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Yeast Cultures in Ruminant Nutrition

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Abstract

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Interest in the use of fungal direct-fed microbials in ruminant nutrition is considerable. The ban of antibiotic growth promoters in feed for production of animal foods has increased interest in evaluating the effect of yeast cultures (YC) on the gastrointestinal ecosystem, rumen microbial populations and function. The effects of specific YC preparations on the rumen environment and performance of ruminants have been well documented, and has generated considerable scientific interest over the last two decades. The precise mode of action by which YC, which are mostly derived from *Saccharomyces cerevisiae,* improve livestock performance has attracted the attention of a number of researchers in the world. It is clear from these research efforts that YC supplements can beneficially modify microbial activities, fermentative and digestive functions in the rumen. The research has demonstrated that viable YC preparations can stimulate specific groups of beneficial bacteria in the rumen, and has provided mechanistic models that can explain their effects on animal performance. The effects of YC on animal productivity are strain-dependant. So, all YC preparations are not equivalent in efficiency. This aspect opens a new field of research for new strains, each being more specialized in its use. The goal of many of these research activities has been to define the application and production strategies that can optimize animal responses to YC supplements. Continuous research with live YC supplements has clearly established scientifically-proven strategies for modifying and optimizing microbial activities in the gastrointestinal ecosystem and techniques for improving performance and health of ruminants. This article reviews the current status of the use of live yeast cultures in ruminant nutrition.

Key words: Yeast cultures, Yea-Sacc® 1026, Rumen microbial populations, Ruminal functions, Ruminant nutrition

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Abbreviations: **DFM -** Direct-Feed Microbials, **YC -** Yeast cultures, **LYC -** Live Yeast Cultures, **DMI -** Dry Matter Intake

Introduction

Direct-Fed Microbials as a Way to Enhance Ruminal Fermentation

The use of live microorganisms as feed supplements for ruminants is not a new concept. The use of microbial preparations has been largely based on empirical observations that suggest that some types of live microorganisms in feeds may beneficially influence animal performance in many types of production systems. Relatively speaking, large-scale applications of live microorganisms in feeds were not common historically. However, in the two last decades, the potential roles of specific microbial supplements have been better defined and there has been considerable interest in using preparations containing live microorganisms as feed supplements for ruminants (Dawson, 2002).

The original concept of administering microorganisms to animals involved the feeding of large amounts of "beneficial" microbes to livestock when they were "stressed" or ill. Microbial products used in this manner were originally called "probiotics", or products "for life." However, the term "probiotic" implied a curative nature. In the U.S., claims by a product to decrease mortality, to improve health, or to increase production (e.g. increased milk production or dry matter intake) cannot be made of any product unless its safety and efficacy have been documented and approved by government regulatory agencies. Thus, to overcome this requirement, the feed industry in conjunction with regulatory agencies, has accepted the more generic term of "Direct-Fed Microbials" (**DFM**) to describe microbial-based feed additives. In addition, a list of accepted microorganisms for use in animal feeds was developed.

Some of the major hypotheses on how DFM may benefit animals can be found in an excellent discussion by Fuller (1989). One of the most common explanations for improved animal health when ruminants are fed a DFM suggests that beneficial microbes compete with potential pathogens and prevents their establishment. DFM may also produce antimicrobial end products such as acids that limit the growth of pathogens (Denev, 1996, 2006). Additionally, metabolism of toxic compounds and production of stimulatory substances has resulted from feeding DFM to ruminants.

Bacterial DFM for Ruminants

The general concept of inoculating ruminants with beneficial microorganisms is not a new practice. For example, many producers and veterinarians have been inoculating sick ruminants (especially those that have been off feed) with rumen fluid from healthy animals in hopes of stimulating normal rumen function and improving dry matter intakes. However, there are no controlled research studies that document the efficacy of this practice and there are no commercial products based on this concept.

