5 | 1.0 | 0.5 | 0.4 | 0.12 | 0.05 | <0.01 | 0.47 |
| Waiting time to access the drinker, min/d | 11.1 | 9.5 | 5.3 | 8.4 | 9.6 | 10.0 | 6.8 | 4.4 | 1.2 | 0.54 | 0.23 | 0.04 | 0.58 |

[1]Treatments were different concentrate feeder design: conventional through feeder (CF), conventional through feeder with less concentrate capacity (CFL), and a single space feeder with lateral protections (SF).
[2]Fixed effects were treatment (T), period (P), and interaction between treatment and period (T x P).
[3]Displacements at the feeder and waiting time to access to the feeder data were analyzed as the root transformation and are presented backtransformed data.

### *3.4. Drinking Behavior*

There was an interaction (*P* < 0.01) between concentrate feeder design and animal BW in occupancy time of the drinker (Table 1). When bulls weighed 130 kg of BW, those fed CF spent more time (47.7 ± 2.08 % of total time analyzed) at the drinker, followed by CFL (35.4 ± 2.08 % of total time analyzed), and, for SF (28.0 ± 2.08 % of total time analyzed). In contrast, at 320 kg of BW, SF bulls showed greater occupancy time of the drinker (33.9 ± 2.08 % of total time analyzed) compared with CF (26.8 ± 2.08 % of total time analyzed). However, at 440 kg of BW, no differences among treatments were observed (which represented 25.2 ± 2.08 % of total time analyzed).

Feeder design did not affect the number of bulls drinking, number of visits recorded at the drinker, and waiting time to access the drinker throughout the study (1.0 ± 0.02 animals, 70.6 ± 17.77 visits, and 1.0 ± 0.21 % of total time analyzed, respectively). The number of bulls recorded at the drinker decreased (*P* < 0.01) with animal BW (1.02, 0.98 and 0.95 ± 0.009 animals at 130, 320 and 430 kg of BW, respectively). In addition, the number of visits recorded at the drinker decreased (*P* < 0.01) from 85.9 ± 16.59 when calves weighed 130 kg of BW to 62.9 ± 16.59 visits for animals with 320 and 440 kg of BW.

Bulls fed CF registered more displacements (*P* < 0.05) at the drinker (2.0 ± 0.05 displacements/h) than CFL and SF bulls (1.6 ± 0.05 displacements/h) throughout the study. In addition, the frequency of displacements recorded at the drinker decreased (*P* < 0.01) as bulls grew (from 3.9 to 1.4± 0.07 displacements/h between 130 and 320 kg of BW, and from 1.4 to 0.6 ± 0.07 displacements/h between320 and 440 kg of BW, respectively).

Also, waiting time to access the drinker decreased (*P* < 0.05) with animal BW, from 130 and 320 kg (1.1 ± 0.12 % of total time analyzed) to 440 kg of BW (0.8 ± 0.12 % of total time analyzed).

## 4. DISCUSSION

To our knowledge, this study is the first to address how concentrate feeder design interacts with eating and drinking behaviors in Holstein bulls fed high-concentrate diets and reared under commercial conditions.

### *4.1. Concentrate Feeder Design*

The percentage of concentrate disappearance throughout the time periods of day was different according to concentrate feeder design. Animals fed on SF attended to feeder earlier in the morning (0000 to 0600 h) to compensate the lesser affluence from 0600 to 1200 h, which was the most crowded time period of day in collective feeders recording an eating peak. Thus, the SF design was able to modify slightly the eating pattern of animals throughout the day, concretely, at the first two time periods of day. Also, animals fed on SF adapted their circadian eating behavior to feeder design, attending earlier to the feeder to counteract the lack of feeding space to eat simultaneously more animals than one.

Moreover, there were 3 other behavioral parameters that were affected by concentrate feeder design (RCD, the occupancy time of straw feeder, and displacements at the drinker). Whereas reducing the concentrate level at the feeder (less concentrate capacity due to less feeder depth) allowed decreasing 14% in RCD, the SF with lateral protections achieved a reduction of 29% in RCD. A plausible explanation about this reduction seems to be more related to feed spillage than “real” eating rate, as Verdú et al. (2015) discussed it taken into account performance and rumen pH data. However, as mentioned before, in this study wastage was not recorded.

In addition, animals fed on SF spent 17% more time at straw feeder than animals in collective feeders, which represented a total of 66 min occupancy in straw feeders. Thus, the space at the straw feeder may be critical to avoid an increase of displacements and occupancy time at straw feeder in case of SF implementation. The greater occupancy time of straw feeder in SF may be explained because animals devoted more time waiting to access to the feeder, and they had the necessity to spend this time redirecting the initial desirable eating concentrate activity to eating straw. Also, this great proportion of time devoted to spend at straw feeder has been observed when competence at the concentrate feeder increases, such as González et al. (2008a) reported during the adaptation to the social environment, in which an increase of straw consumption was detected. Gonzalez et al. (2008b) identified this behavioral change as a response to redirect the eating activity from concentrate to straw feeder when the first is occupied, as a behavior to synchronize eating at peak time. However, in the current study, no differences in straw consumption were observed (Verdú et al., 2015), but this outcome should be considered with caution because, as mentioned before, as pens were bedded with straw and the exact straw consumption could not be registered. In this sense, Miller and Wood-Gush (1991) indicated that a reduction of feeding space may cause a restriction in the heifers' natural feeding behavior that typically consist of attending the feeder in a synchronized manner (or in groups). This would mean that animals were waiting around the straw feeder until the concentrate feeder became available. In the present study, the greater occupancy time of the straw feeder in SF pens may suggest that no animal competition was observed. In contrast, González et al. (2008b) reported that the time devoted to eat straw was reduced in heifers when social pressure increased. Thus, the lesser RCD and greater occupancy time of straw feeder observed in SF could explain the pH values above 6.0 reported by Verdú et al. (2015).

Lastly, animals fed on CF exhibited 20% more displacements at the drinker than those fed on CFL and SF throughout the study. The video recording showed that animals after eating concentrate attended the drinker more frequently. Although water consumption was not measured, the greater RCD recorded in CF supports previous hypothesis, as water and feed intake are closely linked (Murphy, 1992). Thus, the increase of displacements in the CF could consider the possibility to design pens with two drinkers rather than one.

### *4.2. Animal BW*

The animal BW should be an important factor when considering aspects related to feeding system such as feeder design, animal to feeding space ratio, feeding space availability, etc. The results indicated that some behavioral parameters evolved with animal BW, as the age of cattle also affects their eating behavior (Albright, 1993). Thus, in the current study animal BW has been used as a reference of animal age. The percentage of concentrate disappearance throughout the time periods of day evolved differently with increasing animal BW. As expected, the main activity at the concentrate feeder was registered from 0600 to 1800 h, as approximately the 60 % of total daily concentrate disappearance was recorded. In agreement with these results, Putnam et al. (1963; 1964) reported that 75% occupancy time of feeder was recorded around 0600 and 1800 h.

The RCD increased with animal BW (52 % during the growing and 17% during the finishing), independently of concentrate feeder design. This parameter measured simultaneously feed consumption and wastage caused by eating activity, with the drawback that it was not possible to discriminate between them, as spillage was not quantified. Although RCD is not as accurate as eating rate, it could be considered as an indirect measure of eating rate, and also it could be related to the size of each bite. The RCD increased as animals grew, especially during the growing phase, which is in accordance with data reported by Mialon et al. (2008) and González et al. (2008b) in bulls and heifers fed concentrate and straw, respectively.

Analyzing behavior at the straw feeder, there were 3 behavioral traits that changed with animal BW. In the current study the occupancy time of the feeder declined by 26% from 130 to 440 kg of BW, and the straw consumption increased with BW (from 0.3 to 1.2 kg/d of DM, between growing and finishing period; data not shown); consequently, as observed in concentrate eating rate, the straw eating rate increased with BW. These data are not in agreement with another long-term study with heifers, where time spent eating straw increased as the age of animals increased (González et al., 2008b); these differences could be attributed to different experimental conditions (e.g., straw feeder design, bedding material, nutritional quality of straw). In the present study, the daily number of visits decreased as animals grew, and decreased by 40% during the growing and 16% during the finishing phase. In addition, the frequency of displacements decreased 63% from the beginning to the end of the growing phase, but no differences were found during finishing phase. The frequency of displacements decreased probably because the number of visits and occupancy time were reduced with animal BW. Hence, the activity at the straw feeder decreased with animal BW, even if the amount of the straw consumption increases. Thus, the concentrate feeder design did not affect the frequency of displacements at the straw feeder according to González et al. (2008a).

There were also differences in the number of animals drinking as animals grew throughout the study. One explanation could be that when animals weighed 130 kg of BW, sometimes 2 bulls were recorded drinking simultaneously as they had a relatively small BW (size). Another explanation could be that as animals grew they changed towards a more individualized behavior. Daily number of visits was reduced with animal BW, especially between the growing and the finishing phase (decreasing by 27%). Displacements decreased by 62% during the growing phase, and 57% during the finishing phase. Also, a greater waiting time to access the drinker was maintained during the growing phase compared with the finishing phase. In the case of the drinker, the evolution of displacements was different to the one observed at the straw feeder, because the reduction of displacements was slow and progressive throughout the fattening without the predominance of one period over another, as it happened at the straw feeder. One possible interpretation could be explained by relationship established between the competition for a resource and the space availability of this resource. Thus, displacements at the straw feeder decreased earlier probably because animals had greater space availability (7 feeding spaces for 20 animals); contrary, displacements at drinker decreased more slowly suggesting that the space availability was more limited (1 drinker for 20 animals). Supporting this hypothesis, different authors (DeVries et al., 2004; DeVries and Keyserlingk, 2006) have observed mainly in dairy that increasing the availability of space at the feeding zone, the number of displacements decreased. The activity around the drinker did not decrease with animal BW as it happened at the straw feeder probably because there was less drinking space availability and, subsequent, animal competition was maintained more time for drinker resource.

### *4.3. Concentrate Feeder Design and Animal BW*

Most of behavioral parameters that showed an interaction between feeder design and animal BW took place at concentrate feeder. Thus, animals were able to modify their eating and drinking behaviors as they grew to adapt their natural behavior to concentrate feeder design.

There were significant differences among feeder designs in terms of occupancy time of the concentrate feeder according to animal BW. Whereas animals fed SF attended the feeder around 90-80 % of total time analyzed during the whole growing phase, bulls in collective feeders only attended the feeder 80% of total time analyzed at the beginning of growing phase. In this case, at the end of the growing phase, the occupancy time was reduced to 65% of total time analyzed, which was similar to those observed during the finishing phase. However, no differences were observed in occupancy time during the finishing phase of the study, which decreased around 60% for all feeder designs. The practical implications of these data could be that the time availability might be limited in SF during the growing phase (from 130 to 320 kg of BW), and in the hypothetical case that the ratio animal:feeder spaces increases, an additional SF could be necessary. Then, the limiting factor that determines the number of animals that can be fed per feeding space is the total occupancy time of feeder, and this parameter evolves with animal BW.

In addition, in SF one animal was always observed at concentrate feeder throughout the study, which confirms the effectiveness of lateral barriers from SF (single-space feeder design) to force animals accessing one by one and eating individually. In collective feeders, the requirements of feeding space changed with animal BW. When animals weighed 130 kg, they needed more feeding spaces compared with the same animals weighing 320 or 440 kg. Although collective feeders had 4 available feeding spaces, only 2 feeding spaces, usually the central ones were used for 75% of total time analyzed when animals were 130 kg of BW. For the remaining fattening cycle, there were 4 available feeding spaces also, but 2 feeding spaces were used for 92% of total time analyzed (data not shown). These findings were expected in accordance with results reported in swine studies (Gonyou, 1999; Gonyou and Lou, 2000), which indicated that the ratio animal:feeder space needs to be greater during the growing phase compared with the finishing phase because of the eating behavior. As mentioned before, eating behavior changed to a more individualized conduct in animals exposed to collective feeders as BW increased, which is similar to the eating behavior exhibited by the animals fed on SF.

The number of visits in the SF was maintained more or less constant during all the fattening period, whereas in the collective feeders decreased as animals grew. This evolution of number of visits indicates that the activity around concentrate feeder decreased as animals grew in collective feeders, probably as a consequence of greater RCD registered. In the case of SF, animal BW did not affect the number of visits, and the increase in RCD could be more related to the decrease in occupancy time of feeder.

In SF no displacements happened over the fattening due to the lateral protections of feeder design. Then, these data suggest that the SF design with lateral barriers contributed to reduce competition at the concentrate feeder. However, when animals weighed 130 kg of BW, some aggressions were observed to gain access to the feeder even with lateral protections. One of them occurred around lateral barriers when animal tried to access to the feeder and was moved away; and, another could be defined as attempt of displacement, when animal had the intention to displace another while was eating, and lateral protections avoided or dissuaded the action. These behaviors were considered difficult to measure for their subjective nature and for this reason they were omitted. However, it is interesting to consider that these behaviors were only registered during the adaptation period of animals, at the beginning of growing phase, probably when hierarchy was established and animals were adapting to the new feeder design. As a counterbalance of lateral protections, when animals weighed 130 kg, more waiting time was observed to access the feeder. However, this waiting time was progressively reduced as animals grew because of the occupancy time decreased with animal BW, as a possible suggestion. Also, the frequency of displacements at collective feeders decreased drastically with animal BW (85 % from 130 kg to 320 kg), probably because of the establishment of hierarchy (González et al., 2008a). The greater number of displacements at the feeder observed by González et al. (2008a) may indicate that animals are establishing dominance relationships, and the group did not reach a stable social hierarchy. Herein, the reduction of frequency of visits as animals grew also could be related with the establishment of internal order to attendance at feeder or hierarchy within group. In addition, in CFL feeders more displacements were recorded than CF at 130 kg of BW, suggesting that feeders with less depth may prompt for more displacements.

There were more animals observed at straw feeder during the growing phase in SF pens in contrast to collective feeders; however, during the finishing phase no differences among treatments were observed. This greater occupancy of the straw feeder was not associated with an increase of straw consumption (Verdú et al., 2015). The greater animal attendance to the straw feeder could be explained as a redirected behavior against impossibility eating concentrate based on synchronization of eating activity within a group. These data support that in case of SF was implemented, space in the straw feeder can be critical, because animals fed SF spent more time at straw feeder and, during growing phase, this attendance was in groups of 2-3 animals eating simultaneously.

When animals weighed 130 kg, pens equipped with collective feeders registered a greater occupancy time of the drinker in contrast to SF, but this tendency was inverted with BW of 320 kg, and during the finishing phase no differences were detected among feeder designs. There was a direct relationship between occupancy time and displacements recorded at the drinker. In collective feeders, at the beginning of the growing phase, more occupancy time of the drinker led to record a greater frequency of displacements. Thus, animal activity around the drinker in collective feeders was increased during the growing phase, whereas this increase of animal activity was observed around the straw feeder in SF.

In summary, behavioral parameters analyzed that change with animal BW indicated that the most critical stage of fattening is the growing phase (from 130 to 320 kg of BW) because the most significant behavioral eating changes were registered during that period. After that BW (or age), the activity at the feeding area decreased and animal behavior became more individualized. Whereas animals exhibited more synchronized and gregarious eating and drinking behaviors during the growing phase, during the finishing phase bulls tended to individualize these behaviors.

In addition, following conclusions could suggest recommendations for feeder requirements according to animal BW. The RCD increased as animals grew, and it was affected by concentrate feeder design. Also, whereas for SF pens the feeding zone should ensure feeding space at straw feeder, especially when animals weigh around 130 kg and are adapting to concentrate feeder design, in collective feeders during the growing phase animals need more space availability at drinker, or perhaps they need two drinkers instead of one.

Furthermore, this study evidences that drinker and straw feeder, concentrate feeder design, and animal BW are interrelated and affect eating and drinking behaviors. These relationships should be taken into account when the feeding zone is designed in order to adjust the feeder and drinker designs according to animal BW to avoid limiting access to the feed and water.

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# CHAPTER V

# Effect of adaptation strategy to a single-space concentrate feeder design with lateral protections on performance, eating and animal behavior upon arrival of fattening Holstein calves

*This chapter will be submitted for publication in Journal Animal Science*

## ABSTRACT

The objective of the current study was to evaluate the effect of an adaptation strategy to a single-space feeder with lateral protections (SF) on performance, eating pattern, and animal behavior in calves for first 6 wk upon arrival at the feedlot. A total of 216 Holstein calves (120 ± 3.8 kg initial BW and 102 ± 2.7 d of age), from two separate fattening cycles, were randomly allocated in 1 of 6 pens equipped with a computerized concentrate SF, a separated straw feeder, and a water bowl. Pens were assigned to either a conventional adaptation (CA), in which the lateral protections were widened for first 4 d, or an alternative adaptation (AA), in which no lateral protections for the first 4 d were placed and an additional feeder, during the adaptation period (14 d after arrival). All animals received concentrate and straw *ad libitum*. Daily concentrate consumption and eating pattern, weekly straw consumption, and fortnightly BW were recorded. Animal behavior was registered weekly by scan sampling. Eating (concentrate and straw) and drinking behaviors were filmed for 4 h on d 1, 5, and 15 of the study. During the first week of the adaptation period, calves on AA had a greater ($P < 0.01$) concentrate intake than calves on CA, which showed a greater ($P < 0.01$) variable daily intake. In addition, the final BW after 42 d of study was greater ($P < 0.05$) in AA than in CA calves. The adaptation strategy tended ($P = 0.10$) to increase ADG of the smallest animals and in those within the third quartile of initial BW. During the first week of the adaptation period, a greater ($P \leq 0.01$) percentage of animals per pen eating concentrate and drinking was recorded with AA. Moreover, at concentrate feeder and for the first week of adaptation period, the AA strategy registered a lesser ($P < 0.01$) occupancy time, a greater ($P < 0.01$) number of animals and visits, a reduction ($P < 0.05$) of waiting time, and an increase ($P < 0.01$) of the number of displacements. In conclusion, the adaptation strategy (chute not placed and additional feeder) was successful facilitating feed access and encouraging concentrate consumption during the first week of adaptation period after arrival, improving the concentrate intake and growth. Lastly, the main effects of the adaptation strategy on animal and eating behavior were registered during the first week of adaptation period.


