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Review Article

Yeast and yeast derivatives in feed additives and ingredients: Sources, characteristics, animal responses, and quantification methods

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ABSTRACT

Numerous yeast products and yeast-containing feed ingredients are commercially produced, marketed, and used extensively in animal feeds around the world. Considerable research has been conducted to evaluate the potential animal growth performance and health benefits of adding yeast, yeast-derivatives, and yeast-containing ingredients into animal feeds. Active dry yeasts are commonly used solely or in combination with beneficial bacteria in probiotic products. Nutritional yeasts are used as supplements in animal feeds due to their relatively high protein and amino acid, energy, and micronutrient content compared with common feed grains and oilseed meals. Other important yeast-based products contain nutraceutical compounds present in yeast cells and cell walls (i.e. β-glucans, mannanoligosaccharides, nucleotides) that have generally been shown to improve animal growth performance and health. Specialty yeast products, such as selenium yeast (highly concentrated and bioavailable source of selenium) and *Phaffia rhodozyma* yeast (contains pigment that improves flesh color in salmon and trout) have specific applications in some animal feeds. Ethanol co-products such as corn distillers dried grains with solubles (DDGS) and new grains distillers dried yeast ingredients, containing more than 40% crude protein, also contain significant amounts of yeast cell and nutraceutical components. Therefore, because these yeast-based products have several nutritional and health benefits, they are becoming alternative supplements in animal feed due to restrictions on antimicrobial growth promoter use in many countries. However, it is difficult for nutritionists to differentiate the characteristics, composition, and optimal feeding applications among the diverse number of yeast-containing products available. Furthermore, most of these products contain combinations of probiotics and nutraceutical compounds with different modes of action, making it difficult to determine which compounds contribute to specific responses observed. Quantification of these nutraceutical compounds is difficult, and except for methods to determine viable yeast in dried active yeast products, there are no standard methods for determining dead yeast concentration or fast, inexpensive, and accurate methods to estimate the proportion of yeast components in various yeast-containing additives and feed ingredients. Due to the increasing popularity of using yeast-based products in animal feeds, development of analytical approaches to estimate yeast and its components in these products is greatly needed. In this review, various categories of commercially available yeast and yeast-containing additives and feed ingredients will be described along with our current knowledge about their role in improving animal growth performance,

Abbreviations: AAFCO, Association of American Feed Control Officials; ADG, average daily gain; ADFI, average daily feed intake; CFU, colony forming units; DDGS, distillers dried grains with solubles; DFM, direct fed microbial; DNA, deoxyribonucleic acid; EPA, Environmental Protection Agency; IFN, international feed names; MOS, mannanoligosaccharides; N/A, not applicable; RNA, ribonucleic acid

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health, and proposed mechanisms of action, and challenges of quantifying yeast content and their biologically active components.

1. Introduction

Yeasts are single cell, eukaryotic microorganisms classified in the fungi kingdom (Bennett, 1998; Ingraham, 2010). These microscopic fungi are generally about 3–4 μm in size, have a nuclear membrane and cell walls, but unlike plants, they contain no chloroplasts. Yeasts are characterized as heterotrophs in which they rely on living and dead organic material as sources of energy and nutrients (Bennett, 1998). Yeast cells obtain their nutrition by producing and releasing various proteolytic, glycolytic, or lipolytic enzymes to digest organic matter, or by absorbing amino acids and monosaccharides through the cell wall (Baron, 1996). Reproduction occurs by budding and fission. Budding occurs when a parent cell increases in size, and a protrusion forms along the cell wall to form a "bud", which breaks from the parent cell or is partially conjoined in elongated cells (Evans et al., 2000). Fission also occurs when a parent cell divides into two daughter cells (Evans et al., 2000). Yeasts are considered facultative anaerobes which means that they can survive and grow in the presence or absence of oxygen (Stone, 2006). Yeast propagation occurs under aerobic conditions, and cells convert oxygen and sugars into carbon dioxide and energy through oxidative metabolism to allow efficient yeast cell growth. Under anaerobic conditions, such as those used in beverage and fuel ethanol production, yeasts are much less efficient in these processes, which results in the production of ethanol (Bekatorou et al., 2006).

