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CICLO XX

THE USE OF MAIZE SILAGE IN BEEF CATTLE DIETS. CURRENT IN-FARM MANAGING OF THE FORAGE AND DIFFERENT EXPERIMENTAL APPROACHES TO EVALUATE THE POTENTIAL TO INCREASE ITS INCLUSION IN THE DIET

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RIASSUNTO

Nel sistema di allevamento intensivo del bovino da carne i piani di razionamento sono basati su diete preparate con la tecnica dell'unifeed, una miscela unica ricca di alimenti concentrati per permettere alti accrescimenti e con una limitata parte di alimenti fibrosi per promuovere il comportamento naturale della ruminazione. In questo tipo di diete il fabbisogno di fibra è soddisfatto da foraggi come la paglia o il fieno di cereali mentre il silomais (SM) non è solitamente considerato dagli allevatori come possibile alternativa.

Il SM è sempre stato ampiamente riconosciuto come alimento adatto alla nutrizione del bovino da carne e il presente progetto è stato sviluppato attraverso diversi approcci sperimentali a sostegno della tesi di un utilizzo di questo insilato come unico foraggio nelle razioni.

Il progetto ha avuto inizio con un'indagine su un cospicuo campione di allevamenti intensivi di bovini da carne situati in un'area in cui la maggior parte delle attività agricole riguarda i cereali ed in particolare il mais. I dati raccolti riguardavano l'uso corrente del SM, le caratteristiche del suo utilizzo, la qualità del prodotto e delle diete in cui esso viene incluso.

Un campione di 406 allevamenti commerciali situati nella Pianura Padana sono stati selezionati in modo da rappresentare le più diverse situazioni di dimensioni aziendali e tipi genetici in cui il SM viene fornito ai vitelloni nella fase di finissaggio. Ogni azienda è stata visitata per raccogliere informazioni sui piani di razionamento e campioni rappresentativi di unifeed e di SM sono stati raccolti al fine di sottoporli ad analisi fisica e chimica. Indipendentemente dalla lunghezza di taglio, la qualità della popolazione di SM raccolti è risultata soddisfacente sia dal punto di vista nutrizionale che da quello dello stato di conservazione, come indicato dai principali parametri chimici e del profilo fermentativo. Un'analisi della distribuzione particellare del SM ha mostrato un'ampia variabilità di dimensione delle particelle, a testimonianza delle diverse lunghezze di taglio ottenute al momento della trebbiatura. In media, il contenuto di SM nelle razioni si è attestato intorno agli 8 kg di tal quale o il 33.4% della sostanza secca (SS) totale della razione pur con un'ampia deviazione standard registrata tra allevamenti (11.4%) . La decisione sulla quantità di SM da inserire nella razione si è rivelata essere indipendente sia dalla composizione chimica che dalle caratteristiche fisiche del foraggio. In diete con alta inclusione di SM il rischio di insorgere di acidosi ruminale, dovuta all'apporto di amido portato da questo insilato è risultata bilanciata sia da una significativa riduzione dell'inclusione di alter fonti energetiche sia dal maggior contenuto fibroso e dalla maggior lunghezza di particelle che avrebbero il compito di stimolare la ruminazione. Un metodo matematico di stima del rischio della perdita di struttura del SM nelle fasi di preparazione della razione ha mostrato che in oltre il 30% degli allevamenti l'insilato ha subito tale danno con la conseguente riduzione del contenuto di particelle lunghe. L'analisi logistica ha poi

dimostrato che il rischio relativo del danno era accresciuto sia da una maggior inclusione dell'insilato nella razione che dall'utilizzo di SM con maggior contenuto di particelle lunghe.

Partendo dai risultati dell'indagine, un successivo studio ha verificato se diversi livelli d'inclusione di SM nelle razioni di vitelloni in finissaggio potesse avere effetti sulle caratteristiche qualitative della carcassa e della carne. Il livello massimo di inclusione del foraggio nelle razioni poteva essere considerato alto, alla luce dei dati registrati nella precedente indagine, e questo ha permesso di verificare nello specifico l'esistenza di effetti negativi in risposta ad una eventuale spinta sulla quantità di SM nelle razioni. Un ulteriore aspetto interessante dello studio è stato il fatto che gli animali presi a campione erano allevati in condizioni normali di mercato, senza interventi dei ricercatori sulle diete o sulla gestione delle pratiche aziendali.

Un campione di 6 allevamenti di bovini da carne è stato selezionato in base ai piani di razionamento applicati durante la fase di finissaggio di vitelloni Charolais. Due aziende non facevano uso di SM, due ne utilizzavano il 22% e due il 44% della SS totale della razione. Cinque vitelloni sono stati presi a random da ogni allevamento e sono stati macellati a maturazione commerciale nello stesso macello. Le caratteristiche della carcassa, come le qualità organolettiche e l'analisi chimica della carne non hanno mostrato variazioni dovute al diverso quantitativo di SM nelle razioni. Dato che pochi parametri sono stati lievemente influenzati dalle differenze delle razioni, non sono state trovate prove a discapito dell'utilizzo di alte quantità di SM nelle razioni per vitelloni Charolais.

Il successivo studio è stato predisposto per verificare la possibilità che un SM convenzionale, tagliato in campo e insilato tramite normali pratiche comuni nel settore dell'allevamento, fosse in grado di sostituire parzialmente o totalmente la paglia di frumento, ovvero il foraggio di bassa qualità la cui presenza è considerata irrinunciabile dagli allevatori per prevenire i problemi di acidosi ruminale. Quattro diete bilanciate per il contenuto di fibra, energia e proteina, formulate con progressive sostituzione di paglia con SM, sono state fornite a quattro vitelloni Simmental in fase di finissaggio seguendo lo schema sperimentale del quadrato latino con periodi di 28 giorni. Fin dal momento della formulazione delle razioni l'aumento del SM nella razione a danno del contenuto di paglia ha dimostrato il vantaggio di poter ridurre progressivamente anche l'apporto di alimenti concentrati grazie alle caratteristiche di questo insilato di apportare fibra ma anche un discreto contenuto di amido. Il consumo di SS e le performance medie dei vitelloni non sono state significativamente influenzate dalle suddette differenze di razionamento. È stato invece riscontrato un effetto nel comportamento alimentare degli animali nel fatto che essi hanno impiegato maggior tempo a consumare la razione senza SM a cui non ha corrisposto un aumento del tempo speso a ruminare la stessa razione. Anche quando alimentati con un SM di tipo convenzionale rispetto alle condizioni di mercato i vitelloni non hanno dimostrato necessità di

selezionare le particelle più lunghe della razione come ad evitare di cadere in situazione di acidosi ruminale. La sostituzione tra foraggi ha influenzato la digeribilità totale apparente delle razioni: la formulazione con il maggior contenuto di SM ha fatto registrare i più alti valori per tutti i parametri di digeribilità. I parametri relativi all'ambiente ruminale e gli indicatori sanguigni dell'equilibrio acido-base sono risultati simili nei vitelloni alimentati con le diverse razioni e allo stesso tempo erano entro margini di sicurezza per quanto riguarda il rischio di acidosi.
I risultati hanno suggerito che un SM di tipo convenzionale rispetto alle condizioni di mercato ha le caratteristiche adatte all'utilizzo come unico foraggio nelle razioni per bovino da carne, senza generare effetti negativi a livello fisiologico e produttivo.

L'ultimo studio ha rappresentato un approccio diverso a sostegno dell'utilizzo del SM nella produzione del vitellone da carne. In questo caso il modello produttivo era quello dei grandi allevamenti del Nord America, nei quali i piani di razionamento sono basati su contenuti di alimenti energetici maggiori rispetto a quelli comuni in Europa Centrale. Lo studio è stato svolto nell'ambito delle comprovate teorie sulla capacità dei bovini di esprimere preferenze alimentari. L'idoneità dell'uso del SM nelle razioni per bovini all'ingrasso è stata testata attraverso l'interpretazione delle preferenze di animali a cui è stata offerta libertà di scelta tra alimenti offerti singolarmente o mescolati in un unifeed standard per le condizioni produttive locali. Un gruppo di 160 manze di incroci di razze da carne inglesi è stato utilizzato in uno studio della durata di 52 giorni: agli animali sono state offerte 4 alternative ognuna consistente nel libero accesso a 2 alimenti posti individualmente in mangiatoie adiacenti. Le associazioni erano unifeed vs unifeed, (scelta unifeed), SM vs granella schiacciata d'orzo (GO)(scelta SMGO), distillers secchi di frumento (DF) vs GO (scelta DFGO) e SM vs DF (scelta SMDF). Le performance dei bovini non sono variate mentre alcune differenze sono state registrate nel consumo di SS di SMDF. Dai risultati dell'interpretazione del comportamento alimentare sono state trovate alcune differenze specialmente tra le manze alimentate con la scelta unifeed e gli altri gruppi: le prime hanno mostrato maggiori tempi di presenza alla mangiatoia, maggiori valori di lunghezza media dei pasti e maggior numero di pasti durante un periodo di 24h. La preferenza è stata chiaramente manifestata nei confronti di alcune associazioni di alimenti, ad esempio nel caso in cui le manze potendo scegliere hanno consumato il doppio del foraggio rispetto a quando avevano a disposizione una razione con foraggi e concentrati mescolati tra loro; un altro evidente esempio è venuto dal comportamento nel caso di ogni associazione di alimenti: il tempo speso dagli animali in un giorno, la durata del pasto e la quantità di ingredienti assunta sono risultate spesso diversi a seconda delle diverse alternative offerte. A livello di stato di salute, in generale le manze che accedevano alla scelta unifeed hanno mostrato la più alta tendenza all'avvicinarsi del loro pH ruminale a soglie di rischio per l'insorgere di acidosi subclinica mentre gli animali del gruppo MSDG sono apparsi quelli meno esposti al rischio. Anche nel caso degli acidi grassi volatili è risultato esserci un legame con il tipo di scelta alimentare: la concentrazione degli acidi totali è risultata più alta nelle manze del gruppo unifeed mentre a livello di singoli acidi si è verificata una generale prevalenza dei composti C2 su quelli C3 a livello del rumine degli animali della scelta MSDG. Questo studio ha convalidato i precedenti risultati riguardo la capacità dei bovini di manifestare preferenze nei confronti di alimenti specifici ed ha confermato i risultati positivi ottenibili dall'utilizzo del SM come foraggio nelle diete per bovini da carne ad alto contenuto di concentrati.

Come conclusione generale si ritiene di poter rispondere positivamente al quesito posto a inizio progetto riguardo la fattibilità di utilizzo di alte quantità di SM nelle razioni per bovini da carne. I punti critici di questo impiego dell'insilato sono individuabili nella gestione del foraggio durante le fasi di taglio in campo della pianta, della preparazione della trincea e della preparazione della razione. Tutte queste operazioni richiedono particolare attenzione e precisione da parte degli operatori dato che le proprietà ed i vantaggi che il SM può offrire agli allevatori di bovini da carne possono essere facilmente compromessi da errori che possono alterare le caratteristiche nutrizionali e fisiche dell'insilato.

ABSTRACT

In intensive beef cattle production feeding plans are based on Total Mixed Ration (TMR) rich in concentrate feedstuff to promote high daily gain and a limited portion of fibrous ingredients is included to promote rumination. In these type of diets, the requirement of fiber is fulfilled by roughages such as straw or hay while farmers do not consider maize silage (MS) as a possible alternative. The suitability of MS for beef cattle nutrition is amply recognized, however the present project was developed through different approaches to support the thesis of the use of MS as sole forage source in beef cattle diets.

The project started with a survey on a conspicuous sample of intensive Italian beef cattle farms, placed in an area in which most of the farming activities involve cereals and in particular maize. The data collected were about the current use of MS, the characteristics of its utilization, the quality of the product and the diets in which the silage is included. A sample of 406 commercial beef cattle farms located in the Po Valley were selected in order to cover the most diverse rearing situations, in terms of farm size and cattle genotype, in which MS was fed to beef cattle during the finishing period. Each farm was visited to collect information about the feeding regimen and representative samples of TMR and MS were collected for chemical and physical analysis. Regardless of chop length, the quality of MS population was satisfactory both by a nutritional and a preservation standpoint, as indicated by principal chemical parameters and fermentation profile. A physical analysis of MS samples showed a wide range of particle size, as result of the different chopping lengths during harvest. On average, MS content in diets accounted for 8 kg of fresh weight or 33.4% to the total dietary dry matter (DM) but a large standard deviation (11.4%) was observed across farms. The decision about the amount of MS to be included in the TMR has shown to be independent on both chemical composition and particle size of the roughage. In diets with a high quantity of MS the risk of occurrence of rumen acidosis due to the additional starch brought by this silage resulted balanced either by a significant reduction in the amount of other starch sources or by the higher fiber content and the coarser size of the dietary particles which should promote a prolonged rumination. A method of estimation of risk for forage damages during diet preparation was applied and results showed that in more than 30% of the farms MS was damaged during this phase with a loss of long particles. A logistic analysis demonstrated that the relative risk of MS damage was significantly increased either by a larger inclusion of the roughage in the TMR or by the use of silage with coarser particles.

From the outputs of the survey, a study was made to verify if different levels of inclusion of MS in diets fed to finishing bulls had any effects on their carcass traits and meat quality. The top level of inclusion of the forage in diets could be considered high as compared to the averages

registered in the first survey, and this helped to verify in specific any negative effect of pushing on the quantity of the silage in diets. A further interesting aspect of this study was the fact that animals tested were reared in beef farms on common market conditions, without interventions by researchers on diets or farm managing. A sample of 6 intensive beef farms was selected according to the feeding plan adopted during the fattening period of Charolais bulls. Two farms did not include any MS in the diet (MS0), while MS represented 22% of the dietary DM in the second group of 2 farms (MS22), and it raised up to 44% of the dietary DM in the last 2 farms (MS44). Five bulls were randomly selected from each farm to be slaughtered at a standard commercial finishing condition in the same abattoir. Carcass quality evaluation as well as meat physical characteristics and chemical analysis showed no variations due to the different silage inclusion in the diet. Since few parameters were slightly influenced by the difference in diets composition, therefore, based on these findings, there were no substantial arguments against the use of a large amount of MS in the fattening diets of Charolais bulls.

The subsequent experimental study was set to verify on the possibility of a conventional MS, chopped at harvest and ensiled through common market practices, was able to partially or totally substitute wheat straw (WS), the commonly used poor forage considered by operators suitable, or even essential, to prevent risks of feeding misbehaviours or onset of rumen acidosis. Four isofibrous, isocaloric and isonitrogenous diets, formulated with stepped substitution of WS with MS were fed as TMR to 4 Simmental bulls in their finishing phase according to a latin square design with periods of 28 days. The stepped substitution of WS with MS, at time of diet balancing, offered the chance to progressively reduce the need for energy concentrates increasing the forage:concentrate ratio. Dry matter intake (DMI) and bulls' average performance were not significantly affected by the changes in the composition and the physical characteristics of diets. An effect in feeding behaviour was noticed in the fact that bulls took longer to consume the diet without silage (MS0) than any other diet while the time spent ruminating was similar across diets. Even when fed only a conventional MS as dietary roughage bulls did not seemed to try to select for the longest particles in TMR as effect of a potential symptom of acidosis. Total tract apparent digestibility was influenced by diet type: the diet with the higher content of MS showed the highest values for all digestibility parameters. Rumen fluid parameters and blood indicators of acid-base status of bulls were similar across diets and they were at all time within safety range as the risk of acidosis is concerned. The results suggested that conventional market quality MS can be used as sole roughage source in beef cattle diets, without adverse effects on performance, feeding behavior and health status of the animals.

The last study was a different approach to sustain the use of MS in beef production. In this case the rearing model was the North American feedlot system, in which diets are based on a higher content of concentrates compared to those used in Central Europe. A study was carried out based on the concept of ability of cattle to express preferences in feeding behaviour. The suitability of MS was tested through the interpretation of the choices of cattle allowed to chose between ingredients offered individually or as a standard TMR.

A total of 160 continental crossbred beef heifers was used in a 52-d feeding period; animals were offered 4 diet choices each one consisting on free access to 2 ingredients placed in adjacent tubs and being: TMR vs TMR (choice TMR), MS vs tempered barley grain (BG) (choice MSBG), wheat dry distillers grain (DG) vs BG (choice DGBG) and MS vs DG (choice MSDG). Performance of cattle did not differ by treatment while some differences were recorded in DMI in favour to the MSDG choice. According to results coming from analysis of feeding behaviour some differences were found especially between TMR heifers and the other animals fed other associations of ingredients: they showed higher bunk attendance durations, highest values of average meal length, higher average meal size and largest number of meals within a 24 h period. The preference was clearly shown when heifers free to choose their diets ate twice the quantity of forage than when fed the ingredients premixed; it was also shown when considering the behaviour within each association of 2 ingredients: time spent by heifers per day and per meal eating, and quantity of ingredients consumed were all different depending on feed associations. When considering the health status, in general, heifers fed TMR had the highest chance to have their rumen pH to drop to dangerous thresholds in term of subclinical acidosis while those fed MSDG seemed to be the less exposed to the risk. A trend was easily evidenced also in the case of volatile fatty acids (VFA): total VFA concentration was higher in heifers offered TMR while when considering the concentrations of individual acids a general prevalence of C2 over C3 acids was clearly shown in the rumen of heifers fed MSDG. This study submitted previous results on the ability of cattle to choose between specific feed ingredients and confirmed the suitability of MS as fiber source for high grain beef cattle diets.

As a general final conclusion, the answer to the question raised at the beginning of this project about the possibility of a large use of MS in beef cattle diets is positive. The critical points of MS utilization in feeding plans for beef cattle are the managing and handling of the forage during plant harvesting, silage making and diet preparation. All these phases require attention and precision by the operators since the properties and advantages that MS can provide to the beef producer can be easily impaired by errors that can alter nutritional and physical characteristics of the forage.

1. INTRODUCTION

1.1. History of the silage-making technique

The word "silage" derives from the Greek "siros" meaning a pit or a hole sunk in the ground for storing maize (McDonald et al.1991). In the definition of Woolford (1984), silage is "the product formed when grass or other material of sufficiently high moisture content, liable to spoilage by aerobic microorganisms, is stored anaerobically". Silage is produced by *ensilage* that is the placing of crop material inside a vessel or a structure called silo. The material may be an entire crop or only part of the crop, such as the grain portion. Three important factors are necessary for proper ensiling: agricultural crop material, moisture and exhaustion of oxygen inside the silo. A silo is the vessel or structure which is sealed to prevent the movement of air into and out of the crop mass. The process of ensilage involves acidification of the crop by the products of the fermentation of sugars within the plant material. The fermentation products are organic acids, principally lactic acid. The acidification is the natural result of the metabolism of the bacteria present on the crop at the time of harvest. The types of acid their amounts depend on the amount of moisture in the crop at the time of ensiling and on the relative populations of the different species of bacteria on the crop. Adequate acidification is vital to successful preservation, especially when the moisture concentration of the crop is relatively high, because the acidity prevents the development of spoilage microorganisms, which are less tolerant of acid conditions than the lactic bacteria (Woolford, 1984; McDonald et al., 1991).

Silage making is probably more than 3000 years old. There are proofs that ancient Egyptians and Greeks stored grain and whole forage crops in silos and murals were found in the Naples Museum showing whole-crop cereals being harvested and loaded into small stone-built silo. Silo were found in the ruins in Carthage, indicating that forages were ensiled there at around 1200 BC and a practice of storing green fodder in pits in the ground covered with dung was recorded to be seen by Cato among the Teutons (Buxton et al., 2003). Little is known about silage making between 100 AC and the eighteenth century, though grass was found to be ensiled in Italy in the thirteenth century and ensiling was practiced in the northern Alps, Sweden and the Baltic region early in the eighteenth century. By the middle of the nineteenth century, interest in the ensiling of grass, sugar beet tops and other crops had spread beyond the Baltic and Germany to most other European countries (Buxton et al., 2003). Possibly the increased movements of scientists and of scientific information around Europe and North America led to the growth of interest in the ensiling in the nineteenth century. During this period many experiences were made in Europe and in North America by farmers and toward the end of the century also governments became aware of the potentiality of ensiling crops and promoted surveys and studies on the topic (Brassley, 1996). The twentieth century was finally the period in which knowledge was refined and together with the progress of machines ensiling has become a spread effective and economical technique for the conservation of high quality crop-derived feedstuff.