**Key words:** animal behavior, beef, eating behavior, feeder design adaptation, performance

## 1. INTRODUCTION

A single-space feeder with lateral protections (SF) is an alternative design to decrease the total concentrate intake without impairing overall performance, rumen health, and welfare in Holstein bulls fed high-concentrate diets (Verdú et al., 2015). However, the former study revealed that animals on SF showed difficulty to feed access for the first 2 wk upon arrival due to feeder design, even with widening of the chute for first 4 d. Therefore, these calves had diminished concentrate consumption and growth compared with those fed in multiple-space feeders (3.0 vs. 3.8 ± 0.25 kg/d for intake, and 1.3 vs. 1.6 ± 0.12 kg/d for ADG, respectively) during the adaptation period (first 2 wk). Gonyou and Stricklin (1981) also reported lesser growth in cattle during the initial 2 wk while adapting to single feeding stall compared with trough-fed bulls. Furthermore, other parameters (2 animals removed, greater serum NEFA concentration, more waiting time to access to the feeder, and more proportion of animals standing) support the hypothesis that animals did not adapt well to the SF (Verdú et al., 2015). It is well-known that ensuring adequate feed consumption soon after arrival is crucial to improve performance (Kunkle et al., 1976), and increasing the number of feeding places increases intake and ADG in newly arrived fattening calves (González et al., 2008). Thus, it was hypothesized that concentrate consumption and animal growth in SF-fed bulls could be improved by providing free access to feed for the first 4 d (without lateral protections), together with an additional feeder (2 feeding spaces) for the first 2 wk, after arrival to facilitate the feed access and encourage intake. The objective of the present study was to evaluate the effect of an adaptation strategy (SF without lateral protections for the first 4 d and additional feeder in which feed offer was gradually reduced for first 14 d) in SF-fed bulls on performance, eating pattern, and animal behavior in Holstein calves for the first 6 wk upon arrival.

## 2. MATERIALS AND METHODS

### *2.1. Animals, Facilities, and Treatments*

Animals were reared under commercial conditions in a farm owned by Agropecuaria Montgai SL (Lleida, Spain), and were managed following the principles and specific guidelines of IRTA Animal Care Committee.

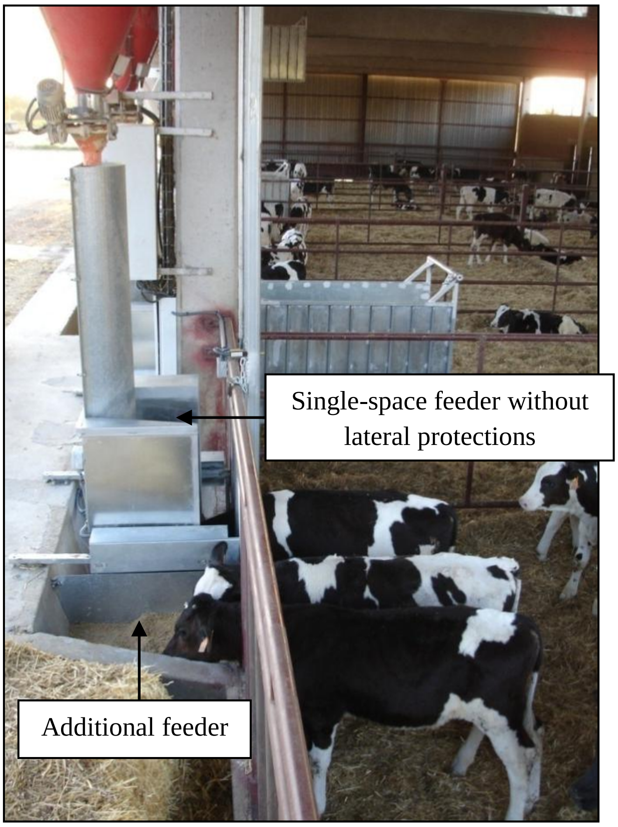
Two hundred sixteen male Holstein calves (120 ± 3.8 kg initial BW and 102 ± 2.7 d of age) from 2 consecutive fattening entrances (114 and 102 animals for each entrance) were used in a replicated study. The length of the experiment was 42 d after arrival (14 d of adaptation period and 28 d of initial growing period). Upon arrival, calves were weighed, fitted with a radio frequency transponder on left ear, and randomly allocated to 1 of 6 pens (19 and 17 animals per pen for each fattening). Each pen was equipped with a computerized concentrate single-space feeder (0.50 m long x 0.26 m wide x 0.15 m depth), with lateral protections (1.40 m long x 0.80 m high) forming a chute (SF; Verdú et al., 2015). Furthermore, covered pens (12 m long x 6 m wide) were deep-bedded with straw, which had a separate straw feeder (3.00 m long x 1.12 m wide x 0.65 m depth; 7 feeding spaces), and a water bowl.

Each pen was assigned to 1 of the 2 treatments that consisted of implementing two different strategies of adaptation to SF design during the adaptation period (14 d after entrance): 1) a conventional adaptation (**CA**), and 2) an alternative adaptation (**AA**). The CA was the strategy followed in Verdú et al. (2015), widening the chute for the first 4 d of adaptation period to facilitate the feeder access; after this adaptation time, the width of the chute was adjusted at 42 cm providing sufficient space for only one animal ate comfortably at a time. Conversely, the AA treatment was designed to enhance the adaptation of the animals to the feeder to facilitate feed access and stimulate intake implementing the following arrangements: 1) the chute was not placed for the first 4 d after arrival, leaving the feeder access completely free without lateral protections, and 2) an additional single-space feeder (0.60 m long x 0.50 m wide x 0.20 m depth), without lateral barriers, was placed on the left side of the computerized feeder (Figure 1) in which supplementary feed was provided daily at 1000 h, diminishing progressively the amount offered each day by 5 kg throughout the initial 14 d of study (from 70 to 0 kg per pen and day).

**Figure 1.** Disposition of the additional single-space feeder (without lateral barriers) on the left side of computerized single-space feeder with lateral protections (SF) in the feeding area of pen. (a) Front view and (b) lateral view more detailed

a)


b)



### *2.2. Concentrate Computerized Feeder*

Animals were fed via a concentrate computerized feeder (Voltec®, Lleida, Spain), which was composed of a single trough with lateral protections forming a chute, and it used a radio frequency technology to record the daily concentrate consumption and eating behavior for each animal within a pen. The detailed description of this computerized feeder, and its validation as an adequate system to monitor the individual eating behavior in beef animals were reported by Verdú et al. (unpublished data; Chapter VI). In addition, all feeders were continuously provided with feed by automatic feeding system, as described in Verdú et al. (2015).

Furthermore, the computerized feeder had an activated alarm system that notified the next day whether a calf had not been detected in a whole day before because it had not attended to the feeder to eat. For the purpose of the present study, an alarm notification was used as an animal badly-adaptation record, which indicated an inability to adapt to the SF design. Each time that one calf registered an alarm, and no consumption was recorded the next day, this particular animal was assisted to access to the feeder ensuring that the transponder worked and the animal ate. Five accumulated alarms for 1 animal were considered as a non-adaptation criterion and, therefore, this calf was removed from the study for that reason. The evaluation of animal ability to adapt to the SF design was performed since the adaptation strategies finished for each treatment (after d 4 and after d 15 for CA and AA, respectively).

### *2.3. Feed Consumption and Performance*

Calves received a commercial concentrate (Table 1) formulated according to the NRC (2001) recommendations, and wheat straw (3.5% CP, 1.6% ether extract, 70.9% NDF, and 6.1% ash; DM basis), both *ad libitum*. During the adaptation period (14 d) all animals were fed a starter concentrate, while the rest of growing period (28 d) they were fed a grower concentrate. Fresh water was available at all times. A sample from each concentrate was taken for DM determination and chemical analysis.

**Table 1.** Ingredients and nutrient composition of the experimental concentrates

| Concentrate | Starter | Grower |
|---|---|---|
| Item | | |
| Ingredients, % of DM | | |
| Corn | 36.0 | 36.1 |
| Barley | 18.9 | |
| Soybean meal 47% CP | 11.8 | 2.7 |
| Corn dried brewer's grains | 10.0 | |
| Wheat middlings | 8.0 | 22.7 |
| Corn gluten feed | 8.0 | |
| Corn grit | | 20.0 |
| Corn dried distillers grains | | 12.0 |
| Soybean hulls | | 3.0 |
| Palm oil | 2.0 | 1.2 |
| Calcium carbonate | 1.8 | 1.4 |
| Urea | | 0.4 |
| White salt | 0.3 | 0.3 |
| Magnesium oxide | 0.2 | |
| Vitamin-mineral premix[1,2] | 3.0 | 0.2 |
| Nutrient composition, % of DM | | |
| Ash | 7.0 | 5.4 |
| CP | 17.2 | 16.0 |
| Ether extract | 5.9 | 7.5 |
| NDF | 17.1 | 23.9 |
| NFC[3] | 52.8 | 47.2 |
| ME, Mcal/kg | 3.1 | 3.2 |

[1]Karimix Terneros Arranque (Laboratorios Karizoo S.A., Caldes de Montbui, Spain): vitamin and mineral premix containing, per kg of DM: 15,000 mg of vitamin A, 3,000 mg of vitamin $D_3$, 70 mg of vitamin E. 60 mg of Zn, 50 mg of Mn, 50 mg of Fe, 15 mg of Cu, 0.7 mg of Co, 0.4 mg of I, 0.2 mg of Se. 890 mg of sepiolite, 8.5 mg of butylhydroxytoluene, 5 mg of etoxiquine, 0.8 mg of butylhydroxyanisole, 1.5 x $10^9$ UFC of *Saccharomyces cerevisiae* CNCM I-1077.
[2]SinuvitTerneros Final (Sinual S.L., Sallent, Spain): vitamin and mineral premix containing, per kg of DM: 4,500 kIU of vitamin A, 1,000 kIU of vitamin $D_3$, 22.5 g of vitamin E, 0.5 g of vitamin $B_1$, 1 g of vitamin $B_2$, 5 mg of vitamin $B_{12}$, 2.5 g of vitamin $B_3$. 15 g of Mn, 3 g of Cu, 30 g of Zn, 0.5 g of Co, 0.5 g of I, 0.1 g of Se, 1 g of butylated hydroxytoluene, 1 kg of calcium carbonate as excipient.
[3]NFC = nonfiber carbohydrates calculated as 100 – (CP + ash + NDF + ether extract).

The computerized feeder recorded the daily concentrate consumption throughout the study. During the first 4 d of adaptation period the intake was collected per pen due to the chutes were not ready (widened or not placed), whereas after 4 d the intake was recorded individually per animal. Moreover, during the adaptation period (initial 2 wk of study), daily concentrate consumption at additional feeder was also registered, and was added to intake from computerized feeder obtaining the total consumption per pen and day. The amount of straw offered to each pen was recorded weekly just as a partial estimation of the total amount of straw consumed, because straw was also used for bedding. Animals were weighed weekly throughout study, and BW data were used to calculate ADG and feed efficiency. To assess the variability of growth among calves sharing the same pen, the within-pen CV of BW and ADG were calculated weekly. Lastly, gain to concentrate ratio (concentrate efficiency) weekly was estimated dividing the BW increase by the average of daily concentrate consumption throughout this 7-d period.

### *2.4. Animal Behavior*

General activities (standing, lying, eating concentrate and straw, drinking, and ruminating) and social behaviors (nonagonistic, agonistic, and sexual interactions) of the calves within the same pen were recorded by scan sampling on d 1, 3, 5, 7, and weekly throughout the study, as described by Verdú et al. (2015).

### *2.5. Eating Behavior*

During the adaptation period (14 d), the feeding area of each pen (including concentrate feeders, computerized and additional, straw feeder, and drinker) was filmed for 24 h the next day after: calves arrival (d 1), the chute was narrowed or arranged (d 5), and the supplementary amount of concentrate in the additional feeder was not further supplied (d 15), using digital cameras (Sony CSM-BV420; Sony Corp., Barcelona, Spain) to analyze the eating pattern. Videotapes were processed by continuous recording of the activities performed by animals. Recorded activities (eating concentrate or straw, drinking, waiting time to access the feeder or drinker, and displacements at feeder or drinker) were registered simultaneously recording the time (min), the number of animals involved, and the frequency (the number by hour), as described by Verdú et al. (unpublished data; Chapter IV). Only 4 h of recordings (0600 to 1000 h) were used to create a data set, as the eating behavior data, from a previous study, showed that during this time frame a first daily peak of eating activity was observed in cattle fed on collective feeders with continuously feed available (unpublished data; Chapter IV). During the adaptation period, the eating behavior recorded at additional and computerized feeders was considered together for behavioral data analysis. For the growing period (28 d), the eating behavior was monitored by concentrate computerized feeder recording individual data from animals (the number of visits per animal, the length of each visit, the amount of concentrate consumed per visit and animal, and the total daily eating time and concentrate consumption per animal).

### *2.6. Chemical Analyses*

Feed samples were analyzed for DM (24 h at 103ºC), ash (4 h at 550ºC), CP by the Kjeldahl method (method 981.10; AOAC, 1995), NDF according to Van Soest et al. (1991) using sodium sulfite and α-amylase, and ether extract by Soxhlet with a previous acid hydrolysis (method 920.39; AOAC, 1995).

### *2.7. Calculations and Statistical Analyses*

Firstly, a power analysis was conducted to check if 4 replicates per treatment would be sufficient to detect differences in concentrate consumption and ADG. The power analyses was conducted for these outcome variables using the SD of this parameter between pens observed in previous study (Verdú et al., 2015), an alpha of 0.05, and a power of 0.80. The power analysis indicated at least that 3 and 4 replicates (pens) per treatment were necessary to detect expected differences among treatments for intake and ADG, respectively. To the extent that individual measurements on animals were possible, animals were included in the analyses as sampling unit and not as experimental unit (Verdú et al., 2015).

The pen was considered the experimental unit for all statistical analysis (n = 4), and animals were considered sampling units for adaptation records and analysis of ADG by BW quartile.

Pen data of daily concentrate consumption, eating behavior, and performance were averaged by week and fattening. Also, individual animal data of daily concentrate consumption, eating behavior, and performance were averaged by pen, week, and fattening.

The frequency of each social behavior was obtained by summing by day, pen, and scan; while, the percentage of each general activity was averaged by day, pen, and scan.

An arcsine plus 1 transformation to achieve a normal distribution was applied to behavioral data. The means presented in the tables correspond to non-transformed data, and SEM and *P*-values correspond to the ANOVA analyses of the transformed data.

The occupancy time of each feeder (concentrate and straw) and drinker (min), and the total waiting time to access to each feeder and drinker (min) were calculated as the sum of total time performing these activities per pen, day, and fattening. The number of bulls eating and drinking, and the number of visits recorded at each feeder and drinker were averaged by pen, day, and fattening. Number of displacements registered at each feeder and drinker were summed by pen, day, and fattening, and divided by total time analyzed to express as frequency of displacements per hour. Feeder and drinker occupancy, and waiting time data were also expressed as the percentage of time devoted to perform these activities from total 4-h time of video recording analyzed (occupancy and waiting time rate). The occupancy and waiting time rates were root-squared to achieve a normal distribution. The means presented in the tables correspond to non-transformed data, and SEM and *P*-values to the transformed data.

To estimate eating pattern, meal criteria for each animal and period were calculated. The meal criterion (maximum amount of time between visits at the feeder to consider a visit as a part of the same meal) was calculated using a model composed of 2 or 3 normal distributions resulting from the natural logarithm of time (in seconds) between feeder visits as described by Bach et al. (2006). Then, visits at the computerized feeders were separated into meals, and meal frequency, meal duration and size, inter-meal duration, and eating rate were calculated.

Consumption, performance, and eating and animal behavior data were analyzed using a mixed-effects model with repeated measures (Version 9.2, SAS Inst., Inc., Cary, NC). The model included initial full BW as a covariate, treatment, period (weekly for performance and consumption pen data; daily or weekly for eating and animal behavior), and their interaction, as fixed effects, and pen and fattening cycle as random effects. Period was considered a repeated factor, and pen nested within treatment was subjected to 3 variance-covariance structures: compound symmetry, autoregressive order 1, and unstructured. The covariance structure that yielded the smallest Schwarz’s Bayesian information criterion was considered the most desirable analysis.

Initial and final full BW, and age data were analyzed using a mixed-effects model (Version 9.2, SAS Inst., Inc., Cary, NC) including treatment as a fixed effect, and pen and fattening cycle as a random effects.

Animal adaptation records were analyzed using a GLIMMIX procedure (Version 9.2, SAS Inst., Inc., Cary, NC) including treatment as a fixed effect, and pen and fattening as a random effects. Herein, the Poisson with repeated measures was used for analysis the count adaptation data.

Finally, even if pen was the experimental unit, initial BW data were distributed by quartiles (< 110.5, 110.5 to 120.5, 120.5 to 131, and > 131 kg) to evaluate the effect of adaptation strategy to SF design on ADG throughout the study. ADG data were also analyzed using the same model for consumption including initial BW quartiles. Significance was established at $P < 0.05$, and trends discussed as $P \leq 0.10$.

## 3. RESULTS AND DISCUSSION

### *3.1. Animal Health Records*

One calf from AA treatment was removed at d 1 from the study as it died as a consequence of pneumonia. Veterinary treatments recorded throughout 6 wk of study did not differ ($P = 0.63$) between adaptation strategies (12.1 and 8.5 ± 4.91 % treated calves for CA and AA, respectively; data not shown).

### *3.2. Animal Adaptation Records*

Two calves were removed from the study because of their inability to adapt to the SF design, one on each treatment. No differences between treatments were observed in number of animals assisted to access the feeder ($P = 0.24$; 5.5 vs. 1.9 ± 1.29 % for CA and AA) and number of assistences registered ($P = 0.11$; 6 vs. 13 ± 1.1 for CA and AA).

Thus, most of calves learned to access the feeder and ate at their own without difficulties. The incidence of adaptation problems in terms of number of calves that received assistance, together with the number of assistences, was very low for both treatments during the adaptation period. Nevertheless, AA strategy minimized numerically these problems of adaptation reducing by a half the frequency of animals assisted, fact that evidenced a better adaptation to the SF design.

This is an important aspect if the SF design was implemented in comercial settings, as a feeding system that required to give assistence to animals would become more labourious, less practical, and, consequently, its application would be difficult to justify on field conditions.