In contrast, there are many bacterial-based DFM that are sold for use in ruminant diets with more specific applications. These products often contain *Lactobacillus* spp. being one of the most common microorganisms used. Other commonly used bacteria include various

species of *Bifidobacterium, Enterococcus,* and *Bacillus* (Denev, 1996). Most bacterial-based DFM are probably beneficial because they have effects in the gut and not in the rumen (Denev et al., 2000; Denev, 2006). For example, *L. acidophilus* produces lactic acid, which may lower the pH in small intestines to levels that inhibit the growth of pathogenic microbes (Denev, 2006). Early research with DFM in ruminants first involved applications for young calves fed milk, calves being weaned, or cattle being shipped (Jenny et al., 1991; Hutchenson et al., 1980). These animals were thought to be stressed and have immature microbial ecosystems in their guts (Vandevoorde et al., 1991). Cattle that are shipped are often limited feed and water for prolonged periods of time during transit and may have abnormal environments in their guts that could lead to establishment of pathogenic microbes. Large doses of beneficial microorganisms have been hypothesized to recolonize a stressed intestinal environment and return gut function to normal more quickly in scouring calves. However, the data supporting such claims have been inconclusive. Calves fed *L. acidophilus* had reduced incidence of diarrhea (Beecham et al., 1977) and reduced counts of intestinal coliform bacteria (Bruce et al., 1979). However, feeding bacterial DFM to calves had no beneficial effects in other studies (Abu-Taroush et al., 1996; Cruywagen et al., 1996).The beneficial use of lactic acid-producing bacteria (largely *L. acidophilus*) in young calves (Gilliland et al., 1980) and as fermentation stimulants in ruminants (Dawson and Newman, 1988; Dawson et al.,1990; Yoon and Stern, 1991) have been described by many other investigators, but the overall mechanisms which explain the beneficial effects of these bacterial supplements have not been clearly defined.

Only a few studies have documented positive effects of feeding bacterial DFM to lactating dairy cows. High producing cows in early lactation would be the best candidates for such products because these cows are in negative energy balance and have diets that contain highly fermentable carbohydrates that sometimes lead to acidosis. Jaquette et al. (1988) and Ware et al. (1988) reported increased milk production from cows fed *L. acidophilus* (1 x 109 colony-forming units per head per day). Jeong et al. (1998) fed *Lactobacillus* spp. and *Streptococcus* spp. to lactating cows and reported a 0.8 kg/d improvement in milk production over control cows. Supplementation of lactobacilli may be useful in the close-up dry period of lactation when intake is depressed and animals are stressed. Savoini *et al*. (2000) reported that cows fed lactobacilli in the transition period produced numerically more milk and had lower blood non-etherified fatty acids, but higher blood glucose than did untreated cows.

A field trial was conducted on a commercial dairy to study the effects of feeding a DFM consisting of 2 strains of the specific bacteria *Enterococcus faecium* plus yeast on prepartum and postpartum performance of 366 Holstein cows. Cows received either the DFM or a placebo from about 10 days before expected calving until 23 or more days after calving. Supplementation with DFM increased milk fat percentage in the first-lactation cows, increased milk protein percentage in the second and greater lactation cows, and decreased the number of antibiotic treatments given to the second-lactation cows (Oetzel et al., 2007).

Propionibacteria may also be

beneficial when fed to ruminants. These bacteria are naturally found in high numbers in the rumen of animals fed forage and medium concentrate diets. They have the ability to convert lactic acid and glucose to acetic and propionic acid. *Propionibacteria* may be beneficial if inoculated into the rumen) because higher concentrations of ruminal propionate would improve the energy status of the animal (Kung et al., 1991. Swinney-Flyod et al. (1999) reported that feedlot cattle fed a diet containing *Propionibacteria* (strain P-63, $1.0x10^9$ cfu/head/day) and *L. acidophilus* (strain 5345, $1.0x10^8$ cfu/head/day) had better feed efficiencies during adaptation to a high concentrate diet and during a 120-d feeding period. Similarly, Huck et al. (1999) reported that cattle fed *L. acidophilus* ($5.0x10^8$ cfu/head/day) strain BG2F04, and *P. freudenrechii* ($1.0x10^9$ cfu/head/day) had better feed efficiencies than those fed a control diet. Kim et al. (2000) reported that *P. acidipropionici* DH42 decreased the molar percentage of propionic acid at the expense of acetic acid when fed to steers at a minimum level of ($1.0x10^7$ cfu/head/day). *P. freudenreichii* has also been used in a commercial product that also contains several strains of lactobacilli and has improved weight gain in some studies with calves (Cerna et al., 1991). Although *Propionibacteria* can metabolize lactic acid, they are probably too slow growing and acid intolerant to prevent an acute lactic acidosis challenge. Because *Propionibacteria* can metabolize nitrates, a commercially available product based on a strain that naturally occurs in the rumen has been claimed to reduce the chance of nitrate toxicity, but definitive data is lacking.