1.2. The evolution of silage making in the twentieth century

The silage making progress in the twentieth century had an important step in the invention of the tower silos, which had great diffusion in Europe and North America. In Italy a great diffusion had the Cremasco tower silos, which number reached several thousand units in the Po valley, where Italian ryegrass (*Lolium multiflorum* L.) was a widespread crop. The structure was an airtight concrete upright silos. At the end of the 1920s the number of tower silos in North America was up to 100.000. The number of structures erected in Europe and North America declined in the 1980s and 1990s, as farms expanded in size and livestock number increased, and made the farmers turn to horizontal storage systems. In the 1920s techniques were developed to try to avoid the onset of cool fermentation in wet crops, and consisted in pre-heating the silos or the crop at ensiling to ensure that the temperature of the crop within the silo reached 50˚C, a threshold at which no undesirable fermentation were considered to take place. The process was then abandoned for the costs and the lack of substantial results (Buxton et al., 2003). Farmers have been using various additives or supplements throughout the twentieth century in the hope of making better silage (McCullough, 1977), especially in order to prevent secondary fermentation and the production of butyric acid. The substances were divided in categories of fermentation inhibitors, fermentation stimulants and substrate or nutrient sources. An early system used to judge the quality of silage was the Flieg point scheme created in 1938, which awarded points according to the relative amounts of lactic, acetic and butyric acids: the higher the proportions of lactic and acetic acids to butyric acid, the higher the score and the better the quality. The method was later modified by Zimmer in 1966, placing less importance on the content of butyric acid, presumably in response to the greater incidence of well-preserved silages on farms (Buxton et al, 2003). Another important chapter of the evolution of silage making was the theory on the direct acidification of crop before ensiling, promoted in Italy, Germany and Finland from the second half of the 1910s. Organic and inorganic acids were added to the crop with the aim of reducing the protein breakdown and prevent the growth of harmful bacteria. The important point of the researches on this aspect was that the onset of pH conditions under 4 would inhibit proteolytic enzyme activity. At the same time researches in France, Germany and North America focused on obtaining the same result as adding acids by acting on the stimulation of fermentation by adding lactic acid bacteria or carbohydrate sources, the most diffused of which was molasses (Watson and Nash, 1960). In the late 1960s a different approach was made to the acidification of the crop mass to be ensiled, with the distribution of formic and other organics on mowers for grass crops (Woolford, 1975). Another important field of research which accompanied the silage making throughout the twentieth century was about bacterial inoculants, which received great attention especially in the 1970s and 1980s (Buxton et al, 2003). During the 1960s some efforts were made to increase the protein content of silages, especially to whole plant sorghum and maize, which have always been considered the easy crop to ensile. The idea was to add non-protein nitrogen (NPN) to the crop prior to ensiling. Many experiments, however, demonstrated that the effects on animal performances were not significantly affected, while it was often noticed a loss of silage dry matter (Muck and Pitt, 1994). The next milestone in silage making was the development of forage harvester, which became popular when it was clear the importance of chopping the crop on the reduction of labor to make silage. It was then soon discovered that a crop chopped prior to ensiling improved the quality of fermentations and allowed the process to maintain a lower temperature than the conventional 50˚C without any development of negative fermentation products. The next major innovation was the plastic sheeting (Shukking, 1976), which allowed to seal the ensiled mass and prevent air movements inside the silage. The subsequent important milestones again came from the progress of technology, and were the development of mower-conditioner, in the early 1970s, and then the equipping of kernel processor to forage harvesters, which raised interest especially recently in North America, where whole-plant maize is the predominant silage crop. The latest field of research has been focused on improving hygienic quality of silage, especially to the regard of reducing the aerobic spoilage during feedout period.

The suitability of maize for ensiling had been recognized from the beginning of the historical evaluations of the ensiling techniques to preserve crops. Proofs can be found such as the results of the survey on silage making instigated by the British Government in 1883, which asked the Royal Agricultural Society to commission a survey on 36 farms. One of the results was that maize was evidenced to be the best crop to be ensiled (Brassley, 1996).

1.3. Maize silage in beef cattle intensive systems

In Italy the origin and fast development of the intensive rearing system for beef cattle production found their roots in two main aspects: the vicinity with countries with availability of land to produce the calves to be imported and fattened and the special suitability to cereal productions of the agricultural area (Rioni and Lanari, 1976). In particular the onset of the use of maize silage (MS) as base ingredient in beef cattle diets came after the introduction of the European Union agricultural policies which generated an increase in the prices of cereals. Up to that change the leading model of beef production was that of North America or North Europe, characterized by feeding plans with high content of concentrate ingredients (baby beef or barley beef) (Bittante et al., 1993).

The current intensive systems of production of beef of Central Europe and Po Valley, is characterized by feeding plans typically based on diets prepared as total mixed ration (TMR), very high in energy content, in order to obtain the best growth performance and with a part of fibrous ingredients to promote rumination (Campbell et al., 1992). The portion of fiber is commonly mostly provided by forages and this need is normally fulfilled by the inclusion of a small amount of cereal straw (Cozzi et al., 2008). MS is usually present in most of the diets for beef cattle, and many proofs can be given to explain the reason of the ample diffusion of this ensiled forage, that in the latest decades had gained a fundamental role in cattle breeding in the regions of Central Europe (Barriere, 1997).

The first important aspect that makes MS an interesting feed is the high amount of vegetable mass that allows it to support a greater output of live weight gain per hectare than other feeds and hence optimize soil yield in comparison to pasture (Abdelahdi et al., 2005) or cereal grain or intensively managed grassland (Wilkinson, 1976). The previously described progress in practices and mechanics made it an ingredient easy and fast to be prepared and stored (Kononoff et al., 2003), and with the fundamental properties to be preserved for long periods maintaining constant quality; this makes the forage a better solution than pasture, which has quality characteristics affected by seasonal changing, or grass silage, which has a lower yield and higher variability in quality (Allen et al., 1996; Steen et al., 1998).

After some initial resistances, a certain interest for this feed raised also in those countries in which there were consolidated successful techniques of conservation of other cut crops such as hay (Brassley, 1996) or grass silage (Browne et al., 2004; Kirkland.et al., 2005).
Recent studies, in fact, demonstrated that the use of MS as sole forage or in association with other forages such as grass silage itself in beef cattle diets allows to obtain better live gains and yields at slaughter rather than feeding animals with sole grass silage (Juniper et al., 2005).

1.4. Nutritional aspects

From the nutritional point of view MS is an ingredient which is an important energy source, but being after all a forage, its point of strength definitely derives from the characteristics related to its fiber composition. Comparing MS with other ingredients of common use in beef cattle feeding plans, either forages or concentrate feeds (Table 1), it is possible to assert that the forage has characteristics that put it in a middle position between a fiber source and an energy ingredient. It is also recognized that a marginal point of weakness of this forage is the protein content which is inadequate and requires addition with other sources, but a minimal integration is sufficient to balance the diets (Juniper et al., 2005; Browne et al., 1998).

Table 1: chemical composition of ingredients available for cattle nutrition

	DM	CP	NDF	Starch	UFV
Maize silage*	33	7.5	45.8	29.3	0.8
Grass silage	26.5	12	53	ND	0.6
Maize meal	87	10	10	75	1.3
Dry beet pulps	87	9	40	0.4	0.9
Wheat straw	88	4	80	1	0.3

* average of analysis of samples of North-East of Italy, season 2005, from Pioneer Hi-Bred Italia (NIRS laboratory, Department of Animal Science, University of Padova). DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; UFV: unitè fouragère viande.

When considering in specific the principal parameters of the chemical composition, MS has a humidity content that makes it an ingredient which allows good mixing with other feedstuffs (De Campeneere et al., 2002), and this is an important characteristic, considering that in beef cattle nutrition the energy and protein portion is provided by ingredients mostly in form of dry meals. The starch has high digestibility (Fernandez et al., 2004b) and the fiber composition also has positive characteristics: MS cell walls are more suitable for microbial fermentation as compared to the lignified structures of wheat straw cell walls compared to straw, which is the most diffused fiber source in beef cattle TMR, as previously described. Straw has a very slow rumen degradability and rate of passage and thus its inclusion in the fattening diet could limit feed intake. Recent studies, instead, evidenced that MS with a chop length kept sufficiently long (19mm), used as sole forage, could fulfil the role of roughage in beef cattle finishing diets (Burato et al., 2001; Cozzi et al., 2005).

In terms of inclusion in diets, the use of MS in cattle diets can reach 60% of diet DM (ZoBell et al., 2002) even if higher levels, i.e. till 80% of diet DM, have been demonstrated not to have negative consequences (Fernandez et al. 2004a). About the association with other ingredients in TMR there are no information about any limitations of use of the forage with any particular feed; it has been instead found to be an ideal complement of diets in which energy is provided by high humidity ingredients (i.e. maize ear silage) and, especially in the finishing phase, in diets in which energy comes from maize meals (Mader et al., 1991).

1.5. Aspects affecting quality of maize silage

The very first aspect that assures the nutritional and structural quality of MS is of course the preparation and maturation: proper practices during these phases are fundamental to avoid deterioration of the crop mass which can lead to great loss of feed and production of substances which can impair the performance but also the health status of cattle. Other important aspects which can influence the nutritional characteristics of this forage, and in particular the aspects related to the structure properties, are the type of hybrid, the period of harvesting and the handling procedures from the field to the silo and then, after maturation of the silage, in all processes involved in diet preparation till the forage reaches the feeding bunk.

The type of hybrid is a choice made for the adaptation of a plant to specific needs in terms of soil and seasonal requirements but also made for the quality characteristics of the plant. The first aspect affects the chemical composition of the plant, first of all, from the standpoint of the nutritionist, in terms of DM content and the fiber:starch ratio (Andrae et al., 2001; Ivan et al., 2004). The choice of special qualities involves mostly the choice between dent and flint genotypes. Dent type maize grains tend to have a greater percentage of flowery endosperm, whereas flint type maize grains have a greater percentage of vitreous endosperm. In vitreous endosperm, the starch granules are surrounded by protein and are embedded in a matrix, which limit digestion (Johnson et al., 1999).

Time of harvest is a basic cause for the DM content of the crop and at the same time for the chemical composition, in particular type of carbohydrates, both aspects which directly affect DMI and performance in general of animals. A range of maturity, described by a DM content of 29 to 30% of fresh weight (Phipps et al., 2000) is often indicated, out of which performance are negatively affected. When the crop is harvested at an immature stage the high content of humidity and a fiber:starch ratio unbalanced toward fiber is the main reason of negative effects on beef cattle performance. As kernel fill increases from two-thirds milkline to blacklayer, DM digestibility decreases in whole-plant MS, despite an increase in starch content and decrease in fiber content (Bal et al., 1997).

The handling procedures to process MS include all mechanical procedures during harvest, and subsequent compression by tractors on the pile of cut forage stored to be ensiled and, after maturation, all the procedures to collect the forage from the silo, mix it in the TMR and distribute it in the feeding bunks. Some critical points can be found in these procedures: in general the chopping length at harvest is the first factor to influence the efficiency of MS as a fiber source (Campbell et al, 1992). This factor is critical for the requirements for a better compression and storing of the vegetal mass in the preparation of the silage (McDonald et al., 1991) or to maximize feed ingestion by animals (SCAHAW, 2001). In addition, modern forage harvesters equipped with on-board rollers, used with increasing frequency to harvest maize, disrupt kernel, cob and stover portions of maize plants harvested for silage with the aim of enhancing in vivo digestion (Johnson et al., 1999); however an improper setting of the devices could easily lead to a lost of structure that could the affect the fiber function in ruminant diets.

The last aspect that needs special care is the handling of the forage during diet preparation. The fiber properties of MS can be compromised by errors in managing, such as when a wrong order of loading ingredients in the mixing wagon or a prolonged time of mixing exposes the forage to an excessive contact with the cutting parts of the machines (Lammers et al., 1996).

1.6. Critical points of maize silage preparation and utilization

Some aspects need special care when using MS for beef cattle diet preparation, and some others could be considered the point of weakness of this ingredient. All these aspects can be summarized as follows:

- the quality of the product, and hence the proper evolution of all the maturation process, must be a warrantee. It has been discussed about the recognized experience and expertise of operators in charge of all the practices of harvest and preparation to conservation, but errors are always possible, and a wrong management of the ensiled forage could vanish all the nutritional and economical advantages it entails.
- a concern is sometimes raised on the limitation of ingestion in case of high level of inclusion of the forage.
- some other criticisms are addressed to the content of organic acids, which may influence the palatability of diets containing MS. Contradictory results can be found on this topic (Ferret et al., 1997 JDS), and anyway a real risk could happen when MS represent high percentage of the diet ingredients (i.e. 90%) (Browne et al., 2004).
- a concern often raised regards the effects on meat quality and colour in particular, since diets rich in forages have shown detrimental effect on this important quality trait (Mandell et al., 1998).
- MS as sole ingredient does not represent a balanced diet. It should be supplemented with protein and minerals such as calcium, phosphorus and sodium, as well as trace elements such as cobalt and possibly zinc (SCAHAW, 2001).

1.7. Maize silage and nutritional aspects concerning animal welfare

As previously said, beef cattle in their finishing phase, are fed diets with high contents of concentrate ingredients to obtain best live weight gain and the inclusion of fibrous components is limited to a small portion to censure a minimal ruminal activity (Campbell et al., 1992). From the standpoint of beef producers, this part of the diet is often considered an encumbrance that could limit the ingestion of higher quantities of feed with higher nutritional values. Hence it is not rare for the fiber provision in the diet to be scarce or with qualities unable to fulfil the aim of promoting rumination and maintain rumen in normal physiologic conditions and avoid the onset of acidosis events. It is important, however, for a portion of physically structured ingredients to be included in cattle feed as a lack of roughage, and thus an excess of concentrates, can lead to rumen acidosis (Owens et al, 1998), and can also generate other disorders. Studies have shown that depriving young bulls of roughage leads to a significantly higher incidence of social licking (Andersen et al., 1991). This is a normal behaviour but, if carried to extremes, can be detrimental or be the expression of disorders.

The importance of ensuring a minimum level of fiber in diets is evidenced by the fact that the Scientific Committee on Animal Health and Animal Welfare (SCAHAW, 2001), the group of scientists gathered by the European Union to study the characteristics of the beef cattle industry in order to prepare suggestions and regulations on animal welfare, takes directly into consideration the part of the diet with the role to promote rumination. In the report some thresholds are indicated for the quantity or quality of the fiber portion, and in particolar the suggestions are to include a minimum of 10% of long fiber ingredients (Journet, 1988) or a minimum of 40% of diet represented by particles with a length higher than 2 mm (Sauvant et al. 1999). The report suggest that due to the high portion of starch, MS is a well-suited forage to obtain high weight gains. It also put evidence on the fact that in the case of very finely chopped maize, the 'roughage effect' is reduced and metabolic disorders and oral stereotypes can occur analogous with those encountered with concentrates or pelleted feeds (SCAHAW, 2001). Otherwise, a diet with a chop length higher than that of the conventional practices (19mm vs 10mm) has been demonstrated to fulfil the fiber requirements of beef cattle diets in which MS was the sole fiber source, with better rumination behaviour and no detrimental effects on performance (Cozzi et al., 2005).

1.8. The intensive beef cattle model of Central Europe and Italy, main characteristics

In Italy beef cattle represents 25% of the agricultural production (Cozzi et al., 2003) and is represented by the intensive rearing system of the Po Valley, the area in which over 75% of the national production takes place (ISMEA, 2001).

Bulls represent the most important category and represents the 73% of the total meat offer. Almost the entire number of animals destined to slaughter derives from national farms (97%), in which 41%of the fattened units are imported from abroad and 59% are of national origin. The latter derive for a 34% from beef specialized farms and for the rest from dairy farms. For the great variety in existing rearing system sit is possible to separate the industry between two main typologies:

- intensive system: bulls are reared in closed buildings in Po plain (Lombardy, Veneto, Piedmont, Emilia Romagna regions) fed diets based on MS and concentrates. There is a light bull, from specialized beef breeds, with a final weight of 450-500 Kg at an age of 14-16 months, or a heavy bull, French beef breeds (especially from import of "broutard" calves: Charolaise, Limousine, Blonde d'Aquitaine) or Italian, with a final weight of 600-650 Kg and an age of 16-20 months (ISMEA, 2006).
- Extensive system: bulls are reared in non-confined systems in Piedmont region, Central Italy and islands, usually through complete cycle (cow-calf till fattened bull). Animals are from original Italian breeds, (Piedmontese, Romagnola, Marchigiana, Chianina, Podolica, Maremmana), fed on pasture with a part of concentrate ingredients till a final weight of 650 Kg. (ISMEA, 2006).

Fattening beef bulls (and heifers) in the intensive system are fed high concentrate diets, provided the diet as total mixed ration (TMR) to promote a synchronized intake of roughage and concentrates which decreases the risk of the occurrence of metabolic acidosis. Maize is the main crop used for the formulation of these diets and it is fed either as dried ground meal or as high moisture ear silage and whole plant silage.

Even considering the same cattle breed, the feed composition of the diets changes according to the geographical location of the fattening unit. Beef farmers of Lombardy feed the maximum amounts of MS and lower the use of cereals meal. In Veneto there is the largest use of dried beet pulps and maize meal while in Piedmont MS is partially replaced by maize ear

Among long fiber roughages, straw is almost the only source included in the beef rations of Veneto and Lombardy while in Piedmont this roughage is partially or fully replaced by meadow hay; in the Veneto region, the fiber portion is generally represented by MS and cereal straw, included in diets at average quantities of 7kg e 0.9kg respectively (ISMEA, 2006).

Feed composition and the physical form of the diet changes significantly in the case of the extensive farms (ISMEA, 2006). The use of MS is marginal and this forage is fully replaced by legume and meadow hays (Sargentini et al., 2005).

2. RESEARCH ACTIVITY

2.1.Use of maize silage in beef cattle feeding during the finishing period*

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An initial survey on a conspicuous sample of intensive beef cattle farms to monitor the current use of MS, the characteristics of its utilization, the quality of the product and the diets in which it is included. Eventually evaluate strength and weakness point of the managing and handling of the forage. For the number of farms involved in this survey and the number of cattle heads the sample can be considered a good representation of the beef industry in year 2005, at least in the Veneto region. This survey gave results which analysis and interpretation provided many of the aspects to be developed and tested in the subsequent studies

Introduction

Under intensive rearing systems, the diets for finishing beef cattle are generally offered as total mixed rations (TMR), rich in concentrate feedstuffs and starch sources, to promote the maximum daily gain. However, the inclusion of roughage in the diet is necessary to maintain normal ruminant function (Campbell et al., 1992). Among forage sources there has been a growing interest towards maize silage (MS) because of its high starch content and the quality of the fibrous portion (Allen et al., 1996). Maize silage is considered a good roughage source for the finishing phase of fattening bulls since it requires a moderate energy and protein supplementation to meet the nutrient requirements of the animals (Browne et al., 1998). As compared with pasture or grass silage, the most common forages used for beef cattle feeding across Europe, MS is an alternative that allows a higher ratio of animals grown per hectare of farm land (Abdelhadi et al., 2005). When properly produced and stored, this roughage is easy to handle and is highly palatable to cattle (Atwood et al., 2001). Moreover, the nutritional quality of MS is more stable than pasture, which quality varies consistently with seasons changes (Allen et al., 1996), or grass silage, because of its wide range of botanical and chemical composition (Steen et al., 1998). A recent study has also demonstrated that the progressive substitution of grass silage with maize silage has the potential to reduce the time required to finish beef cattle with no apparent detrimental effects on meat quality (Juniper et al., 2005). Despite the increased use of MS by beef farmers, there is still a lack of scientific information on how MS should be handled when part of beef cattle diets. Therefore the present study monitored the current use of MS in a large sample of intensive beef farms. The aim of the research was to evaluate the MS quality and to compare the chemical composition and physical properties of finishing TMR which differed for the quantity of MS or for the use of MS with different particle size.

Materials and methods

Location and time of the study

The study was undertaken on a sample of 406 commercial beef farms located in the Po Valley, the main area for beef production in Italy with more than 2 million heads finished per year (Cozzi and Ragno, 2003). The period of data collection lasted from January to July 2005 and only MS harvested in the year 2004 were considered.

Farm selection

The study considered a wide sample of farms in order to cover more diverse rearing situations in terms of farm size and cattle genotype in which MS was fed to beef cattle. All fattening

units housed a minimum of 40 animals above 400 kg live weight in multiple pens indoors. The cattle population of the entire farm sample was 233,664 heads and its distribution is described in Figure 1 where the selected farms are grouped in 4 classes according to their size, measured as number of cattle per farm. Only 15.6% of the total cattle population was raised in farms with less than 331 animals per unit, while more than 60% of the animals were fattened in the biggest farms.
As cattle genotype was concerned, majority of cattle were of French pure breeds (Charolaise 35%; Limousine 16%) or French Crossbreds (35%). The remaining 14% of cattle were dual purpose breeds or crosses between beef bulls and dairy cows. A majority of cattle were imported from France while the percentage of animals native to Italy accounted for less than 5% of the total population.

