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Review Article

Current View of the Significance of Yeast for Ruminants a Review 1- Role of Yeast and Modes of Action

Alsaied Alnaimy Mostafa Habeeb

Department of Biological Applications, Radioisotopes Applications Division, Nuclear Research Center, Atomic Energy Authority, Cairo, Egypt

Email address:
dr_alnaimy@yahoo.com

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Abstract: A variety of mechanisms have been suggested to explain changes in the activity of the rumen and improvements in performance when ruminants are fed yeast-based (Direct-Feed Microbials) DFMs. Yeast may have a buffering effect in the rumen by mediating the sharp drops in rumen pH which follows feeding of higher concentrate rations. Yeast may help to buffer excess lactic acid production when ruminants are fed high concentrate diets. At higher pH levels when feeding yeast caused increased numbers of rumen cellulolytic (cellulose digesting) bacteria and improvements in fiber digestion. Yeast fed has been shown to stimulate the growth and activity of rumen bacteria. Some products have high numbers of live yeast with low recommended feeding rates while other products suggest that live organisms are not required for beneficial effects and that the end products (metabolites produced by the yeast cells) are the active ingredients. Both types of yeast product have been reported to produce a variety of positive effects, especially, when fed to animals on a high forage diet.

Keywords: Yeast, Mode of Action, Rumen Activity, Bacteria, Animals

1. Introduction

The main constrain in animal production in Egypt is the shortage in animal feeds so, the partial solving of this problem is to add certain supplements, i.e. growth promoters to the rations of animals to enhance growth and feed efficiency. Yeast is a live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance [1]. Feed additives such as Active dry yeast (ADYs), which benefit from a natural image by the consumer, can expect a promising future in ruminant nutrition. Most studies indicate that ADYs can be useful to positively balance digestive microflora and improvement of animal production and health. In addition, use of ADYs appears particularly relevant when the digestive microbiota is challenged, for example during a feed transition such as weaning, grazing, supply of high-concentrate diets, or during periods of stress such as hot temperature or transportation [2]. ADYs products are generally characterized by a high concentration of viable cells (>10 billion cfu/g), with the most common species being *Saccharomyces cerevisiae*. Yeast biomass is dried to preserve cell viability and metabolic activity and in some products, the cells are mixed together with their fermentation medium. Other products do not contain any viable cell and are used as a nutritional ingredient. Dietary YC causes a range of effects in the rumen, including increased pH, increased ruminal concentrations of volatile fatty acids (VFA's) decreased methane production and increased total number of microorganisms and cellulolytic bacteria [3].

ADYs are increasingly used in ruminant nutrition as feed additives to improve feed efficiency and performance and effects of ADYs vary depending on biotic factors such as the strain of yeast and its viability but also on a biotic factor such as the nature of the diet or animal management [2]. 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 [4]. 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 [5]. 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 [5].

From a regulatory view, some ADYs have been officially registered as feed additives in Europe [6]. In USA, *Saccharomyces cerevisiae* species is registered in the Generally Recognized as Safe (GRAS) list. In recent years, with increased consumer's concern about safety, quality of animal products and also environmental issues, the current purpose of using these natural additives is not only to increase productivity but also to diminish the risk of animal digestive transfer of potential human pathogens to decrease the antibiotic load and the risk of antibiotic resistance genes transfer and to limit excretion of pollutants [2]. Another possible source of variation in response to supplementation of yeast product may be the type of yeast products that are used. Differences exist between active ingredients and putative modes of action of different products.

Therefore, the objective of this paper was evaluating the beneficial effects of yeast in the livestock production and reviewed the role of yeast in ruminant nutrition and different modes of yeast actions.

2. Role of Yeast in Livestock

2.1. Forms of Yeast Product

There are significant biochemical and functionality differences in the various yeast products and each product should be used for its own unique properties. Yeasts have been fed to animals either in the form of yeast fermented mash produced on the farm, yeast by-products from breweries or distilleries or commercial yeast products specifically produced for animal feeding. Active dry yeast (95% dry matter) is the predominant viable yeast available to the feed industry. Although wet yeast cake (30% solids) and to a lesser extent yeast cream (18-20% solids) are used extensively by the bakery trade and the active dry yeast is the form of viable yeast used in most animal feeds [8]. All three forms of live yeast can be used as inoculums to manufacture yeast culture which is a yeast fermented product. Active dry yeast consists of pure, dried yeast cells with viability counts ranging from 15-25 billion live yeast cells or colony forming units per gram [9].