According to Raeth-Knight et al. (2007) supplementing midlactation cows with DFM products containing *L. acidophilus* and *P. freudenreichii* did not affect cow performance, diet digestibility, or rumen fermentation.

Other investigators have examined the potential for using preparations of the lactic acid-utilizing bacteria, *M. elsdenii* and *P. shermanii* to prevent lactic acid accumulation ruminal dysfunction in cattle fed high concentrate diets (Robinson et al., 1992; Hession and Kung, 1992; Kung and Hession, 1995). Many of the initial in vitro tests and small scale research trials with these bacterial supplements in animals suggest that these materials may have a role in preventing ruminal dysfunction. Despite these promising results, responses to bacterial supplements in practical production settings have been extremely variable, and currently none are routinely used in large scale production systems.

Fungal DFM for Ruminants

Fungal **DFM** have been popular additions to ruminant diets for many years. In general, three types of fungal additives are available. First, some products contain live yeast cultures (**LYC**) (*Saccharomyces cerevisiae*) (Denev, 1996). Second, other additives contain *S. cerevisiae* and culture extracts, but make no guarantee for live organisms. Third, there are fungal additives based on *Aspergillus niger* and *Aspergillus oryzae* fermentation end products that also make no claim for supplying live microbes.

Mode of Action of Yeast Cultures

Effects on Microbial Population and Ruminal Functions

Yeast cultures (**YC**) are very beneficial in the rumen. Several reasons for impro-

vements in ruminal fermentation from feeding YC have been suggested. Numerous studies (Sune et al., 1998; Jouany, 2001a; Alshaikh et al., 2002; Lila et al., 2004; Tricarico et al., 2006; Chevaux and Fabre, 2007) documented positive effects of YC not only on the rumen environment, but also on the improvement of microbial activities.

YC have caused beneficial changes in activity and numbers of rumen microbes. Yeast supplements stimulate the growth of beneficial microorganisms in the rumen. For example, the numbers of total ruminal anaerobes (Dawson et al., 1990; Newbold et al., 1991; Girard, 1997; Jouany, 2001a) and cellulolytic bacteria (Harrison et al., 1988; Girard, 1997; Jouany, 2001a) have been increased with YC. According to Blake (1993) and Girard (1997) YC obviously improve the cellulolytic activities of rumen microorganisms in such a way that they increase their total numbers, improve fiber digestion, reduce lactate accumulation, reduce the concentration of oxygen in rumen fluid and improve utilization of starch supplied in the feeding ration. In this way they influence (inhibit) the rate of volatile fatty acids production and, thus, increase the stability of rumen environment and improve the intensity of digestion. YC have also directly stimulated rumen fungi, which may improve fiber digestion (Chaucheryas et al., 1995a). They increased the number of rumen protozoa and neutral detergent fiber digestion in steers fed straw-based diets (Plata et al., 1994). YC have also been shown to stimulate acetogenic bacteria in the presence of methanogens (Chaucheryas et al., 1995a), which might result in a more efficient ruminal fermentation.

Many other investigators have attributed the beneficial effects of YC preparations directly to changes in the ruminal fermentation and in the microbial population in the digestive tract (Williams and Newbold, 1990; Dawson, 1992; Newbold et al., 1996; Wallace, 1996; Jouany, 2001a; Fallon and Earley, 2004).

