Brewers' Yeast In Human And Livestock Nutrition

A Review of Literature

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C. C. Prouty

INTRODUCTION

Yeast as a feed for livestock was first investigated during the closing years of the past century. The studies were continued with various types of livestock and later were extended to include human nutrition. At the present time, considerable information has been accumulated on the nutritional value of yeast as a protein supplement and as a source of the B-complex group of vitamins.

Many of the early studies of the nutritional value of yeast resulted in contradictory statements. This was due in large part to a lack of knowledge of the highly specific functions of the various vitamins and certain of the amino acids in nutrition. It is apparent that yeast, on numerous occasions, was added to rations in which the nutritive requirements for the test animals were being provided by other constituents. With an increase of knowledge concerning the role of vitamins and amino acids in nutrition, better-controlled experiments were designed and fewer conflicting statements have appeared in recent years concerning the nutritional value of this product.

History of Yeast in Nutrition

Marcas (1900) reviewed the methods of utilizing yeast as a nutritive material. In 1905 and 1907, *Pure Products,* an English periodical, published articles on the preparation of yeast for livestock feeding.

Prior to the outbreak of the first World War (1914-18), a number of German workers (Wuyts and Courtoy 1911; Meyer 1912; Honcamp 1912) reported on the nutritive value of yeast for general livestock feeding. During the war, increased attention was give by the warring nations of Europe to the study of the nutritive properties of yeast. In Germany and in countries allied with her, changes associated with a wartime economy and import restrictions imposed by the Allied blockade created shortages in the supply of high protein livestock feeds. Popp (1915), in a discussion of the industrial manufacture of war feeding stuffs, included the production of yeast.

England was similarly affected but probably to a lesser degree than were Germany and the other Central Power nations. Halnan (1915) discussed yeast as a new foodstuff of promise for use in England.

Before the first World War and throughout its duration, the major interest in yeast centered on its protein content. This had been shown to be as high as 40 to 50 per cent and of a highly digestible nature. Shortly before the war, discoveries were made pointing to the presence in yeast of growth-stimulating and disease-preventive and curative substances, later to be designated as accessory food substances or vitamins. Likewise, during this period, workers in the field of nutrition first observed the important role of certain of the amino acids as essential requirements for growth and well-being.

With the conclusion of the war in 1918 and continuing to the present time many studies were made of yeast as a carrier of the B-complex group of vitamins, particularly thiamine, riboflavin, niacin, pantothenic acid, and pyridoxine. Likewise, yeast has been studied as a protein food, rich in the amino acids essential to the proper nutrition of both man and animal. These studies have established yeast as a food material of considerable potential importance.

Frey (1930), in a review of the history and development of the yeast industry, pointed out the uses to which yeast, as food material, could be put in the event of an emergency. According to Frey, some yeast plants in operation at that time were capable of manufacturing 300,000 pounds of yeast daily, the protein equivalent of 500 steers weighing 1,000 pounds each. Fink (1940) reviewed the development of the production of feed yeast from various sources of raw materials with emphasis upon the commercial production of yeast from wood sugar.

With the outbreak of war in 1939, attention throughout the world was focused again on the food supply for human beings and livestock. Based on the already established fact that yeast constitutes a valuable source of protein and the B-complex group of vitamins, attention again was turned toward it.

Dried Brewers' Yeast and its Preparation

In keeping with a program of conservation in the United States, first consideration was given to the utilization of brewers' yeast, normally a waste product of the brewing industry. Based on an annual beer production of 60 million barrels, the brewing industry of the United States can produce 30 million pounds of dried yeast each year.

Brewers' yeast becomes available as the fermenters and storage tanks are emptied of beer. By the use of special equipment this yeast residue can be dried and preserved in the dry form for an indefinite period of time. In its original state brewers' yeast contains various foreign substances, particularly hop residues which impart a bitter flavor. When brewer's yeast is to be used for livestock feeding, the bitter flavor is not objectionable and the yeast residue is dried without preliminary treatment. However, when brewers' yeast is to be used for human consumption, the foreign substances, particularly those associated with the bitter flavor, must be removed. This is accomplished by washing with an alkaline solution to remove the hop residues carrying the bitter substances. The yeast residue is then separated and rinsed in a slightly acid solution to remove the alkaline substances remaining from the first washing. Following separation from the second wash, the yeast is subjected to the drying process.