2.2. Types of Yeast

The nutritional yeast products consist of yeast biomass or pure, dead yeast cells which are fed for their nutrient value. Yeast products include primary dried yeast, brewers dried yeast, torula dried yeast and whey yeast.

2.2.1. Primary Dried Yeast

Primary dried yeast refers to yeast (usually *Saccharomyces cerevisiae* or *Candida utilis*) which is intentionally grown and harvested as nutritional yeast source and is not a by-product of another industry. It is generally propagated on sugar substrates, like molasses, in aerobic bioreactors much like active baker's yeast, but dried at high temperature to kill the yeast cells. It is predominantly used in the food industry for food enrichment and is generally too expensive for use in the feed trade [9].

2.2.2. Brewers Dried Yeast

Brewer's yeast is a by-product of the beer and brewing industry. After the beer is fermented, the yeast (*Saccharomyces cerevisiae*) is recovered from the fermentation vats, dried at high temperature to kill the yeast and sold to both the food, health food and animal feed trades as a specialty protein, vitamin and mineral supplement.

2.2.3. Torula Dried Yeast

Torula yeast refers to a special yeast species (*Candida utilis*) which is often grown on the waste-water from the paper industry, called sulfite liquor. It provides a marketable by-product and most of it is used by food manufacturers.

2.2.4. Whey Yeast

Whey yeast is yeast grown on whey lactose and consists of yeast from the species *Kluyveromyces marxianus* (formerly classified as *Kluyveromyces fragilis*). When whole yeast cells are fed, their primary nutritional contribution comes from the proteins, peptides, vitamins and minerals contained within the cell and the intracellular bio chemicals found in the yeast cell. Thus, for these nutrients to become available, the yeast cell must be lyses or broken open so that the contents within the cell become available for digestion and absorption [9].

2.3. Special Purposes of Yeast Products

2.3.1. Irradiated Yeast

Yeast contain a sterol, ergosterol, which is converted to form vitamin D2 (ergocalciferol) when irradiated with ultra violet light and then to vitamin D3 (cholcalciferol).

2.3.2. Selenium Yeast

Yeast is also a good source of dietary selenium. The selenium in yeast is generally in the form of selenomethionine, which is an organic form of selenium with selenium replacing the sulfur in the methionine molecule. Selenium is required for the activation of an enzyme system that has protective effects on the liver. Selenium in yeast activated enzyme glutathione peroxidase, prevents oxidative damage of the cell membrane. Brewer's yeast selenium played an early role in animal nutrition, especially in pet food manufacturing. Brewer's yeast contains appreciable amounts of B-vitamins and selenium often accounted for its inclusion in many animal feed formulations. Commercial high selenium yeasts are manufactured and sold through health food stores and sometimes added to vitamin/mineral supplement tablets. Baker's yeast may contain one or two ppm selenium and commercial high selenium yeasts are available containing as much as 2,000 ppm selenium, 75% of which is organically bound [9].

2.3.3. Chromium Yeast

Chromium in yeast is present in the organic form called the glucose tolerance factor and is important in the regulation of sugar metabolism. Chromium yeast consists of trivalent chromium complexes with biologically active peptides, amino acids and niacin. Chromium yeast appears to act in conjunction with insulin to facilitate efficient metabolism of carbohydrates. Studies indicate that individuals who consume chromium in the organic form have a reduction in blood sugar and insulin dependency and a reduction in serum cholesterol and triglycerides. Recent research trials indicate that organic chromium, either as high chromium yeast or chromium picolinate may reduce stress in cattle.

2.3.4. Phaffia Yeast

Phaffia rhodozyma (phaffia yeast) is the yeast product enter the feed industry. Phaffia yeast produces red pigment used in trout and salmon feeds for its red pigmentation of the meat.

2.4. Nutrient Values of Yeast

When whole yeast cells are fed, like brewer's yeast or active dry yeast, their primary nutritional contribution comes from the proteins, peptides, vitamins and minerals contained within the cell. Yeast extracts consist of the intracellular components of the yeast cell, with the yeast cell-wall removed. Thus, for these nutrients to become available the yeast cell must be lyses or broken open so that the contents within the cell become available for digestion and absorption.