The ability of specific yeast culture preparations to stimulate the growth of ruminal bacteria and to increase the concentrations of specific groups of beneficial bacteria in the rumen has been well documented (Jouany, 2001a; Dawson, 2002; Dawson and Tricarico, 2002). Increased concentrations of the total anaerobic bacteria and of cellulolytic bacteria in the rumen have been one of the most consistently measured responses to YC in the rumen (Wiedmeier et al., 1987; Harrison et al., 1988; Dawson et al., 1990; Newbold and Wallace, I992; Girard, 1997; Jouany, 2001a). However, other studies have also suggested that YC preparations can enhance the growth of lactic acid-utilizing bacteria (Edwards, 1991; Girard et al., 1993; Girard, 1997; Jouany, 2001a), proteolytic bacteria (Yoon and Stern, 1996), and bacteria that convert molecular hydrogen to acetate in the rumen (Chaucheyras et al., 1995a). In addition, YC preparations have been shown to enhance the activities of fiber-digesting fungi in the rumen (Chaucheyras et al., 1995c; Jouany, 2001a). Increased concentrations of beneficial microorganisms and enhanced microbial activities can be expected to lead to enhanced digestive processes and the destruction of metabolic intermediates that can result in ruminal dysfunction.

The ability of yeast to stimulate specific groups of bacteria is consistent with many of the other physiological and metabolic effects of yeast observed in the rumen and can explain enhanced protein synthesis,

improved ruminal stability, and improved microbial activities.

The importance of viable or metabolically active yeast cells in an YC preparation for optimal stimulatory activities in the rumen has been established by a number of investigators. Autoclaved YC pre-parations were ineffective at increasing the numbers of viable bacteria in the rumen (Dawson et al., 1990; El Hassan et al., 1993). However, irradiated yeast cells that cannot reproduce, but maintain their metabolic activities, have been successfully used to stimulate microbial activities in the rumen (El Hassan et al., 1993). These studies suggest that metabolic activity, and not active reproduction, is an integral part of the basic process that leads to a maximal beneficial response to yeast supplementation. This requirement for metabolically active yeast should be considered in any model used to explain the overall effects of yeast in the rumen.

Several lines of evidence suggest that LYC supplementation can beneficially alter nitrogen metabolism in the rumen (Dawson, 2002). This is reflected in lower ruminal ammonia concentrations observed in animals receiving yeast supplements and is consistent with observed increases in the concentrations of bacteria in the rumen. In addition, these changes are reflected in an increased flow of bacterial nitrogen to the small intestines (Erasmus et al., 1992). Altered nitrogen flow has also been associated with shifts in the basic amino acid flow out of the rumen. The beneficial increase in the flow of microbial protein from the rumen is consistent with models that predict stimulation of microbial growth in the rumen and more efficient conversion of ammonia nitrogen into microbial protein. Since microbial protein is often used to drive protein synthesis in high-producing ruminants, these observations suggest a role for specific yeast culture supplements in stimulating protein synthesis in both beef and dairy production systems.

YC supplementation influences ruminal lactic acid metabolism. YC prevent the accumulation of excess lactic acid in the rumen when cattle are fed diets containing highly fermentable carbohydrates. Sullivan and Martin (1999) reported that the supplement of a *S. cerevisiae* yeast culture into the diet of dairy cows improved the utilization of lactate and digestion of cellulose. Lyons (1993), Jouany (2001a), and Strohlein (2003) stated that some yeast strains showed a better capability to use lactate because they stimulated its utilization by propionic acid bacteria. The utilization of lactate by these bacteria is of the major importance for the stabilization of rumen environment. Doreau and Jouany (1998), Back (2006), and Chevaux and Fabre (2007) observed that in individual animals yeasts reduced daily fluctuations in pH values and also decreased differences existing between them. This resulted in a higher stability of rumen environment during the day. Increased metabolism of lactic acid should theoretically raise ruminal pH and this may be one reason why these YC increased numbers of rumen cellulolytic bacteria and improved fiber digestion (Arambel et al., 1987). Chaucheyras et al. (1995b) reported that *S. cerevisiae* was able to prevent the accumulation of lactic acid production by competing with *Streptococcus bovis* for glucose and by stimulating the uptake of lactic acid by *Megasphaera elsdenii* perhaps by supplying amino acids and vitamins. In contrast, added yeasts were unable to prevent acute episodes of lactic acidosis when fermentations were challenged with a diet rich in fermentable

carbohydrates (Aslan et al., 1995; Dawson and Hopkins, 1991; Jouany, 2001a).