Special Food Yeast

As a second consideration, studies were undertaken with the objective of developing methods of yeast production capable of providing large amounts of yeast protein and vitamins at a cost comparable with the cost of other similar foodstuffs.

Governmental Agencies Interested in the Nutritional Value of Yeast

In the United States, several governmental agencies have been active in directing attention toward yeast as a source of food for human and livestock consumption. At the request of the Yeast Industry Advisory Board, War Food Administration, many breweries of the nation have installed yeast processing and drying equipment and are converting this former waste material into a usable product. Under the direction of the United States Department of Agriculture, studies have gone forward in methods of yeast production utilizing fermentable byproducts from various sources (Nolte, von Loesecke, and Pulley, 1942; and Stubbs, Nolte, and Lewis, 1944). Spokesmen for the Food and Nutrition Board of the National Research Council (Gunderson and Gortner, 1944; Gortner and Gunderson, 1944; Wilder, Russell, and Keys, 1942) evaluate yeast as a valuable food stuff.

Yeast Production in Other Countries

In England studies with yeast were undertaken at the request of the Agricultural Research Council and the Scientific Committee on Food Policy (Thaysen, 1943). These have resulted in the development of a special yeast strain, together with production methods capable of yielding large amounts of yeast protein at relatively low costs (Thaysen, 1945).

While information is not available concerning the ways in which Germany met this problem, it appears likely that major consideration centered in the development and utilization of yeast products (Bickel, 1941; Fink, 1941).

Before the Japanese invasion of the Dutch East Indies, the production of food yeast was being studied in Java (Van Veen, 1942). Although not a nation engaged in the World War, Sweden found it necessary to seek new sources of protein food (Rosenquist, 1944). To meet this need, in part, methods were developed for the large-scale production of yeast using sulfite waste liquor as the source of the fermentable carbohydrate in growing the yeast. This product is considered to be a satisfactory meat substitute.

During the last few years, numerous articles have appeared in which the merits of yeast as a vitamin and protein food are discussed. Some of these are from European sources and others from the United States. Some have appeared in trade journals, were written in popular style, and presented no original experimental data. Others consist of reviews with interpretations being made by the reviewer. These, in part, are Alter (1941); Brown (1941); Steuart (1942); Grew (1944); Siebel, Weber, and Singruen (1941, 1941a, 1942, 1942a, 1942b, 1942c, 1942d); Siebel, Weber, and Fitzsimmons (1943); Coats (1941); Sarles (1942); Durfee (1943); Burton (1943); Leavell (1943); Gray (1943); and Fischer (1944).

THE NUTRITIVE PROPERTIES OF BREWERS' YEAST

The value of yeast in human and livestock nutrition has been investigated largely for its protein and vitamin contents. In addition, yeast contains carbohydrate, fat, and minerals. An average analysis of dried brewers' yeast is as follows: protein 46 per cent, carbohydrate 36 per cent, mineral 8.0 per cent, fat 1.0 per cent, fiber 1.0 per cent, and moisture 8.0 per cent. Yeast contains the following amounts of the B-complex group of vitamins: thiamine 125 to 150, riboflavin 40 to 50, niacin 350 to 450, pantothenic acid 180 to 220, and pyridoxine 45 to 55 micrograms per gram. Yeast also contains small amounts of choline, para-amino-benzoic acid, biotin, inositol, and certain, as yet, unidentified factors.

Yeast Protein

Voltz (1915), using dogs in a study of the utilization of yeast, found the coefficient of digestibility to be 85, 34.1, and 54.5 per cent respectively for the protein, fat, and carbohydrate. He concluded that the feeding of artificially cultivated and brewers' yeast may be used occasionally to replace meat in the diet.

Funk (1916) observed that small additions of yeast added to the diet of the rat accelerated growth but that yeast cannot substitute for the casein in the diet, probably because of its toxic properties.