Diet info and sample collection

Each farm was visited to collect information about the feeding regimen of the finishing cattle. The composition of the TMR offered to animals was recorded and, due to the variety of feedstuff in diets of the whole farm sample, each ingredient was associated to one of the following 7 feed categories to simplify the analysis of the diet composition (as fed):

- maize silage;
- maize ear silage;
- cereal grains and meals;
- dried sugar beet pulps and other fibrous concentrates;
- long fibre roughages (i.e. hay, straw);
- protein sources (i.e. soybean meal, maize gluten feed, protein-vitamin-mineral premixes with crude protein > 150 g/kg of dry matter (DM);
- molasses and vegetal fats.

In each farm, a representative sample of TMR and MS were collected for subsequent chemical and physical analysis. The TMR sample was taken from the manger of one pen at time of feeding to avoid any selection by the animals. The sample of MS was collected directly from the silo.

Chemical and physical analysis

All samples of TMR and MS were chemically analysed for dry matter (DM), crude protein, ether extract, ash and starch according to AOAC (1990). The analysis of neutral detergent fibre (NDF) and acid detergent fibre of the same samples was conducted according to Van Soest et al., (1991) and the content of non-fibrous carbohydrates was calculated as 100 – (crude protein + ether extract + ash + NDF). Maize silage pH was measured with a glass electrode on squeezed juice taken from the fresh sample. Silage volatile fatty acids and lactic acid content were measured by high performance liquid chromatography according to Canale et al., (1984). Silage ammonia nitrogen was measured with a specific ion-selective electrode.

The particle size distribution of TMR and MS samples was determined using a mechanical siever derived from the Penn State Forage Particle Separator (Nasco, Fort Atkinson, WI, USA). The instrument had four screens with hole sizes of 19, 13, 8 and 4 mm respectively and a bottom pan. Samples were separated into five fractions following the procedure of Lammers et al., (1996). Each fraction was then weighed and divided by total sample weight to calculate the percentage of the five fractions of particles. The amount of long particles of TMR and MS samples were then calculated by summing the percentages of particles retained by the 13mm and the 19mm sieves.

Maize silage damage during diet preparation

The mechanical equipment used to handle the forages after the harvest may reduce particle size. In the case of MS, the silo unloaders and TMR mixers often grind and churn the forage particles causing a loss of the roughage long particles (Lammer et al., 1996). A simple mathematical method was developed in order to verify the occurrence of any silage particles damage. For each farm, the percentage of long particles (19mm + 13mm) of MS, measured by mechanical sieving, was multiplied by the amount of silage included in the TMR to obtain the fresh weight of long particles of MS in that ration. The former value was then expressed as percentage dividing it by the total fresh weight of the TMR and the result represented the minimum acceptable value, or the situation in which long particles of TMR would be represented only by MS. If the percentage of long particles actually measured by the mechanical sieving of the TMR sample collected in the same farm was below this minimum acceptable value, a loss of MS long particles had certainly occurred.

A: percentage of MS long particles in TMR

B: percentage of all TMR long particles

A = B: minimum acceptable value

A<B: acceptable value

A>B: MS structure damage

Statistical analysis

Two specific classification factors of the farm population were created to allow the statistical analysis of the experimental data. The former factor classified the farms according to the amount of MS included in the TMR (Figure 2). Mean and standard deviation (SD) of the distribution obtained for this classification factor were used to assign each farm to one of the three following classes:

'Low' which included all samples with a value below the mean value minus 0.5*SD;

'Middle' which included all samples of the population between 'low' and 'high' classes;

'High' which included all samples with a value above the mean value plus 0.5*SD;

A similar procedure was adopted for the latter classification factor which was based on the content of long particles of the MS (Figure 3) and the three resulting classes were named as 'Short', 'Long' and 'Mid' respectively. All the experimental data were submitted to analysis of variance within the GLM procedure of SAS (2001) and the statistical model considered the effects of the class of MS in the diet, the class of long particles content of MS and the relative interactions. Two separate logistic analysis were performed within PROC LOGISTIC of SAS (2001) to calculate the odds ratio estimates for the occurrence of MS damage during the TMR preparation. The first one considered the risk of MS damage due to the use of an increasing amount of the roughage in the diet, while the second tested the risk due to the use of MS with a different content of long particles.

Results

The overall average inclusion of MS in the diet was 7.79 kg of fresh weight but there was wide variation among farms with a SD of 2.45 kg. As shown in Figure 2, 8 kg of MS fresh weight was the amount fed by the largest number of farms (20% of the total farm sample) followed by 10 kg (14%) and 6 kg (12%) and these three different values closely reflected the three classes of silage inclusion in the TMR used in the statistical processing of the data (Table 1). The results of the partition of the farms sample according to the content of long particles of MS are reported in Table 2. On average the content of long particles was 143 g/kg of silage fresh weight with a SD of 73 g/kg. The Short class included all the farms in which the content of MS long particles resulted below 107g/kg of MS fresh weight while in Long class the minimum percentage of long particles was 179 g/kg of fresh weight.

Maize silage chemical composition and particle size

Chemical composition and fermentation profile of MS samples are shown in Table 3. All these variables were not affected either by the different level of inclusion of MS or by its content of long particles. Consistent with the chemical composition, the particle size distribution of MS did not change according to its rate in the diet (Table 4). The partition of the silage particles among the different sieves showed on average that 50% of the particles were retained by the 8 mm sieve. This fraction of particles as well as the one retained by the 4 mm sieve and that of the bottom pan were significantly reduced by a progressive increase in the content of the longer particles of the silage (Table 4).

Diet formulation and analysis

As shown in Table 5, the inclusion of increasing amounts of MS had a significant impact on the feed composition of the TMR for finishing beef cattle. In comparison with the Low class of diets in which there was a moderate inclusion of MS, the average increase of 2.7 kg of MS as fed in the Middle class significantly reduced the amounts of cereals and fibrous concentrates. A further increase in the amount of MS in the High class diets lowered either some of the energy sources included in the TMR such as maize ear silage and fibrous concentrates or the long fibre roughages. On the contrary, the use of MS with a different particle size had no effect on the feed composition of the TMR, neither on the content of long fibre roughages (Table 5).

As expected, the inclusion of increasing amounts of a wet roughage like MS progressively lowered the DM content of the TMR (Table 5). Within DM, starch content was similar across the 3 classes of MS inclusion, whereas there was a progressive increase in the fibrous content of the TMR from Low to High diets.

The chemical composition of the TMR was very similar across the three classes obtained when considering the content of long particles of the silage (Table 5).

The results of the physical analysis of the TMR samples are reported in Table 6. The inclusion of increasing amount of MS in the diet had no effect on the percentage of long particles of the TMR, while it resulted in a significant increase of the particles retained by both the 8 mm and the 4 mm screens lowering the percentage of feed material recovered in the bottom pan. When the class of silage long particles was considered, there was significant increase in the percentage of TMR particles retained by the 19, 13 and 8 mm screens in diets using a Mid silage in comparison to the Short. The diets made with the Long silage showed a further increase in the particles retained by the 13 and 8 mm screens to the detriment of the ones accumulating on the 4 mm screen. No silage long particles effect was observed on the percentage on TMR particles recovered on the bottom pan of the instrument (Table 6).

Maize silage damage during diet preparation

The proposed procedure to assess the maize silage damage during the preparation of the TMR demonstrated the loss of MS long particles in 32% of the samples. Considering the different class of MS inclusion in the diet, the percentage of damaged diets was 23% for the Low class and it was increased up to 31% in the Middle one. However the logistic analysis reported in Table 7 showed that the risk of silage damage was similar between the two classes. In the case of the High class the estimated percentage of damaged TMR (42%) almost doubled that of Low class and the relative risk set by the logistic analysis was 2.44 time higher. When diets were analyzed according to the class of silage long particles (Table 7), a loss of MS long particles was observed only in 12% of the Short class samples. The percentage of damaged diets increased to 30 and 67% for the Mid and Long classes respectively. The logistic analysis showed that the relative risk of long particles damage was increased 3.1 and 14.8 times respectively when the Mid and the Long class diets were compared with the Short class ones.

Discussion

The study considered a large number of beef cattle farms in which MS was included in the TMR fed during the finishing period. The amount of inclusion of the roughage in the diet showed a wide variation across farms but on average MS represented 33.4% of the total DM. Maize silage was the main constituent of the dietary DM in 194 farms (48% of the total sample) and in these diets the contribution of MS as percentage of the total DM increased up to 40.3%. According to Allen et al., (1996), the high starch content and the quality of the fibrous portion are the main reasons of the large inclusion of MS in beef cattle diets. These nutritional properties offer the potential to lower the amount of energy concentrates given during the finishing period or to reduce the duration of the finishing period itself (Juniper et al., 2005). The chemical characteristics of MS have shown to affect its intake by beef cattle (Wilkinson et al., 1978), therefore MS quality is a key factor when aiming at a large inclusion of the roughage into a finishing TMR. With this in mind, the average quality of MS samples analysed in the present study was satisfactory as indicated by the DM and starch content and by the satisfactory fermentation profile with a predominant lactic acid fermentation and a modest content of ammonia nitrogen (McDonald et al., 1991). It is of particular interest to note that the silage quality did not decline with a coarser chopping of the plant. This result should address the farmers towards the increase of the chopping length which should maximise the amount of silage particles capable to stimulate chewing (Mertens, 1997). In a recent study carried out by Cozzi et al., (2005) with finishing Limousin bulls, the animals fed a coarsely chopped MS (chop length = 19mm) as the sole roughage source of the TMR showed similar growth performance and a prolonged rumination time per unit of DM intake than the control bulls fed a diet made of conventional MS (chop length = 9mm) and straw.

Data about the feed and chemical composition of the TMR recorded in the present study showed how beef farmers who are using large quantities of MS in the finishing diet are aware of the high amount of starch brought by the roughage and, in order to prevent the occurrence of rumen acidosis, they lower the quantity of other starch sources such as maize ear silage and cereals. Always at this regard, it must be noticed that feeding diets with high quantities of MS should give a further prevention of rumen acidosis through the increase of dietary NDF and acid detergent fibre (Rebhun, 1995).

The physical analysis of the MS samples collected in the farms showed a wide range of the roughage particle size as the result of different chopping lengths adopted during the harvest of the crop. However, the amount of inclusion of MS in the TMR has shown to be absolutely unaltered by the content of long particles of the roughage. The practical consequence of this decision is that even in diets made with the coarsest class of MS there wasn't any reduction in the amount of straw or other long fibre roughages. A clear explanation for this decision came from the analysis of TMR particle size which showed that for more than 30% of samples there was a loss of MS long particles during diet preparation. The relative risk of this loss has shown to be increased either by a large inclusion of MS in the TMR or by the use of silage with coarser particles. Several strategies should be recommended to prevent MS long particles losses during TMR preparation. The roughage should be carefully loaded into the mixing wagon avoiding any potential grinding during this process. The use of silage cutters is likely to increase the risk of particles damages and at this regard it must be noticed that this device was operating in 95% of the farms in which the finishing diet showed a loss of MS structure. In the case of the farms in which TMR was undamaged, the use of silage cutter was reduced down to 88%. A further guideline to minimize the loss of the long particles brought by MS regards the order of feedstuffs load in to the mixing wagon during the TMR preparation. Maize silage should be the last feedstuffs to be loaded and its mixing time should be the minimum required to allow the proper amalgamation with the other ingredients of the TMR. In the present study, 28% of the farms in which the diet showed a loss of MS long particles did not follow this recommendation.

The prevention of MS long particles from the mechanical damage during the TMR preparation could avoid the current inclusion of straw or other long fibre roughages required to increase the physical effectiveness of the dietary particles (Mertens, 1997). In this way, the energy density of the diet should be increased with a likely positive outcome by the animals during the finishing period.

Conclusions

Data from a large sample of intensive beef farms have shown the good nutritional quality and the satisfactory fermentative pattern of MS which makes this roughage an interesting forage base for finishing cattle diets. The decision about the amount of MS to be included in the TMR has shown to be independent on both chemical composition and particle size of the roughage. The risk of a greater occurrence of rumen acidosis in diets with a large inclusion of MS has shown to be controlled either by balancing the additional starch brought by the roughage with a significant reduction in the amount of other starch sources or by the increase of the NDF content and the coarser size of the dietary particles which should promote a prolonged rumination.

A more careful handling of MS during the TMR preparation could reduce the damage and the consequent loss of its long particles which at the moment imposes the inclusion of straw or other long fibre roughages in the TMR for rumination purpose. By increasing the energy density of the TMR, this strategy should lead to improved growth performance of beef cattle during the finishing period.

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Tables

Table 1. Classification of the farm population according to the amount of maize silage (kg of fresh weight, unless otherwise stated) included in the diet for finishing beef cattle.

	Class of maize silage inclusion in the diet		
	Low	Middle	High
Farms (n)	130	172	104
Mean quantity	5.1	7.9	10.9
Minimum	1.0	7.0	9.5
Maximum	6.5	9.0	17.9

Table 2. Classification of the farm population according to the content of long particles of maize silage (g/kg of fresh weight, unless otherwise stated).

	Class of maize silage long particles		
	Short	Mid	Long
Farms (n)	149	166	91
Mean content	79	140	251
Minimum	22	107	179
Maximum	106	178	443

Table 3. Change in chemical composition and fermentation profile of maize silage (g/kg dry matter basis, unless otherwise stated) due to the class of inclusion of the roughage in diets for beef cattle and to the class of long particles content of the feed.

	Maize silage									
	Class of inclusion in the diet (I)			Class of long particles (LP)			SE	Significance (*P*)		
	Low	Middle	High	Short	Mid	Long		I	LP	I*LP
Chemical composition										
Dry matter (g/kg fresh weight)	352	350	344	352	348	346	3.8	ns	ns	ns
Ash	40	41	41	40	41	41	0.4	ns	ns	ns
Crude protein	75	77	76	76	76	75	0.5	ns	ns	ns
NDF[a]	440	442	446	441	444	443	2.5	ns	ns	ns
ADF	250	251	255	250	253	253	1.9	ns	ns	ns
NFC	409	406	402	408	404	405	2.8	ns	ns	ns
Starch	314	308	306	312	307	308	2.8	ns	ns	ns
Fermentation profile										
pH (units)	3.8	3.8	3.8	3.8	3.8	3.8	0.1	ns	ns	ns
Lactic acid	48	50	49	48	49	49	1.2	ns	ns	ns
Acetic acid	24	26	26	25	25	25	0.8	ns	ns	ns
Propionic acid	6.4	6.5	6.7	6.5	6.6	6.8	0.2	ns	ns	ns
Butyric acid	0.7	0.7	0.7	0.7	0.7	0.7	<0.1	ns	ns	ns
Ethanol	6.2	5.9	5.6	6.0	5.9	5.8	0.2	ns	ns	ns
Ammonia N (g/kg total N)	67	68	67	68	68	66	1.1	ns	ns	ns

[a] NDF, neutral detergent fibre; ADF, acid detergent fibre; NFC, non-fibrous carbohydrates.

Table 4. Change in particle size distribution of maize silage (g/kg of fresh weight) due to the class of inclusion of the roughage in diets for beef cattle and to the class of long particles content of the feed.

	Maize silage									
	Class of inclusion in the diet (I)			Class of long particles (LP)			SE	Significance (P <)		
	Low	Middle	High	Short	Mid	Long		I	LP	I*LP
Particle size distribution										
Particles retained by a sieve of 19 mm	34	38	40	17y	35x	61w	22	ns	0.001	NS
Particles retained by a sieve of 13 mm	125	121	115	62y	105x	194w	34	ns	0.001	NS
Particles retained by a sieve of 8 mm	500	495	502	507w	507w	482x	72	ns	0.02	NS
Particles retained by a sieve of 4 mm	238	243	242	300w	250x	174y	53	ns	0.001	NS
Particles on the bottom pan	103	104	101	114w	103x	90y	33	ns	0.001	NS

Within a row and class, means with different letters (w,x,y) differ for the reported threshold of significance.

Table 5. Effects of the class of inclusion in the diet and of the class of long particles of maize silage on feed (kg of fresh weight) and chemical composition (g/kg of dry matter, unless otherwise stated) of total mixed rations for beef cattle.

	Class of inclusion in the diet (I)			Class of long particles (LP)			SE	Significance (P <)		
	Low	Middle	High	Short	Mid	Long		I	LP	I*LP
Feed categories										
Maize silage	5.17y	7.90x	11.28w	8.07	8.08	8.21	1.06	0.001	ns	ns
Maize ear silage	1.13w	0.91w	0.57x	0.87	0.77	0.98	1.45	0.05	ns	ns
Cereals meals and grains	2.71w	2.38x	2.43x	2.50	2.53	2.50	1.31	0.05	ns	ns
Fibrous concentrates	1.00w	0.77x	0.52y	0.78	0.75	0.76	0.72	0.001	ns	ns
Long fibre roughages	0.78w	0.71wx	0.65x	0.75	0.75	0.65	0.37	0.07	ns	ns
Protein sources	2.18	2.17	2.28	2.33	2.16	2.15	1.04	NS	ns	ns
Molasses and vegetal fats	0.08	0.09	0.01	0.08	0.07	0.03	0.31	NS	ns	ns
Chemical composition										
Dry matter (g/kg of dry matter)	591w	550x	500y	552	551	540	7.2	0.001	ns	ns
Ash	54	53	53	53	54	53	0.7	NS	ns	ns
Crude protein	130w	129w	127x	128	127	130	1.0	0.05	ns	ns
Ether extract	35	34	33	34	33	34	0.8	NS	ns	ns
NDF[a]	307y	316x	331w	316	324	314	4.9	0.001	ns	ns
ADF	154x	158x	169w	158	164	159	5.0	0.001	ns	ns
NFC	474w	469w	457x	469	462	469	3.2	0.01	ns	ns
Starch	322	323	316	322	315	323	2.9	NS	ns	ns

[a] NDF, neutral detergent fibre; ADF, acid detergent fibre; NFC, non-fibrous carbohydrates. Within a row and class, means with different letters (w,x,y) differ for the reported threshold of significance.

Table 6. Effects of the class of inclusion in the diet and of the class of long particles of maize silage on particle size distribution (g/kg of fresh weight) of total mixed rations for beef cattle.

	Maize silage									
	Class of inclusion in the diet (I)			Class of long particles (LP)			SE	Significance (P <)		
	Low	Middle	High	Short	Mid	Long		I	LP	I*LP
Particle size distribution										
Particles retained by a sieve of 19 mm	35	37	38	32x	42w	37w	28	NS	0.01	NS
Particles retained by a sieve of 13 mm	60	60	57	50y	59x	68w	31	NS	0.001	NS
Particles retained by a sieve of 8 mm	178y	196x	245w	185y	205x	233w	67	0.001	0.001	NS
Particles retained by a sieve of 4 mm	203y	220x	237w	247w	227x	187y	64	0.003	0.001	NS
Particles on the bottom pan	523w	483x	422y	487	466	475	96	0.001	NS	NS

Within a row and class, means with different letters (w,x,y) differ for the reported threshold of significance.

Table 7. Logistic analysis of the relative risk of occurrence of maize silage damage during diet preparation.

Effect	Point estimate	95 % Wald confidence limits	
Class of silage inclusion in the diet			
Middle vs. Low	1.57	0.93	2.63
High vs. Low	2.44	1.39	4.30
Class of silage long particles			
Mid vs. Short	3.14	1.73	5.68
Long vs. Short	14.80	7.66	28.59

Figures

Figure 1: Partition of the farms sample according to the number of cattle raised per single farm (□) and distribution of the cattle population in percentage within classes (▓)

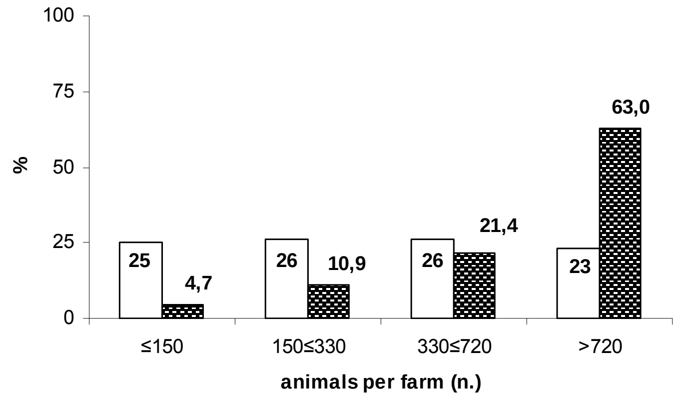


Figure 2: Distribution of the farm population according to amount of maize silage (kg of fresh weight) included in the diet for finishing beef cattle.