### *3.3. Feed Consumption and Performance*

A week by treatment interaction was observed ($P < 0.01$) on concentrate consumption (Table 2). During the first week of the adaptation period, calves reared with AA (3.5 ± 0.12 kg/d) recorded a greater concentrate intake than calves on CA (2.8 ± 0.12 kg/d). However, no differences ($P > 0.10$) between treatments in concentrate intake were observed for the remaining study, which increased from 3.3 at wk 2 to 4.2 ± 0.12 kg/d at wk 6. Furthermore, the adaptation strategy to SF design had an effect ($P < 0.05$) on final BW after 42 d of the study, resulting in a greater final BW in AA group (178.8 ± 3.37 kg) than in CA (174.9 ± 3.37 kg). Nevertheless, ADG (1.36 ± 0.040 kg/d), feed efficiency (0.37 ± 0.011 kg/kg), accumulative concentrate consumption (144.8 ± 1.78 kg after 42 d), and straw consumption (0.4 ± 0.03 kg/d) were not influenced ($P > 0.10$) by the adaptation strategy used.

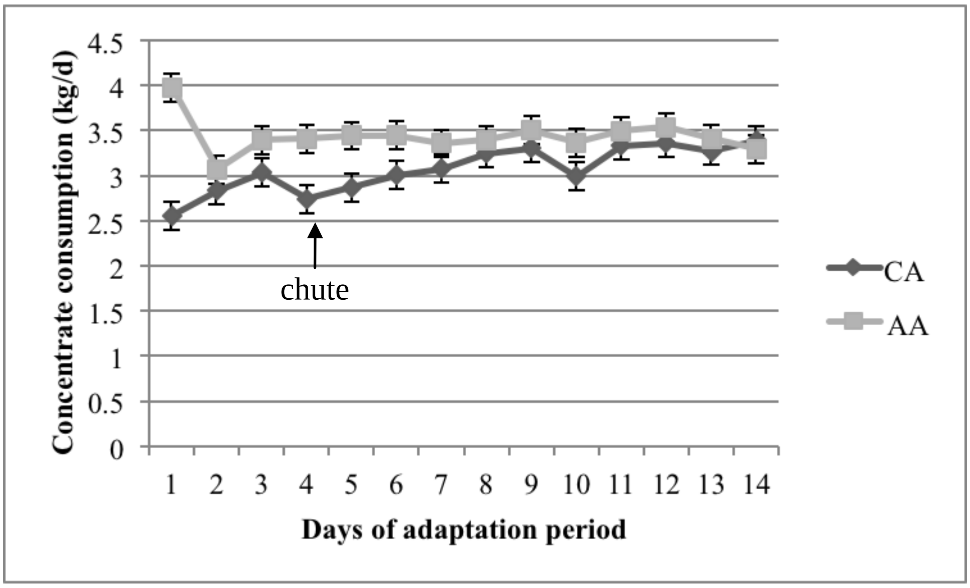
**Table 2.** Performance and concentrate consumption of Holstein bulls fed a high-concentrate diet with single-space feeder design for 42-d of study

| | Treatment[1] | | | *P*-value[2] | | |
|---|---|---|---|---|---|---|
| Item | CA | AA | SEM | T | D | T x D |
| Initial age, d | 101.9 | 102.2 | 2.72 | 0.77 | | |
| Initial BW, kg | 120.2 | 120.3 | 3.81 | 0.88 | | |
| Final BW, kg | 174.9[b] | 178.8[a] | 3.37 | 0.04 | | |
| CV BW within-pen, % | 12.2 | 12.6 | 1.14 | 0.72 | 0.50 | 0.22 |
| Concentrate DM consumption | | | | | | |
| Mean, kg/d | 3.6 | 3.7 | 0.06 | 0.34 | <0.01 | 0.01 |
| CV, % | 8.5 | 8.1 | 1.10 | 0.79 | 0.10 | 0.18 |
| Accumulative concentrate DM consumption after 42-d, kg | 143.2 | 146.4 | 1.78 | 0.21 | | |
| Straw DM consumption, kg/d | 0.40 | 0.41 | 0.03 | 0.69 | 0.49 | 1.00 |
| ADG, kg/d | 1.31 | 1.40 | 0.040 | 0.12 | <0.01 | 0.70 |
| CV of ADG within-pen, % | 38.2[a] | 32.2[b] | 2.14 | 0.05 | 0.85 | 0.57 |
| Gain to concentrate ratio, kg/kg | 0.37 | 0.38 | 0.011 | 0.46 | <0.01 | 0.12 |

[a-c]Means within a row with different superscripts are differ ($P < 0.05$).
[1]Treatments were different strategy of adaptation to a single space feeder design with lateral protections: conventional strategy (CA) and an alternative strategy (AA).
[2]Fixed effects were treatment (T), day (D), and interaction between treatment and day (T x D).

These results indicate, as expected, that the greatest impact of the adaptation strategy was the increase of concentrate intake for first week after arrival (short-term effect). The evolution of concentrate consumption day-to-day during the first 2 wk corroborates this difference in concentrate intake observed between treatments for first week of the adaptation period (Figure 2). A previous study (Verdú et al., 2015) also showed another effect due to the adaptation strategy on concentrate consumption during the adaptation period, which was the day-by-day pattern of intake variation. Whereas calves on the AA strategy maintained consumptions around 3.4 kg/d, animals on CA exhibited more variable intake between days, especially for the first week of adaptation period. The CV of daily concentrate consumption for first 2 wk of adaptation period was greater ($P < 0.01$) in calves on the CA strategy (11.3 ± 1.11%) in contrast to those on the AA (7.6 ± 1.11%; data not shown).

**Figure 2.** The concentrate consumption day-by-day for first 2 wk of adaptation period according to adaptation strategy applied. The arrow indicates the day when the chute was narrowed (CA) and placed (AA)




The narrowing of chute at d 4 interrupted the increasing trend of concentrate intake recorded by CA calves for first 3 d of adaptation period, which registered again less intakes as initially recorded (Figure 1). Consequently, calves under CA strategy needed one additional week to reach similar concentrate intakes than animals on AA. Thus, the chute management is particularly critical during the first week of adaptation to ensure expected concentrate consumptions.

To our knowledge, there are no studies contrasting adaptation strategies to a single-space concentrate feeder in cattle. However, many other strategies are available to foster intakes in calves after feedlot arrival (Loerch and Fluharty, 1999), because newly received calves have low feed intakes (Hutcheson and Cole, 1986) and that may compromise the growth rate. In addition, the feed intake data from the current study denote that the first week after fattening entrance was the most crucial time for adaptation to SF design. For all these reasons, this study suggests that the effects combination of adaptation arrangements (chute not placed and additional feeder) allowed reaching the initial purpose of adaptation strategy (to ease the feed access and encourage the concentrate consumption) during the first week. No studies related to chute management on feeder have been found, but data of the current study support that to ensure opened and free feed access for 4 d after arrival is necessary. Simultaneously, the synergistic effect of the additional feeder contributed also to achieve the initial objective of the study, being in agreement with González et al. (2008) who reported greater concentrate intakes increasing the number of feeding places (from 1 to 2) in pens with 8 calves.

Although no differences ($P$ = 0.12) in growth rate were observed according to adaptation strategy, the increased final BW recorded by AA group suggests a midterm effect of strategy of adaptation on animal growth. Also, as occurred with concentrate intake variability, the adaption strategy had an effect on growth pattern. Then, animals on CA tended ($P$ = 0.05) to show more growth variability (38.2 ± 2.14%) in contrast to AA animals (32.2 ± 2.14%) based on within-pen CV in ADG within-pen. In addition, individual ADG data were analyzed using initial BW quartiles to assess the effect of adaptation strategy on growth throughout the study (data not shown). As expected, the feeder adaptation strategy was effective in animals with lowest initial BW (BW < 110.5 kg) because calves on AA strategy tended ($P$ = 0.10) to have greater growth rates compared with CA at wk 3 and 4 (1.25 and 1.22 vs. 0.93 and 0.97 ± 0.120 kg/d, respectively). Perhaps, the arrangements of adaptation strategy facilitated the access to the feeder. Moreover, animals within the third quartile of initial BW (120.5 to 131 kg) reared with the AA strategy exhibited greater ($P$ < 0.05) ADG (1.48 ± 0.076 kg/d) than CA (1.36 ± 0.076 kg/d) throughout 6 wk of the study.

### *3.4. Animal Behavior*

***General Activities.*** During the 2.5-h observation time in the morning (from 0830 to 1100), the proportion of calves per pen standing (64.0 ± 0.87%), lying (36.0 ± 1.12%), eating straw (10.2 ± 0.40%), and ruminating (16.4 ± 0.74%) were not affected by strategy of adaptation to the SF design throughout the 6 wk of the study, including first week of the adaptation period (data not shown). However, during the first week of adaptation period, a greater ($P \leq 0.01$) percentage of animals per pen eating concentrate and drinking were recorded in AA strategy (8.9 ± 0.26% and 2.6 ± 0.13%) compared with CA strategy (6.2 ± 0.26% and 1.3 ± 0.13%) for first week of the study (adaptation period).

Obviously, AA strategy recorded more calves eating at first week of the study due to arrangements for the adaptation to the SF design (chute not placed and additional feeder). Also, this great proportion of animals eating concentrate was related with the increase of concentrate consumption. The reduced amount of concentrate supplied by additional feeder in the second week of the adaptation period could be the reason behind the lack of differences between treatments in the number of animals eating concentrate during this week. Thus, general activities from behavioral data indicate that the first week of the study is the most important and crucial time to adapt the animals to the feeder design. Also, these behavioral traits confirm that the adaptation arrangements accomplished their aim (to facilitate the feed access and encourage eating).

The great percentage of animals drinking in the AA strategy could be related to the greater concentrate intake recorded at first week compared with CA. It is known that the ingestion of concentrate and water are strongly correlated (Rodríguez-Prado et al., 2012). Other evidence with its arrangements achieved the objectives. Animals synchronize the feeding and drinking behaviors, altering the feed and water consumption (Nocek and Braund, 1985; González et al., 2009).

Unexpectedly, no differences in proportion of standing animals were observed between treatments, as this trait have been considered an evidence of adaptation problems (Verdú et al., 2015).

***Social behavior*****.** In the morning (from 0830 to 1100), no differences between treatments were found in behaviors related to nonagonistic interactions (23.2 ± 0.11 times/15 min of self-grooming, 3.4 ± 0.67 times/15 min of social, and 2.6 ± 0.42 times/15 min of oral; data not shown). Likewise, the agonistic interactions were not affected by strategy of adaptation (2.0 ± 0.27 times/15 min of fighting, 1.2 ± 0.25 times/15 min of butting, 0.2 ± 0.06 times/15 min of chasing, and 0.1 ± 0.03 times/15 min of chasing-up). However, calves under the AA strategy experienced a greater ($P < 0.01$) frequency of displacements (2.6 ± 0.31 times/15 min) compared with CA (1.3 ± 0.31 times/15 min) for first week of adaptation period. This great incidence of displacements was probably consequence of the absence of a chute for first 4 d, and the increased feeding concentrate places promoting the competition to feed access. For the rest of the study no displacements were observed. Lastly, no differences between treatments were observed in sexual behaviors (0.8 ± 0.26 times/15 min flehmen, 2.0 ± 0.49 times/15 min attempted mounts, and 0.6 ± 0.14 times/15 min completed mounts) over 6 wk of the study. Moreover, no stereotypies were observed throughout the experiment.

### *3.5. Eating Behavior*

Regarding the eating behavior at concentrate feeder, there was an interaction between adaptation strategy and filming day for occupancy time ($P$ < 0.01), number of bulls ($P$ < 0.01), number of visits ($P$ < 0.01), displacements ($P$ < 0.01), and waiting time to access the feeder ($P$ < 0.05) throughout the 2 wk of the adaptation period (Table 3). Contrarily, no differences ($P$ > 0.10) between strategies of adaptation were found in eating and drinking behaviors at straw feeder and drinker during this period. Besides, for the remaining 4 wk of the study (growing period), the adaptation strategy did not affect ($P$ > 0.10) eating pattern at concentrate feeder (6.4 ± 0.30 number of daily visits, 9.7 ± 0.74 min of meal duration, 649.9 ± 28.15 g of DM basis of meal size, 55.5 ± 3.57 min of total daily meal duration, 80.0 ± 9.83 g of DM basis/min of eating rate, 240.8 min of inter-meal duration, and 1,319.5 ± 7.61 min of total daily inter-meal duration). Then, no mid-term effect of adaptation strategy on eating behavior at the concentrate feeder was observed.

At d 1 and 5 of adaptation period, a greater ($P$ < 0.01) occupancy time of concentrate feeder was recorded in AA feeders (296.8 and 300.7 ± 10.26 min, respectively) than CA feeders (200.4 and 215.4 ± 10.26 min, respectively), as AA strategy had 2 available feeding places instead of 1 feeding space in CA strategy. Accordingly, González et al. (2008) reported similar results in calves, where the time devoted eating concentrate increased as number of feeding places per pen increased. Contrarily, at d 15 of the adaptation period, no differences ($P$ > 0.10) between treatments in time attending the feeder (203.4 ± 10.26 min) were observed, as both treatments had a single-space feeder. Thus, an additional feeding place without chute increases the time spent at the concentrate feeder by 37% (90 min) during the adaptation period (d 1 and 5). Moreover, the occupancy time rate for SF design registered in the current study (89 ± 1.0% of total time analyzed) was similar to obtained in a previous study (90.6 ± 1.0% of total time analyzed; Verdú et al., 2015), where the same SF design was used with similar experimental conditions in terms of number of calves per pen and initial BW.

However, when expressing the occupancy time of concentrate feeder per available feeding spaces, at d 1 and 5 of adaptation period (data not shown), the AA feeders had a lesser ($P$ < 0.01) occupancy time (147.8 and 149.7 ± 1.50 min, respectively) compared with CA feeders (200.9 and 215.9 ± 1.50 min, respectively). Unexpectedly, the occupancy time decreased around 30% (60 min) when the number of feeding places per pen increased by the provision of an additional feeder. Then, the occupancy time when it is expressed by feeding space decreased in AA strategy indicates that more competition around feeder may be happened, even though it took into account 2 available feeding spaces. This hypothesis is supported by the increased displacements at the concentrate feeder in AA treatment and by the fact that only a total of 60 min of occupancy time was recorded by additional feeder. Anyhow, surprisingly, this great level of competition at the concentrate feeder in the AA strategy could be considered a positive effect to encourage the feed consumption, such as it was corroborated by intake and growth results described previously. Moreover, an increase of feed consumption when the level of competition for feed increased has been also reported by others in dairy cows (Friend et al., 1977; Elizalde, 1993; Olofsson, 1999). Lastly, when only one feeding place was available after 2 wk of adaptation, the feeder occupancy time was the same between treatments (around 200 min), independently of previous adaptation strategy. From previous eating pattern data, an occupancy time around 80% of total daily time could be used as a reference in pens of 18 animals, with 120 kg BW, and for SF design.

On d 1 and 5 of adaptation period a greater number of animals was registered ($P$ < 0.01) at AA feeders (2.4 and 2.2 ± 0.36 animals, respectively) than CA feeders (1.3 and 1.1 ± 0.36 animals, respectively). In contrast, no differences ($P$ > 0.10) between treatments were observed in number of animals at the feeder (1.0 ± 0.36 animals) at d 15 of the adaptation period. This data indicate that calves show preference to occupy all of available feeding spaces at arrival, which is in agreement with results observed by Verdú et al. (unpublished data, Chapter IV). Thus, during growing phase, and especially for an adaptation period, a great ratio animal:feeder space seems an effective strategy to stimulate feed intake because of the eating behavior, as it has been reported by Gonyou (1999) in swine.

**Table 3.** Eating and drinking behaviors at concentrate and straw feeders, and at drinker registered by video recordings (0600 to 1000 h) on d 1, 5, and 15 of the study from calves were adapted to a concentrate single feeder design with lateral barriers at entrance to fattening farm

| | Treatment[1] | | | *P*-value[2] | | |
|---|---|---|---|---|---|---|
| Item | CA | AA | SEM[3] | T | D | T x D |
| Concentrate feeder | | | | | | |
| Occupancy time, min | 207.9 | 265.4 | 4.61 | <0.01 | <0.01 | <0.01 |
| Occupancy time rate[4], % | 88.7 | 70.1 | 1.05 | <0.01 | 0.01 | <0.01 |
| Number of bulls, n | 1.1 | 1.9 | 0.53 | <0.01 | <0.01 | <0.01 |
| Number of visits, n | 19.7 | 59.2 | 5.88 | <0.01 | <0.01 | <0.01 |
| Displacements, n/h | 4.2 | 11.4 | 1.61 | <0.01 | <0.01 | <0.01 |
| Waiting time to access, min | 60.1 | 51.1 | 5.76 | 0.29 | <0.01 | 0.02 |
| Waiting time rate[5], % | 25.2 | 21.3 | 0.23 | 0.15 | <0.01 | <0.01 |
| Straw feeder | | | | | | |
| Occupancy time, min | 132.2 | 130.0 | 12.35 | 0.87 | <0.01 | 0.33 |
| Occupancy time rate[4], % | 56.2 | 55.4 | 0.40 | 0.82 | <0.01 | 0.32 |
| Number of bulls, n | 2.1 | 1.9 | 0.11 | 0.21 | 0.02 | 0.76 |
| Number of visits, n | 49.2 | 53.7 | 14.77 | 0.32 | <0.01 | 0.48 |
| Displacements, n/h | 1.3 | 2.4 | 0.60 | 0.36 | <0.01 | 0.79 |
| Drinker | | | | | | |
| Occupancy time, min | 57.1 | 54.9 | 3.50 | 0.66 | 0.22 | 0.46 |
| Occupancy time rate[4], % | 24.3 | 23.4 | 0.16 | 0.59 | 0.11 | 0.41 |
| Number of bulls, n | 1.0 | 1.0 | 0.01 | 0.82 | 0.01 | 0.15 |
| Number of visits, n | 23.6 | 23.4 | 1.13 | 0.91 | 0.02 | 0.30 |
| Displacements, n/h | 2.2 | 2.1 | 0.11 | 0.49 | 0.44 | 0.41 |
| Waiting time to access, min | 0.9 | 1.2 | 0.09 | 0.39 | 0.11 | 0.63 |
| Waiting time rate[5], % | 0.4 | 0.5 | 0.04 | 0.51 | 0.20 | 0.78 |

[1]Treatments were different strategy of adaptation to a single space feeder design with lateral protections: conventional strategy (CA) and an alternative strategy (AA).
[2]Fixed effects were treatment (T), day (D), and interaction between treatment and day (T x D).
[3]Occupancy and waiting time rates were analyzed as the root transformation and are presented non-transformed data.
[4]Percentage of occupancy time from total 4-h time of video recording analyzed.
[5]Percentage of waiting time from total occupancy time recorded at feeders or drinker.