In 1982, Alltech Inc. introduced Yea-Sacc®1026, a natural feed additive containing metabolically active *S. cerevisiae* strain 1026, which was identified and registered at the National Centre for Yeast Cultures (NCYC), Norwich in 1957. Registration number CBS 493.94. Yea-Sacc®1026 has not been genetically modified in any way (Lyons, 1997). The product was researched extensively between 1980s and 2000s by universities and research institutes in the world. Twenty years research has allowed Alltech to select the most efficient YC. Yea-Sacc®1026 is the naturally produced LYC that has been specifically chosen due to its superior ability to stimulate rumen microflora and to optimize rumen function.

Many studies have demonstrated a role of Yea-Sacc®1026 in stabilizing ruminal fermentations and in addressing ruminal disorders. Williams et al. (1991), and Jouany (2001a) demonstrated the beneficial effects of the Yea-Sacc®1026 on lactic acid concentrations in the rumen in high concentrate diets. In animals fed high-energy diets, decreased lactic acid concentrations are associated with higher ruminal pH, and are characteristic of much more stable ruminal fermentation. These alterations in ruminal fermentations can be expected to provide for improved digestion, and could also be reflected in improved intake. The ability of Yea-Sacc®1026 to prevent the accumulation of lactic acid in the rumen suggests a role for viable yeast in overcoming ruminal dysfunctions associated with the use of high energy diets used in both high-producing dairy and fast-growing beef cattle. Studies by Girard et al., (1993; Girard, 1997; Jouany, 2001a), suggest that lower lactic acid concentrations are likely due to enhanced growth and activities of lactic acid-utilizing bacteria in the rumen and are not the result of a direct inhibition of starch-digesting lactate producers.

LYC may improve ruminal fermentation because they are able to scavenge excess oxygen (Newbold et al., 1996; Jouany, 2001a) creating a more optimal environment for rumen anaerobic bacteria. Importantly, not all strains of *S. cerevisiae* have stimulatory effects on rumen fermentation. For example, Newbold et al. (1995) reported that the stimulation of rumen bacteria was different with specific strains of *S. cerevisiae,* but the reasons for these differences were unknown.

Despite the basic understanding of some of the beneficial effects of yeast cultures on the microbial populations in the rumen, the physiological basis for the enhanced microbial growth has not been completely described. A number of specific hypothetical biochemical mechanisms have been developed to explain the stimulatory effects of yeast cultures in the rumen (Dawson and Girard, 1997; Chevaux and Fabre, 2007). Some of these have been based on the ability of yeast to provide important nutrients or nutritional cofactors that stimulate microbial activities, while others suggest that the ability of yeast to control the oxygen levels in the ruminal environment is important. Other more recent models suggest that yeast can provide a focal point for the development of a stable microbial consortium (Jouany, 2000). In this model, the yeast cells provide a site for metabolic exchanges and an environment that promotes the growth of beneficial microorganisms around substrates. These kinds of models have many attractive features, but are individually limited in their ability to explain

all of the effects associated with yeast supplementation in the rumen.

Recent studies have suggested that more basic mechanisms are involved in the overall stimulation of beneficial ruminal bacteria (Girard and Dawson, 1994, 1995; Girard, 1996, 1997). These studies have resulted in the isolation of a group of small, nitrogen-containing compounds that stimulate bacteria to enter into logarithmic growth and thus stimulate microbial activities. The basic chemical characteristics of these stimulatory compounds are consistent with those of small, biologically active peptides. The stimulatory activities of these small peptides can readily be demonstrated in studies with pure cultures of ruminal bacteria (Girard, 1996). Synthetic tryptophan-containing peptides have also been shown to bring about similar stimulatory effects and to stimulate the growth of representative fiber digesting bacteria from the rumen. These stimulatory activities were not associated with individual amino acids, and occurred at concentrations that were well below those that would suggest that these compounds are limiting nutrients. Instead, these compounds appear to serve as metabolic triggers that stimulate beneficial ruminal bacteria to enter into an exponential growth phase. This stimulatory activity toward specific strains of ruminal bacteria can explain many of the observed effects of yeast culture in the rumen.