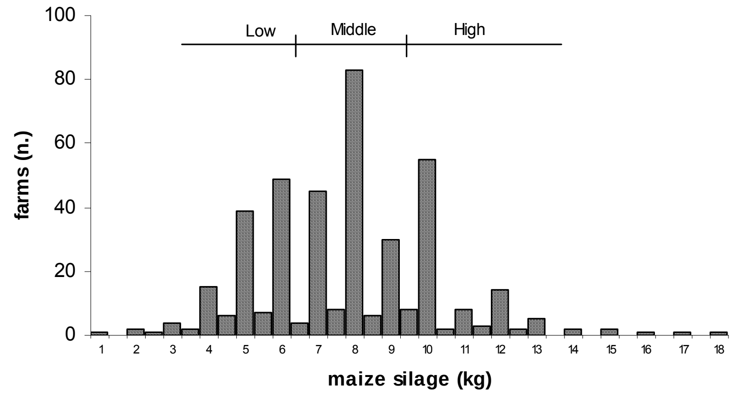
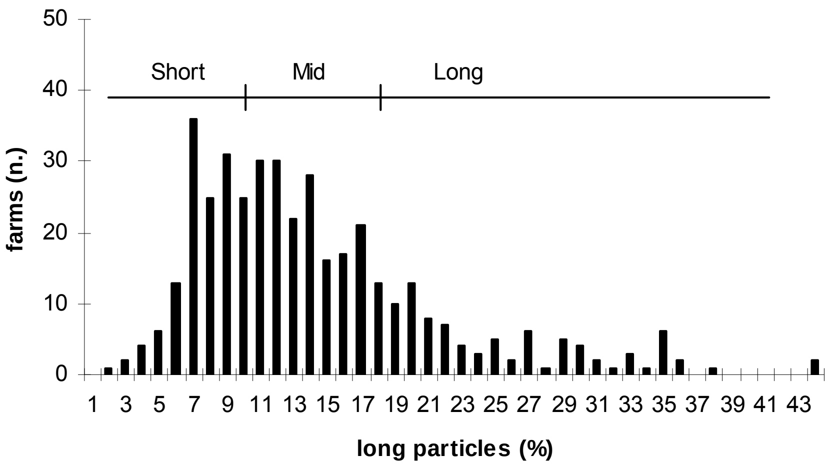


Figure 3: Distribution of the farm population according to the percentage of long particles of maize silage.



2.2. Meat quality from charolais bulls fed diets with different levels of maize silage inclusion*

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A concern is often raised by meat market operators on the use of large quantities of ensiled forages in beef cattle diets regarding possible detrimental effects on meat quality and colour in particular. From the outputs of the previous survey, a study was made to verify if different levels of inclusion of MS in diets fed to finishing bulls had any effects on their carcass traits and meat quality. The top level of inclusion of the forage in diets could be considered high as compared to the averages registered in the first survey, and this helped to verify in specific any negative effect of pushing on the quantity of the silage in diets. A further interesting aspect of this study was the fact that animals tested were reared in beef farms on common market conditions, without interventions by researchers on diets or farm managing.

Introduction

Maize silage (MS) has shown to be an interesting feedstuff for beef cattle because of the joint provision of starch and physical effective fiber (Cozzi et al., 2005) and its palatability (Atwood et al., 2001). Nowadays, the adequate management of maize plant at harvest and its proper ensiling allow stockmen to produce a home grown forage, which preserves good quality standards for long periods. The great field yield and the energy content of this roughage have shown to increase the number of cattle grown per unit of farm land (Abdelhadi et al., 2005) and this justifies the great interest towards the use MS by beef production systems traditionally based on other forage sources, such as grass silage (Browne et al., 2005; Juniper et al., 2005) or hay (Comeford et al., 1992). Even the cost of feeding should benefit from a large inclusion of MS in the beef cattle diets due to a reduced need for other energy and fiber sources generally bought by the farmer from the feed market (Juniper et al., 2005). However, some aspects related to the large use of MS in beef cattle feeding still need some further discussion. One main concern regards the effects on meat quality and colour in particular, since diets rich in forages have shown detrimental effect on this important quality trait (Mandell et al., 1998). The aim of this study was to verify if the inclusion of increasing amounts of MS in diets fed to Charolais bulls have any effects on their carcass traits and meat quality.

Material and methods

The research considered a sample of 6 beef cattle farms located in the Veneto region which finished Charolais bull imported from France. The farms were selected based on the percentage of the total dietary dry matter (DM) provided by the inclusion of MS in the ration fed during the fattening period. Two farms did not use any maize silage (MS0), while this roughage represented 22% of the dietary DM in the second group of 2 farms (MS22), and it raised up to 44% of the dietary DM in the last 2 farms (MS44). In order to describe the feed composition of the diets, five categories of ingredients were considered: maize silage, other forage sources, sugar beet pulps, cereal based concentrates and protein sources (Table 1).

Five bulls were randomly selected from each farm by a cattle market expert and they were transferred to the same abattoir for the slaughter. Age and carcass weight data were collected along with the carcass fleshiness and fatness scores given by a trained inspector according to the European grading scheme (OFIVAL, 1984). Twenty-four hours after slaughtering, a joint sample of the m. *Longissimus thoracis* was excised from the 5th to the 9th rib of each right half carcass and vacuum packaged to be stored at 4°C for an ageing period of 8±2 days. After this period, meat pH and colour were measured on samples after exposure to air for 1 hour at 2°C (Boccard *et al.*, 1981). Colour was determined using a CR 100 Chromameter (Minolta Camera, Osaka, Japan) equipped with C illuminant, and colour data were expressed according to the Hunter-Lab system (Boccard et al., 1981). Cooking losses were calculated for a 2.5 cm thick steak by difference in weight before and after a period of 50 min at 75°C water bath. Five cylindrical meat cores 1.25 cm in diameter were then excised from the cooked steak for the instrumental measurement of tenderness using a Warner-Bratzler shear force meter. Uncooked meat samples were freeze-dried and ground to measure DM, crude protein, intramuscular fat and cholesterol content (AOAC, 1990). All data were submitted to GLM procedures of SAS (2001) and the statistical model considered the effects of diet (level of MS inclusion) and farm within diet. The significance of the diet effect was tested by using farm within diet as error term and its 2 degrees of freedom were used to test the significance of linear and quadratic trend for the level of MS inclusion. The minimum threshold for the statistical significance was $P<0.05$.

Results and discussion

The average composition of the 3 types of diets based on the main feedstuffs categories (Table 1) showed, as expected, that the inclusion of increasing amounts of MS allowed a progressive reduction of long fiber roughages and energy feedstuffs, either sugar beet pulps or starch sources. A decreasing trend was observed also the protein sources but this was only the consequence of the different choice among protein feedstuffs made by different farms. The slaughter age was similar for all the bulls (Table 2) but those fed the MS44 diet showed the lightest carcass weight. This result confirms previous studies in which the administration of finishing diets for beef cattle with a high Forage:Concentrate ratio led to lower final carcass weights (Coombs et al., 1990; O'Sullivan et al., 2003). Based on the feed chemical composition data obtained from the literature (NRC, 2000; INRA, 1988) diets had a similar protein and NDF content and energy density (on DM basis: CP 13 to 14%, NDF 30 to 32%, Unitè Fouragère Viande 0.9 to 1.0 per kg DM).

Browne et al. (2004) hypothesized that a negative effect of diets rich in MS on growth performance should be the consequence of a lower voluntary intake induced by the fermentation acid content of the roughage. However results on this topic have often shown to be contradictory, as reported by Ferret et al. (1997). In the present research, the different level of MS inclusion in the diet had no effect on carcass quality as shown by the similar scores given for fleshiness (SEUROP) and fatness by the trained inspector (Table 2). This result was consistent with those of Brennan et al. (1990) who found no differences on main carcass traits feeding diets ranging from low to high maize silage:maize grain ratios. Confirming the previous results reported by Cozzi et al., (2005) feeding finishing Limousin bulls a diet in which MS provided 45% of the total DM, meat pH and the colour parameters were not affected by an increasing inclusion of this roughage in the diet (Table 3). The ensiling process it is likely to lower the carotenoid content of the fresh forage which has been demonstrated to be the key factor to worsen meat colour (Knight et al., 1998). Therefore, the previous evidences clearly demonstrate the inconsistency of the hypothesized negative effect of a large dietary inclusion of MS on cattle meat colour.

Consistent with the colour evaluation, meat cooking losses and tenderness (measured as shear force) were similar across dietary treatments (Table 3). Chemical analysis of meat samples showed no effects of MS inclusion on meat DM, intramuscular fat and protein content and these results were in agreement with other studies which compared MS diets with various Forage:Concentrate ratios (De Campeneere et al., 2001).

Only the cholesterol content was progressively reduced according to a linear trend when MS increased in the diet. A similar result was obtained by Descalzo et al. (2004) comparing grain finishing diet with pasture.

Conclusions

Based on these findings, there are no substantial arguments against the use of a large amount of maize silage in the fattening diets of Charolais bulls. No detrimental effects on carcass traits and meat quality were observed even when MS represented 44% of the total DM fed during the finishing period. Therefore, the ultimate decision about the amount of MS to be included in the diet of beef cattle must be based only on the daily gain over feed cost ratio.

Acknowledgments

The Authors want to thank Pioneer Hi-bred Italy for the financial support to the carrying out of the study.

Tables

Table 1. Average composition of the experimental diets by main feedstuff categories (% of total DM)

	Diet		
	CS0	CS22	CS44
Maize silage	0	22	44
Other forages	11	7	5
Sugar beet pulps	22	15	0
Cereal based concentrates	53	47	43
Protein sources	14	9	8

Table 2. Carcass evaluation of Charolais bulls fed diets with increasing levels of maize silage

		Diet			Significance		SE
		CS0	CS22	CS44	Lin.	Quad.	
Age at slaughter	Months	20.4	19.7	19.7	ns	ns	2.7
Carcass weight	Kg	436	446	396	*	ns	30
SEUROP	score†	4.1 ± 0.3	4.1 ± 0.3	4.0 ± 0.0			
Fatness	score‡	2.7 ± 0.5	2.7 ± 0.5	2.5 ± 0.5			

† 1 = poor to 6 = super; ‡ 1 = minimum to 5 = maximum.

* P<0.05; ns = not significant.

Table 3. Meat quality traits from Charolais bulls fed diets with increasing levels of maize silage

		Diet			Significance		SE
		CS0	CS22	CS44	Lin.	Quad.	
pH		5.51	5.58	5.57	ns	ns	0.07
Colour:							
Lightness	L	42	40	42	ns	ns	2.6
Redness	A	23	24	24	ns	ns	1.4
Yellowness	B	12	12	12	ns	ns	1.4
Cooking losses	%	28.8	29.8	28.9	ns	ns	3.2
Shear force	kg/cm^2	3.4	3.1	3.4	ns	ns	1.0

ns = not significant.

Table 4. Chemical composition of meat from Charolais bulls fed diets with increasing levels of maize silage

		Diet			Significance		SE
		CS0	CS22	CS44	Lin.	Quad.	
Dry matter	%	26.4	26.5	27.3	ns	ns	0.9
Crude protein	% DM	84.7	86.3	89.1	ns	ns	2.6
Intramuscular fat	% DM	11.7	10.3	7.3	ns	ns	2.7
Cholesterol	mg/100g fresh weight	59.5	58.4	52.4	**	*	1.3

**P<0.01; * P<0.05; ns = not significant.

2.3. Feeding behaviour, diet digestibility, rumen fluid and metabolic parameters of beef cattle fed total mixed rations with a stepped substitution of wheat straw with maize silage.*

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The following study was planned on basis of the results of the two previous studies, especially as regards chemical and physical characteristics of MS, and as a development of a study carried out by the department in 2005 on the possibility of substituting straw with longer chopped MS in beef cattle diets (Cozzi et al., 2005). This experimental study was set to verify on the possibility of a conventional MS, chopped at harvest and ensiled through common market practices, to be able to partially or totally substitute wheat straw, the commonly used poor forage considered suitable, or even essential, to prevent risks of unpaired feeding behaviour or onset of rumen acidosis.

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Introduction

During the fattening period, beef cattle are usually fed diets rich in concentrate to promote maximum daily gain. However, a minimum amount of coarse fibrous ingredients must be included in their diet in order to promote adequate rumination (Campbell et al., 1992). A lack of fiber in the diet can lead to abnormal behaviours such as stereotypes, as expression of nutritional disorders (SCAHAW, 2001), and is a major cause of ruminal acidosis (Owens et al., 1998). Several studies have in fact recommended a minimum requirement of long fiber roughage in beef cattle diets (INRA, 1988; Sauvant et al., 1999; SCAHAW, 2001).

In many of the intensive fattening farms of Central Europe and Po Valley, where beef cattle are fed diets prepared as total mixed ration (TMR) usually containing maize silage (MS), this need for long fiber is normally fulfilled by the inclusion of a small amount of cereal straw (Cozzi et al., 2008). The addition of straw to the TMR is chosen because the main forage source of the diet, whole plant maize silage, is processed into small particles which size is considered unable to fulfil the physiological and ethological needs of cattle. However, straw has a very slow rumen degradability and rate of passage and thus its inclusion in the fattening diet could limit feed intake. An alternative solution to avoid this intake limitation could be to increase the particle size of MS in the TMR, since this roughage has a fibrous portion more degradable than straw. This feeding strategy has been successfully proven by Cozzi et al. (2005), who reported no detrimental effects on growth and slaughter performance of Limousin bulls fed a TMR in which coarsely chopped MS (19 mm theoretical chop length) fully replaced wheat straw. However, beef farmers still refrain from introducing this practice in their feeding plan, because the conventionally finely chopped maize crop at harvest (<10 mm of theoretical chop length) ensure better ensiling results (McDonald et al., 1991). In this feeding situation, it becomes important to define if using a conventional MS in beef cattle feeding plans requires an addition of straw and eventually what is the optimum amount of straw to be included in the TMR. Thus, the present study investigated the effects of a stepped substitution of wheat straw (WS) with a conventional MS in a TMR fed to beef cattle during the fattening period on growth performance, dry matter intake (DMI), feeding behaviour, digestibility, rumen fluid parameters and blood metabolites.

Material and methods

Experimental design and diet formulation

The study was carried out according to a 4 x 4 latin square design with periods of 28 days. Four experimental diets were formulated using different combinations of maize silage (MS) and wheat straw (WS) as forage portion. MS was a conventional roughage produced in the 2006 season with the harvester theoretical chop length set at 9 mm and the processor roll clearance at 1 mm. WS was pre-chopped to avoid day to day variations of its particle size during the trial (Table 1). All the remaining feedstuffs were standard commercial ingredients and they were coarsely ground (2 mm) before being used in the preparation of the diets. The four experimental diets were formulated to be isofibrous and this criteria was obtained by a stepped substitution of WS with MS as follows:

- MS0: wheat straw 20% - maize silage 0% of total dietary dry matter (DM);
- MS20: wheat straw 10% - maize silage 20% of total dietary DM;
- MS35: wheat straw 5% - maize silage 35% of total dietary DM;
- MS50: wheat straw 0% - maize silage 50% of total dietary DM.

All diets had the same net energy content estimated by using Unité Fouragère Viande table values for all ingredients INRA (1988). Energy density and protein content of the diets were similar and set according to the INRA (1988) requirements for dual purpose breed young bulls with an average daily gain (ADG) of 1.2 kg/d and an average live weight of 450 kg. The mineral and vitamin supplementation of the diets was provided by a commercial premix (Omnibeef light, Methodo Chemicals, Novellara – RE –Italy) which had a minimum content of buffers. Diets were prepared as TMR by manually mixing all feed ingredients. The moisture content of MS50 diet was equalized by thoroughly mixing different amounts of water to the other rations (Table 2). This allowed for better mixing of the feed ingredients minimizing the separation among dry feed particles within each TMR.

Animals, housing structures and management

The research was carried out at the experimental farm of the University of Padova, located in Legnaro, Italy. The trial took place between October 2006 and February 2007. Four Italian Simmental bulls with an average live weight of 384±45 kg and an age of 10.5±0.6 months were brought from the same Simmetal Breed Center. The animals were housed in 4 individual concrete-floor tie stalls within an enclosed barn. Straw was used as bedding material during the first 3 weeks of each period of the latin square which represented the adaptation phase to the new TMR. Wood shavings replaced straw as bedding material during the last week of the period which was dedicated to experimental measurements and sample collection. All stalls had a separate feed bunk and a watering point. Diets were provided daily as TMR for *ad libitum* intake based on 10% feed refusal (as-fed basis) and delivered once at 09:00 h. Bull health status was monitored daily and, to avoid the risk of too stressful frequent handlings, their live weight was recorded only at the beginning and at the end of each period. The difference between these two values was used to calculate ADG for the period.

Feeding behaviour and diet selection

Daily DMI was calculated based on the average intake over three consecutive days (22-24) of each period in which the amount of feed distributed and the orts collected from the feed bunk after 24 h were weighed. Bull feeding behaviour was recorded for 24 h on day 24 starting in the morning at the time of feed delivery. The animals were monitored using 2 wide angle black and white video cameras placed in front of the feed bunks and connected to a time-lapse video recorder. Eating activity and rumination were recorded every 5 min, using the scan sampling technique (Martin and Bateson, 1993). Animals were considered on eating activity when they had the head in the feed bunk and were in contact with the diet. According to Maekawa et al. (2002), each activity was assumed to persist for the entire 5 min interval. Eating and ruminating times per kilogram of dietary DM and NDF were calculated by dividing the total time spent performing these activities by the intake of DM and NDF, respectively.

Partition of the total DMI into consecutive time intervals of the day and diet selection was measured the day after each observation session to avoid any interference on bulls' behaviour. On these days, original dietary samples were collected from each feed bunk at the time of feed delivery. Samples of the diet remaining in the bunk of each pen were collected 8 and 24 h after diet delivery in order to determine if feed sorting was occurring. During 8 h samplings, the diet left in the bunk was collected, weighed, sampled and returned to the bunk; while at 24 h sampling, feed residues were weighed, sampled and discarded. DM intake for two time intervals of the day (0-8 h and 9-24 h from diet delivery) was measured by subtracting the weight of residual diet from the initial amount, taking into consideration the weight of the samples collected for laboratory analysis. These samples along with those of the original diets and those of the two roughage sources used for their formulation were submitted for subsequent physical analysis using a Penn State Forage Particle Separator (Nasco, Fort Atkinson, WI, USA).

The instrument had two screens with hole sizes of 19 and 8 mm, respectively, and a bottom pan. Following the procedure of Lammers et al. (1996), each sample was separated into three portions: 1) greater than 19 mm in length retained by the top screen, 2) between 19 and 8 mm in length retained by the middle screen, 3) less than 8 mm in length accumulating on the bottom pan. Each portion was weighed and divided by total sample weight to obtain the percentage of three fractions of particles. Diet selection activity was monitored by comparing the particle size distribution of a given TMR at the time of feed delivery with those measured on samples taken from the bunk after 8 and 24 h. Selection indices were calculated for the three fractions of dietary particles obtained with the physical analysis by dividing the content measured in the feed residue of the specified time interval by the content of the original diet. Index values < 1 indicated preferential consumption, > 1 indicated selective refusals, and = 1 indicated no selection (Cozzi et al., 2005).

Diet digestibility assessment

Samples of each diet fed on days 26 and 27 of the latin square period were collected at the time of feed delivery and composited. Faecal samples were taken from each bull by grab sampling from the rectal ampoule at 08:00, 16:00 and 24:00 h on day 26, and 04:00 and 12:00 and 20:00 h on day 27. The faecal samples of a given bull were composited by period and stored along with the corresponding sample of the TMR for subsequent analysis. Digestibility coefficients for DM, organic matter (OM), crude protein (CP), NDF, ADF and starch were calculated using acid-insoluble ash (AIA) as marker following the procedure reported by Merchen (1988).

Chemical analysis

Samples of MS, WS and experimental diets were collected during the four periods of the study and then submitted for chemical analysis including DM, CP, ether extract, ash and starch (AOAC, 1990). Their fibrous portion was measured as NDF and ADF according to Van Soest et al. (1991), whereas the content of NFC was calculated as 100-(crude protein+ether extract+ash+NDF). Measures of MS pH were taken with a glass electrode on squeezed juice taken from fresh samples. The determination of silage VFAs and lactic acid content was carried out by high-performance liquid chromatography according to Canale et al. (1984). Silage ammonia-nitrogen content was measured with a specific ion-selective electrode.

Dietary and faecal samples collected during the digestibility trial were analyzed in duplicate for DM, CP, ash, starch, NDF and ADF using the same methodologies previously mentioned. The analysis of AIA was performed in duplicate as proposed by Van Keulen and Young (1977).