Although both treatments registered ($P < 0.01$) a reduction in number of visits at the feeder at the beginning (from d 1 to 5), this decline varied depending on adaptation strategy. Whereas on d 1 and 5, the number of visits was greater ($P < 0.01$) for AA strategy (114.7 and 53.1 ± 7.28 visits, respectively) than CA strategy (39.7 and 9.5 ± 7.28 visits, respectively), at the end of adaptation period (d 15) no differences were observed between treatments (9.9 ± 7.28 visits). Then, the great frequency of feeder visits exhibited in AA strategy indicates that their arrangements promoted an increased activity around the feeder. Therefore, an additional feeding space stimulates the feeder visits and feed intake by social facilitation (Curtis and Houpt, 1983), and facilitating the adaptation to SF design. Also, this increase in the number of visits has been associated with a high level of competition in two studies (Elizalde, 1993; Olofsson, 1999). Obviously, in both strategies, the number of visits decreased ($P$ < 0.01) the day after chute was narrowed or placed, for CA and AA, respectively.

At d 5 of adaptation period, CA strategy recorded greater ($P$ < 0.05) waiting time to access the concentrate feeder than AA strategy (89.3 and 61.4 ± 9.03 min, respectively). However, no differences ($P$ > 0.10) between treatments were observed at d 1 and 15 (30.4 and 61.1 ± 9.03 min, respectively). At d 5, the AA strategy reduced to 30% the waiting time compared with CA strategy. However, in both treatments, the waiting time increased ($P$ < 0.01) from d 1 to 5 (55% for CA and 65% for AA) when chute was ready, showing the effectiveness of lateral protections from SF to force animals accessing one by one and eating individually. Also, the CA strategy was able to reduce ($P$ < 0.01) the waiting time from d 5 to 15 in contrast to AA strategy, indicating a better ability to adapt to SF design because of calves were more familiarized.

As observed in social behavioral data, at d 1 of adaptation period, AA feeders registered a greater ($P$ < 0.01) frequency of displacements at concentrate feeder than CA feeders (28.3 and 11.5 ± 2.49 displacements/h, respectively). No differences between treatments were found in the number of displacements at d 5 and 15 (3.5 and 0.0 ± 2.49 displacements/h, respectively). Arrangements from AA strategy contributed to increase the number of displacements recorded at the feeder, as a main drawback associated to facilitate the feed access and stimulate the intake. These results are similar to those found by González et al. (2008), which observed an increase of the number of displacements when increasing the number of feeding spaces from 1 to 2. In addition, the reduction of displacements, in both treatments, was drastically ($P$ < 0.01) from d 1 to 5 of adaptation period, in the moment that chute was narrowed (CA) or placed (AA). Then, these data confirm the effectiveness of lateral protections of the chute to avoid the displacements around the feeder.

The straw feeder eating and drinking behavioral data were not affected by strategy of adaptation to concentrate feeder design over the adaptation period of the study (Table 3). The straw feeder results are in disagreement with those reported by Verdú et al. (unpublished data, Chapter IV) and González et al (2008), which observed an increase of time spent eating straw when the feeding space:animal ratio decreased. Moreover, a great occupancy time of the drinker was observed by Verdú et al. (unpublished data, Chapter IV) in SF design at first 2 wk of the study; also, González et al. (2008) found the greatest frequency of displacements at the drinker when increasing the feeder places from 1 to 2.

In summary, the AA strategy had a positive effect on concentrate intake for first week after arrival (short-term effect), and on BW after 6 wk (mid-term effect). Moreover, AA resulted in a greater attendance (reducing the waiting time to access the feeder) and more competition (increasing the frequency of displacements) at the concentrate feeder during the first week of adaptation. In conclusion, the adaptation strategy (chute not placed and additional feeder provided) proposed herein eased access to feed and encouraged concentrate consumption during the first week of adaptation after arrival, improving concentrate intake and growth (mid-term). Lastly, the main effects of adaptation strategy on animal and eating behavior were registered during first week of adaptation period.

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# CHAPTER VI

## Effect of physical form of concentrate on performance, eating pattern, and feed preference in Holstein bulls fed a finishing high-concentrate diet

*This chapter has been submitted for publication in Journal Animal Science*

## ABSTRACT

Two studies were conducted to evaluate the effects of physical form of concentrate on performance, eating pattern, and feed preference in Holstein bulls fed a finishing high-concentrate diet. Also, the evolution of physical pellet quality from the pellet mill to the feeder was analyzed. In Study 1, 112 Holstein bulls (272 ± 4.4 kg of BW and 216 ± 1.0 d of age) were randomly distributed in 6 pens equipped with a computerized concentrate single-space feeder with lateral protections, a separated straw feeder, and a water bowl. Pens were assigned to either a feed in pellet (PE) or in crumble (CR) form, the latter simulated a poor pellet quality. The study followed a replicated Latin square design with 28-d periods. All animals received concentrate and straw *ad libitum*. Daily concentrate consumption and eating pattern, weekly straw consumption, and twice-weekly concentrate wastage were recorded for the last 14 d of each period. Animals were weighed fortnightly. For each concentrate manufacture, durability, hardness, density, and particle size distribution were determined at the pellet mill, silo, feeder, and spillage collectors. In Study 2, 6 Holstein bulls (404 ± 14.1 kg of BW and 254 ± 3.6 d of age) were enrolled to assess dietary preference of the 2 concentrate presentations (PE or CR). The study consisted in a 7-d adaptation period and a 6-d free-choice period during which PE and CR were offered simultaneously. In Study 1, bulls fed PE had greater ($P < 0.01$) concentrate consumptions, lesser ($P < 0.01$) wastage, and tended ($P = 0.08$) to exhibit greater ADG than CR bulls; however, these results did not affect feed efficiency. Bulls receiving CR spent more time at the feeder ($P < 0.01$) than bulls fed PE. In Study 2, animals preferred PE over CR. Lastly, as expected, pellet quality was not a stable parameter and it progressively deteriorated ($P < 0.01$) from the pellet mill to the feeder. The present study supports the hypothesis that pellet quality is important to reduce feed wastage, and, also, it affects eating pattern, reducing the time spent at the feeder, and increases the concentrate intake. Finally, animals prefer a good pellet quality.

**Key words:** beef, eating behavior, feed preference, performance, physical form of concentrate

## 1. INTRODUCTION

A pelleted concentrate is the most common feed presentation (Acedo-Rico, 2001) in Mediterranean beef feeding systems, representing an estimated extra cost in feed manufacturing of 1 €/t compared with mash presentation (Capdevila, 1993). Extensive research, mostly in non-ruminant animals, has demonstrated that a good pellet quality improves intake, performance and feed efficiency compared with concentrate presentations with poor quality such as reground pellets, or pellets with a high percentage of fines (Jensen and Becker, 1965; Trevis, 1979; Kertz et al., 1981; Jones, 1985; Zatari et al., 1990; Stark et al., 1994). The impaired performance when feeding poor quality pellets may be attributed to an increase in feed wastage and fines content (Behnke, 1994). The physical quality of pellets is defined by durability and hardness to withstand the rigor of transportation and handling (Thomas and van der Poel, 1996; Boac et al., 2008). The potential economic benefit of improving pellet quality on performance and profitability in beef cattle is unknown. The hypothesis of the present study was that the impoverishment of pellet quality by regrinding pellets could negatively affect: 1) intake, performance and feed efficiency due to an increase of fines content at the feeder, and consequently feed wastage would increase; 2) eating pattern, showing an increase of concentrate eating time that not necessary would be translated in an increase of intake; and, 3) the particle size distribution at the feeder because bulls would prefer intact pellets over reground pellets. Thus, the objectives of the current study were: 1) to evaluate the effect of pellet quality on performance and eating pattern (Study 1); 2) to assess the evolution of pellet quality from the pellet mill to the feeder (Study 1); 3) to determine the feed preference for two different physical forms of concentrate (Study 2) in Holstein bulls fed a high-concentrate diet.

## 2. MATERIALS AND METHODS

The study was conducted according to the principles and specific guidelines of the IRTA Animal Care Committee.

## 2.1. Study 1

### *2.1.1. Animals, Experimental Design, and Diets (Study 1)*

A total of 112 Holstein bulls (272 ± 4.4 kg of BW and 216 ± 1.0 d of age) were reared under commercial conditions until they were sent to the slaughterhouse (436 ± 4.8 kg of BW and 328 ± 1.0 d of age). Animals were randomly allocated in one of 6 pens equipped with a computerized concentrate single-space feeder (0.50 m long x 0.26 m wide x 0.15 m depth), with lateral protections (1.40 m long x 0.80 m high) forming a chute. Pens also had a separated straw feeder (3.00 m long x 1.12 m wide x 0.65 m depth; 7 feeding spaces), and a water bowl. Furthermore, covered pens (12 m long x 6 m wide) were deep-bedded with straw.

The study was designed as a replicated Latin square involving 2 treatments and 3 replications. Each square had 2 pens and 2 periods, and each experimental period consisted of 28 d (14 d for dietary adaptation and 14 d for measurements and data collection). Pen was the experimental unit. Treatments were: 1) pellet form (**PE**), and 2) crumble form (**CR**), the latter was obtained regrinding pellets to worsen pellet quality. The CR treatment was chosen to simulate bad pellet quality. The pellet quality could be modified by using different ingredients (Thomas et al., 1998) or pelleting conditions (Thomas et al., 1997); however, these two methods affect the starch availability in the rumen, and pellet quality could be confounded by rumen starch availability. Crumbling (grinding) could also increase the surface area for microbial attack and thereby increase rumen nutrient digestion. Therefore, CR was chosen because it allows altering pellet quality without modifying ingredients and pelleting conditions, and it was the method that better simulated a continuous and stable pellet quality improvement. The ingredient and nutrient composition, following the NRC (2001) recommendations, was the same for both treatments: 25.4 % cracked corn, 25 % barley, 14 % wheat, 12.8 % wheat middlings, 10 % corn gluten feed, 7 % soybean meal 47 % CP, 2.7 % palm oil, 1.8 % calcium carbonate, 0.5 % sodium bicarbonate, 0.3 % vitamin/mineral premix, 0.2 % urea, 0.2 % white salt, 0.1 % manganese oxide; 88.6 % DM, 82.7 % OM, 5.9 % ash, 15.5 % CP, 18.2 % NDF, 6.2 % ADF, 5.6 % ether extract, 54.8 % NFC, 3.3 Mcal of ME/kg; DM basis. The dietary ingredients were ground through a roller mill with screen openings of 2.75 mm. The mixed mash was steam-conditioned at 80ºC with a 0.5 min retention time, and then pelleted. The pellet mill was equipped with a die ring (3.5 mm diameter holes and 70 mm thickness). The corresponding pellet exit temperatures, after pelleting, ranged ± 10ºC in relation to conditioning temperature. The pellet die knife was set at 10 mm from the die face. The pellets were pneumatically transferred to a cyclone cooler with a retention time of 20 min. The CR concentrate was obtained grinding cooled pellets with a roller mill using a 3.0 mm sieve, and crushing them to a consistency coarser than a mash obtaining a product with a more variable granulometry than pellets. Diets were manufactured from a 9,000 kg master-batch, of which 4,500 kg were in pellet form, and the other 4,500 kg in crumble form. Each treatment concentrate was transported to the farm with the same truck, and stored into two different silos under the same conditions. During the study, 11 batches were manufactured. Animals had also *ad libitum* access to wheat straw (3.5% CP, 1.6% ether extract, 70.9% FND, and 6.1% ash; DM basis), and fresh water.

***2.1.2. Computerized Concentrate Feeder***

Animals received *ad libitum* concentrate via a computerized feeder (Voltec®, Lleida, Spain). The feeder consisted of a single-space trough with lateral barriers forming a chute (Verdú et al., 2015). The chute provided protection when an animal accessed the feeder to eat, and prevented interferences from other close animals from the sides, as the antenna detected transponders whenever animals were within 50 cm of feeder. Each feeder was equipped with an antenna (Azasa-Allflex, Madrid, Spain), that emitted a 130-kHz electromagnetic field to detect each animal visit via passive transponder (half-duplex), which was encased in plastic ear tags (Azasa-Allflex, Madrid, Spain) and placed on the left ear of each bull. In addition, the feeder was suspended on 4 load cells (Utilcell, Barcelona, Spain), which constituted a scale. This scale was programmed to transmit the feed weight, at 1-min intervals or when a weight change was detected, to a PLC (Allen-Bradley model 1769-L35E; Rockwell Automation, Milwaukee, USA, Programmable Logic Controller), and, lastly, displayed on a personal computer. The scales were calibrated weekly. At each animal visit at the feeder the bull was identified, and the computer recorded the initial and final feed weight, with its corresponding initial and final time. The antenna logged the presence of each transponder every 5-s for as long as the transponders were within the read panel range as an animal visit; when another transponder was detected or the antenna did not log any transponder for 60-s a new visit was created. Before the study started, the computerized concentrate feeder was validated using data from the 6 feeders. The validation was conducted in random different days during a period of 4 m; each day was performed by one of 2 observers, who observed 2 feeders simultaneously for 60 min. A digital timer synchronized with the time of computer and reader scale panel of feed weight were used. A total of 510 events or visits were registered. The validation method consisted in recording visually for each visit the animal number identification, the initial time and feed weight when animal acceded to the feeder, and the final time and feed weight when animal leaved the feeder. After, from two sources of data collection (software and observations), the meal size and meal duration was calculated as parameters to validate the accuracy of system (Devant et al., 2012). A great ($P < 0.01$) coefficient of determination for meal size ($r^2 = 0.97$) and meal duration ($r^2 = 0.98$) were obtained. Furthermore, the sensitivity (99.5%) and the specificity (99.9%) were calculated (Bach et al., 2004) obtaining greater values than others reported by DeVries et al. (2003). In conclusion, the high values for sensitivity, specificity and predictability indicated that the described concentrate computerized feeder was an adequate system to monitor individual eating behavior in beef animals (the number of visits per animal, the length of each visit, the amount of concentrate consumed per visit and animal, and the total daily eating time and concentrate consumption per animal).

The feeding system ensured continuously feed availability as described in Verdú et al. (2015). The feeders were cleaned at the end of each 28-d experimental period to remove fines avoiding the carryover effect, and the adaptation phase was used as washout period.

#### *2.1.3. Feed Consumption and Performance*

The computerized feeder recorded the daily concentrate consumption for each animal within each pen. The amount of straw offered to each pen was recorded weekly; however, the straw intake was an estimation of total amount of straw consumed because straw was also used for bedding. Animals were weighed every 14 d throughout the study. The amount of concentrate spillage from each pen was recorded fortnightly to estimate the waste associated with eating activity. The concentrate wastage was collected by a groove (0.020 m long x 0.26 m wide) at the lip of feeder (0.045 m long x 0.26 m wide) and a spillage basket (0.10 m long x 0.45 m wide x 0.20 m depth) in front of the feeder (Figure 1). The waste from the feeder fell through the groove into the old concrete feeder (0.75 m long x 1.64 m wide x 0.55 m depth) above which the computerized feeder was suspended, and the spillage near the feeder lip was collected by a spillage basket (Figure 2).

**Figure 1.** Schematic representation of a top view of the wastage collection system added to single concentrate feeder

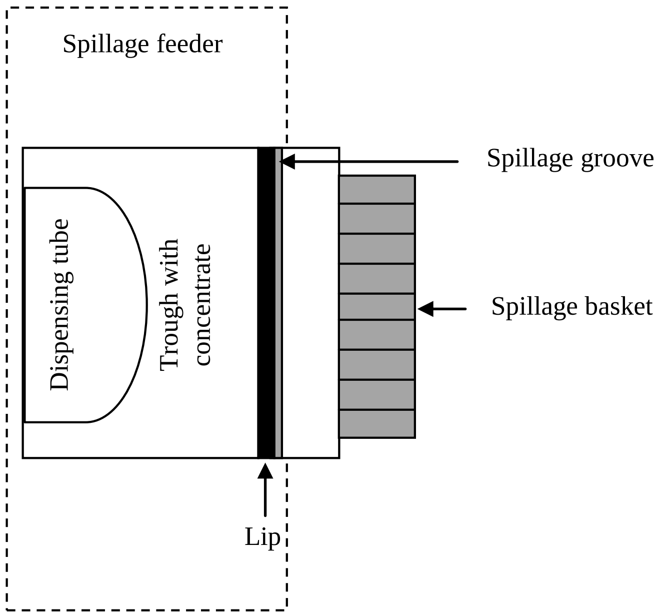
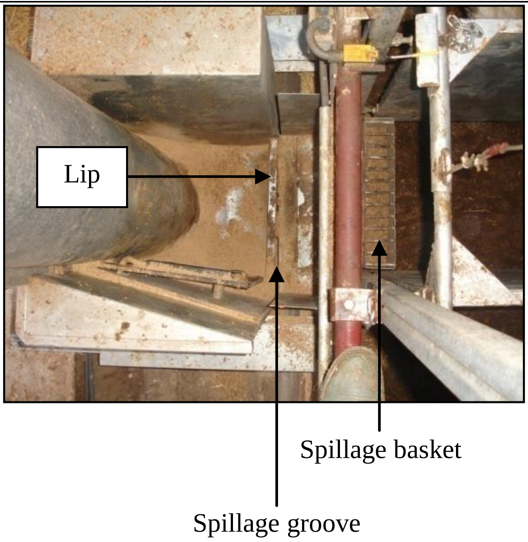


**Figure 2.** Old concrete feeder used to collect concentrate wastage (front view), above which was suspended the computerized feeder, and in front of the feeder was the spillage basket (top view). Figure 4.a. Front view. Figure 4.b. Top view

a)


b)




### *2.1.4. Pellet Quality Measurements*

During experimental period, one 500 g sample was collected after each concentrate manufacture to analyze physical quality of the pellet at four different points: pellet mill, silo, feeder, and spillage collectors. These data were used to assess feed physical characteristics by different analyses to determine the durability, hardness, density, percentage of fines, and nutritional composition (DM, ash, CP, NDF, and ether extract). Granulometry for each treatment was determined from silo samples of each manufacture using a wide rank of particle fractions (< 1, 1-2, 2-2.5, 2.5-3, 3-4, 4-5, > 5 mm). Granulometry was assessed as the weight of the different fractions and expressed as a percentage of total sample weight [(g of fraction/g of total sample) x 100].