The stimulatory peptides are apparently not stable in the ruminal environment. Attempts to measure their presence in rumen fluid have been unsuccessful. The activities of proteolytic enzymes and rapid uptake of the peptides by microorganisms probably eliminates these compounds from the rumen very rapidly. This observation is consistent with the requirements for metabolically active yeast preparations that have been observed by a number of investigators (Dawson et al., 1990; El Hassan et al., 1993; Girard, 1997). It appears that the metabolically active yeast cells provide a continuous source of such peptides, and thus can continually provide low levels of stimulation for beneficial ruminal bacteria. Taken together, these observations suggest that the stimulatory effects of yeast in the rumen can be explained by the presence of these biologically active compounds in the rumen.

Effect on Dry Matter Intake and Ruminant Productivity

YC supplementation influences ruminal digestion. Most investigators agree that YC can have measurable effects on ruminal fermentation and results in beneficial changes in digestion. Studies in several laboratories have demonstrated that YC supplementation can influence digestive process in the rumen and feed intake (Kumar et al., 1997). DMI is often considered to be a function of the initial rate of fibber digestion; early stimulation of ruminal activity can be expected to have a major impact on the feed consumption and can provide a driving force for improved animal performance. Such studies suggest an important role of YC supplementation in digestion in animals maintained on high forage diets (Dawson and Tricarico, 2002).

Under farm conditions, producers are most concerned how a feed additive effects animal production (gain and milk) and feed efficiency. The action of LYC at the animal level has been well documented during the last two decades, mainly in dairy and meat production (Jouany, 2001a; Chevaux and Fabre, 2007). There have been numerous studies reporting positive

effects, but also lack of effects, of different LYC on intake and milk production of lactating cows. Dawson and Tricarico (2002) analyzed the results gained from 22 studies with Yea-Sacc®1026 involving more than 9039 lactating dairy animals. He found an average increase in milk production of 7.3% in yeast-supplemented animals. Responses to supplementation were variable and ranged from 2 to 30% increase in milk production. The improvement of milk production was 1.8 l in the controlled experiments which is probably significant. It became 1.4 l in the field studies. According to Gunter (1989), the effects of yeast were highest within the first 100 days of lactation. YC can also action the persistence of lactation after the production peak of dairy cows (Alonzo et al., 1993). Growth responses to YC in meat-producing ruminants was also variable and ranged from no significant increase in average daily gain to an increase of more than 20%, with an average daily gain of 8.7%.

In general, YC preparations are least effective when animals are fed well-balanced diets that promote the stability of the gastrointestinal microbial population and are more likely to have dramatic effects under conditions of dietary and environmental stress. However, data from a wide range of both controlled studies and field trials suggest that YC supplements can have a significant role in strategies for economically enhancing the performance of ruminant animals (Dawson and Tricarico, 2002).

The positive effect on animal production, when observed, is better explained by an increase of feed intake rather than a better feed digestibility. The YC stimulated the rate of degradation of solid feeds in the rumen within the first 6 to 8 hrs after the meal; the animals can ingest more dry matter to fill their digestive compartment at the same level. This physical regulation could be involved to explain the higher feed intake in treatment animals. Another factor that can influence the physical regulation of intake is the outflow rate of digesta from the rumen, but the effect of yeast on this parameter is really inconsistent (Jouany, 2001a).

Feeding YC has increased dry matter intake (**DMI**) in some (Williams et al., 1991; Wohlt et al., 1991; Dawson and Tricarico, 2002) but not in other studies (Arambel and Kent, 1990; Kung and Muck 1997). Milk production has been increased in some studies (Piva et al., 1993; Kung et al., 1996) but not in others (Erdman and Sharma, 1989; Swartz et al., 1994). Yeast cultures have also been fed to pre-partum cows improving DMI in some studies (Dann et al., 2000; Wohlt et al., 1991), but not in others (Robinson, 1997; Soder and Holden, 1999). These results indicate that, although the same YC preparation was given, the animal response varied between experiments.