Ruminal measurements

Individual rumenocentesis were carried out 4 h after feed delivery on day 28 of each period according to Nordlund et al. (1995). Rumen fluid was collected using a 13G 105-mm needle from a 20x20 cm disinfected area in the left flank, from the ventral sac of the rumen, approximately 15–20 cm caudal and ventral to the costocondral junction of the last rib. An aliquot of 8 ml of rumen fluid was immediately acidified with metaphosphoric acid (25% wt/vol) and stored at 4ºC until samples arrived at the laboratory where they were stored at -80ºC until subsequent analysis. Ruminal pH was measured immediately after sampling using a portable pH meter (Model HI98150, Probe Model FC201D; Hanna Instruments, Villafranca Padovana, Italy). Rumen fluid samples were thawed, then centrifuged at 1300 rpm for 15 min. Concentration of the VFAs was determined on the supernatant by gas chromatography as described by Hamada et al. (1968).

Blood sampling

Individual blood samples were collected by venipuncture from the jugular vein into heparinised 10 ml test tubes (Venoject, Terumo Europe, Leuven, Belgium) 3 h after feed delivery on day 28 of each period. Samples were stored on ice after collection, transferred to the laboratory and analyzed within 15 min upon arrival for the assessment of blood gas and acid-base status. Blood pH, $P0_2$ and pCO_2 concentrations were measured with a blood-gas analyzer (IL-Synthesis 15, Instrumentation Laboratory, Barcelona, Spain). From CO-oxymetry output data obtained by the same instrument, HCO_3, base excess in blood (BEb) and base excess in extra cellular fluid (BEecf) were calculated.

Statistical analysis

Data were analyzed using MIXED procedure of SAS (2001) and the statistical model considered the main effects of period, animal and diet of the latin square design. Differences among diets were determined using the LSMEAN option. Feed selection data were analyzed within diets, taking the effects of animal and time of sampling (8 and 24 h) into consideration. All analysis considered $P<0.05$ as the minimum threshold for statistical significance.

Results

Roughage sources and diet characteristics

The chemical composition and particle size of the two roughage sources used in the study are reported in Table 1. MS had satisfactory chemical composition as shown by its content of DM, NDF and starch. It also had low pH and good fermentation profile with a prevalence of lactic acid and low content of butyric acid, ethanol and $N\text{-}NH_3$. The physical analysis on the two forages showed that MS had more than 800 g/kg of particles greater than 8 mm but only 69 g/kg of the silage particles were retained by the 19 mm screen. WS had the same percentage of particles greater than 8 mm but most of them were retained by the 19 mm sieve of the instrument (Table 1).

The gradual substitution of WS with increasing the amounts of MS had a significant impact on the feed composition of the TMR (Table 2). In comparison with the MS0 diet, in which there was no MS, the inclusion of silage progressively reduced the amounts of maize meal and dried beet pulp. As a consequence, the forage:concentrate ratio of the diets increased from 17:83 in MS0 to 29:71, 41:59 and 53:47 in MS20, MS35 and MS50, respectively.

Since the two roughage sources used for the diet formulation had different particle sizes (Table 1), the substitution of WS with MS also had a significant impact on the particle sizes of the four experimental diets (Table 3). The longest dietary particles retained by the 19 mm sieve decreased as MS increased in the TMR. Conversely, as the MS contribution to the total dietary DM increased, there was a parallel increase of the particles retained by the 8 mm screen (Table 3). The percentage of the finest particles collected by the bottom pan was higher in MS0 and MS20 diets due to their greater content of ground concentrate (Table 2).

Feeding behaviour and feed selection activity

Bulls DMI ranged between 8.8 and 10.0 kg/d and it did not vary with the progressive substitution of WS with MS as a dietary roughage source (Table 4). Feed intake was greater during the first 8 h after feed delivery than during the following 16 h (Figure 1). During this interval, the animals consumed on average more than 70% of their daily DMI which was not affected by the type of diet offered. Feed intake was reduced during the evening hours and overnight when bulls consumed only one third of their total daily intake of DM (Figure 1).

Similarly, bulls spent more time eating during the 8 h interval following feed delivery, but spent significantly more time consuming the MS0 diet than all other diets, either in the first 8 h after feed delivery ($P<0.01$) or during the entire daytime ($P<0.05$) (Table 4). Bulls fed the MS0 diet required on average 22 min to eat 1 kg of dietary DM. This time was significantly lowered to 14 min/kg of DM ($P<0.05$) when bulls consumed the MS20 diet in which MS represented averagely 20% of the total DM and WS was reduced from 17 to 11% of the total dietary DM (Table 2). The gradual increase of MS in the DM composition of the TMR did not further reduce the time required for bulls to eat 1 kg of DM (Table 4).

The different roughage composition of the experimental diets did not affect either the total time spent ruminating or the partition of this activity during the two time periods of the day (0-8 and 9-24 h from feed delivery) and no effects were also recorded on the time required by the bulls to ruminate 1 kg of DM or NDF (Table 4).

The cumulative average of the time spent eating by the bulls during the 24 h of observation clearly demonstrated that the prolonged time required to consume the MS0 diet was recorded since the time of feed delivery and the difference between this diet and those containing MS continuously increased over time (Figure 2).

Regardless of the diet, feed selection by bulls was minimal, particularly during the first 8 h interval after feed delivery, during which the highest feed intake was recorded (Table 5).

Animals did not eat the wood shavings used as bedding material to replace the straw during the observation period of experimental measurements and sample collections.

Diets digestibility and rumen fluid parameters

The stepped substitution of WS with MS significantly affected the total tract apparent digestibility of the diets (Table 6). The MS0 and MS20 diets which included none or a minimum amount of MS as partial replacement for WS (Table 2) had the lowest digestibility coefficients for all chemical constituents considered (Table 6; $P<0.001$ for DM, OM, CP, NDF and ADF; $P<0.05$ for starch). Greater levels of MS in the TMR resulted in a significant increase of diet digestibility due to the contribution of either the fibrous fraction or of protein and starch. In fact, for all chemical constituents considered, the highest digestibility coefficients were recorded when the MS50 diet was fed.

Ruminal fluid samples taken 4 h after feed delivery for all diets showed no differences in pH values, which ranged from 6.5 to 6.7 (Table 7). These values were obtained despite the high energy density of the diets and minimal supplementation with mineral buffers (Table 2). The different forage:concentrate ratio of the experimental diets resulting from the stepped substitution of WS with MS did not affect the total concentration of VFAs in the ruminal fluid as well as the contribution of the individual VFAs (Table 7).

Performance, health status and blood sample analysis

The animals weighed 384 ± 45 kg and 551 ± 43 kg at the beginning and end of the trial respectively and their ADG, ranging from 1.4 to 1.6 kg/d, was not significantly affected by the type of diet (Table 4). The small number of animals and their frequent stressful handling imposed by sampling protocol of the study were the more reasonable explanations for the lack of significant difference in ADG across dietary treatments. The health of the young bulls was satisfactory throughout the trial and no specific medical treatments were required during the four periods of the latin square. Similar results among dietary treatments were observed for blood pH and for a set of metabolic parameters used to assess cattle blood gas and acid-base status (Table 8). The values recorded for all these blood parameters were within the ranges found in the literature (Goad et al., 1998; Brown et al., 2000).

Discussion

MS is considered a good roughage source for fattening bulls since it requires a moderate energy and protein supplementation to meet their nutrient requirements (Browne et al., 1998). When properly made and stored, this roughage is easy to handle and highly palatable (Allen et al., 2003). A recent survey carried out by Cozzi et al. (2008) indicated that on average MS represented 33% of the dietary DM in a large number of farms in the Po Valley. Two key reasons for the inclusion of a high percentage of MS in beef cattle diets include the high starch content and the quality of the fibrous fraction (Allen et al., 2003). In addition the nutritional properties of MS have been shown to reduce the time required to finish beef cattle with no apparent detrimental effects on meat quality in comparison with other roughage sources (Juniper et al., 2005).

The results of this study clearly show that the inclusion of MS in beef cattle diets is also advantageous in lowering the amount of concentrates required to meet the growth requirements of the animals. This should result in a lower cost of feeding (Juniper et al., 2005), since concentrate is generally more expensive than roughage.

The progressive substitution of WS with a conventional MS significantly modified the physical properties of TMR. Since most of particles brought by MS were retained by the 8 mm screen of the Penn State Forage Particle Separator, diets with a high level of inclusion of this roughage increased the presence of this fraction of particles to partially replace both the longest (> 19 mm) and the smallest ones (< 8 mm). However, feed intake and feeding behaviour were not affected by these changes in the physical properties of the TMR with the exception of prolonged eating time observed for the MS0 diet during the first 8 h post-feeding. Regardless of the diet, the partition of DM intake during the day and the total time spent ruminating observed in the present study closely resembled those reported by Cozzi and Gottardo (2005) for Limousin bulls fed a TMR in which a coarse MS was the only roughage source.

Even the rumen environment did not seem to be impaired by the stepped substitution of the two forages in diets. Ruminal pH was above 5.6 in all cases which, according to Nagaraja and Lechtenberg (2007) should be considered the threshold for rumen acidosis in beef cattle fed high concentrate diets. The profile of VFAs was stable across diets with acetate:proprionate ratios always above 2.2 which have been suggested as a cut off value for being at risk of ruminal acidosis (Kleen et al., 2003; Morgante et al., 2005).

Bulls did not benefit from the inclusion of WS as part of the roughage portion of their TMR; in fact the animals were not actively sorting and selecting long particles of the diet to attenuate ruminal pH. Based on these findings the use of conventional MS as the sole roughage source within TMR appears to provide enough physical structure for optimal growth performance by beef cattle. Consistent with this results, De Campeneere et al. (2002) concluded that there were no health and welfare problems associated with feeding beef bulls diets formulated with MS as the sole roughage source in which the forage:concentrate ratio reached 37:63% of the total DM.

Further support for using MS as the sole roughage source for beef cattle diets was observed in digestibility trials: the results showed a positive relation between the amount of silage included in the TMR and the apparent digestibility coefficients of dietary DM and organic matter. The highest digestibility data of MS50 diet observed in the present study were consistent with those measured by

French researchers (Fernandez et al., 2004a) on dairy cows fed diets made with 80% MS on DM basis and they were obtained with a positive contribution of both fibrous and non-fibrous constituents of the diet.

The increase in digestibility associated with the substitution of WS with MS could be attributed to several factors. If the improved apparent digestibility of NDF was due to the higher availability of MS cell walls to microbial fermentation as compared with the lignified structures of WS cell walls, the positive results for dietary starch and protein were likely consequent to a change in their site of digestion along the gastrointestinal tract. Cattle fed WS ate more starch from maize meal and they spent more time eating (significantly for MS0 and numerically for MS20) than cattle fed higher proportions of MS. A prolonged eating time may have increased liquid outflow rate from the rumen (Seo et al., 2007) which acts as vehicle for transporting digesta out of the forestomachs. Hence, diets with a high straw content may have generated a higher flow of finely ground feed particles of maize meal from the rumen to the small intestine increasing the post-ruminal load of starch. Support to this hypothesis comes from Yang and Beauchemin (2006) who reported that feeding highly fibrous forages like WS shifts the site of starch digestion from the rumen to the intestine. The increased availability of starch in the intestine has been shown to reduce digestion efficiency in cattle (Nocek and Tamminga, 1991) and to promote hind gut fermentation which can also lead to the loss of endogenous nitrogen and reduction of the apparent CP digestibility (Arieli et al., 2001). In addition, NDF is inefficiently digested past the rumen and this could have increased the rate of passage of the whole digesta through the intestine further compromising digestion of nutrients.

Finally, the concern for potential risks of ruminal acidosis related to feeding conventional MS as the sole roughage in beef cattle TMR was not sustained by the results obtained in the present study. Bull health and feeding behaviour, as well as the values measured for a wide set of metabolic acidosis indicators clearly demonstrated that this risk is overestimated particularly considering the minimum quantity of buffers included in the mineral supplement of the experimental diets.

Conclusions

The study has verified that a conventional MS obtained by chopping the maize plant at the theoretical length of 9 mm can be used as sole roughage source in beef cattle diets. The stepped inclusion of this roughage to replace WS in a TMR made with a minimal use of buffers as mineral supplements had no adverse effects on health, DM intake and feeding behaviour of Simmental young bulls. Since MS is a source of fiber and starch, its inclusion in large quantities in beef cattle diets as an alternative to WS could allow to markedly reducing the need for inclusion of other energy supplements. Positive outcomes of this substitution should be a significant feed cost reduction and a higher TMR digestibility due to the increased contribution of NDF and the reduction of the post-ruminal burden of starch. Furthermore, bulls fed MS as the sole forage source had no evidence of increased risk of acidosis and they did not generally sort for the longest particles of the TMR. Based on these findings, the inclusion of a small amount of WS in beef cattle rations as an additional source of roughage, like in the case of MS35 diet, should be advisable only when the physical structure of MS were damaged by improper use of silage cutters and/or during TMR preparation.

Acknowledgements

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Tables

TABLE 1. Chemical composition and physical properties of the roughage sources used for the formulation of the experimental diets

		Maize silage	Wheat straw
Chemical composition:			
DM	g/kg	338	914
Ash	g/kg DM	36	82
CP	"	76	28
NDF	"	424	782
ADF	"	222	472
NFC	"	429	93
Starch	"	330	
pH	units	3.74	
Lactic acid	g/kg DM	60	
Acetic acid	"	18	
Propionic acid	"	4	
Butyric acid	"	1	
Ethanol	"	3	
N/NH_3	% of total N	52	
Particle size distribution:			
Particles retained by a sieve of 19 mm	g/kg	69	659
Particles retained by a sieve of 8 mm	"	737	165
Particles on the bottom pan	"	194	176

DM: dry matter; CP: crude protein; NDF: neutral detergent fiber: ADF: acid detergent fiber; NFC: non-fibrous carbohydrates calculated as 100-(ash+EE+CP+NDF).

TABLE 2. Feed and chemical composition of total mixed rations for beef cattle with a stepped substitution of wheat straw with maize silage

		Diets			
		MS0	MS20	MS35	MS50
Feed ingredients:					
Maize silage	g/kg	0	182	358	532
Wheat straw	“	168	107	52	0
Dried beet pulps	“	258	238	186	127
Soybean meal	“	103	109	107	118
Maize meal	“	414	340	262	189
Wheat bran	“	56	24	35	35
Mineral and vitamin premix[1]	“	1	1	1	1
Water	kg/diet	6.5	3.5	1.5	0
Chemical composition					
DM	g/kg	512	518	506	477
Ash	g/kg DM	46	43	40	38
EE	“	28	27	27	26
CP	“	131	130	130	133
NDF	“	324	321	328	331
ADF	“	186	186	185	184
NFC	“	472	480	475	472
Starch	“	305	298	294	291
UFV	/kg DM	7.3	7.3	7.2	7.1

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter. DM: dry matter; EE: ether extract; CP: crude protein; NDF: neutral detergent fiber: ADF: acid detergent fiber; NFC: non-fibrous carbohydrates calculated as 100-(ash+EE+CP+NDF); UFV= Unitè Fouragère Viande; [1]Contained per kilogram of premix: Ca, 210g; Na, 60g; P, 40g; Mg, 10g; Fe, 1,130mg; Cu, 170mg; Zn, 5,000mg; Mn, 2,000mg; Co, 40mg; I, 120mg; Se, 5mg. 500,000 IU of vitamin A; 50,000 IU of vitamin D3; 500mg of vitamin E; 60mg of vitamin B1; 30mg of vitamin B2; 20g of vitamin B6; 0,1mg of vitamin B12; 4,000mg of vitamin PP; 12,500mg of choline.

TABLE 3. Particle size distribution of total mixed rations for beef cattle with a stepped substitution of wheat straw with maize silage

		Diet				Significance	SE
		MS0	MS20	MS35	MS50	(P<)	
Particle size distribution:							
Retained by a 19-mm sieve	g/kg	126a	74b	73b	38c	0.01	14
Retained by a 8-mm sieve	“	62d	123c	247b	340a	0.001	28
On the bottom pan	“	812a	804a	680b	622b	0.001	33

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter.
Means with different letters (a,b,c,d) within the same row differ for the reported threshold of significance.

TABLE 4. Feed intake, average daily gain and feeding behaviour of beef cattle fed fattening diets with a stepped substitution of wheat straw with maize silage

		Diet				Significance	SE
		MS0	MS20	MS35	MS50	(P<)	
Feed intake:							
Total DM	kg	8.8	9.8	9.7	10.0	ns	0.6
ADG	kg/d	1.6	1.5	1.4	1.5	ns	0.9
Time spent eating							
0-8h after feed delivery	min	111a	73b	70b	68b	0.01	9
9-24h after feed delivery	min	71	66	59	60	ns	11
Total	min/d	183a	139b	124b	128b	0.05	17
/ kg DM	min	22a	14b	13b	13b	0.05	3
Time spent ruminating							
0-8h after feed delivery	min	81	106	105	106	ns	15
9-24h after feed delivery	min	221	210	218	244	ns	28
Total	min/d	303	316	323	350	ns	37
/ kg DM	min	35	32	33	35	ns	4
/ kg NDF	min	108	99	102	109	ns	13

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter. DM: dry matter; NDF: neutral detergent fiber. Means with different letters (a,b) within the same row differ for the reported threshold of significance. ns = P>0.05

TABLE 5. Selection indexes for three fraction of dietary particles after 8 and 24 h of diet distribution

			Time after feed delivery		Significance	SE
			8 h	24 h	(P<)	
Diet:	Particles:					
MS0	retained by a 19 mm sieve	Selection index	1.1	1.4	ns	0.3
	retained by a 8 mm sieve	"	1.2	1.2	ns	0.1
	on bottom pan	"	1.0	0.9	ns	0.1
MS20	retained by a 19 mm sieve	"	1.9	2.7	ns	0.7
	retained by a 8 mm sieve	"	1.1	1.1	ns	0.1
	on bottom pan	"	0.9	0.8	ns	0.1
MS35	retained by a 19 mm sieve	"	1.4	1.9	ns	0.5
	retained by a 8 mm sieve	"	1.2	1.3	ns	0.1
	on bottom pan	"	0.9	0.8	ns	0.1
MS50	retained by a 19 mm sieve	"	1.3	1.8	ns	0.3
	retained by a 8 mm sieve	"	1.2	1.2	ns	0.1
	on bottom pan	"	0.9	0.9	ns	0.1

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter. Selection index: <1 preferential consumption; > 1 selective refusals, and = 1 no selection. ns = P>0.0

TABLE 6. Apparent digestibility of diets for fattening beef cattle with a stepped substitution of wheat straw with maize silage

		Diet				Significance	SE
		MS0	MS20	MS35	MS50	(P<)	
Digestibility:							
DM	g/kg	553c	534c	681b	763a	0.001	26
OM	"	571c	551c	695b	776a	0.001	27
CP	"	383c	345c	507b	722a	0.001	27
NDF	"	430c	458c	595b	664a	0.001	35
ADF	"	420b	464b	664a	674a	0.001	35
Starch	"	792bc	778c	857ab	912a	0.05	41

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter. DM: dry matter; OM: organic matter; CP: crude protein: NDF: neutral detergent fiber; ADF: acid detergent fiber. Means with different letters (a,b,c) within the same row differ for the reported threshold of significance.

TABLE 7. pH and volatile fatty acids content of rumen fluid samples taken from beef cattle fed fattening diets with a stepped substitution of wheat straw with maize silage

		Diet				Significance	SE
		MS0	MS20	MS35	MS50	(P<)	
Rumen fluid:							
pH	units	6.45	6.70	6.52	6.50	ns	0.16
Total VFAs	mmol/L	109.1	87.5	91.8	88.0	ns	12.4
Acetate (C_2)	"	70.4	56.3	57.1	56.8	ns	8.0
Propionate (C_3)	"	21.9	17.2	17.0	16.9	ns	1.1
Butyrate	"	13.7	12.1	14.1	13.6	ns	1.6
Valerate	"	2.0	2.1	2.5	2.5	ns	0.1
C_2/C_3	units	3.2	3.4	3.4	3.3	ns	0.1

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter.VFA: volatile fatty acid; ns = P>0.05

TABLE 8. Blood parameters of beef cattle fed fattening diets with a stepped substitution of wheat straw with maize silage

		Diet				Significance	SE
		MS0	MS20	MS35	MS50	(P<)	
Blood parameters:							
pH	units	7.34	7.41	7.39	7.39	ns	0.03
pCO_2	mmHg	56.3	44.6	50.3	50.3	ns	4.0
PO_2	"	38.5	37.3	36.3	39.0	ns	3.9
HCO_3	mmol/L	30.2	28.9	30.4	31.1	ns	1.2
BEb[1]	"	3.8	4.3	5.0	5.8	ns	1.4
BEecf[2]	"	4.3	4.1	5.2	6.1	ns	1.4

MS0 (20WS:0MS), MS20 (10WS:20MS), MS35 (5WS:35MS), MS50 (0WS:50MS): ratios are between percentages of wheat straw (WS) and maize silage (MS) in the total dietary dry matter. [1]BEb = base excess in blood. [2]BEecf = base excess in extra cellular fluid. ns = P>0.05

Figures

Figure 1. Partition of the total intake of dry matter during two consecutive intervals of the day by Simmental young bulls fed fattening diets with a stepped substitution of wheat straw (WS) with maize silage (MS). MS0 (20WS:0MS as percentage of total dietary dry matter), MS20 (10WS:20MS), MS35 (5WS:35MS) and MS50 (0WS:50MS).