A modified method based on ASAE Standard S319.3 (ASAE Standards, 2003b) was conducted to determine the fines content in a feed sample. The percentage of fines was analyzed using a sieve with 2.5 mm pore sizes. A total of 300 g of concentrate were placed on a 2.5 mm sieve and shook for 30 s. The reference acceptable value of fines at the silo was below 10% of particles < 2.5 mm. Moreover, concentrate samples from each feeder and pellet mill were collected during the experimental period to analyze chemical composition of each separated fraction (> 2.5 and < 2.5 mm) to assess whether the presence of fines at the feeder could alter the nutritional composition of concentrate.

Pellet and crumble feed durability (%) was evaluated using a durability method modified by the feed manufacturer (Corporació Alimentària Guissona S.A., CAG, Guissona) following the procedure described by Pfost (1963). A concentrate sample was screened through a 2.5 mm sieve for 30 s to obtain 150 g of sieved feed sample, which was then placed into a tumbling rotating device for 5 min at 50 rpm. The sample was then removed and the fines screened through a 2.5 mm sieve, and the percentage of durability expressed as the ratio of the weight after tumbling over the weight before tumbling, multiplied by 100. The manufacturer stablished that the standard of quality for beef concentrate at the pellet mill should be above 97.5 %.

The pellet hardness (kg) was determined using a Kahl device following the method described by Thomas and van der Poel (1996), which measures the compression force required to fragment a pellet into smaller particles and fines. To determine pellet hardness, the uniform feed pellets were chosen, prior the hardness analysis, by measuring the same length and diameter with visual inspection. Since, whereas larger pellets need more force to break them compared with smaller pellets (Obaldo, 2001); contrary, pellets with small diameters are more susceptible to breakage than those with larger diameters (Thomas and van der Poel, 1996). Hardness was expressed as an average of 10 measurements. The hardness of the crumble concentrate could not be analyzed.

Density ($kg/m^3$) of the concentrates was estimated by weighing the feed necessary to fill a test tube of 100 $cm^3$ striking off level with the top surface, a modified method suggested by ASAE Standard S269.4 (ASAE Standards, 2003a).

### *2.1.5. Chemical Analyses*

From one random manufacture, concentrate samples for each feeder were analyzed for humidity, CP, ether extract, ash, and NDF by near infrared reflectance (NIR) analysis (FOSS 5000; NIR Systems, Hilleroed, Denmark). The NIR was calibrated against standard reference for each nutrient base on equations according to type of concentrate: humidity (n

= 946 samples; $r^2$ = 0.97), CP (n = 626 samples; $r^2$ = 0.91), ether extract (n = 652 samples; $r^2$ = 0.95), ash (n = 1,406 samples; $r^2$ = 0.87), and NDF (n = 202 samples; $r^2$ = 0.80). The DM was calculated as 100 – humidity. An estimate of NFC content of concentrate samples was obtained as 100 – (CP + ash + NDF + ether extract).

### *2.1.6. Calculations and Statistical Analyses*

The pen was considered the experimental unit for all statistical analysis with animals considered sampling units.

All individual animal data of daily concentrate consumption, eating behavior, and performance were averaged by experimental period (last 14 d of each 28-d period). Gain to concentrate ratio (concentrate efficiency) after 14 d was estimated dividing the BW increase by the accumulative concentrate consumption of this 14-d period.

To estimate eating pattern, meal criteria for each animal and period were calculated. The meal criterion (maximum amount of time between visits at the feeder to consider a visit as a part of the same meal) was calculated using a model composed of 2 or 3 normal distributions resulting from the natural logarithm of time (in seconds) between feeder visits as described by Bach et al. (2006). Then, visits at the computerized feeders were separated into meals, and meal frequency, meal duration and size, and inter-meal duration were calculated.

Consumption, performance, and eating behavior were analyzed using a mixed-effects model (Version 9.2, SAS Inst., Inc., Cary, NC) with treatment, square, period nested with square, and pen nested within square as fixed effects, and animal nested within square as random effect. The model contained initial BW of each experimental period as a covariate. Straw consumption was analyzed using the previous model without animal nested within square. Differences between treatments were compared using the PDIFF option in the LSMEANS statement.

Pellet quality data from feeder and spillage collectors were averaged by treatment for each manufacture batch. Granulometry data from each manufacture were averaged by treatment according to different particle size distribution (< 1, 1-2, 2-2.5, 2.5-3, 3-4, 4-5, >

5 mm), and analyzed using a mixed-effects model (Version 9.2, SAS Inst., Inc., Cary, NC) including treatment as a fixed effect, and batch of manufacture as a random effect. Pellet quality data were analyzed using mixed-effects ANOVA with repeated measures (Version 9.2, SAS Inst., Inc., Cary, NC) with treatment, sampling place, and their interaction, as fixed effects, and batch of manufacture as random effect. Sampling place was considered a repeated factor, and batch of manufacture was subjected to 3 variance-covariance structures: compound symmetry, autoregressive order one, and unstructured. The covariance structure that yielded the smallest Schwarz's Bayesian information criterion was considered the most desirable analysis.

Concentrate efficiency data were transformed into arcsine plus 1 to achieve a normal distribution. The means presented in the tables and figures correspond to non-transformed data, and, SEM and *P*-values correspond to the ANOVA analyses of the transformed data. Differences were declared significant at $P < 0.05$, and trends were discussed at $0.05 \leq P \leq 0.10$ for all models.

Regarding chemical analyses, each nutrient was multiplied by the percentage of each particle size fraction (> 2.5 and < 2.5 mm) to obtain the final nutrient composition corrected by particle size distribution. A descriptive statistic (mean and SEM) of nutrient composition was conducted by treatment to analyze the evolution of nutrient content from the formula (theoretical values) to the feeder (true values). Data for each treatment were analyzed using the SAS PROC MEANS (Version 9.2, SAS Inst., Inc., Cary, NC).

## 2.2. Study 2

### *2.2.1. Animals, Housing, and Feeding*

A dietary preference test was designed to assess animal preferences for two different physical forms of concentrate (PE vs. CR) offered simultaneously and continuously for 6 d. The two concentrates tested were the same as the ones described in Study 1. Concentrate selection (preference) was based on physical form of concentrate, and was evaluate by voluntary consumption of concentrate during two-way choice period of 6 d.

Six Holstein bulls (404 ± 14.1 kg of BW and 254 ± 3.6 d of age) participated in this trial. Bulls were managed under the guidelines and approval of the Animal Care Committee of Institute for Research and Technology in Agrifood (IRTA, Barcelona, Spain). The experiment was conducted at the experimental farm from Corporació Alimentària Guissona, SA (CAG, Guissona, Spain) for 2 wk.

Previous to the preference study, all animals were reared under the same conditions. Bulls were housed individually in a slat-surface adjacent pens (4.7 x 2.8 m; long x wide) within the same indoor barn. Each pen was equipped with 2 buckets for concentrate (42 L capacity) and one trough for the straw (2.4 m long x 0.7 m wide x 0.4 m depth), in front of the pen, and a water bowl drinker behind the pen. All bulls received concentrate and wheat straw *ad libitum*, and had free access to fresh water.

### *2.2.2. Experimental Design, Treatments, and Feeding*

A preliminary adaptation period (7 d) was conducted during which only crumbles were offered in order to adapt animals using one bucket where crumble concentrate was available. The aim of this adaptation period was to free of bias in preference related to previous feeding (PE form), which might cause bulls to make certain selections. The preference test had an experimental free-choice period of 6 d during which two different presentations of concentrate (**PE** vs. **CR**) were offered simultaneously to animals in 2 separate buckets. Concentrates were offered every morning (1000 h) ensuring daily feed *ad libitum*. To minimize possible interferences on intake or eating behavior due to potential presence of fines in the bucket, fresh concentrate was offered on daily basis. Every morning, daily concentrates offers and refusals were weighed. To ensure *ad libitum* concentrate intake, the daily concentrate offer was increased by a 25 % of previous day consumption. The location of the test feeds (right or left) was reversed across all calves as a precaution to minimize any effects of side preference. Also, straw feeders were checked daily and provided with sufficient amounts of straw to ensure *ad libitum* consumption. Straw refusals were weighed weekly to calculate straw consumption per week. In addition, animals were weighed at the beginning (d 1) and at the end (d 14) of the study.

#### *2.2.3. Calculations and Statistical Analyses*

The amount of each physical form of concentrate consumed (PE or CR) was expressed as the percentage of total daily concentrate consumption (PE plus CR) for each animal using an average of the last 6 d of the study.

## 3. RESULTS

### 3.1. Study 1

#### *3.1.1. Animal Health*

Five animals were removed from the study during the first experimental period due to different health problems: 3 bulls from PE (2 due to chronic lameness, and 1 for weight loss) and 2 bulls from CR because of chronic pneumonia. No differences between treatments were found in health status.

#### *3.1.2. Physical Pellet Quality Measures*

Particle size distribution, except for 3-4 mm fraction, was affected ($P$ < 0.01) by physical form of concentrate (Figure 3). There was an interaction ($P$ < 0.05) between treatment and sampling place in the durability of the concentrate (Figure 4). The durability of PE (96.7 ± 1.00%) was greater than CR (87.1 ± 1.00%) in all sampling places. Whereas durability of PE did not change throughout different sampling places (97.2 ± 1.00%) except for spillage collectors (95.2 ± 1.00%), durability of CR evolved differently depending on sampling place. Herein, the durability of CR increased from pellet mill (86.1 ± 1.00%) to silo (90.8 ± 1.00%), conversely, from silo to feeder (87.2 ± 1.00%) and feeder to spillage collectors decreased (84.0 ± 1.00%). Hardness of PE was affected by sampling place ($P$ < 0.01). Whereas the hardness at pellet mill and silo was similar (8.9 ± 0.46 kg), in feeder and spillage collectors hardness was reduced (6.9 ± 0.46 kg; data not shown). Percentage of fines was affected by feed physical form ($P$ < 0.01) and sampling place ($P$ < 0.01). As expected, the percentage of fines was lesser in PE (5.7 ± 1.54%) than in CR (44.0 ± 1.54%). Moreover, the sampling place where more percentage of fines were registered was the feeder (33.6 ± 1.96%) in contrast to other sampling places (21.9 ± 1.96%), independently of physical form of concentrate (data not shown). The concentrate presentation form and sampling place had an effect (*P* < 0.01) on density. The density of PE (620.1 ± 4.04 kg/m$^3$) was greater compared with CR (561.2 ± 4.04 kg/m$^3$). In addition, the density (623.9 ± 4.97 kg/m$^3$) at the silo was greater than those recorded at pellet mill or feeder (597.8± 4.97 kg/m$^3$), and spillage collectors (543.1 ± 4.97 kg/m$^3$; data not shown).

**Figure 3.** Particle size distribution of pelleted (PE) or crumble (CR) concentrates from 11 batches throughout 100 d of study

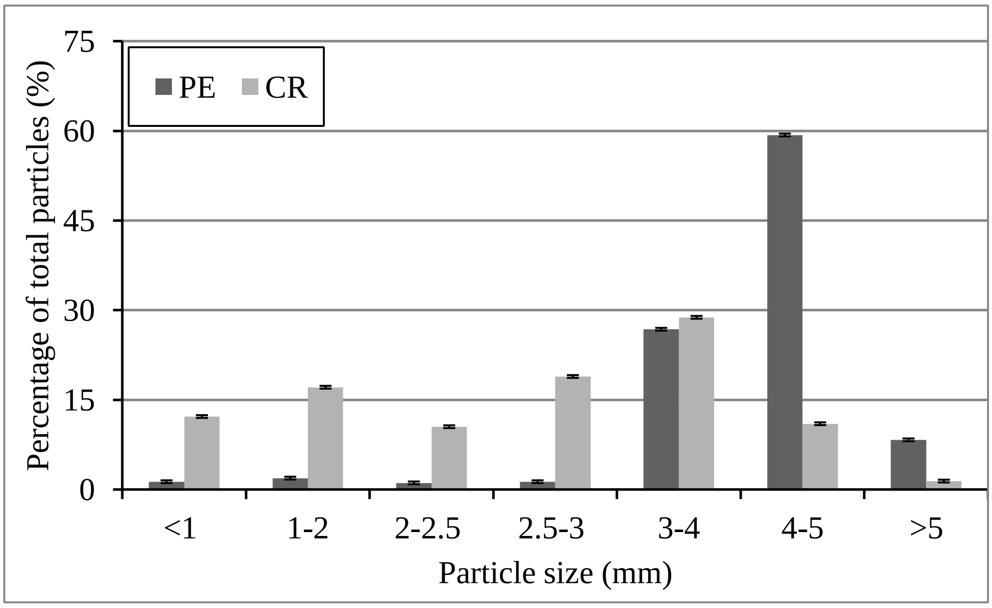
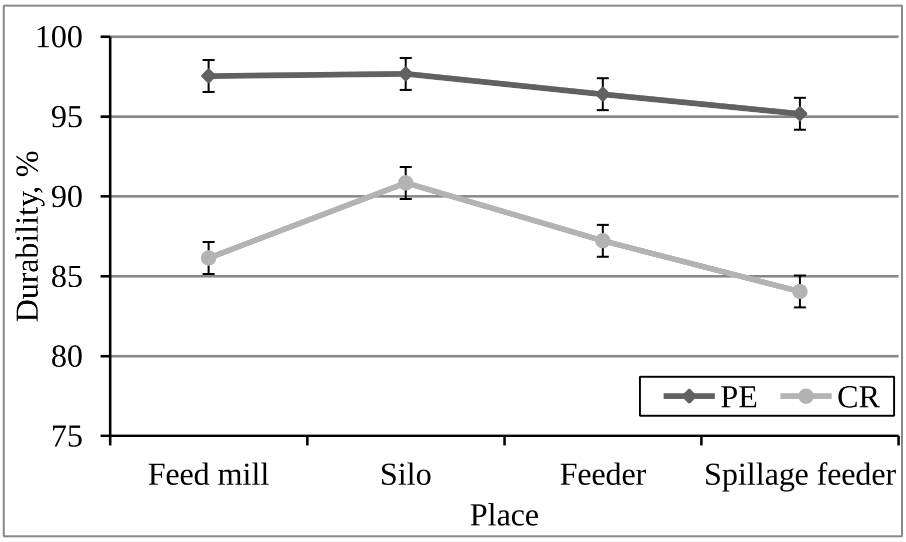


**Figure 4.** The evolution of durability from feed mill to spillage collector of each physical form of concentrate from 11 batches manufactured throughout 100 d of study




### *3.1.3. Nutritional Analyses*

Data corresponding to nutritional composition for each concentrate presentation (PE and CR) recorded at the feeder are presented in Table 1. Values of nutritional composition were within the expected values of diet formula, with the exception of DM content.

**Table 1.** Nutrient content for each concentrate presentation (PE and CR) from the formula to the feeder corrected by particle size distribution (DM basis)

| | Formula | Feeder Treatment[1] | |
|---|---|---|---|
| Item | | PE | CR |
| DM, % | 88.6 | 83.2 | 85.5 |
| CP, % | 15.5 | 15.4 | 15.7 |
| Ether extract, % | 5.6 | 5.5 | 5.1 |
| Ash, % | 5.9 | 5.2 | 5.9 |
| NDF, % | 18.2 | 16.7 | 18.1 |
| NFC[2], % | 54.8 | 54.9 | 55.1 |

[1]Treatments were different physical form of concentrate: pellet (PE), and crumble (CR).
[2]NFC = nonfiber carbohydrates calculated as 100 – (CP + ash + NDF + ether extract).

### *3.1.4. Feed Consumption and Performance*

The physical form of the concentrate affected (*P* < 0.01) the mean and CV of daily concentrate consumption, weekly concentrate wastage, and both accumulative concentrate consumption and wastage (Table 2). Animals fed PE exhibited a greater (*P* < 0.01) mean daily concentrate consumption and a lesser (*P* < 0.01) day-to-day CV of concentrate consumption compared with animals fed CR. Consequently, the accumulative concentrate consumption per animal for 14-d was greater (*P* < 0.01) for PE than CR. The amount of concentrate waste recorded in CR doubled that in PE. Consequently, the accumulative concentrate spillage for 14-d was greater (*P* < 0.01) for CR than PE. In addition, ADG recorded in PE tended (*P* = 0.08) to be greater than in CR. However, the straw consumption and gain to concentrate ratio were not affected by concentrate physical form. Lastly, no differences between treatments were found when concentrate consumption was corrected by concentrate wastage (6.9 and 6.8 ± 0.09 kg of DM/d for PE and CR) in contrast to intake data without considering wastage (7.3 and 7.2 ± 0.09 kg of DM/d for PE and CR; data not shown).

### *3.1.5. Eating Behavior*

Physical form of concentrate affected (*P* < 0.01) all measured parameters related with eating pattern: meal size, meal duration, number of daily visits or meals, total daily meal duration, inter-meal duration, and eating rate (Table 3). Bulls fed PE registered a lesser (*P* < 0.01) meal size, meal duration, and a greater (*P* < 0.01) meal frequency compared with animals fed CR. Also, animals on PE exhibited lesser (*P* < 0.01) total daily eating time and inter-meal duration than CR bulls. Then, animals fed PE showed a greater (*P* < 0.01) eating rate than those fed CR. In addition, PE bulls had a lesser (*P* < 0.01) CV of meal size, number of daily meals, and inter-meal duration than CR bulls.

**Table 2**. Effect of physical form of concentrate on concentrate consumption and performance in Holstein bulls fed a high-concentrate finishing diet (100 d)

| | Treatment[1] | | | P-value[2] |
|---|---|---|---|---|
| Item | PE | CR | SEM[3] | T |
| ADG, kg/d | 1.51 | 1.44 | 0.032 | 0.08 |
| BW increment after 14-d, kg | 20.0 | 19.0 | 0.42 | 0.08 |
| Straw DM consumption, kg/d | 0.9 | 0.9 | 0.04 | 0.74 |
| Without wastage | | | | |
| Concentrate DM consumption | | | | |
| Mean, kg/d | 7.18 | 6.87 | 0.07 | <0.01 |
| CV, % | 16.4 | 20.9 | 0.47 | <0.01 |
| Gain to concentrate ratio, kg/kg | 0.21 | 0.21 | 0.006 | 0.87 |
| Accumulative concentrate DM consumption after 14-d, kg | 100.5 | 96.1 | 0.93 | <0.01 |
| Gain to concentrate ratio after 14-d, kg/kg | 0.20 | 0.20 | 0.006 | 0.79 |
| With wastage | | | | |
| Concentrate DM wastage, kg/d | 0.06 | 0.11 | 0.001 | <0.01 |
| Concentrate DM consumption corrected by wastage | | | | |
| Mean, kg/d | 7.12 | 6.76 | 0.067 | <0.01 |
| Gain to concentrate ratio, kg/kg | 0.21 | 0.22 | 0.006 | 0.59 |
| Accumulative wastage DM wastage after 14-d, kg | 0.9 | 1.5 | 0.02 | <0.01 |
| Accumulative concentrate DM consumption after 14-d, kg | 99.6 | 94.6 | 0.94 | <0.01 |
| Gain to concentrate ratio after 14-d, kg/kg | 0.20 | 0.21 | 0.006 | 0.59 |

[1]Treatments were different physical form of concentrate: pellet (PE), and crumble (CR).
[2]Fixed effect of treatment (T).
[3]Gain to concentrate ratio data were analyzed using the arcsine + 1 transformation and are presented non-transformed data.