Crowther and Woodman (1917), using sheep as the test animals, concluded that dried yeast ranks with the most highly digestible foods used on the farm. They found the organic matter, crude protein, and nitrogen-free extractives of yeast to have digestion coefficients of 81.5, 86.6, and 81.5 per cent respectively. Schill (1918) found the protein to be well utilized in feeding experiments with dogs.

Osborne and Mendel (1919), using rats, fed yeast as the sole source of protein. It was utilized to the extent of 74 to 83 per cent. Normal growth was obtained at the 40 per cent level, whereas at the 30 per cent level growth was somewhat less.

Voltz (1919), using dogs and sheep, found brewers' yeast to be better than yeast grown in a solution composed of inorganic salts and sugar. He found that live yeast was not well utilized and stated that yeast should not be fed in the living state. Hawk, Smith, and Holder (1919), using human subjects, obtained favorable results with bakers' yeast.

Meisenheimer (1919) found yeast protein to contain the following amino acids: glycocoll, alanine, valine, leucine, proline, phenylalanine, aspartic acid, glutamic acid, tyrosin, tryptophane, and possibly serine and cystine. Shakhnovich-Smirnova (1941) studied the relationship between the glutathione content and the quality of yeast. He concluded the glutathione content to be an index to yeast quality. Just (1941) compared the nutritive value of brewers' yeast, bakers' yeast, and edible yeast on the basis of protein content. All three were considered of equal value for nutritional purposes. He found brewers' yeast to have the greatest glutathione content.

Melnick (1943) stated that the nutritive value of food is not only based on the essential amino acid composition of the protein, but also on the availability of these amino acids for tissue protein anabolism. In addition, there is the third criterion of the actual amount of protein present as expressed in terms of total solids. On the basis of these, Melnick stated that yeast powder compares favorably with meat, eggs, milk, and defatted soybeans.

Hock and Fink (1943) found yeast to be poorly balanced with respect to certain amino acids, and concluded that it must be supplemented in order to prevent symptoms of deficiency disease. Rats fed on a diet in which yeast constituted the protein content showed poor growth, and autopsies revealed pathological liver lesions. Cystine served as a satisfactory supplement to yeast protein and gave protection against liver injury.

Renshaw (1921), using white mice as experimental animals, found that when growth was stabilized, 3.0 to 5.0 per cent amounts of yeast added to the diet resulted in appreciable gains in weight. Nelson, Heller, and Fulmer (1923) fed rats on diets containing 25 to 50 per cent of dried brewers' yeast. At the 45 per cent level of yeast, normal growth and reproduction of the rats took place. At the 50 per cent level, the growth rates flattened out after three months' time, and at the 25 per cent level growth was sub-normal.

Mitchell (1924) found yeast protein at the 5.0 per cent level in the diet to be very completely utilized and to have a biological value of 88.5. Rosell (1942) compared the biological values of yeast, meat, and plant protein to which he gave numerical values of 100, 80, and 40 to 60, respectively.

Plimmer, Rosendale, and Raymond (1927) investigated the effect of yeast as a carrier of B-vitamin in balancing the protein, fat, and carbohydrate in the diet. Using chickens, pigeons, and rats as test animals, the dried yeast-caloric ratio was found to be 1 to 40, 1 to 60, 1 to 80, and 1 to 160, respectively.

Still and Koch (1928) used bakers' yeast to replace the casein in the diet of rats. They found that young rats did not do so well as with casein in the diet, whereas older rats did equally well. This diet contained 38 per cent of bakers' yeast as the sole source of protein and had a digestibility value of 72 per cent.

Dukler (1941) found that the addition of 10 per cent of brewers' yeast to a diet in which the protein was casein prevented the loss of stores of body fat in rats and mice. This addition also restored the body fat previously lost on the casein diet.

Webster (1942) fed rats a low protein, high fat diet and noted that they developed fatty degeneration, necrosis, and cirrhosis of the liver. The kidneys also became necrotic, hemorrhagic, and developed fibrosis. The additions of two grams of brewers' yeast daily prevented all lesions, while additions of thiamine and riboflavin were without effect. The preventive properties may have been due to the extra protein and choline supplied by the yeast.

Von Soden and Dirr (1942) found the rate of digestion higher for yeast protein than for horse serum, milk, fish protein, soybean meal, and egg albumen.