This can happen in two ways:

1) Protease and glucanase enzymes from microorganisms in the digestive tract can break open the cell via hydrolysis from the outside-in, and

2) The enzymes within the live yeast cell can cause autolysis of the yeast cell by digesting the cell-wall from the inside-out.

When dead yeast cells, like brewers dried yeast, are fed hydrolysis is the only way the intracellular yeast nutrients are made available. When live yeast cells are fed, both hydrolysis and autolysis may play a role in rupturing the cell for digestion. As for digestibility or availability of the intracellular yeast nutrients, the nutrients from live cells are probably more available assuming the cell is lyses. Live yeast cells, per se, are more nutritious than dead yeast cells, but that dead yeasts are generally dried at much higher temperatures, which are dead and nutrient availability is generally lower. The higher temperature used to dry the yeast caused the more denaturization or destruction of the nutrients.

Yeasts are a good source of protein or amino acids and approximately 40% of the weight of dried yeast consists of protein. The quality of yeast protein is excellent for a vegetable protein and it is about equivalent in quality to soybean protein. Both are rich in lysine and are excellent supplements to cereals, whose proteins are generally low in lysine. Yeast protein is low in the sulfur amino acids but supplementing dried yeast with 0.5% methionine can raise its protein quality up to that of casein. In addition, yeast has long been recognized as a rich source of natural B-vitamins.

Yeast cell nutrients are shown in Table 1.

Table 1. *The gross composition of the yeast biomass [8].*

Gross composition of yeast biomass (%)	
Moisture	2-5
Crude Protein	50-52
True Protein	42-46
Nucleic Acids	6-8
Minerals	7-8
Lipids	4-7
Carbohydrates	30-37

Crude protein minimum 46%, lysine up to 3%, methionine up to 1%, methionine + cystine up to 1.6%, lipids up to 8%, ash up to 4%, cellulose up to 3%, phosphorus1.5%, calcium 0.2% and vitamins (vitamin E-120, vitamin B_1 (thiamine)–10, vitamin B_2 (riboflavin)-160, vitamin B_3 (pantothenic acid)-140, B_4 (choline)-5200, B_5(nicotinic acid)–450, B_6 (pyridoxine free)–40, H (biotin)– 0.50, B_9(folic acid)–14, B_{12}-0.6 mg/kg). Microelements: iron–1200, manganese- 140, zinc–90, copper–10 mg/kg [8].

2.5. Yeast Fractions

Yeast extracts and autolysates are produced from whole yeast cells and are used extensively in the food industry for flavor enhancement. Yeast extracts consist of the intracellular components of the yeast cell with the yeast cell-wall removed. Yeast autolysates consist of ruptured or lysed cells and contain both the intracellular and cell-wall fractions. Both contain 5'-nucleotides and glutamate which enhance flavor recognition. Yeast extracts are also used as microbial stimulants in the fermentation industries and microbiologists use them in their laboratory growth media to optimize bacterial growth. Yeast cell-walls remaining as a by-product in the manufacture of yeast extracts are often called yeast hulls and consist predominantly of beta-glucans and mannans with some chitin and protein.

3. Modes of Yeast Action

The mode of action of yeast cultures and extracts may exert their beneficial effects through antagonism against specific groups of pathogenic organisms, increased enzyme activity in the gut and stimulation of immunity. Yeast produces enzymes such as amylases, proteases, lipases and celluloses and also considered is good sources of B-vitamins [3]. *Saccharomyces cerevisiae* (Sc) yeast is used as the source of biologically active matters of microbiological origin and cultivated on the basis of grain substrate. Sc yeast are subject to a special treatment allowing make available protein, amino acids, vitamins of B group for assimilation by an organism of animals and poultry. In addition, the activation of mannaoligosaccharides existing in yeast takes place which are adsorbents and exterminate pathogenic microorganisms and toxins from an organism of animals and poultry [10]. However, Yeast cells are unable to develop in a durable manner in the ruminal milieu, so that they have to be fed every day and they can stay alive in the rumen up to about 30 hours [5].