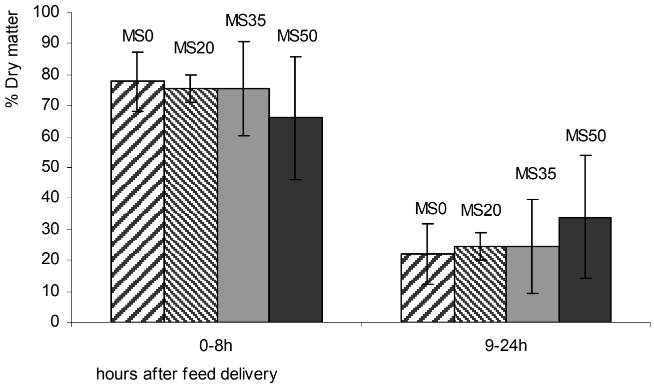
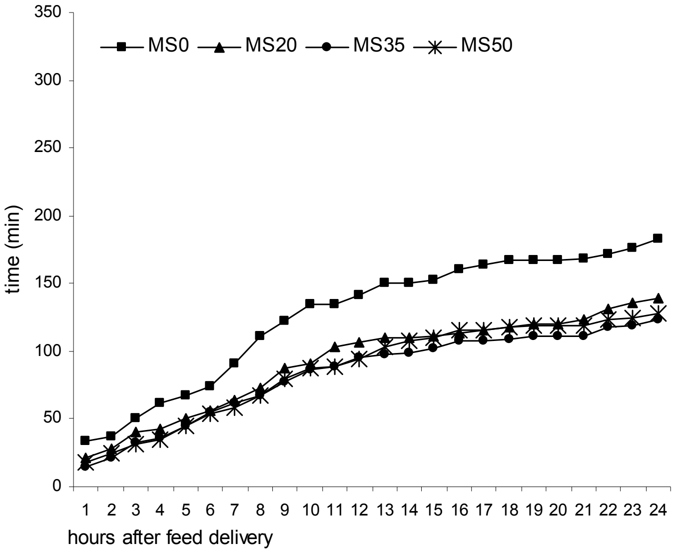


Figure 2. Cumulative averages of time spent eating by Simmental young bulls fed fattening diets with a stepped substitution of wheat straw (WS) with maize silage (MS). MS0 (20WS:0MS as percentage of total dietary dry matter), MS20 (10WS:20MS), MS35 (5WS:35MS) and MS50 (0WS:50MS)



2.4. Performance, health status and feeding behaviour of beef cattle fed a total mixed ration or a free choice between maize silage and different concentrate sources

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In this study the rearing model was that of the North American feedlot system, in which diets are based on a higher content of concentrates compared to those used in Central Europe. A study was carried out based on the concept of ability of cattle to express preferences in feeding behaviour. The suitability of MS was tested through the interpretation of the choices of cattle allowed to chose between ingredients offered individually or as a standard TMR.

Introduction

In current condition of feedlot production, beef cattle are fed diets prepared as total mixed ration (TMR), which includes all the ingredients and supplements to fulfill growing requirements. In order to obtain the best growth performance diets contain high levels of concentrate ingredients and the forage content is often limited to minimal percentages (Beauchemin and McGinn, 2005). Studies to find the proper level of inclusion of fiber in finishing cattle diets are available in literature (SCAHAW, 2001; De Campenere et al., 2002) and in their investigations researchers mostly based the threshold on metabolic and health status indicators. A method of evaluation based on the interpretation of animal behaviour could give information on a possible ability of the animal to modulate its choice according to its requirements or as consequence to signs of unpaired health status, and eventually suggest a proper real content of fiber to be included in its diet.

Cattle offered free choice diets have been demonstrated the capability to chose combinations of ingredients and optimize feed intake (Van Dorland et al., 2007) feed efficiency and thus farmer profit (Atwood et al., 2001) and ruminants have also demonstrated to be able to choose on basis of their nutritional requirements (Kyriazakis and Oldham, 1993).

In the specific case of cattle fed finishing diets, animals showed a preference for high energy feeds like grains, but they limited intake of grain and increased intake of alternative feeds once grain were over ingested (Britton and Stock, 1987).

The present study intended to evaluate for feedlot cattle the advantages of allowing the animal to choose a desired proportion of grain and forage, using the most common grains used currently in feedlots and maize silage, since this forage, has a widely accepted suitability for growing cattle (Allen et al., 2003) and is able to represent itself the fiber source of a beef cattle diet (Mazzenga et al., 2008).

Material and Methods

Animals, housing and feeding protocol

A total of 160 continental crossbred beef heifers with a initial weight of 408.3±2.0 kg was used in a 52-d feeding period commencing February 25, 2008 until April 18, 2008. Animals were already hosted in the experimental farm of the Lethbridge Research Centre (Lethbridge, AB, CA) where they arrived in November 2007. At time of entry into the feedlot, all heifers were randomly assigned to 1 of the 16 pens with 10 animals per pen. Pens were outdoor fences with windbreakers, measured 21 m × 27 m with 15 mq of concrete pavement on the bunk side, and were provided with a continuous supply of fresh water and a bedded area away from the feed bunk. Linear bunk space and pen space available for each steer were 25.4 cm and 12.6 mq, respectively. Eight pens (GS) were equipped with an electronic feed bunk monitoring system (GrowSafe Systems Ltd., Airdrie, AB), as previously described by Gibb et al. (1998) and Schwartzkopf-Genswein et al. (1999). The other 8 pens (NGS) had a conventional concrete bunk divided in two parts by a separator. Heifers assigned to the 2 groups with different feeding systems remained in their group during all their staying at the experimental feedlot. Before the start of the finishing phase animals spent 92-d on backgrounding in which they were fed a diet consisting of 55% forage (maize silage), 40% concentrate and 5% mineral and vitamin supplement. A 28-d transition phase followed, in which animals were gradually adapted to diets with higher level of inclusions of concentrates. At the end of this phase heifers were considered adapted to a finishing diet containing 85% tempered-rolled barley, 10% whole crop maize silage, and 5% supplement (DM basis). At the beginning of the experimental trial animal were weighed and re-randomized within groups with the same type of feeding bunk, (GS and NGS). During the trial heifers were offered 4 diet treatments or "choices" with the aim to distribute individual ingredients in each of two tubs placed in each pen, in order to have 4 alternatives:

- TMR vs TMR (choice TMR)
- maize silage vs tempered barley grain (choice <MSBG)
- wheat dry distillers grain vs tempered barley grain (choice DGBG)
- maize silage vs wheat dry distillers grain (choice MSDG).

Each choice was repeated 4 times, 2 among the 8 GS pens and 2 among the 8 NGS pens. Ingredients composition and chemical analysis of choice treatments are shown in Table 1. A supplement was included at 5% of DM of each individually offered ingredients containing trace minerals and vitamins to meet or exceed NRC (2000) recommended levels and a melengestrol acetate source for suppression of estrus . All heifers received a Component E-H implant (Elanco Animal Health, Guelph, Ontario, Canada). MS, when used as a sole choice ingredient, for its low CP content, was also added with 12% wheat dry distiller's grain on DM basis. Feed was delivered once per day, starting at 0900 and finishing at 1100, this for the time required to operators to prepare all treatments and fill the different bunks.

Within pens the location of ingredients was shifted between the two tubs every 7 d over the length of the trial to eliminate the confounding of feed type and tub location.

Animal were weighed on two consequent days at the beginning of the period and at the end, while the mid-term weighing was made on one day, to avoid an excess of stressful handlings of animals. On basis of the weighing sessions, the whole period was divided in 3 sub periods, corresponding with 3 weight sessions, at 21 d, 42 d and 52 d. The shorter duration of the third period was due to the difficulty to provide for enough wheat distillers grains from the market.

Performance

Feed intake per pen was determined weekly the day before the shift of position of ingredients on tubs within pens and averaged by period: after drying the samples collected, DMI was determined on basis of the feed offered and orts refused. The ADG was determined by weighing the animals at 21 d, 42 d and 52 d throughout the trial and dividing weight gain by the number of days. Feed efficiency was calculated as G:F (kg of gain/kg of DMI) on a pen basis.
A short term observation, by mean of cameras pointed on each pen, was made during the first period to check on the possible interest of heifers to eat the straw from the bedding.

Feeding behaviour

Animal behaviour data were obtained using the feed bunk monitoring system, and data were collected for 80 steers for 24 h/d throughout the 52-d trial. Heifers in GS pens were fitted with radio frequency transponders ear tags (Allflex, Dallas Ft. Worth, TX) and each GS pen was fitted with 2 electronic feeders for automatic recording of feed intake and behaviour (GrowSafe Systems Ltd., Airdrie, AB, Canada). Each feeder measured 0.91 × 0.38 × 0.53 m (height × depth × width) and was mounted onto 2 load cells. Feeders allowed only 1 calf to eat at a time and had an antenna over the rim that read electromagnetic signals from the ear transponders when they were within approximately 0.5 m. A reader panel recorded one reading every 2 s and identified the transponder number present above the feeder, feeder number, feed weight, and time of the day. All data were stored into a personal computer and later analyzed with GrowSafe Data Acquisition and Analysis Software. Individual feed intake and feeding behaviour were registered daily throughout the experiment using Growsafe®. To isolate distinct feeding events, a meal was defined as attendance at the feed bunk after an absence of at least 5 min; a return within 5 min was considered to be continuous attendance. The definition of a visit was based on survival analysis theory (de Haer et al., 1992), as well as work by Gibb and McAllister (1999) and Sowell et al. (1998) in beef cattle. Daily feeding time, measured as bunk attendance per day, was the sum of all meal duration within day; duration and size of each meal were calculated as the time elapsed and the feed disappearance from the feeders within each meal and meal frequency was was calculated average number of meals per day over the whole period.

The system was checked every 2 d throughout the trial to ensure that all cells within the mat were operational (Schwartzkopf-Genswein et al., 2001). Frequent system monitoring indicated that there were no inoperable cells during the trial. All occasions when animals were removed from their pens were recorded, and data for that day and animal were discarded from the behavioural data set.

Feed analysis

Feed orts were sampled five times per week and composited while samples of MS silage, tempered rolled barley grain, dry distiller's grain, supplement and standard TMR were collected once a week to be then composited by period and retained for chemical analysis. Dry matter was determined on a portion of each weekly composite feed and the values were used to adjust the theoretical composition of TMR and ingredients when necessary. All samples of feed and orts were stored for subsequent laboratory analysis.

All chemical analysis was performed on each sample in duplicate, and when the coefficient of variation for the replicate analysis was >5%, the analysis was repeated. Weekly feed DM was determined by oven drying at 55°C for 48 h. Analytical DM content of composited samples was determined by drying at 135°C for 3 h (AOAC, 1990), followed by hot weighing. The NDF and ADF contents were determined by the methods described by Van Soest et al. (1991) with amylase and sodium sulfite used in the NDF procedure. The concentration of CP (N*6.25) in feed was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy).

Ruminal measurements

Ruminal pH was measured continuously from 0 d to 4 d, and then for the last 7 days of each of the three periods in which the study was subdivided. The values were then averaged by days of each measurement session and by period. An indwelling electrode (model PHCN-37; Omega Engineering, Stamford, CT) was inserted into the rumen of each heifer through the cannula. A weight was attached to the electrode to ensure that it remained in the ventral sac.

In addition, a protective shield with large openings that allowed ruminal fluid to percolate freely was placed around the electrode to prevent it from coming in contact with the ruminal epithelium.

The pH was measured every 5 s, and an average of these readings was recorded every 15 min using a data logger. Ruminal pH data were summarized daily for each heifer in each period as daily mean pH, maximum and minimum pH, proportion of the measurement period in which pH was below 5.8 and below 5.5 and area below pH 5.8 and pH 5.5 curve. The proportion of time during which pH was below the particular threshold value was calculated using the actual duration that pH was measured for that animal. The threshold values of 5.5 and 5.8 were chosen because these values have been used previously to indicate subclinical ruminal acidosis (Brown et al. 2000; Ghorbani et al. 2002). The area under the curve (AUC) was calculated by adding the absolute value of negative deviations in pH from pH 5.8 or 5.5 for each 15-min interval. The number was divided by 60 in order to get the units h × pH units per day.

Rumen liquid samples were taken from animals during the trial at the beginning on 0, 4, and 7 d and at the end on 42 and 49 d of the trial. The samples were taken on days in which the pH probes were put in and out of the cannulae animals. In particular on 0, 7 and 42 d samples were taken before heifers were fed the new daily diet and on 4 and 49 d after 2 hours from the feed distribution. Ruminal contents (250 mL per site) were obtained from four sites within the rumen (reticulum, dorsal and ventral sac, and the mat), composited, and strained through a polyester monofilament fabric (Pecap 7-355/ 47, mesh opening-355 µm, Tetko Inc., Scarborough, ON, Canada). Five milliliters of filtrate was preserved by adding 1 mL of 25% (wt/vol) HPO3 to determine VFA and lactate, and 5 mL of filtrate was preserved by adding 1 mL of 1% (wt/vol) H2SO4 to determine NH3. The samples were subsequently stored frozen at 20°C until analyses.

Ruminal VFA were quantified using crotonic acid as the internal standard, and gas chromatography (model 5890, Hewlett Parkard, Little Falls, DE) with a capillary column (ZB-FFAP, 30m×0.32mm i.d., 1 µmphase thickness, bonded PEG, Phenomenex, Torrace, CA) and flame ionization detection. The oven temperature was 170°C for 4 min, which was then ramped by 30°C/min to 170°C, and held at this temperature for 2 min. The injector temperature was 225°C, the detector temperature was 250°C, and the carrier gas was helium. Ruminal NH3-N concentration was determined by the salicylate-nitroprusside-hypochlorite method using a flow injection analyzer (Sims et al., 1995). Concentrations of Yb in the samples were determined using atomic absorption spectrophotometry (AOAC, 1990). Lactic acid was determined by gas chromatography after derivatization with boron trifluoride-methanol as described by Supelco (1998).

Blood Chemistry

On 0, 21, 42 and 52 d, coinciding with weighing sessions, blood samples were taken in the morning, before new feed distribution. The blood was collected in 10-mL vacuum tubes containing Naheparin (Vacutainer, No. 6480, green stopper, Becton Dickinson, Franklin Lakes, NJ), and blood pH and CO2 were analyzed within 2 h.

The values of pH and pCO_2 were determined using an electrolyte and blood gas analyzer for veterinary use (Vetstat, IDEXX Lab, Westbrook, ME); tCO_2 HCO_3^- were calculated from parameters derived by the same instrument.

Packed cell volume was determined by collecting a blood sample in a 7-mL vacuum tube containing K3EDTA solution (Vacutainer, No. 6450, purple stopper, Becton Dickinson). The blood was transferred to a microhematocrit capillary tube, the end was sealed, and the tube was centrifuged for 6 min with a hematocrit centrifuge and read with a microcapillary reader (model MH, International Equipment Co. Boston, MA).

Statistical Analyses.

Data were analyzed using the mixed model procedure in SAS (2001) which was applied to three different models. Fixed effects were classified by pen or animal, type of choice and/or ingredient of the choice, type of bunk (GrowSafe vs conventional feed bunk) and repetition (REP) of choice treatment within Grow Safe pens, and time; the effects were used as specified in the following description.

For performance data pen was used as unit of analysis and the model included choice, time, type of bunk and their interactions: period was included as a repeated measure using the covariance structure which gave the lowest AIC value. Initially animal weight on day 0 of the study was included as a covariate, however, it was not found to be significant and was therefore removed form the model..

For metabolic parameters animals in GrowSafe pens fitted with a cannula were used as unit of analysis. Fixed effects included diet choice, period? and their interactions. Period was included as a repeated measure using the variance-covariance structure which gave the lowest AIC value. For both models the Kenward Roger method was used to approximate the degrees of freedom.

Behaviour parameters were analyzed using animals in GrowSafe pens as the unit, and the model included the effect of individual ingredients of the diet choices and the interaction between ingredient*choice, with choice*REP as random effect.

Significance was declared at P<0.05 while values between 0.05 and 0.1 were considered to have a tendency towards significance.

Results

Performance

Overall final weights in the heifers ranged between 406.3 and 410.0 kg and were not affected by treatment (Table 2). Similarly both ADG and G:F did not differ by treatment and ranged between 1.7 and 1.8 kg/d and 0.165 and 0.190, respectively. Heifers fed the MSDG choice had a DMI of 10.4 kg/d which was significantly higher (P < 0.01) than that of TMR and BGDG heifers (9.67 and 9.83kg/d, respectively) with BGMS in between. Significant interactions between the performance parameters and the periods of the trial showed how treatment differences where concentrated at the beginning of the trial and were mostly due to higher consumption rates of MSDG (Figure 1). Heifers offered MSDG had higher (P < 0.0001) DMI in the first two periods than those in all other choice groups including the TMR. In the third period DMI of the MSDG group decreased and was lower than the BGMS and TMR treatments. Feed efficiency revealed a tendency to be influenced by period (P =0.07) with MSDG having a lower gain:feed ratio than BGMS and TMR heifers during the first and second periods. In the second period G:F of MSDG heifers were also lower than BGDG. The efficiency of MSDG improved in the third period resulting in no difference between any of the treatments. Significant differences in DMI and ADG were observed between GS and NGS pens (Table 3). DMI was higher (P<0.01) in NGS pens and ADG tended (P=0.06) to be higher in the NGS pens. The effect of the type of feeding system used (Figure 1) differed by period (P<0.05). ADG was highest during period one after which no differences between the GS and NGS pens were observed. Figure 2 illustrates the average DMI per ingredient within each choice diet to evidence the general choices of animals.

Feeding behaviour

From the monitoring on possible consumption of bedding material it was observed that animals used to play and eat a little straw in the first 3 days after renewal of the bedding. As during the trial, thanks to averagely dry weather conditions, straw was not added from the previous period, this behaviour was considered not influencing the results. TMR fed heifers had higher (P < 0.0001) bunk attendance durations compared to the MS and DG treatments (Table 4) (82.9, 53.0, and 43.6 min/d, respectively). The same results were observed for the average meal length, with TMR having the

highest (P < 0.0001) average values compared to the BG, DG and MS groups (7.6, 4.5, 5.4 and 5.6 min/d, respectively). The size of meals (DM basis) was significantly different for each of the different ingredients (P<0.0001). Heifers consuming the TMR had an average meal size of 815.3g while heifers consuming BG, DG and MS ingredients only had average meal sizes of 624, 518.6 and 269g per meal, respectively. Heifers given the TMR also had the largest (P<0.001) number of meals within a 24 h period compared to those consuming the MS, BG and DG ingredients (10.9, 9.3, 9.3 and 9.8 meal per day, respectively). The analysis of the interactions ingredient*choice, for each of the parameters considered for the feeding behaviour, showed some clear relations between the type of ingredient and its relationship with the other ingredient with which it was offered (Figure 3). In the case of bunk attendance, meal duration and meal size, heifers spent more time per day and per meal eating, and consumed more MS when it was offered with DG than with BG (P < 0.0001). Similarly, heifers spent more time per day and per meal when DG was offered with MS than with BG (P<0.0001). Conversely no differences in feeding behaviour were observed when BG was offered with MS or DG.
Heifers attended the bunk more frequently when BG was offered with MS then with DG (P<0.05).

Ruminal measurements

Minimum and mean ruminal pH values were significantly higher (P<0.05) in animals fed MSDG, than TMR but not different from BGMS and BGDG (Table 5). No treatment differences were observed for maximum ruminal pH. The percentage of time per day that ruminal pH was < 5.5 was significantly (P<0.05) lower in MSDG animals compared to all other treatments. These results were confirmed by the observation that the area under the curve at ruminal pH < 5.5 tended to be lower (P = 0.09) in MSDG and BGMS heifers than the other treatments. Similar results were found for the percentage of time per day that the ruminal pH was < 5.8; MSDG heifers had less time per day (P < 0.01) at pH <5.8 than either BGDG or TMR treatments but not different from BGMS.
The area under the curve at ruminal pH < 5.8 followed the same pattern as the time spent at ruminal pH <5.8 with only a tendency towards significance (P < 0.08).