Animals have been fed various forms of yeast and yeast derivatives for more than 100 years (Stone, 2006). However, recent government restrictions and elimination of the use of growth promoting antibiotics in animal feed in the European Union and United States have led to a significant increase in interest in using alternative products (including yeast products) to provide animal health and growth performance benefits. Furthermore, feed ingredients produced from yeast fermentation processes (e.g. distillers dried grains with solubles; DDGS) in animal feeds has increased dramatically in recent years (Shurson, 2017). Therefore, there are many types of feed additives and feed ingredients that contain yeast in various forms, but animal nutritionists are often uncertain about the unique differences among these products and their potential roles in animal nutrition and health. Furthermore, despite the fact that yeast-containing additives and feed ingredients have been widely used in the feed industry for decades, there are no standard analytical methods to quantify yeast and their biologically important chemical components. Unfortunately, limited information has been published on the accuracy and use of practical methods to quantify yeast components for the feed industry. Our inability to accurately quantify yeast and yeast components in feed additives and feed ingredients has become a significant issue requiring investigation because of the need to accurately determine the dosage and diet inclusion rates to achieve desired concentrations of biologically active substances. Quantification of yeast and yeast components is essential for achieving their desired potential benefits in animal health and performance and preventing excessive feeding of biologically active components of yeast. Therefore, the purpose of this review is to 1) describe the various forms of yeast in feed additives and feed ingredients, 2) briefly review their benefits to animal health and growth performance, and 3) review various methods to quantify the concentrations of yeast and their known active components.

2. Yeast species of commercial importance

Yeasts are found in abundant quantities and are almost everywhere in the environment. They have been isolated in fruit, honey, soil, water, and plant stems, leaves, and flowers (U.S. EPA, 1997), and are naturally present in common feed ingredients such as grains, grain co-products, silage, and hay fed to animals. Most species of yeast are neither harmful nor beneficial to humans and animals. A few genera of yeast are known to be pathogenic (*Candida*, *Cryptococcus*, *Torulopsis*, and *Trichosporon*; Kandel and Stern, 1979), while some species (*Saccharomyces cerevisiae*, *Kluyveromyces marxianus*, *Candida utilis*) provide beneficial effects.

There are about 60 different genera of yeast, which are comprised of about 500 different species (Stone, 2006). Yeast species vary in their cellular morphology, metabolism of different substrates, and reproduction processes (Stone, 2006). However, only a few of these species are used commercially. Commercial applications for yeast include the production of alcoholic beverages (i.e. beer, wine, and spirits), non-alcoholic beverages (i.e. root beer, kvass, kombucha, kefir, mauby), bread and pastry baking, bioremediation, industrial ethanol production, nutritional supplements, probiotics, aquarium hobbies (to generate carbon dioxide for support plant growth in aquaria), food additives and flavoring agents, scientific research, and genetically engineered biofactories. *Saccharomyces cerevisiae* is the predominant species used in food, beverage (distilled spirits and beer), and fuel ethanol production processes, where selected strains convert glucose and sucrose to ethanol (Reed and Nagodawithana, 1991). Other commercially important yeast strains include *Kluyveromyces marxianus* (whey yeast) which uses glucose and lactose in milk as its substrates, and *Candida utilis* (Torula yeast) which uses xylose and glucose in wood pulp from paper manufacturing as substrates (Reed and Nagodawithana, 1991).

The intracellular chemical components of yeast cells include amino acids, peptides, carbohydrates, salts, monosodium glutamate, nucleic acids (RNA), enzymes, and cofactors (Hassan, 2011; Dubey et al., 2010). Yeast cell walls are comprised of glucans, glycoproteins, mannans, and chitin (Alexandre and Guilloux-Benatier, 2006; Kollar et al., 1997). The combination of these compounds make them attractive not only as nutritional supplements in animal feeds, but also useful nutraceuticals.