The mode of action of yeast in stimulating animal production may be possesses a natural attractive flavor which can improve the palatability of the feed, contains B-complex vitamins and unknown growth factors both of which may be essential for the nutrition of specific gastro-intestinal microorganisms and for the host animal metabolism, assimilates many proteins and secretes many essential amino acids, provides minerals which are available in chelated form after yeast cell autolysis and such minerals are more readily absorbed by the animal, excretes digestive enzymes including protease, lipase, proteinase, and invertase and produces sterols, lipids and glycolipids [11]. Newbold et al. [12] suggested two modes of action of yeast in stimulating rumen fermentation. The first, that yeast respiratory activity protects anaerobic rumen bacteria from damage by O_2. The authors added yeast to rumen fluid in vitro and found that the rate of O_2 disappearance increased by 46-89% and also stimulated the total and cellulolytic bacterial population numbers. The second hypothesis, that yeast provides malic and other dicarboxylic acids which stimulate the growth of some rumen bacteria. The authors were examined by comparing between the effects of yeast and malic acid on rumen fermentation in sheep. The authors found that yeast increased significantly the total viable count of bacteria whereas malic acid did not and concluded that the stimulation of rumen bacteria yeast is at least partly dependent on its respiratory activity and is not mediated by malic acid.

The mode of action of yeast in ruminant involves modification of rumen fermentation, related to increased bacterial numbers and concluded that yeast effect in ruminants is strongly dependent on the diet and also that particle yeast size (5x10μm) is also significantly higher than bacteria size (0.5x5μm). Among yeast, *Saccharomyces serevisiae* is industrially important due to its ability to convert sugars (i.e. glucose, maltose) into ethanol and carbon dioxide [13].

Generally, there are several modes of action have been demonstrated to clear the role of yeast in ruminant nutrition:

(1) Oxygen scavenger: Yeast respiratory activity lowers the redox potential and live yeast use oxygen to metabolize sugars and small oligosaccharides solubilized from feed particles and produce peptides and amino acids as end products which are used by the bacteria in the vicinity of yeast [14].

Because main ruminal microorganisms are strictly anaerobic, removal of O_2 improves anaerobiosis in the microenvironment of solid feed particles, protects anaerobic rumen bacteria from damage by O_2, increases the number of cellulolytic bacteria, provides better conditions for the growth of cellulolytic bacteria and improves ruminal digestion [15]. The author proposed an original model to explain how yeast cells can interact with other microbes in a micro-consortium structure (Figure 1).

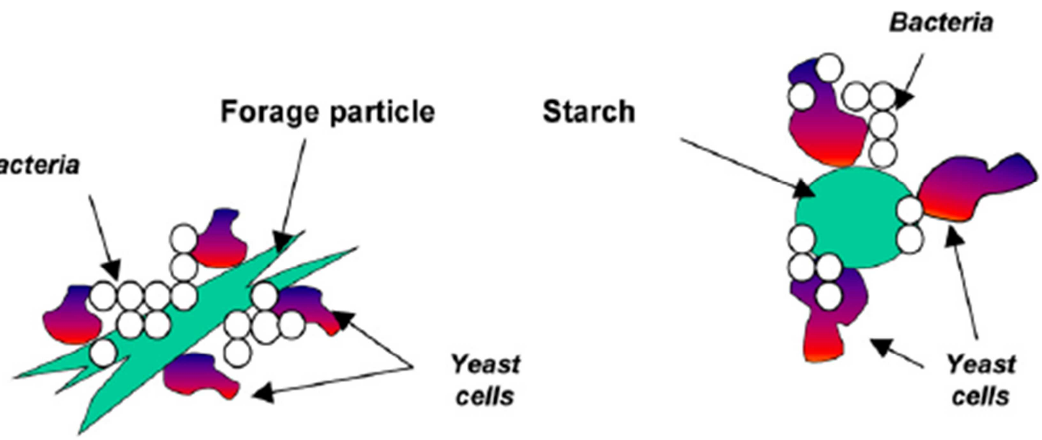

Figure 1. *Mode of action of live yeast in ruminants [15].*

(2) Supply of growth factors: Yeast supply some growth factor like metabolically active yeast cells, short chain peptides, stationary phase of bacteria, and protein synthesis in bacteria, transition to exponential growth, increases bacterial growth and activity [16].