**Table 3.** Effect of physical form of concentrate on eating pattern in Holstein bulls fed a high-concentrate finishing diet (100 d)

| | Treatment[1] | | | P-value[2] |
|---|---|---|---|---|
| Item | PE | CR | SEM | T |
| Meal visits | | | | |
| Mean, n | 11.8 | 10.9 | 0.15 | <0.01 |
| CV, % | 18.2 | 19.9 | 0.36 | <0.01 |
| Meal size, DM basis | | | | |
| Mean, g/meal | 631.7 | 668.8 | 9.16 | <0.01 |
| CV, % | 18.0 | 21.6 | 0.43 | <0.01 |
| Total meal duration | | | | |
| Mean, min/day | 40.7 | 44.4 | 0.71 | <0.01 |
| CV, % | 27.7 | 28.8 | 0.78 | 0.23 |
| Meal duration | | | | |
| Mean, min/meal | 3.6 | 4.2 | 0.07 | <0.01 |
| CV, % | 28.6 | 29.6 | 0.74 | 0.32 |
| Total Inter-meal duration | | | | |
| Mean, min/inter-meal | 1378.2 | 1382.8 | 3.53 | 0.36 |
| CV, % | 12.3 | 14.6 | 0.43 | <0.01 |
| Inter-meal duration | | | | |
| Mean, min/inter-meal | 125.9 | 140.7 | 2.38 | <0.01 |
| CV, % | 20.3 | 22.9 | 0.56 | <0.01 |
| Meal eating rate, DM basis | | | | |
| Mean, g/min | 193.1 | 174.5 | 2.38 | <0.01 |
| CV, % | 20.6 | 21.2 | 0.53 | 0.38 |

[1]Treatments were different physical form of concentrate: pellet (PE), and crumble (CR).
[2]Fixed effect of treatment (T).

## 3.2. Study 2

### *3.2.1. Concentrate Consumption*

Bulls showed a preference for PE (65.5 ± 4.89% pellet consumption to total concentrate consumption ratio, which corresponded to 5.2 ± 0.37 kg of pellet DM consumption per day) instead of CR (34.5 ± 4.89 % crumble consumption to total concentrate consumption ratio, which corresponded to 2.8 ± 0.40 kg of crumble DM consumption per day) during the preference test (data not shown).

# 4. DISCUSSION

### *4.1. Physical Pellet Quality Measures (Study 1)*

As expected, when concentrate presentation was CR, because of grinding process a more variable granulometry was obtained in contrast to PE.

In a manufacturing context, pelleted feeds are subject to shearing and abrasive actions during transportation and distribution (Thomas and van der Poel, 1996), in which fines are generated, and pellets are subjected to fragmentation and abrasion events. Durability is a simple test in which pellets are tumbled in a mixer for a defined period of time that simulates the transfer and handling of feed (Fairfield, 1994). Handling by auger conveying and automated feeding distribution to animals can produce excessive dust and fines (Walker, 1999) by either fragmentation or abrasive stresses. As expected, the durability of PE form was greater than CR in all sampling places. The CR exhibited lesser durability because, initially, it had a particle size distribution with less proportion of particles above 2.5 mm. These particles had less integrity to resist fragmentation or abrasion forces as they had more fractures, edges or surface-unevennesses (Thomas and van der Poel, 1996) produced by the regrinding process. In addition, the durability was maintained constant from the pellet mill to the feeder in PE, ranging from 97 to 95 %; conversely, the durability of CR was quite variable from 91 to 84 %. Thus, the first conclusion that can be extracted is that if the durability at pellet mill is not good, the durability throughout the concentrate handling will exponentially decrease increasing the presence of fines at the feeder.

Why the durability from pellet mill to silo in both treatments increased is unknown; one hypothesis could be that as the temperature of concentrate decreases, the durability increases. Although at pellet mill coolers reduce the temperature of concentrate before loading trucks, the refrigeration process is not completely successful reducing the concentrate temperature. Thus, an improper cooling could decrease the durability due to stresses in the pellet by the differences in physical properties between the cooled surface and the still warmer center of pellet (Thomas and van der Poel, 1996). This phenomenon may be accentuated in case of CR, as they were regrounded on cooling process conducted.

Hardness is the force necessary to crush a pellet or a series of pellets at a time (Thomas and van der Poel, 1996). The hardness at pellet mill or silo (around 9 kg) was reduced 2 kg at feeder or spillage collectors. This reduction of pellet hardness may be attributed to increase of moisture content from ambient or salivary contaminant of feed at the feeder (Tabil, 1996), and was not affected by transport and storage conditions (silo).

As expected, the pelleting increases the density (Behnke, 1994), circumstance that improves storage capabilities of most facilities, and, also, increases shipping facilities reducing transportation cost (Thomas and van der Poel, 1996). The decrease in density registered in spillage collectors was expected because the feed was contaminated with other particles like straw, little stones, sand, etc., and also it contained a high content of humidity. The evolution of density from pellet mill to spillage collectors was similar to the durability because both parameters are related, as reported by Aarseth (2004).

Pellet quality (durability and percentage of fines) can have an impact in concentrate consumption and feed sorting, as it will be discussed later. To our knowledge there are no published data that analyze if pellet quality is maintained from pelleting to the feeder. As the pelleting is a manufacturing procedure that has an extra cost, it is important to confirm that the parameters of pellet quality are preserved.

### *4.2. Consumption and Performance (Study 1)*

Physical form of concentrate affected the daily concentrate consumption and wastage associated, and ADG, without affecting concentrate efficiency. Thus, animals fed CR consumed lesser amounts of concentrate (5.1%) and generated a greater amount of concentrate wastage (45.5%) compared with bulls fed PE. These findings are in accordance to the advantages attributed to pellet compared with mash such as reducing waste, improving palatability, and animals consume large amounts of concentrate spending less time (Behnke, 1994; Winowiski, 1995). In one of the few studies that evaluated the physical form of concentrate in cows (Kertz et al., 1981), a greater concentrate intake was reported when cows were fed pellets in contrast to mash. One of the benefits feeding pellet versus mash is the improvement of feed efficiency; it has been particularly and extensively reported in pigs (Vanschoubroek et al., 1971; Pond and Maner, 1984) and poultry (Calet, 1965; Quemere et al., 1988; Moran, 1989). One explanation whereby pellet feeding could improve feed efficiency is the reduction of wastage during the eating process (Behnke, 1996), as observed in the present study. It should be remarked, that concentrate wastage could be greater under commercial conditions than in the current study, as feeders of the present study were designed to reduce concentrate spillage (Verdú et al., 2015). The pellet concentrate decreased concentrate wastage and thus reducing feed cost, and it should be interesting to conduct an economic analysis to contrast whether the extra cost of manufacturing pellet is justified by the benefits derived from the reduction of concentrate spillage and the improvement of performance. In the literature, there are contradictory results when evaluating the effects of pellet on ADG, whereas some studies in finishing pigs observed an improved growth (Wondra et al., 1994), other studies did not observe ADG improved (Stark, 1994). Other benefits of pellet versus mash in feed efficiency would be the greater starch availability (Xiong et al., 1991), which should be discussed with caution in the present study as CR had the same pelleting conditions as PE. However, CR compared with PE due to the regrinding could have an increase in the attachment surface for the rumen microbiota, and this could favor starch digestion. Nevertheless, Owens et al. (1997) have associated the reduction of daily concentrate consumption to an increase in grain processing, because of the rapid fermentation of starch increasing the risk of an establishment of subclinical acidosis situation (Fulton et al., 1979a,b). Also, another indicator of rumen acidosis risk would be the increase of day-to-day variation of concentrate consumption, as reported by Stock et al. (1995). In the present study animals fed CR exhibited less concentrate consumption and greater day-to-day CV of concentrate consumption compared with bulls fed PE. Thus, animals fed CR exhibited some eating behavioral parameters (reduced concentrate intake, greater day-to-day CV) that could be associated with subclinical acidosis. However, in the present study, no clinical evidences were found that indicated those animals may have suffered clinical or subclinical acidosis; and no rumen pH data were recorded to evaluate the effect of physical form of presentation on rumen acidosis. Moreover, a long-term study would be needed to detect effect of concentrate presentation form on rumen health and growth. In the light of the outcome of the present study, a long-term effect of poor pellet quality would affect the concentrate consumption, and, consequently, decreasing ADG.

### *4.3. Eating Behavior (Study 1), and Preference (Study 2)*

The physical form of concentrate had an impact on animal eating behavior (Albright, 1993). As mentioned above, animals fed CR registered lesser daily concentrate consumptions than PE. Thus, the reduction of concentrate intake in CR bulls was the result of decreased visits to the feeder, although meal size increased compared with PE bulls. Moreover, bulls fed CR exhibited, together with the increase in meal size, an increase in meal duration causing a decrease in the eating rate. In addition, CR bulls devoted more time per day at the feeder and the time between meals increased. This eating pattern registered in animals fed CR could be related to particle size sorting avoiding fines, as indicated by the increase in the percentage of fines recorded in CR feeders and by the results of Study 2. This selective behavior avoiding fines may be negative consequences on animal growth in case that nutritional composition of the different particle size fractions could differ greatly unbalancing the diet. However, the lack of differences observed on the nutritional analyses of concentrates from the feeder, corrected by the particle size distribution, could not support the hypothesis that particle size selection could cause an imbalance in nutritional composition of the concentrate. To support the hypothesis that animals would select PE avoiding the presentation form with fines (CR), which was based on the increase of percentage of fines registered in the feeder and spillage collectors, Study 2 was designed to analyze whether animals preferred PE over CR. The greater PE consumption compared with CR during this preference test confirmed that bulls preferred PE over CR. These findings are in agreement with results reported by Ray et al. (1959) in beef, which observed that pellets were more preferable than ground pellets independently of cereal source. Other authors also observed the preference for pellets over meal or ground barley in heifers (Arave et al., 1983; Spörndly and Åsberg, 2006). Thus, these evidences suggest that cattle discriminate the feed by its physical form or particle size, choosing pellets as the most desirable presentation form. One of the weaknesses of preference tests is avoiding the effects of learning and earlier feed experience on later animal selection (Forbes and Kyriazakis, 1995; Arave, 1996); for this reason in the current choice feeding test a preliminary adaptation period (7 d) was conducted.

The preference for PE together with the large amount of fines observed in the CR feeders support that bulls were sorting, and this forced animals to spend more time at the feeder increasing the meal duration when bulls are fed CR. In the current study, one single feeder was used for 18 animals within a pen. Feeder time occupancy can be a limiting factor (Verdú et al., 2015) for concentrate consumption. The meal duration in PE bulls was reduced by 9% (corresponding to 3.8 min/d) compared with CR bulls, and this could suppose at the end of the day an increase of a total of 68 min available for feeder attendance. Then, using PE could be beneficial economically, as the increase in time availability for feeder attendance may allow an increase in the number of animals per feeder.

In the present study, animals exhibited faster eating rates when fed PE. These findings are in accordance to Kertz et al. (1981), who hypothesized that high eating rates initially may be related to concentrate form and with the degree of mastication or deglutition. This circumstance would suggest the correlation that rapid concentrate consumptions could promote greater rumen fermentation (Owens et al., 1997; Sauvant et al., 1999). Moreover, Bertipablia et al. (2010) reported that pelleting conditions enhances starch gelatinization and reduces particle size of ingredients increasing rumen starch fermentation; however, by contrast, pelleting may prolong the time needed to disintegrate pellets (Castrillo et al., 2013), and thus, together the size and hardness of pellet, may delay the microbial accessibility decreasing rate of fermentation. Several authors have hypothesized that grain processing may counteract the adverse effects of ruminal acidosis (Huntington, 1997; Owens at al., 1998). Nevertheless, as mentioned before, although no rumen pH data were recorded in the present study, no clinical signs of rumen acidosis were observed. Then, further research is needed to understand the relationship among grain processing, starch availability in the rumen, eating behavior and its impact on rumen acidosis.

In summary, as expected, crumbles had an impoverished pellet quality (less durability and density). The deterioration of physical pellet quality had negative effects reducing the concentrate consumption, increasing the wastage, and increasing the percentage of fines at the feeder. In addition, animals fed poorer pellet quality spent more time at the feeder, reducing the eating rate and number of daily visits. Animals selected PE over CR form, supporting the explanation that animals fed CR spent more time eating without increasing the intake because they were sorting avoiding fines.

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# CHAPTER VII

# GENERAL DISCUSSION

The discussion of the current work has been organized in the following way. Firstly, several recommendations are suggested to design the pen feeding area based on data from Study 2 (Chapter IV), in which eating and drinking behaviors were analyzed relative to concentrate feeder design and animal BW; data from Study 3 (Chapter V) where animal adaptation ability to single-space feeder design with lateral protections was evaluated; and data from Study 4 (Chapter VI) where the physical form of concentrate was assessed. After that, the effect of different feeding strategies studied (feeder design, feeder depth, adaptation strategy to single-space feeder design, and physical form of concentrate) on concentrate consumption and performance are discussed to determine the possible benefits and inconvenients of their implementation in terms of fattening profitability. Finally, an extra section dealing with some pre-established concepts in intensive beef production, thoughts and comments raised during work are presented in order to share concerns and curiosities.

## 1. RECOMMENDATIONS BASED ON BEHAVIORAL OBSERVATIONS

The study of eating and drinking patterns is necessary to understand the way in which design features of feeding facilities and their management affects the efficiency/response of feeders and drinkers in intensive beef conditions, as these represent the final interface between animals and diet or water (Gonyou and Lou, 2000). Then, analyzing the eating and drinking behaviors is very important to determine the feeder's usefulness, to check the expected eating patterns from animals according to the feeder design, cattle age or BW, feed presentation, etc., and to decide the feeder design as suitable as possible to animal production targets (BW, age, days on feed, grouping, breed, etc.).

Furthermore, understanding eating (concentrate and straw) and drinking behaviors at feeding zone depending on the concentrate feeder design, animal BW, animal adaptation ability to single-space feeder design, and physical form of concentrate was also considered interesting and useful to establish practical management and technical considerations throughout the fattening cycle, and definitively to use the behavioral knowledge to optimize the feeder design under our productive conditions and to improve in these both directions, animal welfare and productivity. Therefore, from the current work, after studying eating and drinking behaviors, following practical recommendations could be formulated.

### *1.1. RECOMMENDATIONS ACCORDING TO CONCENTRATE FEEDER DESIGN*

There were behavioral parameters influenced exclusively by concentrate feeder design, which deserve our attention when the corresponding feeder design is implemented to ensure the optimal feeder utilization, an expected good animal feeder adaptation, an expected good performance, and to preserve animal welfare.

The percentage of concentrate disappearance throughout the day varies depending on concentrate feeder design. As González et al. (2008) indicated groups of animals synchronize their behavior trying to eat and rest at the same time. Whereas an eating peak time (0600 to 1200 h) was recorded in collective feeders coinciding with the most attendance as a reference value of eating behavior most frequently observed in cattle commercial settings, animals fed on SF had to modify their circadian rhythm of eating, attending earlier to the feeder to counteract the lack of feed access at the most crowded time period of day. Thus, cattle chose eating at less preferred times of the day, behavioral response also observed by González et al. (2008).

The rate of concentrate disappearance velocity, which could be considered an equivalent of eating rate, was affected by concentrate feeder design resulting in a decrease of 14% for collective feeder with less concentrate capacity and 29% for single-space feeder with lateral protections compared with conventional collective feeder. This difference among feeder designs has been hypothesized as a reduction of feed wastage in absence of performance and rumen pH data differences among treatments, despite spillage was not measured. In conclusion, an evidence that feeder design is able to minimize the total concentrate consumption and feed spillage seems to be discerned, but it should be contrasted by measurements of spillage in future studies.

The implementation of single-space feeder with lateral protections design implied a greater straw feeder daily occupancy of 17% in response to a redirected behavior because of increased competition at concentrate feeder and/or the synchronization of eating activity. Then, the straw feeder space available becomes critical throughout all fattening.

Lastly, a 20% more displacements were recorded at drinker in conventional collective feeder compared with collective feeder with less concentrate capacity and single-space feeder with lateral protections; this could suggest that a synchronized eating activity leads also to a synchronized drinking activity because usually the latter activity goes after first in accordance with our observations. Then, the activity synchrony in the herd and the sequence of activities caused a greater competition at the drinker and, this fact questions us if in conventional feeders pen design with only one drinker is enough or a better option would be to have 2 drinkers. Anyhow, to answer this question the water consumption should recorded or a study should be conducted to test the effect of one vs. two drinkers on eating, drinking, and animal behaviors, and also on performance, without forgetting indicators in animal welfare.

### *1.2. RECOMMENDATIONS DEPENDING ON ANIMAL BW OR AGE*

Some eating and drinking behavioral parameters evolved with animal BW or age (rate of concentrate disappearance velocity at the feeder, and competition around straw feeder and drinker), independently of concentrate feeder design, circumstance that should be taken into account in the design of pen feeding facilities. In addition, this previous statement also questions if using the same feeder or drinker design throughout the fattening should be the best approach to optimize the cattle productivity, welfare, and feeding facilities use.

Firstly, from percentage of concentrate disappearance data, the time period of the day when a greater feeder attendance was observed ranged from 0600 to 1800 h. In addition, the activity at the feeder changed slightly with animal BW, and the fourth time period of the day (from 1800 to 2400 h) registered an increase of concentrate disappearance as animals grew at the expense of a reduction of disappearance in third time period (from 1200 to 1800 h). Thus, animals preferred to eat in the fourth time period of day as they grew. Animals space out substantially in time the feeder attendance as a response to an individualized eating behavior as they grew.