Total VFA concentration was significantly higher (P<0.001) in the TMR group than in MSBG and MSDG (127.6 vs 107.5 and 97.9, respectively) (Table 6), with BGDG values being intermediate between them. Acetic acid was 7 to 8 % higher (P<0.0001) in MSDG heifers compared to all other treatment groups. Butyric acid followed the same trend (11.6% vs 7.63 to 8.72%) (P<0.0001) while the situation was reversed in the case of Propionic acid, in which MSDG had the lowest values (P<0.0001) compared to the other treatments. The proportion of Valeric acid did not vary between treatments. Finally the C2:C3 ratio was higher (P<0.001) in MSDG than for all the other treatment groups (2.03 vs 1.19 to 1.34, respectively). Lactic and Succinic acid concentrations could not be reported as they were below the limits of instrumental detectability.

Blood chemistry

Ruminal pH values in this study were between 7.44 and 7.46, pCO2 between 39.15 and 41.95 mmHg, HCO_3^- between 25.4 and 26.8mmol/l, tCO_2 between 26.6 and 28.2 mmol/l and PCV between 41.2 and 44.0 %. None of the blood parameters measured were influenced by diet treatments (Table 7).

Discussion

The condition in which heifers were given freedom to choose their desired quantity of ingredients did not show any particular advantage from a production standpoint. Performance parameters were equivalent between the choice groups, suggesting that none of the treatments limited or enhanced the growth potential of the animals. Atwood et al. (2001) found similar results whereby animals provided a free-choice versus a mixed ration selected the best combination of ingredients which reduced the costs of the diet, however no performance benefits were observed between the treatments. These considerations give support to the belief that providing animals with choice between ingredients is not meant as a first aim to improve growing performance but instead as an effort to reduce the stress of animals by allowing natural behaviour (Manteca et al, 2008)

Preference was demonstrated for one of the choice, proved by an higher DMI for CSDG diets, and it was not supported by better performance and even with tendency to worse results, suggesting a need for the choices of animals to meet farmer's objectives of profit.

From a wider angle preference was shown from results of average DMI per ingredient. A general diversity in consumption depending on associations came to evidence, but what emerged the most was the fact that in the case of the association of MS with BG, heifers ate 10% more, or twice, the quantity of forage when allowed to choose than when fed the ingredients premixed to well represent the formulation of a standard diet commonly used in feedlots (Beauchemin and McGinn, 2005).

Though animals were long adapted to the practice of eating from a unconventional bunk, however shifting from the common TMR offered during adaptation to choice treatments, heifers fed through the GS tubs needed little longer to get used to the new system. As GS allows only one animal at a time to access the tub the delay in adaptation my be due to the need to establish a new order in dominance between heifers to cope with the new situation (Zobel, 2007). Adaptation mechanisms were already proven to exist to a new type of feeding system (Gonzalez et al., 2008).

Observing the feeding behaviour of heifers at individual tubs, when animals were offered TMR and they had a complete ration, they were not able to select the components of the mixture, and they made longest and bigger meals. When allowed to choose, they seemed to gorge with BG and, to a minor extent, with DG, showing their preferences for concentrates (Provenza, 1995).

The possible overload of grain could shift the interest of cattle to the other ingredients (Britton and Stock, 1987): in fact heifers ate also a second ingredient available to complete their diets and finally the time they spent considering each choice association is longer than that of TMR. The described behaviour had been discovered to be a result of both senses (taste, smell) and post-ingestive feedback (Provenza, 1995).

A possible confirmation to the latter could be red from the samplings of rumen fluids and in situ pH measurements. The diet with the compelled high ratio of concentrates over forages, TMR, gave the higher risk of acidosis. When heifers were able to combine ingredients for their meals they seemed to be able to avoid low pH conditions. In the particular case of animal fed MSDG the highest levels of pH can be considered expected, for the fact that these animals ate more fiber, provided by MS but also by DG, which though are mostly used as a protein or an energy source, they comprise properties of a soluble fiber source (Klopfenstein et al., 2008).

Finally the rumen environment and the VFA profile in particular, gave another information about the suitability of free choice diets and certain associations of ingredients. A load of VFA was found in animals fed TMR, to support the previous results on pH measurements. However, the prevalence of acetic to propionic acid obseved for the MSDG diet raised some concern on the long term negative effects on growth performance and final meat quality.

Conclusions

This study confirmed previous results on the ability of cattle to choose between specific feed ingredients. This eating behaviour may be based on factors such as taste or palatability of ingredients, but in some cases it is driven by the metabolic outcome of feed digestion. Perhaps the most significant finding in this study is the fact that feedlot cattle selected a higher level of forage than what is normally provided in a standard feedlot TMR. Once again, in a production reality characterized by feeding plans with high content of concentrates, MS demonstrated to well suit the role of structured forage when fed in association with different grain sources. The choices made by animals revealed the need of a compromise between healthy diets and cattle performance and carcass quality since what is preferred by the cattle may not fully meet producer expectations for daily gain and meat quality.

Tables

Table 1. Chemical composition of choice treatments

		Choice treatments			
Ingredient composition		TMR	BG	DG	MS
Barley	% diet DM	85	95	.	.
Wheat dry distillers grains	"	.	.	95	12
Corn Silage	"	10	.	.	83
Supplement	"	5	5	5	5
Chemical composition					
DM	%	81.21	86.15	93.08	46.03
CP	% DM	14.08	15.56	40.68	12.87
ADF		6.92	4.44	16.75	26.63
NDF	"	20.33	17.52	27.77	42.18
NEm	Mcal/kg	1.97	2.03	2.03	1.56
NEg	"	1.33	1.38	1.38	0.97

TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; DM: dry matter; CP: crude protein; ADF: acid detergent fiber; NDF: neutral detergent fiber; NEm: net energy for maintenance; NEg: net energy for growth

Table 2. Performance of heifers offered free choice diet treatments

		Choice treatments				Significance	
		TMR	BGMS	BGDG	MSDG	(P)	SE
All cattle							
n. of heifers (pens)		40 (4)	39 (4)	40 (4)	40 (4)		
Initial weight	kg	416.1	413.7	415.3	416.3	ns	8.67
Final weight	kg	511.6	508.45	504.0	502.8	ns	9.61
DMI	kg DM/d	9.67b	9.83b	9.41b	10.38a	<0.0001	0.11
ADG	kg/d	1.83	1.81	1.81	1.70	ns	0.08
G:F		0.191	0.184	0.192	0.165	ns	0.01

TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; DMI: dry matter intake; ADG: average daily gain; G:F: growth to feed ratio; DM: dry matter. Means with different letters (a,b) within the same row differ for the reported threshold of significance; ns: non significant.

Table 3. Effect of type of feeding bunk on performance of heifers offered free choice diet treatments

		Type of bunk		Significance (P)	SE
		GS	NGS		
DMI	kg /d	9.63b	10.2a	<0.01	0.08
ADG	kg/d	1.70b	1.87a	0.06	0.05

GS: pens with Grow Safe monitoring system; NGS: pens with normal bunks with separator; DMI: dry matter intake; ADG: average daily gain. Means with different letters (a,b) within the same row differ for the reported threshold of significance.

Table 4. Feeding behaviour of heifers offered free choice diet treatments

		Ingredients in individual tubs				Significance	
		TMR	MS	BG	DG	(P)	SE
Bunk attendance	min/d	82.9a	55.1b	43.6c	50.7b	<0.0001	2.35
Meal duration	min	7.64a	5.56b	4.48c	5.40b	<0.0001	0.28
Meal size	g DM/meal	815.3a	269.0d	624.0b	518.6c	<0.0001	21.1
Meal frequency	n./day	10.87a	9.81b	9.81b	9.30c	<0.001	0.23

TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; DM: dry matter; means with different letters (a, b, c, d) within the same row differ for the reported threshold of significance.

Table 5. pH measures on heifers offered free choice diet treatments

		Choice treatments				Significance	
		TMR	BGMS	BGDG	MSDG	(P)	SE
Minimum		4.97b	5.00ab	5.24ab	5.42a	<0.05	0.10
Mean		5.65b	5.85ab	5.80ab	6.23a	<0.05	0.12
Maximum		6.62	6.83	6.60	6.92	ns	0.13
Duration<5.5	% day	43a	35a	40a	7.0b	0.05	9.0
AUC<5.5		3.13a	2.79ab	3.40a	0.27b	0.09	0.91
Duration<5.8	% day	61a	50ab	55a	17b	<0.05	8.0
AUC<5.8		6.87a	5.83ab	6.82a	1.12b	0.08	1.62

TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; AUC: area under the curve; means with different letters (a,b) within the same row differ for the reported threshold of significance; ns: non significant.

Table 6. Volatile fatty acids measures on heifers offered free choice diet treatments

		Choice treatments				Significance	
		TMR	BGMS	BGDG	MSDG	(P)	SE
Total VFA	mM	127.6a	107.5b	109.5ab	97.9b	<0.001	4.87
Acetic	m/100mol	46.7b	47.1b	47.4b	54.5a	<0.0001	1.20
Propionic	"	40.1a	40.2a	38.0a	28.2b	<0.0001	1.39
Butyric	"	8.72b	7.63b	8.91b	11.56a	<0.0001	0.51
Valeric	"	2.75	2.49	3.05	2.80	ns	0.25
C2:C3	"	1.33b	1.19b	1.34b	2.03a	<0.001	0.13

TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; VFA: volatile fatty acids; Means with different letters (a,b) within the same row differ for the reported threshold of significance

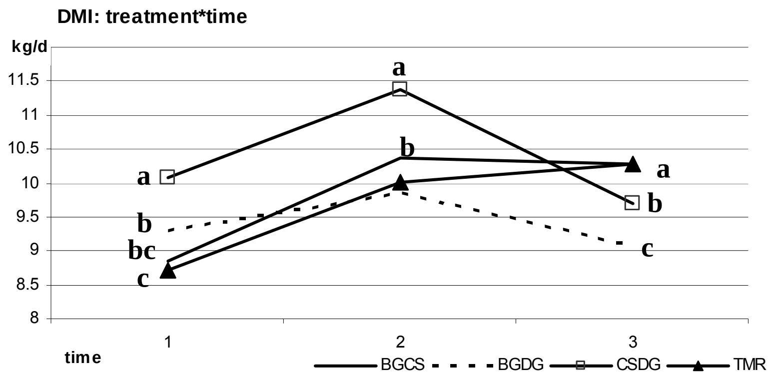
Table 7. Blood parameters of heifers offered free choice diet treatments

		Choice treatment				Significance	
		TMR	BGMS	BGDG	MSDG	(P)	SE
Blood pH		7.46	7.45	7.44	7.45	ns	0.08
pCO3	mmHg	40.05	41.95	41.82	39.15	ns	1.91
HCO3	mmol/l	26.17	26.88	26.10	25.38	ns	1.16
tCO2	mmol/l	27.40	28.17	27.39	26.58	ns	1.22
PCV	%	43.20	41.20	43.99	43.78	ns	1.62

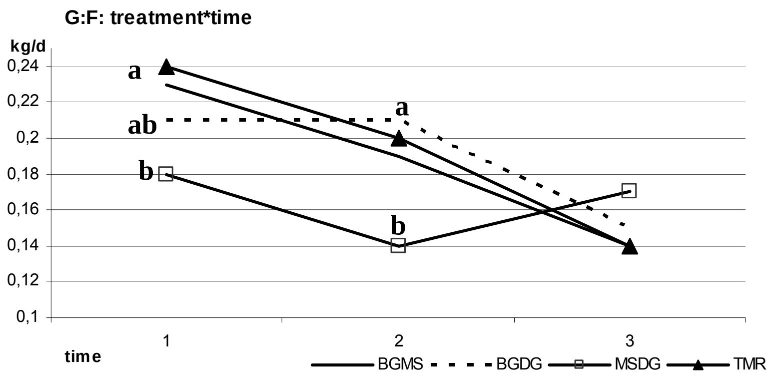
TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; PCV: packed cells volume; ns: non significant.

Figures

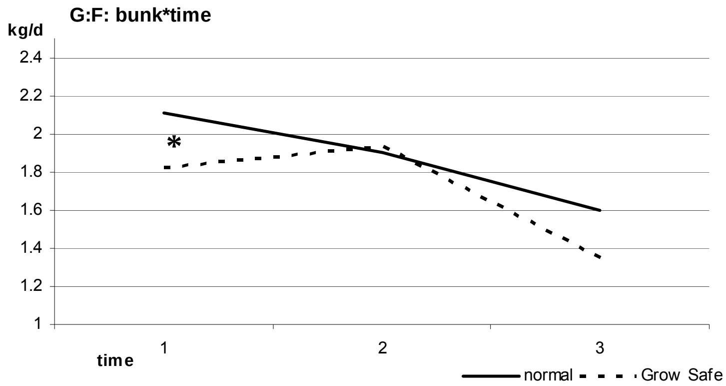
Figure 1: interactions of performance parameters with time and bunk type



DMI: dry matter intake; TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; letters (a,b,c) differ for the threshold of significance of P<0.0001



G:F: Growth to feed ratio; TMR: total mixed ration; BG: tempered barley grain; MS: maize silage; DG: dry distillers grains; letters (a,b,) differ for the threshold of significance of P<=0.07



G:F: Growth to feed ratio; *threshold of significance of P< 0.05

Figure 2: Dry matter intake by ingredient within each choice treatment

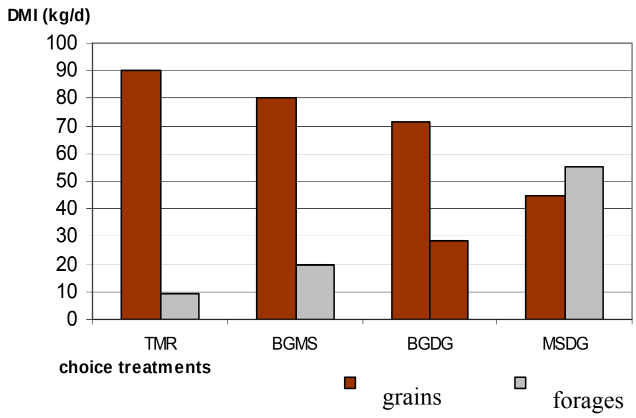
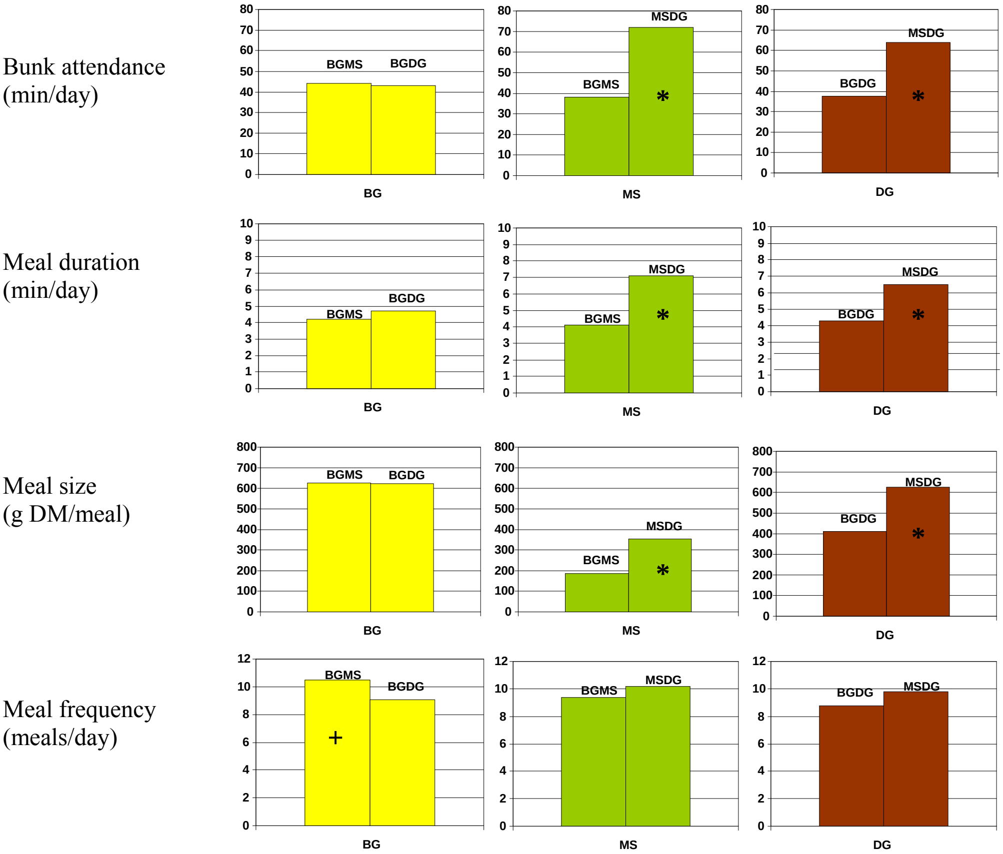


Figure 3: Interactions ingredient*choice for feeding behaviour parameters of beef heifers



BG: tempered barley grain; MS: maize silage; DG: dry distillers grains. Threshold of significance: *: P<0.0001; +: P<0.05.

3. CONCLUSIONS

The present thesis has tried to give a comprehensive view of the use of MS in the diet formulation for beef cattle. The results of a set of studies have strengthened the conviction that this forage has important nutritional properties which should be fully exploited by beef farmers at the time of diet formulation.

An initial survey carried out in a large sample of intensive beef farms locate in the Po Valley showed that MS is a typical ingredient of the diet fed to fattening bulls but farmer do not try to take full advantage of its nutritional properties and particularly of its fibrous portion. Even when a coarse MS is available, farmers do not reduce the amount of other long fiber ingredients such as straw of grass hay. This mistrust on the capacity of MS fiber to stimulate an adequate rumination activity in beef cattle has shown to arise from an improper handling of the forage in the transfer from the silo to manger. Significant damages of MS long particles have been observed due to the silage cutters and over-mixing during TMR preparation.

However, when the damage of the forage long particles is prevented through a proper handling of MS, this feedstuffs has shown to be a feasible alternative to the use of long fiber roughage source in beef cattle diets. In a specific feeding trial a stepped inclusion of this roughage to replace wheat straw in a TMR made with a minimal use of buffers had no adverse effects on health, DM intake and feeding behaviour of Simmental young bulls. Since MS is a source of fiber and starch, its inclusion in large quantities in beef cattle diets replacing other roughages could also allow to markedly reducing the need for inclusion of other energy supplements. Positive outcomes of this substitution should be a significant feed cost reduction and a higher TMR digestibility due to the increased contribution of NDF and the reduction of the post-ruminal burden of starch.

A further study carried in a production reality characterized by feeding plans with high content of concentrates such as a Canadian feedlot, demonstrated that MS well suit the role of structured forage when fed in association with different grain sources. When given the opportunity to choose freely their diet , feedlot cattle selected a higher level of forage than what is normally provided in a standard feedlot TMR. This eating behaviour may be based on factors such as taste or palatability of ingredients, but in some cases it is driven by the metabolic outcome of feed digestion. The choices made by animals towards a more fibrous DM intake may not fully meet producer expectations for daily gain and meat quality. Therefore, there is a need to find a compromise between healthy diets and cattle performance and carcass quality if the welfare of beef cattle is taken into account.

A further concern on the use of large quantities of MS in beef cattle diets regarded the effects on meat quality and colour in particular. According to meat market opinions diets rich in ensiled forages might have detrimental effect this important quality trait. A study carried out under commercial condition by sampling carcasses and meat from Charolais bulls fed increasing amounts of MS showed that there are no substantial arguments against the use of a large amount of MS in the fattening diets. Therefore, the ultimate decision about the amount of MS to be included in the diet for beef cattle must be based only on the daily gain over feed cost ratio.

As a general final conclusion, the answer to the question raised at the beginning of this project about the possibility of a large use of MS in beef cattle diets is positive.

The critical points of MS utilization in feeding plans for beef cattle are the managing and handling of the forage during plant harvesting, silage making and diet preparation. All these phase require attention and precision by the operators since the properties and advantages that MS can provide to the beef producer can be easily impaired by errors that can alter nutritional and physical characteristics of the forage.

4. REFERENCES

Formatted: Italian (Italy)

Abdelhadi, L.O., Santini, F.J., Gagliostro, G.A., 2005. Corn silage or high moisture corn supplements for beef heifers grazing temperate pastures: effects on performance, ruminal fermentation and in situ pasture digestion. Anim. Feed Sci. Technol. 118, 63-78.