Several studies have demonstrated that not all yeast strains are equally capable of stimulating ruminal bacteria. Evidence for strain differences has been obtained from studies with pure cultures of ruminal bacteria and with mixed populations. Only 7 strains of over 50 strains tested had the ability to stimulate the growth of fiber digesting bacteria from the rumen (Dawson and Hopkins, 1991). Other studies suggest that few strains of yeast have the ability to stimulate both the beneficial fiber-digesting bacteria and the bacteria associated with lactate utilization. Similarly, Newbold et al. (1996) demonstrated that Brewer's yeast strains and Baker's yeast strains differed in their abilities to stimulate

critical groups of ruminal microorganisms. Baker's yeast strains had limited ability to bring about stimulation. These studies suggest that care must be taken in selecting *S. cerevisiae* strains for use in YC preparations for ruminants. Such studies also explain some of the variability in production responses, since many of the early studies relied on poorly defined yeast culture supplements and may have used strains with little stimulatory activity.

Most investigators agree that only LYC supplementation strategies can have measurable effects on ruminal fermentations and result in beneficial changes in digestion. Studies in several laboratories have demonstrated that LYC supplementation can influence digestive processes in the rumen (Williams and Newbold, 1990; Dawson, 1992; Newbold *et al.*, 1996; Wallace, 1996; Chevaux and Fabre, 2007). In these studies, the total extent of dry matter digestion was not drastically altered. However, the initial rate of digestion was readily influenced by the addition of LYC preparations to the diets of ruminants. This is a characteristic of yeast supplementation that has been measured in both *in vitro* (Dawson and Hopkins, 1991) and *in vivo* (Williams and Newbold, 1990; Smith et al., 1993; Kumar et al., 1997) studies. Since feed intake is often considered to be a function of the initial rate of fiber digestion, early stimulation of ruminal activity can be expected to have a major impact on feed consumption and can provide a driving force for improved animal performance. Such studies suggest an important role of LYC supplementation in digestion in animals maintained on high forage diets.

The effect of LYC supplementation on the performance of dairy cows during the transition period was studied by Nocek et al. (2003). During the postpartum period, dry matter intake, milk yield, and milk protein content were higher in cows receiving direct-fed microbial supplementation compared with the control group. Effects of different doses and rations of roughage and concentrates on the milk performance and efficiency of rumen digestion were discussed also by Hoover et al. (1986), and Strzetelski et al. (1996).

The effect of different doses of LYC (*S. cerevisiae,* strain SC-47) (0, 3, 6 and 12 g of yeast/day respectively) on the lactating performance of Holstein dairy cows was described by Nikkhah et al. (2004). They drew a conclusion that the LYC had a beneficial effect on the rumen health. Other available data indicated that in the rumen fluid of animals receiving supplements of LYC the total content of volatile fatty acids, and the percentage of propionic acid (Sullivan and Martin, 1999), and acetic acid (Nursoy and Baytok, 2003) increased, the content of ammonia decreased (Enjalbert et al., 1999; Kamra et al., 2002; Nursoy and Baytok, 2003; Strohlein, 2003) and the total numbers of ruminal bacteria and infusoria significantly increased (Sune, 1998; Kamra et al., 2002, Alshaikh et al.,2002, Ando et al., 2004). Ando et al. (2004) stated that dietary supplementation of Yea-sacc®1026 a significant increase in degradability of roughage in 6 h ($P<0.05$) after live yeast addition.

Doreau and Jouany (1998), Zheng et al. (2000) and Strohlein (2003) also reported that the addition of LYC (*S. cerevisiae*) into the feeding ration of dairy cows improved their milk performance significantly. A positive effect of yeasts on the performance of dairy cows and on the content of milk components resulted from increased daily feed intake and im-proved

digestibility of nutrients (Jouany, 2001). In their experiment Nikkhah et al. (2004) did not find the dry matter intake and milk yield in cows to be affected ($P>0.05$) by experimental diets but milk composition including fat and percent total solids were improved by the addition of LYC ($P<0.05$).