The rate of concentrate disappearance velocity increased as animals grew (52% and 17% during the growing and finishing phase, respectively), which represented simultaneously the concentrate consumption and wastage without being able to distinguish between them. Thus, it could be hypothesized that both, intake and spillage, increased with animal BW, especially during growing phase this increment had a greater magnitude compared with finishing (782 vs. 665 kg of cumulative concentrate consumption per animal and phase, respectively). Probably during the growing phase animals attended at feeder in groups of 2-3 calves, there may be still a certain degree of competition and the hierarchy to feeder attendance may be established. Despite the greatest consumptions recorded during the finishing phase and thereby also greatest spillages would be expected in absolute terms at least, it is during the growing phase when bulls probably exhibited a remarkable rise in feed wastage (greater competition at the feeder, more wastage occasions). In conclusion, as a suggestion, the strategy to minimize the feed spillage should be implemented as soon as possible after at fattening entrance, after a prudent period of adaptation, because the feed wastage is occasioned and practically duplicated during the growing phase.

Another interesting behavioral finding was the decrease of straw feeder activity (occupancy time, visits and displacements) with animal BW, despite straw consumption increased. Thus, to ensure the straw feeding space availability during the growing phase is an important requirement. In addition, the decrease of straw feeder activity may also indicate that animals increase the straw eating rate with BW or age, which could be related with size of bite, such as it was hypothesized for the rate of concentrate disappearance.

Conversely, the activity around the drinker also decreased as animals grew but much more slowly, fact that may indicate the prolongation of a certain degree of competition for this resource during more time because of the limitation of an available drinking space. Then, this result questions if water consumption might have been impaired, despite performance obtained (were within the commercial range) did not support this hypothesis. However, further research is necessary to collect more information, and if use of one drinker for 20 animals guarantees enough water provision is guaranteed. Accordingly, producers also question if one only drinker is enough to avoid water limitation in cases where water supply is limited.

### *1.3. RECOMMENDATIONS ACCORDING TO THE INTERACTION BETWEEN CONCENTRATE FEEDER DESIGN AND ANIMAL BW OR AGE*

In summary, the analysis of behavioral data allows us to conclude that animals showed more gregarious and synchronized eating and drinking behaviors during the growing phase; in contrast, during the finishing period animals tended to individualize these behaviors. Then, the design of collective feeders would adjust better to eating and drinking behaviors exhibited in the growing phase; conversely, the single-space design with lateral barriers and its individualized behavior would be very close to individual eating behavior observed in collective feeders during the finishing phase. Thus, analyzing eating behavior evolution with age, single-space feeder with lateral protections would be more adequate to the finishing phase.

### *1.4. RECOMMENDATIONS FROM ADAPTATION STRATEGY TO SINGLE-SPACE FEEDER DESIGN WITH LATERAL BARRIERS*

A greater waiting time to feeder access recorded at first 2 wk after fattening entrance supported from behavioral perspective the hypothesis that animals had adaptation problems to single-space feeder design with lateral protections (Chapter V).

The adaptation arrangements (chute not placed and additional feeder) increased feeder attendance and competition at both concentrate feeders during the first wk of adaptation period, after fattening arrival. Thus, the adaptation strategy eases the feed access and encourages concentrate consumption for first wk of adaptation period, and also increases competition without detrimental effects on performance. No impact on straw feeder and drinker by adaptation strategy to SF design was observed.

### *1.5. RECOMMENDATIONS ACCORDING TO PHYSICAL FORM OF CONCENTRATE*

Differences in concentrate consumption were observed between physical forms of concentrate tested (pellet vs. crumble), thereby, different eating patterns were also expected, as physical form of feed influences eating behavior in cattle (Albright, 1993). Animals fed poor pellet quality showed an eating pattern characterized mainly by greater daily feeder occupancy time, lesser frequency of daily feeder visits, greater meal size and lesser eating rate. The sorting behavior in favor of intact/whole pellets could explain the eating pattern observed. The practical implications of the effect of feed presentation on eating behavior could be characterized that mainly by the fact that animals fed crumble form (or bad pellet quality) devoted more time per day eating at the feeder. Consequently, if the feeder space or feeding space to animal ratio is not increased, this could have limited feeder attendance and in turn intake and growth.

The Table 1 summarizes the main recommendations resulting of the analyses of the eating and drinking behaviors according to concentrate feeder design, animal BW or age, animal adaptation ability to single-space feeder design, and physical form of concentrate.

**Table 1.** Recommendations deduced from the study of eating and drinking behaviors

**Recommendations for the concentrate feeder**

- The strategies to reduce the concentrate wastage should be implemented in growing phase, as soon as possible, after prudential period of adaptation (between 14 and 30 d after arrival).

- The adaptation strategy (chute not placed and additional concentrate feeder for first 4 d and 14 d after fattening arrival) is successful facilitating feed access in animals fed single-space feeder with lateral protections.

- Animals are fed crumble form (bad quality pellet), the feeding space to animal ratio of 1 to 20, when the feeder design is the single-space feeder with lateral protections, can limit feed intake and thereby impair growth. This recommendation can also probably be extrapolated to collective feeders, where a greater competition takes place during the growing phase.

**Recommendations for the straw feeder**

- If the concentrate feeder design is the single-space feeder with lateral barriers, then it is important to ensure straw feeder space availability during the growing phase.

**Recommendations for the drinker**

- For conventional collective feeder design, two drinkers per pen with 20 animals should be considered at least during the growing phase.

## 2. EFFECT OF SEVERAL POSTFORMULA FEEDING STRATEGIES TO REDUCE FEED COST AND ENHANCE FATTENING PROFITABILITY

### *2.1. THE PHYSICAL FORM OF CONCENTRATE*

First of all, it is necessary to clarify the indistinct use of the terms “physical form of concentrate” and “physical quality of pellet” throughout the study. To simulate a bad pellet quality the crumble presentation form by regrinding pellets was chosen. Both pellet and crumble can be also considered two different physical presentations of concentrate, as they are composed by a different particle size distribution (granulometry). Crumble form utilization was decided to simulate bad pellet quality in order to avoid the use of different ingredients and/or different manufacture conditions that could affect starch digestibility. Obviously, the different particle size between pellet and crumble forms can also affect starch digestibility. This option (crumble) was finally chosen because it was the option that better simulated the bad pellet quality and could also guarantee a continuous/homogeneous treatment effect throughout the study.

The Study 4 (Chapter VI) corroborated that the utilization of pellets with a good physical quality (durability and percentage of fines) has a positive effect on feed intake and performance. Furthermore, the physical pellet quality data collected in this study indicated that pellets had an average of the durability above 97% (a good physical pellet quality), which was registered indistinctly at the pellet mill or at the feeder. Thus, whether initial pellet quality is good, transportation has not a big detrimental effect. This information can be relevant for producers and manufacturers to establish standards of physical pellet quality and evidences of its repercussion on animal performance.

Hence, an increased daily concentrate consumption (360 g/d, 5%) and reduced feed wastage associated (50 g/d, 45%), a decreased day-to-day CV of concentrate intake (4.5%, 22%), and also a tendency to increase ADG (70 g/d, 5%) were observed when feeding good quality pellets in contrast to pellets with poorer quality. Despite feed efficiency was not affected, improvements in performance achieved when animals were fed good quality pellets have also a positive economic impact on fattening profitability (Table 2). In Table 2 is presented a simplified economic analysis to show the importance of working with good physical pellet quality based on benefits estimated from improved growth (output, kg carcass) and costs only associated to feed (input).

**Table 2.** Economic analysis corresponding to feed animals with good vs. bad quality pellets

| Item | Good pellet quality | Bad pellet quality | Differential pellet vs. crumble |
|---|---|---|---|
| Consumption cost[1] | 7.12 kg/d x 210 d x 0.21 €/kg = 314 € | 6.76 kg/d x 210 d x 0.21 €/kg = 298 € | - 16.0 €/animal and fattening |
| Wastage cost[1] | 0.06 kg/d x 210 d x 0.21 €/kg = 2.6 € | 0.11 kg/d x 210 d x 0.21 €/kg = 4.9 € | + 2.3 €/animal and fattening |
| Total concentrate cost | 314 + 2.6 = 316.6 € | 298 + 4.9 = 302.9 € | - 13.7 €/animal and fattening |
| Kg carcass from growth benefit[2] | 1.51 kg/d x 210 d x 3.15 €/kg x 53.5 % = = 534.4 € | 1.44 kg/d x 210 d x 3.15 €/kg x 53.5 % = = 509.6 € | + 24.8 €/animal and fattening |
| Final result | 534.4 - 316.6 = 217.8 € | 509.6 - 302.9 = 206.7 € | + 11.1 €/animal and fattening |

[1]Both data are feed cost estimations from concentrate consumption and wastage based on a fattening length of 210 d on feed, together with an illustrative price of concentrate around 0.21 €/kg (Corporació Alimentària Guissona, SA, 2015).

[2]It is a benefit estimation of carcass weight based on an average of ADG throughout 210 d of fattening duration, using a reference value of dressing percentage (53.5%), and the application of illustrative carcass price perceived for producers around 3.15 €/kg at 44th wk (Mercabarna, 2015).

From Table 2 data calculations, it can be concluded that use of pellets with good physical quality provides an increase of economic benefit of 11.1 €/animal and fattening cycle compared with animals fed pellets with poor physical quality. To obtain a good pellet quality the concentrate price may raise (ingredient + manufacturing); with the prices used in these previous economic calculations, the strategy to improve pellet quality could be interesting if it would increase the feed price up to 0.007 €/kg of concentrate (11 € / [7.12 kg/d x 210 d]). In other studies (MAGRAMA Project 20130020000779; unpublished results) conducted to improve pellet quality (durability from 95 to 98%) by selection of dietary ingredients (corn vs. wheat) or changing velocity of pellet mill (14 vs. 17 t/h) the cost of this strategies were below 0.007 €/kg of concentrate. Thus, despite the good pelleting practices have an extra cost, the improvement of pellet quality is completely justified in terms of fattening profitability.

The increased animal growth could be explained hypothetically by an increase in concentrate intake with a reduction of wastage. In addition, the less daily CV of concentrate consumption would contribute to have better expected growths due to healthier rumen environment, as fluctuations in intake can cause acidosis (Britton and Stock, 1987; Galyean et al., 1992). However, some studies have been postulated that the best-performing cattle exhibit the most variable feeding patterns (Zinn, 1994; Cooper et al., 1998; Hickman et al., 2002) and, thereby, the erratic consumption paradigm is controversial. Lastly, it is important to remark that the small amount of concentrate wastage was collected due to feeder design used in the study (single-space feeder with lateral protections), which is purpose-designed to minimize the spillage in great measure. However, the wastage registered was sufficient to conclude an effect of physical form of concentrate on feed spillage. Then, a greater wastage recorded would be expected in commercial conditions with conventional collective feeders according to accumulative concentrate consumptions reported by Verdú et al. (2015a).

Moreover, it would be necessary to conduct a long-term study to evaluate more consistently the effect of physical form of concentrate on performance and carcass data, and, also, the evolution of latter main effect through the time. To our knowledge, despite the statistical limitation derived from Latin square design (loss of precision and carry over effects) becomes the main weak point of the Study 4 (Chapter VI), the conclusions obtained remark the reliable impact of physical form of concentrate on performance and, thereby, it establishes a starting point to conduct further research in this direction.

Concurrently, the Study 4 (Chapter VI) also concluded that it is important to preserve parameters of pellet quality (durability, percentage of fines, density) from the pellet mill to feeder to expect the beneficial impact of good physical pellet quality on performance, eating behavior, feed sorting, feed transport and storage, etc. If pellet quality is bad at the pellet mill, the quality will decrease linearly at the feeder due to deterioration during the transportation and handling. Thus, it is important to ensure an initial durability value at the pellet mill above 97%.

### *2.2. THE CONCENTRATE FEEDER DESIGN*

Study 1 (Chapter III) demonstrated that features of feeder design such as feeder depth or single-space with lateral protections were able to decrease the total cumulative concentrate consumption by animal and fattening cycle in contrast to conventional feeder (4.4 and 6.7 %, respectively). Thus, changing certain aspects of feeder design (reducing concentrate capacity and/or single-space feeder with lateral barriers) can be suggested as feeding strategies to reduce the total concentrate consumption in cattle without impairing performance, eating and animal behavior, rumen health, and other welfare indicators. In the light of the results, the most plausible hypothesis that explains the reduction in concentrate consumption is the favorable effect of feeder design on concentrate wastage, which is probably minimized. In addition, the less cumulative concentrate consumption resulted in a favorable economic impact on feed costs.

Before the study began, it was expected a reduction of animal growth to the extent that reducing feeder depth or feeder space could limit the concentrate availability and, in consequence, the feed intake, even though the feed efficiency could improve or remain unchanged. However, modifications in feeder design did not negatively affect performance and feed conversion. Moreover, there were numerically differences among feeders in carcass weight which can have a significant economic impact. Hence, a reduced carcass weight was observed in alternative feeder designs (collective feeder design with less concentrate capacity and single-space feeder with lateral protections) compared with conventional feeder design. This finding has been also observed in another study (MAGRAMA Project 20130020000779; unpublished results) where a single-space feeder with lateral protections was contrasted with a self-feeder with feed adjustment and 3 feeding spaces. After 182 d of fattening, no statistically significant differences were observed between designs of concentrate feeder in accumulative concentrate consumption, performance and carcass data. However, as in the Study 1 (Chapter III), again a numerical decrease in carcass weight was observed (- 5 kg) when bulls were fed single-space feeder with lateral barriers.

Another hypothesis contrasted (Behnke, 1994; Mateos y Grobas, 1993) was that feeder design could have a greater impact reducing the total concentrate intake when the presentation form of concentrate was mash instead of pellet. Hence, a second study was conducted to assess the effect of concentrate form of presentation (mash vs. pellet) and concentrate feeder design (self-feeder with 3 feeding spaces and low concentrate capacity vs. single-space feeder with lateral protections) on performance and carcass data (Verdú et al., 2015b). The best strategy to improve performance and save concentrate was to feed animals with pellet and using a self-feeder with 3 feeding spaces, followed by pellet with a single feeder, meal with a single feeder, and, lastly, meal with a self-feeder 3 feeding spaces.

Table 3 shows the concentrate intake and the main performance data recorded for each concentrate feeder design. In addition, a basic summarized economic analysis is calculated to illustrate possible benefits and costs for each one design.

**Table 3.** A comparative analysis among several concentrate feeder designs (Chapter III and MAGRAMA): An economic analysis for each feeder design is calculated

| Item | CFL | vs. | CF | SF | vs. | CF | SF | vs. | Self-feeder |
|---|---|---|---|---|---|---|---|---|---|
| Reference | | | Chapter III | | | | | MAGRAMA | |
| Initial BW (kg) | 120.7 | | 121.1 | 121.0 | | 121.1 | 232.5 | | 231.8 |
| Final BW (kg) | 445.4 | | 449.8 | 441.4 | | 449.8 | 466.2 | | 476.2 |
| ADG (kg/d) | 1.50 | | 1.54 | 1.49 | | 1.54 | 1.32 | | 1.38 |
| Days on feed of fattening (d) | | 214.5 | | | 214.5 | | | 177 | |
| HCW (kg) | 247.9 | | 249.7 | 244.1 | | 249.7 | 242.9 | | 248.5 |
| Dressing percentage (%) | 53.6 | | 53.7 | 53.5 | | 53.7 | 52.1 | | 52.1 |
| Cumulative concentrate DM intake per animal and fattening (kg) | 1,264 | | 1,322 | 1,234 | | 1,322 | 1,321 | | 1,323 |
| Feed cost[1] (€/kg) | | | | | 0.21 | | | | |
| Savings in total concentrate cost (€/animal and fattening) | | 1,322 - 1,264 = 58<br>58 x 0.21 = + 12.2 | | | 1,322 - 1,234 = 88<br>88 x 0.21 = + 18.5 | | | 1,323 - 1,321 = 2<br>2 x 0.21 = + 0.4 | |
| Carcass price[2] (€/kg) | | | | | 3.15 | | | | |
| Benefits from kg carcass (€) | | 249.7 - 247.9 = 1.8<br>1.8 x 0.536 x 3.15 = - 3.0 | | | 249.7 - 244.1 = 5.6<br>5.6 x 0.536 x 3.15 = - 9.5 | | | 248.5 - 242.9 = 5.6<br>5.6 x 0.521 x 3.15 = - 9.2 | |
| Economic balance (€) | | 12.2 - 3.0 = + 9.2 | | | 18.5 - 9.5 = + 9.0 | | | 0.4 - 9.2 = - 8.8 | |
| Investment of feeder[3] (€/animal) | 10 | | 5 | 30 | | 5 | 30 | | 10 |

[1]Illustrative concentrate price around 0.21 €/kg (Corporació Alimentària Guissona, SA, 2015).

[2]Illustrative carcass price perceived for producers around 3.15 €/kg at 44th wk (Mercabarna, 2015).

[3]Estimated feeder design investment (€/animal) considering a pen of 20 animals.

Furthermore, at the beginning of this work it was hypothesized that both new arrangements in the feeder would difficult to feed access, they could also affect the eating behavior increasing the competition to obtain feed, increasing the time spent eating, increasing the eating rate, etc. This hypothetical altered eating pattern could cause fluctuations in feed consumption and, subsequently, affect rumen pH; this situation could finally lead to rumen acidosis impairing rumen and animal health.

Although the great CV of concentrate consumption observed in SF may be interpreted as an evidence of erratic consumption pattern compatible with rumen acidosis, the lack of other signs related to rumen acidosis (feed intake reduced, impaired growth, low pH data, rumen wall lesions, and liver abscesses) do not support this hypothesis. Thus, the arrangements in feeder design (feeder depth and SF with chute) did not have negative impact on variables that would suggest that these animals could suffer rumen acidosis or other digestive disorders.

Moreover, in all studies conducted (Verdú et al., 2015a; Verdú et al., 2015b; MAGRAMA Project 20130020000779; unpublished results) no adverse effects on digestive health (bloat, laminitis) have been observed.