(3) pH stabilization: Yeast increase lactate utilization and also yeast is a source of dicarboxylic acid and malic acid which is utilized by yeast of ruminant to produce propionate from lactate to protect on pH stabilization [17].

(4) Stimulation of rumen microbes: O_2 uptake, supply of growth factors and pH stabilization synergistically act for stimulation of rumen microbes. In addition, yeast culture also directly stimulates rumen fungi which may improve fiber digestion and increases concentration of cellulolytic and total anaerobic bacteria by creating more favorable environment for growth of rumen microbes [18]. Plata et al. [19] added that yeast culture increase the number of rumen protozoa and neutral detergent fiber digestion. Callaway and Martin [20] reported that yeast culture and aspergillus oryzae stimulates rate of fiber degradation.

(5) Microbial protein synthesis (Methionine and Lysine): The authors suggested that yeast culture caused reduction in rumen NH3-N concentration, increase incorporation of NH3 into microbial protein, improved amino acid profile of duodenal digesta [18, 20].

Schematic depicting yeast cells using oxygen located within and immediately around freshly ingested solid particles. This improves an aerobiosis and thus benefits bacteria closely associated with yeasts in a micro-consortium structure (Figure 2).

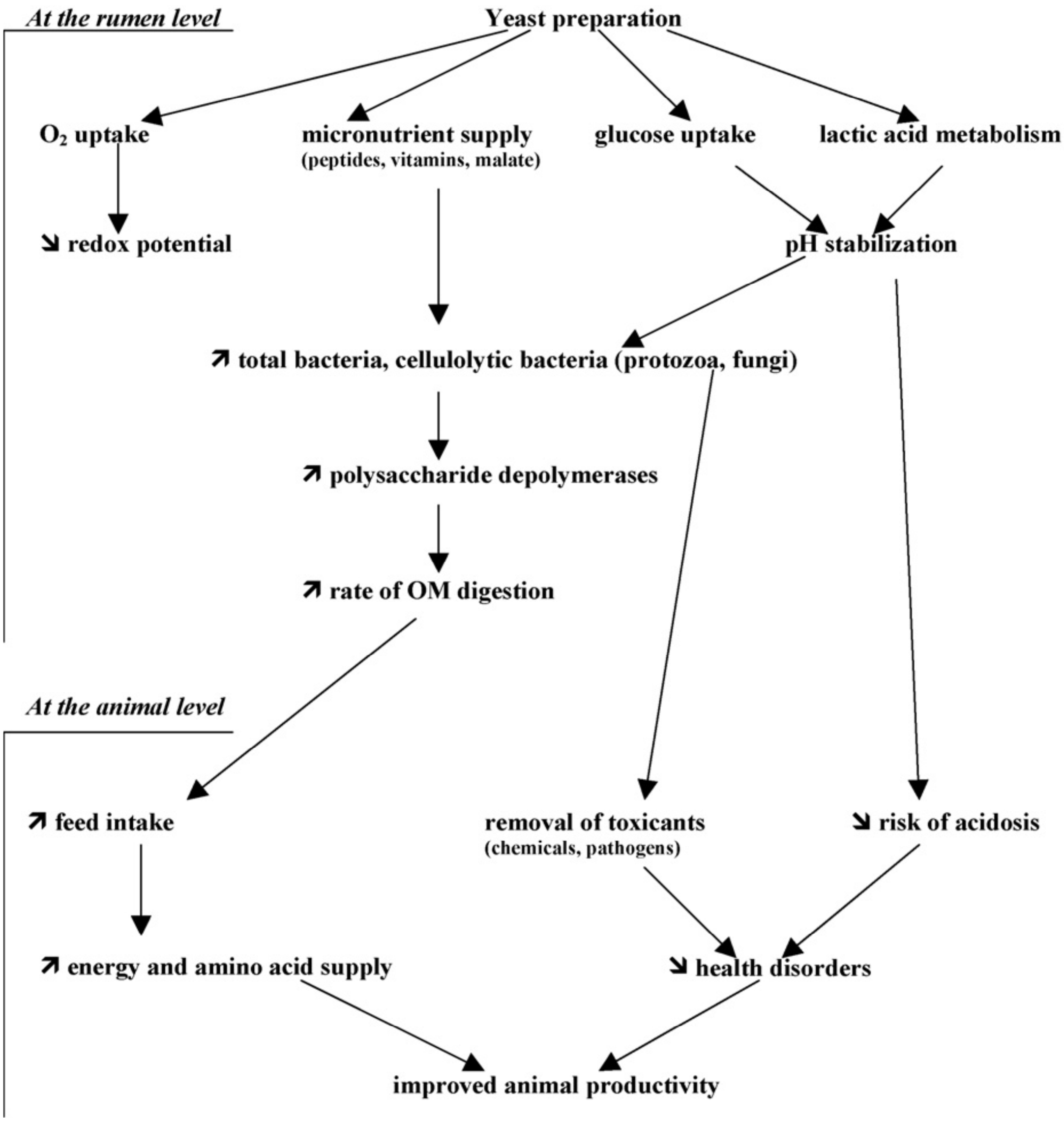

Figure 2. *Proposal model for the action of yeast at the rumen and the animal levels [21].*

Yeasts are aerobes and cannot survive in an anaerobic environment in the rumen. However, traces of oxygen are present in the micro-environment surrounding solid particles which have just been ingested. This explains why the majority of live yeast cells are attracted by the solid matrix immediately after ingestion, whereas their concentrations remain low in the liquid phase of rumen digest [22]. Live yeast cells use oxygen to metabolize the sugars and small oligosaccharides solubilized from the feed particles or produced by amylolytic bacteria attached to starch grains and produce ethanol, glycerol, peptides and amino acids which are then used by other bacteria associated with yeasts in atrophic chain that is physically organized in micro-consortium structures. The removal of oxygen improves anaerobiosis in the microenvironment of solid particles after feed intake which thereby creates better conditions for the growth of anaerobic cellulolytic bacteria and their attachment to cellulosic material [23].