Formigoni et al. (2005) reported that Yea-Sacc®1026 improved significantly the DMI and milk yield of dairy cows, on the overall period, but also, during heat stress period. Yea-Sacc®1026 improved significantly the composition of cow's milk, including fat ($P<0.01$) and protein ($P<0.05$) content. Bertin and Andrieu (2005) demonstrated the beneficial effect of Yea-Sacc®1026 on the performance of high-producing dairy cows. Yea-Sacc®1026 significantly improved milk production among high-producing dairy cows. Dairy cows fed Yea-Sacc®1026 were better able to rebuild body stores better than control cows. Kravale et al. (2005) also reported that Yea-Sacc®1026 significantly improved milk yield of dairy cows, fat and protein content in cow's milk especially during the hot season. Economic results of the dairy herd were improved in the Yea-Sacc®1026 group in comparison with untreated control.

Many other investigations demonstrated a significantly positive effect of Yea-Sacc®1026 on a) DMI (Fallon and Earley, 2004a, 2004b; Bertin et al., 2005; Sinclair et al., 2006); b) Milk production of dairy cows (Sinclair et al., 2006; Tricarico et al., 2006), lactating buffalo (Abo El-Nor and Kholif, 1998; Agovino, 2006), dairy sheep and goats (Sara et al., 2004; Spruzs and Selegovska, 2004); c) Meat production of lambs (Sara et al., 2004), calves (Fallon and Earley, 2004b), and finishing bulls (Fallon and Earley, 2004a).

Yea-Sacc®1026 is the world's leading YC and the essential performance-enhancing ingredient for today's genetically advanced and high potential dairy cows. By naturally boosting the population of beneficial rumen bacteria, Yea-Sacc®1026 helps of ruminant animals achieve their full potential-cost effectively – through better utilization of feed. Yea-Sacc®1026 reduces digestive disorders, drives dry matter intake, improves feed efficiency, increases milk yield, improves milk composition, and improves meat production. Yea-Sacc®1026 is the first LYC to gain EU approval as performance-enhancing product for dairy cows, fattening cattle and calves (EU, 2003; OJEU, 2004a, 2004b).

According to Chevaux and Fabre (2007) LYC supplementation in the diet of dairy goat and sheep had a positive effect on reducing the somatic cell count in milk. When the goats received live yeast products and especially (*S. cerevisiae* SCI-1077) their fecal *E. coli* population decreased, while total *Lactobacilli* population – the „friendly bacteria", significantly increased. The authors suggest that the increased *Lactobacilli* level in treated animals may have been responsible for the reduction in level the opportunistic pathogen *E. coli*, not only through pH control, but also by competing for receptors at the surface of the gut, thereby improving the stability of the intestinal ecosystem. In addition, knowing that LYC optimizes ruminal digestion, another hypothesis is that the live yeast could help control the lower gut flora balance by limiting the amount of residual nutrients, thus limiting opportunistic microorganisms and pathogens development.

In general, most would agree that DFM based on yeast must be "live." Thus, they must survive processing, storage and the

gut environment. In contrast the need to provide a high numbers of LYC (*S. cerevisiae*) has been the subject of many debates. As previously mentioned, some products guarantee live yeast cells (e.g., $1.0x10^9$ cfu/per g) and are fed at low inclusion rates (only 10-20 g per day), but other products suggest that live organisms are not required for beneficial effects. The metabolites present in the culture extracts have been suggested to be the "active" ingredients. Dawson et al. (1990) reported that the stimulatory effect of yeast on numbers of rumen cellulolytic bacteria was negated when yeasts were autoclaved. Although there have been implications that suggests yeasts were able to grow in continuous rumen cultures (Dawson et al., 1990), we reported that *S. cerevisiae* did not multiply in sterile ruminal fluid although they were metabolically active (Kung et al., 1996). Durand-Chaucheyras et al. (1998) confirmed the fact that added *S. cerevisiae* did not colonize the rumen of lambs, and Kung and Muck (1997) reported that yeasts were essentially washed out of ruminal continuous fomenters. The debate on the need for LYC with beneficial properties will continue, unless more definitive studies addressing this issue are conducted. The goal of many of these research activities has been to define the application and production strategies that can optimize animal responses to LYC supplements. Continuous research with LYC supplements has clearly established scientifically-proven strategies for modifying and optimizing microbial activities in the gastrointestinal ecosystem and techniques for improving performance and health of ruminants.

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