### *2.3. THE ADAPTATION STRATEGY TO SINGLE-SPACE FEEDER DESIGN*

The Study 3 (Chapter V) indicated that adaptation strategy to single-space feeder design at the entrance (chute not placed for first 4 d and an additional single-space feeder during the initial 14 d) increases the concentrate intake and growth. The combination of arrangements as adaptation strategy was successful to facilitate feed access and to encourage the concentrate intake during the first wk of adaptation period after the fattening arrival (short term effect), and also had a positive mid-term effect on BW at 6 wk (4 kg increase in BW). Thus, the BW difference at 6 wk after fattening entrance could have an economic benefit of 6.9 €/animal (2.2 kg extra HCW x 3.15 €/kg of carcass price) if performance could be maintained to the end of fattening and compensatory growth would have no influence. Although adaptation strategy increased concentrate intake during the first wk after fattening arrival, no differences in accumulative concentrate consumption after 6 wk of study were observed and, thereby, the adaptation strategy had not extra cost in feed.

In fact, an adaptation strategy to facilitate the feed access and encourage the concentrate intake is important at fattening entrance and, it is more important, if animals must adapt to new feeder design. Also, when calves weigh around 120 kg, they have a synchronized and gregarious eating behavior (Chapter IV, Study 2). Thus, the number of feeding spaces or animal:feeding spaces ratio can have a positive effect based on social facilitation behavior such as reported by Devant et al. (2015).

### *2.4. EATING PATTERN AND FEED PREFERENCE*

The Study 4 (Chapter VI) also showed that the impoverished pellet quality alters substantially eating pattern affecting concentrate consumption. Furthermore, the preference study (Chapter VI) demonstrated a strong preference for good pellet quality and sorting ability for that concentrate presentation, when animals were challenged to choose between pellets of good or bad physical quality. The greater selection in favor of pellets of good quality could explain why when a bad pellet is offered (great percentage of fines) animals spent more time at the feeder (lesser eating rate, longer time spent at the feeder, greater meal sizes, lesser visits).

This study points out an interesting ascertainment, the narrow grade of interrelation among feed preference, eating pattern and intake, suggesting that when evaluating the effects of feed presentations on intake and performance these 3 variables should be studied.

The Table 4 shows the most relevant results in concentrate intake, growth, and feed efficiency achieved by the different feeding strategies postformula; it is a summary of previous discussion. In conclusion, it is true that feeding strategies suggested by the current thesis (concentrate feeder design, adaptation strategy to concentrate feeder design, physical form of concentrate) had a small impact on performance and economic profitability. However, the additive effects of small benefits of these different feeding approaches could contribute to be more competitive and less dependent of feed prices in intensive beef production.

**Table 4.** Summary of the different feeding strategies postformula in performance, carcass, animal and eating behaviors in Holstein bulls fed high-concentrate diets. Data are expressed as percentage of improvement relative to the most common commercial feeding practices

| Item | Concentrate feeder design[1] | | | | Adaptation strategy to SF design[2] | Physical presentation of concentrate (pellet quality)[3] | Interaction between feeder design and feed presentation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Concentrate feeder design | | Physical presentation of feed | |
| Reference | Chapter III[4] | | MAGRAMA | | Chapter V | Chapter VI | ITEA | | | |
| | CFL | SF | Self-feeder | SF | Adaptation strategy | Good pellet quality | Self-feeder | SF | Mash | Pellet |
| Days of study (d) | 215 | | 154 | | 42 | 112 | 154 | | 154 | |
| Initial BW (kg) | 121 | | 232 | | 120 | 272 | 219 | | 219 | |
| Total concentrate consumption | - 4.4 | - 6.7 | 0.0 | - 0.1 | NS[5] | + 5.1 | NS | - 2.0 | NS | - 4.0 |
| CV of concentrate consumption | NS | + 13.0 | NS | NS | NS | - 27.4 | 0.0 | + 10.7 | + 7.6 | 0.0 |
| Concentrate wastage | | | | | | - 45.5 | | | | |
| ADG | NS | | NS | NS | NS | + 4.6 | + 4.6 | 0.0 | NS | NS |
| Final BW[6] | NS | | NS | NS | + 2.2 | NS | | | | |
| Feed efficiency[7] | NS | | NS | NS | NS | NS | NS | NS | 0.0 | + 7.7 |

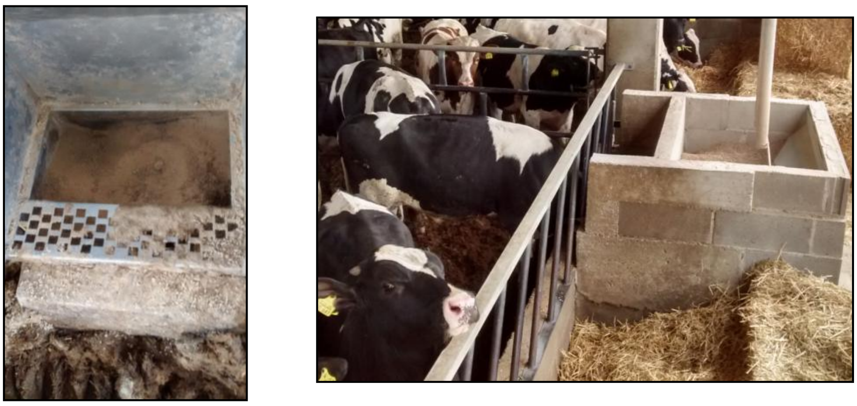
[1]Different concentrate feeder designs. CF = a conventional collective feeder with 4 feeding spaces; CFL = a feeder (like CF) with less concentrate capacity; SF = a single-space feeder with lateral protections; Self-feeder = self-feeder with feed adjustment and 3 feeding spaces.
[2]Different strategies of adaptation to a SF desing. CA = a conventional strategy (chute widened for first 4 d after fattening entrance); AA = an alternative stategy (chute not placed for first 4 d after fattening entrance, an additional concentrate single-space feeder without lateral barriers with supplementary feed reduced gradually for first 14 d after fattening entrance).
[3]Different physical form of concentrate or pellet quality. PE = pellet form (good pellet quality); CR = crumble form (bad pellet quality).
[4]Differences relative to conventional collective feeder with 4 feeding spaces (CF).
[5]NS = nonsignificant ($P > 0.10$).
[6]An interaction between concentrate feeder desing and physical form of presentation ($P = 0.08$; + 2.5% for CFL and pellet combination).
[7]Resulting from kg carcass to concentrate ratio (kg/kg).

Furthermore, the simple fact of evidencing that these postformula strategies (feeder design and physical form of concentrate) have an impact on performance, eating pattern, and profitability is sufficient to raise awareness to producers that other alternative managements or approaches are possible to improve efficiency and profitability. Some of the strategies studied are very simple to implement. In Figure 1 some modifications of feeders to reduce feed wastage in commercial farms can be appreciated. These farmers have visited the farms where feeders were tested or have participated in seminars were results from the present work have been presented.

**Figure 1.** Pictures of concentrate feeders modified in order to reduce the feed wastage from some farmers

Exemples of feeder with less concentarte capacity

Exemples of single space-feeders



However, the first step to be successful in the reduction of feed wastage, it is important to manage well the feeder (cleanness, adjustment of the concentrate at the feeder according to age).

## 3. PRE-ESTABLISHED CONCEPTS, ASPECTS OF EXPERIMENTAL DESIGN, AND RESEARCH TOPICS IN BEEF CATTLE

Finally, the discussion finishes with some personal thoughts and comments relative to pre-established concepts, aspects of experimental design, and research topics in beef cattle, which have been discovered and questioned during the realization of the thesis.

### *3.1. RUMEN ACIDOSIS*

Rumen acidosis is one of the most important cattle digestive disturbances described extensively in the literature and it is perceived as a prevalent issue for producers and nutritionists (Penner et al., 2009; Aschenbach et al., 2011). It is a sensitive and controversial research topic studied profoundly from several points of view.

The common feeding system in intensive beef cattle in Mediterranean countries provides animals are fed high-concentrate diets, and it is presupposed that animals will suffer rumen acidosis by the simple fact that huge amounts of highly fermentable cereal sources are consumed.

One of the main concerns when implementing a single-space feeder with lateral protections was the risk that animals could suffer rumen acidosis as eating pattern was altered by feeder design. The increased competence around the feeder due to reduction of feeder space could lead to irregular intakes (day-to-day variations), with fluctuations in amount of feed consumed that could cause sudden and great ruminal fermentations. For that reason, in the Study 1 (Chapter III), indicators that were compatible with rumen acidosis signs (rumen pH, liver abscesses, visual inspection of ruminal epithelium, and health status) were evaluated to detect the risk or establishment of rumen acidosis. However, unexpectedly, no compatible signs of rumen acidosis were observed during the current thesis. In contrary, animals fed SF design visited the straw feeder more frequently. In our experimental conditions, although roughage intake is very low (10%) compared with concentrate consumption (90%), it can hypothesize that the amount of straw provided by *ad libitum* availability would be enough to prevent occurrence of ruminal acidosis bouts.

Thus, consuming high amounts of highly fermentable carbohydrates by itself is not sufficient to presuppose the risk of rumen acidosis; behavior and other management factors can be helpful and crucial to avoid the rumen acidosis establishment.

### *3.2. ANIMAL VARIABILITY OBSERVED IN CONCENTRATE CONSUMPTION AND WASTAGE*

Studies of feeding and animal behavior typically focus on responses estimated from the average of the animals in a pen and they neglect the importance of variation among individuals (Atwood et al., 2001). This concern also is supported by other authors which indicate that as many as half of animals within a group may differ significantly from the mean in food preferences and nutrient tolerances (Provenza et al., 1996; Villalba and Provenza, 1996; Scott and Provenza, 1999).

From acquired experience working with computerized feeding systems collecting individual intake data, and after measuring the feed wastage during a finishing study, we are more conscientious about the real animal variability in these two parameters. Measuring the feed wastage within pen, a tremendous amount of wastage was observed in one pen. Firstly, the explanation more plausible was that this finding was due to a possible effect of feeder design or pen facilities (as they were hand-made and small differences in dimensions were observed). To contrast the before mentioned hypothesis, after finishing the study, animals of one pen were moved to another pen. Our surprise was to observe that great feed wastage was observed in the new pen where those animals have been moved. Thus, feed wastage was more animal or group dependent than facilities or feeder dependent. This individual variability in feed wastage was also observed in other studies conducted in our research group (Devant et al., 2015). Due to this large animal variability is crucial to conduct a power analysis and to use the correct experimental unit number (sample size) in studies where consumption or wastage is evaluated.

### *3.3. BEHAVIORAL STUDIES ARE NECESSARY TO ADAPT FACILITIES TO ANIMALS NEEDS*

The study of eating behavior is indispensable to make decisions in design of pen facilities (feeders or drinkers). Both eating and drinking animal requirements evolve with animal BW and age, thereby, the pen facilities should be designed or adjusted thinking in animals needs in terms of feeding or drinking space, to reduce the competition, and, lastly, to improve animal well-being. Logically, all of these factors during implementation in the farm have an economic cost that must be argued from the productive point of view before the decision takes place. However, some modifications are not more expensive and can be suggested in order to adequate the feeding facilities to animal requirements.

### *3.4. CHANGES IN FEED EFFICIENCY ARE DIFFICULT TO OBSERVE. OTHER REFERENCE PARAMETERS TO ASSESS THE ECONOMIC PROFITABILITY COULD BE QUESTIONED?*

Usually, the term of feed efficiency is used as a reference parameter on which the effect of strategies or improvements is measured to determine the benefits and costs of its implementation in fattening profitability. Feed efficiency or feed conversion is a ratio between ADG and daily concentrate consumption, which indicates the growth gained for each 1 kg of feed. Feed is one of the most production costs, and the growth is the main output that will represent the carcass weight from which benefits are obtained. This term has an economic meaning and it indicates how much efficient animals are.

To our knowledge, big changes in feed efficiency are not easy to observe because intake and growth are interrelated, and they have a directly proportional relationship. However, interpreting together feed efficiency and growth or carcass weight can be more helpful to tackle economic profitability than using feed efficiency alone. Furthermore, in the present work, although most strategies affected growth and concentrate consumption and did not affect feed efficiency, they improved the economic profitability.

### *3.5. THINKING ABOUT PREFERENCE TEST TRIALS*

Lastly, a short-term dietary preference test was conducted to try to answer which concentrate presentation (feed in pellet or in crumble form) was the more desired for animals. After 7-d adaptation period to "wash" feed preference related to previous feeding experience (crumble concentrate was available), a 6-d free-choice period was performed during which two concentrate presentations (pellet vs. crumble) were offered simultaneously to animals. Fresh concentrate in both forms was provided *ad libitum* to minimize possible undesirable effects due to presence of fines and/or limited concentrate amount in one of two presentations.

During preference test, bulls consumed daily on average 65% of pellet form vs. 35% of crumble form in relation to total concentrate consumption. These findings are in agreement with results reported by Ray et al. (1959) in beef, Arave et al. (1983) in dairy, and Spörndly and Åsberg (2006) in heifers, which determined an explicit preference for pellets over meal or ground pellets, as a preferred feed presentation, regardless cereal source that composed the feed form. In all of these studies, the feed preference was based on these parameters: intake measurements, time spent eating, eating rate, or feed presentation choice when animal started to eat. In conclusion, the results of Study 4 (Chapter VI) corroborated the hypothesis that animals preferred pellet over crumble and, consequently, they select favorably pellet vs. crumble. This preference for physical form of concentrate could result in sorting behavior exhibited at the feeder in the study with the Latin square design, which probably could explain the differences in daily eating pattern (increased concentrate eating time/feeder occupancy time and reduced feeder visits); and, by extension of eating behavior, daily concentrate consumption, its wastage associated, and ADG were reduced and, thereby, performance was impaired without affecting feed conversion. Besides, the increased percentage of fines recorded at the feeder and spillage collectors in the treatment with crumbles also supported the hypothesis that animals selected by presentation of concentrate or particle size avoiding the fines that remained at the feeder.

However, the preference test data should be interpreted with caution because, for instance, the result of choice test is influenced by the duration of experiment and by the amount of feed offered to animals (Baumont, 1996). In addition, intake measurements are controversial as a reliable response of feed preference because there are many other factors (digestive, metabolic, hormonal, etc.), apart from palatability, that influence on voluntary consumption; for that reason, behavioral measurements like eating rate is a good option to evaluate the preference because it denotes the motivation to eat feed (Baumont, 1996).

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# CHAPTER VIII

# FINAL CONCLUSIONS

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The different feeding strategies studied in the current thesis to reduce the total concentrate consumption without impairing performance and animal welfare (animal and eating behaviors, rumen health) and, thereby, to improve feed efficiency in Holstein bulls fed high-concentrate diets allow us to conclude that in our experimental conditions:

1. Both alternatives of feeder design studied (reduction of concentrate level at the feeder and a single-space feeder with lateral barriers) tended to be good strategies to reduce total concentrate consumption (4.4 and 6.7% of reduction in cumulative concentrate intake, respectively).

2. Growth rate, feed efficiency, and carcass traits were not negatively affected by alternative feeder designs studied.

3. Although animals fed single-space feeder with lateral protections showed a greater coefficient of variation in concentrate consumption that could suggest a greater risk of rumen acidosis, the remaining indicators compatible with rumen acidosis (laminitis, bloat, rumen wall lesions, liver abscesses, ruminating data, concentrate disappearance velocity, performance, and rumen pH data) do not support this hypothesis.

4. Most of behavioral animal data indicated that alternative feeder designs did not compromise cattle behavior (feeding, resting or rumination patterns, and social interactions). Although remaining unclear certain interpretations of some behaviors observed (oral behavior, time devote to eat straw, sexual activity), these behaviors did not have negative impact on performance and welfare indicators (serum haptoglobin, health status, and rumen health).

5. Pen feeding facilities design (concentrate and straw feeders, and drinker) and animal BW are interrelated and determine the eating and drinking behaviors. These relationships should be taken into account when the feeding zone is designed in order to adequate the feeder and drinker designs according to animal BW requirements to avoid limiting the access to feed and water.

6. Animals fed collective feeders exhibited eating and drinking behaviors more synchronized and gregarious compared with those fed single-space feeder with lateral protections during the growing phase (from 130 to 320 kg of BW); whereas bulls fed collective feeders during the finishing phase (from 320 to 440 kg of BW) adopted a more individualized behavior similar to described in single-space feeder with lateral protections.

7. The rate concentrate disappearance increased as animals grew (52 and 17% during the growing and finishing phase, respectively), and it was also affected by concentrate feeder design. Reducing the concentrate level at the feeder allowed 14% decrease in rate concentrate disappearance, whereas the single-space feeder with lateral protections reached a reduction of 29% in rate concentrate disappearance. This reduction in rate of concentrate disappearance could be related to a decrease in concentrate spillage.

8. The single-space feeder design with lateral protections was able to modify slightly the eating pattern of animals throughout the day, concretely, attending the feeder more frequently at the first two time periods of day (0000 to 0600h and 0600 to 1200 h).

9. The lateral barriers of single-space feeder design (chute) were effective to avoid displacements at concentrate feeder. However, as a counterbalance of this design, the chute originated an increase of waiting time to feed access, especially at the beginning of growing phase, which declined progressively as animals grew and it ceased to be a problem later.

10. The implementation of single-space feeder design with lateral protections requires an adequate feeding space in the straw feeder, especially during the growing phase when the greatest animal straw feeder attendance would be expected.

11. Some evidences were observed in animals fed single-space feeder design with lateral protections (NEFA concentration, some behavioral traits, concentrate intake and growth) during the first 2 wk after fattening arrival that suggested adaptation problems. Calves reared under adaptation strategy (chute not placed and additional feeder) recorded a 25% increase in concentrate intake during the first wk after fattening arrival, and, a 2.2% increased BW on wk 6 after entrance.

12. The adaptation strategy had the main effect on animal behavior and eating pattern during the first wk of adaptation period after calves arrival, increasing the feeder attendance (a great number of animals and feeder visits, and less waiting time to feed access) and also, as a counterpart, increasing the feeder competition (great frequency of displacements).

13. An impoverished physical pellet quality (a durability value below 95%) increased the fines content at the feeder and had a negative impact on cattle performance, reducing the concentrate consumption and increasing the wastage, and tended to decrease the animal growth without influence on feed efficiency.

14. Physical pellet quality alters the eating pattern, thereby, bulls fed poorer pellet quality spent more time at the feeder, reducing the eating rate and number of feeder visits, which lastly resulted in decreased concentrate consumption. This altered eating pattern was interpreted as a selective behavior to particle size sorting avoiding fines (a great percentage of fines at the feeder recorded). In turn, these results were supported by the feed preference test.

15. The physical pellet quality (durability) progressively deteriorated from the pellet mill to the feeder, and the grade of this worsening is determined by pellet quality registered at the pellet mill.