Allen, M.S., Coors, J.G., Roth, G.W., 2003. Maize silage. In: D.R.Buxton, R.E.Muck and J.H.Harrison (Ed.) Silage science and technology, pp.547-595 Series Agronomy, n.32.ASA-MSSA-SSSA, Madison, Wisconsin, USA.

Allen, V.G., Fontenot, J.P., Kelly, R.F., Notter, D.R., 1996. Forage systems for beef production from conception to slaughter: III. Finishing Systems. J.Anim.Sci. 74, 625-638.

Andersen, H.R., Krohn, C.C., Foldager, J., Musksgaard, L., Klastrup, S., (1991). Influence of housing and feeding on behaviour, feed intake, growth and carcass and meat quality. Nat. Inst. Anim. Sci. Foulum, Denmark, Report 700, p. 39.

Andrae, J.G., hunt, C.W., Pritchard, G.T., Kennington, L.R., Harrison, J.R., Kezar, W., Mahanna, W., 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J. Anim. Sci. 79, 2268-2275.

AOAC – Association of Official Analytical Chemists., 1990. Official methods of analysis, 15th edition. AOAC, Washington, DC.

Arieli, A., Abramson, S., Mabjeesh, S.J., Zamwel, S., Bruckental, I., 2001. Effect of site and source of energy supplementation on milk yield in dairy cows. J.Dairy Sci. 84, 462-470.

Atwood, S.B., Provenza, F.D., Wiedmeier, R.D., Banner, R.E., 2001. Influence of free-choice vs mixed-ration diets on food intake and performance of fattening calves. J.Anim.Sci. 79, 3034-3040.

Bal, M.A., Coors, J.G., Shaver, R.D., 1997. Impact of the maturity of corn for use as silage in the diets of dairy cows on intake, digestion, and milk production. J.Dairy Sci. 80, 2497-2503.

Barriere, Y., Argillier, O., Michalet-Doreua, B., Hébert, Y., Guingo, E., Giauffret, C, Emile, J.C., 1997. Relevant traits, genetic variation and breeding strategies in early silage maize. Agronomie 17, 395-411.

Beauchemin and McGinn, 2005. Methane emissions from feedlot cattle fed barley or corn diets J Anim Sci 2005. 83, 653-661

Bittante, G., Andrighetto, I., Ramanzin, M., Fondamenti di Zootecnica1999, 6th Edition. Liviana Editrice, Torino, Italy.

Boccard R.L., Buchter L., Casteels E., Cosentino E., Dransfield E., et al. (1981). Procedures for measuring meat quality characteristics in beef production experiments. Report of a working group in the commission of the European communities (CEC) beef production research programme. Livest. Prod. Sci. 8, 385-397.

Brassley, P., 1996. Silage in Britain, 1880-1990: the delayed adoption of an innovation. Agric. History Rev.44, 63-87.

Brennan, R.W., Hoffman, M.P., Parrish, F.C., Epplin, F., Bhide, S., Heady, O., 1987. Effects of differing ratios of corn silage and corn grain of feedlot performance, carcass characteristics and projected economic returns. J. Anim. Sci. 64, 23-31.

Britton, R.A., Stock, R.A., 1987. Acidosis, rate of starch digestion and intake. P 125-137. *In*: Feed intake by beef cattle. Agr.Exp.Sta MP 121, Oklahoma State Univ.

Brown, M.S., Krehbiel, C.R., Galyean, M.L., Remmenga, M.D., Peters, J.P., Hibbard, B., Robinson, J., Moseley, W.M., 2000. Evaluation of models of acute and subacute acidosis on dry matter intake, ruminal fermentation, blood chemistry, and endocrine profiles of beef steers. J.Anim.Sci. 78, 3155-3168.

Browne, E.M., Bryant, M.J., Beever, D.E., Thorp, C.L., 1998. Effect of forage maize harvested at different stages of maturity on feed intake and performance by growing beef cattle. In: Proc. Brit. Soc. Anim. Sci. p.148.

Browne, E.M., Juniper, D.T., Bryant, M.J., Beever, D.E., Fisher, A.V., 2004. Intake, live-weight gain and carcass characteristics of beef cattle given diets based on forage maize silage harvested at different stages of maturity. Animal Science, 79, 405-413.

Burato, G.M., Cozzi, G., Berzaghi, P., Gottardo, F., Mirisola, M., Andrighetto, I., 2001. Effect of corn silage chopping lenght on feed quality, feeding behaviour and production of lactating cows. Proceedings of the XIV Congress of the Italian Scientific Association of Animal Production, Florence, pp. 216-218.

Buxton, D.R., Muck, R.E., Harrison, J.H., 2003. Silage science and technology, pp.547-595 Series Agronomy, n.32.ASA-MSSA-SSSA, Madison, Wisconsin, USA.

Campbell, C.P., Marshall, S.A., Mandell, I.B., Wilton, J.W., 1992. Effect of source of dietary neutral detergent fiber on chewing behaviour in beef cattle fed pelleted concentrates with or without supplemental roughage. J.Anim.Sci. 70, 894-903.

Canale, A., Valenti, M.E., Ciotti, A., 1984. Determination of volatile carboxilic acids (C_1-C_{5i}) and lactic acid in aqueous acid extracts of silage by high performance liquid chromatography. J.Sci.Food Agric. 35, 1178-1182.

Comeford, J.W., House, R., B., Harpster, H.W., Henning, W.R., Cooper, J.B., 1992. Effects of forage and protein sources on feedlot performance and carcass traits of Holstein and crossbred beef steers. J. Anim. Sci. 70, 1022-1031.

Coombs, D.F., Bagley, C.P., Hill, G.M., Knox, J.W., Loyacano, A.F., Oliver, W.M., Wyatt, W.E., Huffman, D.C., McMillin, K.W., Bidner, T.D., Saxton, A.M., 1990. Year round production of beef using maximum level of forages. II. Finishing phase. Applied Agriculture Research 5, p 35.

Cozzi G., Gottardo F., 2005. Feeding behaviour and diet selection of finishing Limousin bulls under intensive rearing system. Appl. Anim. Behav. Sci. 91, 181-192.

Cozzi, G., Gottardo, F., Andrighetto, I., 2005. The use of coarse maize silage as a dietary source of roughage for finishing Limousin bulls: effects on growth performance, feeding behaviour and meat quality. Anim. Sci. 80, 111-118.

Formatted: Italian (Italy)

Cozzi G., Mazzenga A., Contiero B., Burato G., 2008. Use of maize silage in beef cattle feeding during the finishing period. Ital. J. Anim. Sci. 7, 39-52.

Cozzi, G., Ragno, E., 2003. Meat production and market in Italy. Agric. Conspec. Sci. 68, 71-77.

De Campeneere, S., Fiems, L.O., De Boever, J.L., Vanacker, J.M., De Brabander, D.L., 2002. Decreasing the roughage:concentrate ratio of a diet to determine the critical roughage part for beef cattle. Arch.Anim.Nutr. 56, 1-12.

De Campeneere, S., Fiems, L.O., De Bosschere, H., De Boever, J.L., Ducatelle, R., 2002. The effect of physical structure in maize silage-based diets for beef bulls. J.Anim.Physiol.a.Anim.Nutr. 86, 174-184.

de Haer, L. C. M., and J. W. M. Merks. 1992. Patterns of daily food intake in growing pigs. Anim. Prod. 54, 95–104.

Descalzo, A.M., Insani, E.M., Biolatto, A., Rancho, A.M., Garcia, P.T., Pensel, N.A., Josifovich, J.A., 2004. Influence of pasture or grain based diets supplemented with vitamin E on antioxidant/oxidative balance of Argentine beef. Meat Sci. 70, 35-44.

Fernandez, I., Martin, C., Champion, M., Michalet-Doreau, B., 2004a. Effect of maize hybrid and chop length of whole-plant maize silage on digestion and intake by dairy cows. J. Dairy Sci. 87, 1298-1309.

Formatted: Italian (Italy)

Fernandez, I., Noziere, P., Michalet-Doreau, B., 2004b. Site and extent of starch digestion of whole-plant maize silages differing in maturity stage and chop lenght, in dairy cows. Livest. Prod. Sci. 89, 147-157.

Ferret, A., Gasa, J., Plaixats, J., Casañas, F., Bosch, L., Nuez, F., 1997. Prediction of voluntary intake and digestibility of maize silages given to sheep from morphological and chemical composition, in vitro digestibility or rumen degradation characteristics. Anim. Sci. 64, 493-501.

Ghorbani, G. R., D. P. Morgavi, K. A. Beauchemin, and J. A. Z. Leedle. 2002. Effects of bacterial direct-fed microbials on ruminal fermentation,blood variables, and the microbial populations of feedlot cattle. J. Anim. Sci. 80, 1977–1986.

Gibb, D. J., and T. A. McAllister. 1999. The impacts of feed intake and feeding behaviour of cattle on feedlot and feed bunk management. Pages 101–116 in Proc. 20th Western Nutr. Conf. Marketing to the 21st Century. Calgary, Alberta, Canada.

Gibb, D. J., T. A. McAllister, C. Huisma, and R. D. Wiedmeier. 1998. Bunk attendance of feedlot cattle monitored with radio frequency technology. Can. J. Anim. Sci. 78, 707–710.

Goad, D.W., Goad, C.L., Nagaraja, T.G., 1998. Ruminal microbial and fermentative changes associated with experimentally induced subacute acidosis in steers. J.Anim.Sci. 76, 234-241.

Formatted: Italian (Italy)

González, L. A.,. Ferret, A., Manteca, X., Ruíz-de-la-Torre, J.L., Calsamiglia, S., Devant, M., Bach, A., 2008. Performance, behavior, and welfare of Friesian heifers housed in pens with two, four, and eight individuals per concentrate feeding place J. Anim. Sci. 86, 1446-1458.

Hamada, T., Omori, S., Kameoka, K., Horii, S., Morimoto, H., 1968. Direct determination of rumen volatile fatty acids by gas chromatography. J. Dairy Sci. 51, 228-229.

Formatted: Italian (Italy)

INRA, 1988. Alimentation des Bovins, Ovins et Caprins. INRA, Paris.

Formatted: English (U.K.)

ISMEA, 2001. http://ismea.it

ISMEA, 2006. Il mercato della carne bovina. Franco Angeli, Milano, Italy.

Ivan, S. K., R. J. Grant, D. Weakley, and J. Beck. 2005. Comparison of a corn silage hybrid with high cell-wall content and digestibility with a hybrid of lower cell-wall content on performance of holstein cows. J. Dairy Sci. 88, 244-254.

Johnson, L., Harrison, J.H., Hunt, C., Shinners, K., Doggett, C.G., Sapienza, D., 1999. Nutritive value of corn silage s affected by maturity and mechanical processing: a contemporary review. J. Dairy Sci. 82, 2813-2825.

Journet, M., (1988). Optimisation des rations. In: Alimentation des bovins, ovins et caprins, Ed. R. Jarrige, pp 121-133.

Juniper, D.T., Browne, E.M., Fisher, A.V., Bryant, M.J., Nute, G.R., Beever, D.E., 2005. Intake, growth and meat quality of steers given diets based on varying proportions of maize silage and grass silage. Anim. Sci. 81, 159-170.

Kirkland, R.M., Steen, R.W.J., Gordon, F.J., Keady, T.W., 2005. The influence of grass and maize silage quality on apparent diet digestibility, metabolizable energy concentration and intake of finishing beef cattle. Grass Forage Sci. 60(3), 244-253.

Kleen J.L., Hooijer G.A. Rehage J., Noordhuizen J.P., 2003. Subacute ruminal acidosis (SARA): a review. J. Vet. Med. Series A. 50, 406-414.

Klopfenstein, T. J., Erickson, G. E., and Bremer, V. R. 2008. BBoard invited review: use of distillers by-products in the beef cattle feeding industry. J.Anim.Sci. 86, 1223-1231.

Knight, T.W., Death, A.F., Boom, C., J., Litherland, A.J., 1998. The relationship between carotenoid concentration and fat colour in beef carcasses. Proceedings of the New Zealand Society of Animal Production 58, 256-258.

Kononoff, P. J., Heinrichs, A. J., Lehman, H. A., 2003. The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating dairy cows. J. Dairy Sci. 86, 3343-3353.

Kyriazakis, I., Oldham, J.D., 1993. Diet selection in sheep: the ability of growing lambs to select a diet that meets their crude protein (nitrogen x 6.25) requirements. Brit. J. Nutr. 69, 617-629.

Lammers, B. P., Buckmaster, D.R., Heinrichs, A.J., 1996. A simple method for the analysis of particle sizes of forage and total mixed ration. J.Dairy Sci. 79, 922-928.

Mader, T.L., Dahlquist, J.M., Schmidt, L.D. 1991. Roughage sources in beef cattle finishing diets. J. Anim. Sci. 69, 462-471.

Maekawa, M., Beauchemin, K.A., Christensen, D.A., 2002. Chewing activity, saliva production, and ruminal ph of primiparous and multiparous lactating dairy cows. J. Dairy Sci. 85, 1176–1182.

Mandell, I., B., Buchanan-Smith, J.G., Campbell, C.P., 1998. Effect of forage vs grain feeding on carcass characteristics, fatty acid composition, and beef quality on Limousin-cross steers when time on feed is controlled. J. Anim. Sci. 76, 2619-2630.

Martin P., Bateson P., 1993. Measuring behaviour, an introductory guide. Cambridge University press, Cambridge, UK.

Mazzenga, A., Gianesella, M., Brscic, M., Cozzi, G., 2008. Feeding behaviour, diet digestibility, rumen fluid and metabolic parameters of beef cattle fed total mixed rations with a stepped substitution of wheat straw with maize silage. In press in: Livestock Science, available on internet: September 2008.

McCullough, M. E. 1977. Silage and silage fermentation. Feedstuffs 49 (13) p.49.

McDonald, P., Henderson, A.R., Heron, S.J.E., 1991. The biochemistry of silage, Second Edition. Chalcombe Publications, Marlow, GB.

Merchen, N.R., 1988. Digestion, absorption and escretion in ruminants. Pages 188-189 in The ruminant animal. Digestive physiology and nutrition. D.C. Church, ed. Reston, Prentice Hall, Englewood Cliffs, New Jersey 07632.

Mertens, D.R., 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80, 1463-1481.

Morgante M., Stelletta C., Gianesella M., Berzaghi P., Badan M., Lotto A., Andrighetto, I., 2005. Correlation among ruminal pH and short chain fatty acids in dairy cows affected by subacute ruminal acidosis (SARA). J.Dairy Sci. 83, Suppl. 1, 132-133.

Muck, R.E., Pitt, R.E., 1994. Aerobic Deterioration in Corn Silage Relative to the Silo Face. Transactions of the ASAE 37(3), 735-743.

Nagaraja, T.G., Lechtenberg, K.F., 2007. Acidosis in Feedlot Cattle. Vet.Clin.Food Anim. 23, 333-350.

Nocek, J.E., Tamminga, S., 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. J.Dairy Sci.74, 3598-3629.

Nordlund K.V., 1995. Herd based rumenocentesis: a clinical approach to the diagnosis subacute rumen acidosis. Pag. 1-11 in Proc. of the Northeast Medical Symposium. Ed. R. Saltman Syracuse N.Y.

NRC, 2000. Nutrient Requirements of Beef Cattle, seventh revised ed. National Academy Press, Washington, DC.

O'Sullivan, A., Galvin., K, Moloney, A.P., Troy, D.J., O'Sullivan, K., Kerry, J.P., 2003. Effect of pre-slaughter rations of forage and/or concentrates on the composition and quality of retail packaged beef. Meat Sci. 63, 279-286.

OFIVAL - Office National Interprofessionnel des Viandes, de l'Elevage et de l'Aviculture. 1984. Coupes et découpes. OFIVAL, Paris.

Owens, F.N., Secrist, D.S., Hill, W.J., Gill, D.R., 1998. Acidosis in cattle: a review. J.Anim.Sci. 76, 275-286.

Phipps, R.H., Sutton, J.D., Beever, D.E., Jones, A.K., 2000. The effect of crop maturity on the nutritional value of maize silage for lactating dairy cows 3. Food intake and milk production. Anim. Sci. 71, 401-409.

Provenza, F.D., 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. J.Range Manage, 48, 2-17.

Rebhun, W.C., 1995. Diseases of Dairy Cattle. Williams & Wilkins, Media, PA.

Rioni, M., Lanari, D., 1976. Bull-beef production from the maize crop in Italy in large and small units. Anim. Feed Sci. Technol. 1, 531-544.

Sargentini, C., Giorgetti, A., Bozzi, R., Lorenzini, G., Perez Torrecillas, C., Martini, A., 2005. Performance produttive di vitelli Maremmani allevati secondo il metodo biologico e macellati a 19 e 23 mesi di età. Atti 4th World Italian Beef Cattle Congress, Gubbio April 29th – May 1st, pp. 383-388.

SAS Institute, Inc. 2001. SAS/STAT user's guide. Version 6. SAS Institute Inc., Cary, NC, USA.

Sauvant, D., Meschy, F., Mertens, D., 1999. Les composantes de l'acidose ruminale et les effets acidogènes des rations. INRA. Prod Anim. 12, 49-60.

SCAHAW (2001). Scientific Committee on Animal Health and Animal Welfare. The Welfare of Cattle kept for Beef Production. Sanco.C.2/AH/R22/2000. http://europa.eu.int/comm/food/fs/aw/aw_scahaw_en.html

Schwartzkopf-Genswein, K. S., Huisma, C., McAllister, T. A. 1999. Validation of a radio frequency identification system for monitoring the feeding patterns of feedlot cattle. Livest. Prod. Sci. 60, 27-31.

Formatted: English (U.K.)

Schwartzkopf-Genswein, K. S., Atwood, S., McAllister, T. A., 2001. Relationships between bunk attendance, intake and performance of steers and heifers on varying feeding regimes. Appl. Anim. Behav. Sci. 76, 179–188.

Seo, S., Lanzas, C., Tedeschi, L.O., Fox, D.G., 2007.Development of a mechanistic model to represent the dynamics of liquid flow out of the rumen and to predict the rate of passage of liquid in dairy cattle. J.Dairy Sci. 90, 840-855.

Shukking, S. 1976. The history of silage making. Stikstof 19, p. 2.

Sims, G.K., Ellsworth, T.R., Mulvaney, R.L., 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Commun. Soil Sci. Plant. Anal. 26, 303–316.

Sowel, B.F. Bowman, J.G.P., Branine, M.E., Hubbert, M.E., 1998. Radio frequency technology to measure feeding behaviour and health of feedlot steers. Appl. Anim. Behav. Sci. 59, 277-284.

Steen, R.W.J., Gordon, F.J., Dawson, L.E.R., Park, R.S., Mayne, C.S., Agnew, R.E., Kilpatrick, D.J., Porter, M.G., 1998. Factors affecting the intake of grass silage by cattle and prediction of silage intake. Anim.Sci. 66, 115-127.

Supelco. 1998. Analyzing fatty acids by packed column gas chromatography. Pages 5–7 in Bull. 856, Sigma-Aldrich Corp., Bellefonte, PA.

Van Dorland, H.A., Kreutzer, M., Leuenberger, H, Wettstein H.R., 2008. Eating behaviour of dairy cows offered fresh or ensiled white clover, red clover and ryegrass to choose from in a mixture. Appl. Anim. Behav. Sci. 111, 205-221.

Van Keulen, J, Young, B.A., 1977. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. J.Anim.Sci. 44, 282.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Method for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583-3597.

Watson, S. J., Nash, M. J., 1960. The conservation of grass and forage crops. Oliver and Boyd, Edinburgh and London.

Wilkinson, J.M., Huber, J.T., Henderson., 1976. Acidity and proteolysis as factors affecting the nutritive value of corn silage. J.Anim.Sci. 42, 208-218.

Wilkinson, J.M., Penning, I.M., Osbourn, D.F., 1978. Effect of stage of harvest and fineness of chopping on the voluntary intake and digestibility of maize silage by young beef cattle. Anim. Prod. 26, 143-150.

Woolford, M..K., 1984. The chemistry of silage. In: The Silage Fermentation pp. 71-132. New York: Marcel Dekker

Woolford, M. K., Wilkins, R.J., 1975. The evaluation of formaldehyde, bronopol, tylosin and pimaricin as additives in simulated silage. J. Sci. Fd. Agr. 26, p. 869.

Yang, W.Z., Beauchemin, K.A., 2006. Increasing the physically effective fiber content of dairy cow diets may lower efficiency of feed use. J.Dairy.Sci. 89, 2694-2704.

ZoBell, D.R., Olson, K.C., Wiedmeier, R.D., Sass, D., Shinners, K.J., McAllister, T.A, 2002. Effects of precessed corn silage on its digestibility and production of growing beef replacement heifers. Anim. Feed Sci. Technol. 96, 221-228.