Yeasts release very low amounts of micronutrients but due to the close association between yeasts and bacteria they are directly used by associated bacteria without dilution in the rumen liquid. Taken together, the effects described for live yeasts can be considered as positive factors for the growth of anaerobic bacteria and thus for digestion in the rumen, which in turn stimulates voluntary feed intake as well as nutrient supply to the animals, thereby promoting animal performance. In addition, yeast is considering the source of B-complex vitamins which represent the digestion and appetite stimulating vitamins. These vitamins make as important co-enzymes like Nicotine-amide Adenine Dinucleotides (NAD) and Flavin Adenine Dinucleotides (FAD) which responsible on biological oxidation to produce the necessary ATP for protein, fat and carbohydrate biosynthesis. It is interesting to observe that that the yeast species of *Saccharomyces serevisiae* is an especially attractive organism in ruminants because it is metabolically active in the rumen but does not grow which means that its construction and activity can be readily controlled by its dietary inclusion level for ensuring maximum efficacy. The yeast does not grow in the rumen due to the high concentration of volatile fatty acids, but remains biochemically active [24]. In the rumen, the main electron donors are carbohydrates and some important electron acceptors are CO_2, formate, oxaloacetate, fumerate, pyruvate and others. In addition, the main electron uptakes in the rumen are NH_3, propionate and microbial mass and the carbon uptakes are acetate, propionate, butyrate, CO_2, NH_3 and microbial biomass and the ruminal fermentation pathways compete between electrons and carbon [24, 25].

4. Conclusion

It is can concluded that yeast is a source of live cell yeast culture plus digestive enzymes. Live cell yeast culture is fed primarily as a digestive aid because it produces enzymes which assist animal digestion as well as nutrients which feed and stimulate digestive bacteria found in the gut. Yeast culture is palatable, stimulates the appetite and is a recognized source of B-vitamins, minerals and other nutritional factors. Yeast builds on the improved digestion of yeast by providing the digestive enzymes amylase for starch digestion, protease for protein digestion, lipase for fat digestion and cellulose for butterfat synthesis. Yeast stimulates the appetite of animals and helps maintain maximum dry matter intake by stimulating rumen fermentation and improving fiber digestion. Yeast helps incoming animals on to full feed quicker with an improvement in rate of gain and/or feed conversion, consequently reduction in overall feed cost per kilogram gain. In addition yeast has the Generally Recognized As Safe status from The US Food and Drug Administration

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