Hock (1942) studied the replacement of animal proteins by yeast protein, using rats as the experimental animals. The basal diet contained a protein content of 9.3 per cent of which 15.5 per cent was secured from wheat and rye with the balance made up of fish meal and yeast. When fish meal and yeast were equal, no deficiency appeared, but when yeast protein amounted to 77.5 per cent, a 15 to 23 per cent reduction in growth appeared.

Fink (1944) fed white rats on a diet in which 15 per cent of the protein consisted of those from wheat and rye with the remaining protein content being variable. When the milk protein of this portion was completely substituted by yeast protein, the animals lost weight and some of them died in less than 180 days from deterioration of the liver. Inclusion of 2.0 per cent of cystine in the diet restored the growth curve to normal.

Sure (1945), using rats, fed yeast at the 30 to 40 per cent levels in the diet. Yeast at this level furnished a protein content of 14 to 18 per cent. The rats made excellent growth and grew as well as they did on a ration containing 15 per cent casein. Sure added yeast in 1.0, 3.0, and 5.0 per cent amounts to enriched flour with very definite increases in the biological value of the bread made from the flour.

The B-Complex Group of Vitamins

Funk (1912), reporting on the etiology of the deficiency diseases, coined the term "vitamin" for a substance believed to be specific in preventing and curing beri-beri or polyneuritis. In the same year, Funk (1912b) reported the isolation of this substance from yeast.

Hopkins (1912) conducted feeding experiments with rats and showed the importance of accessory food factors in normal diets. He likewise demonstrated the presence of these accessory substances in yeast.

Osborne and Mendel (1917) added dried yeast to a diet containing purified casein, artificial protein-free milk, starch, lard, and butter fat. On a 1.5 per cent dried yeast diet, the rats grew well and reproduction was normal. The benefits derived from the yeast were thought to be due to vitamins.

Mattill and Conklin (1920), in a study of the nutritive properties of milk, found that both reproduction and rate of growth were benefited by additions of yeast to the milk diet. Normal growth and improved reproduction occurred when yeast was added at a 5.0 per cent level.

Subsequent studies have increased our knowledge of the sources and the significant role of these accessory substances in nutrition, particularly as related to the B-complex group of vitamins. As a result, yeast is considered as one of the best naturally-occurring sources of this group of vitamins.

Reports of the amounts of the specific components of this group vary rather widely. Among the factors responsible for these variations are the strain of the yeast (Karr, 1920; Just, 1940); the medium used for its growth (Pavcek, Peterson, and Elvehjem, 1938; Fink and Just, 1942); and the extent and nature of the processing method (Voltz, 1915). Walker and Nelson (1933); Parsons and Collard (1942, 1942a); Parsons, Collard, Gradner, Strong, and Peterson (1942); and Parsons, Williams, and Johnson (1945) have presented evidence showing that the vitamins of fresh yeast, particularly thiamine and riboflavin, are poorly utilized and that boiling or drying the yeast increases the utilization of these vitamins.

Brewers' yeast, bakers' yeast, and a special food yeast known as torula yeast have been studied for their B-complex vitamin content. Numerous studies in which these yeasts were compared have shown brewers' yeast to contain the greatest amount of B-complex vitamins.

Thiamine. The thiamine or B_1 content of dried brewers' yeast is reported as ranging from 24 to 490 micrograms per gram. Hennessey and Cerecedo (1939) used five different yeast samples and obtained values in the above range. Schwarz, Laufer, and Brenner (1942) reported 215 micrograms for debittered brewers' yeast. Booher, Hartzler, and Hewston (1942), in a review of the values of thiamine in dried debittered brewers' yeast from various sources in the United States, reported values of 150 to 200 micrograms with most of the values between 150 and 160 micrograms. Fink and Just (1941) reported thiamine values of 180 to 240 micrograms; Laufer, Brenner, and Laufer (1940), 96 to 183; Rothchild and Gray (1942), 93 to 162; Williams (1942a), 60 to 180;

and MacDonough and Haffenreffer (1944), 130 micrograms for plain debittered yeast.

Just (1940); Plimmer, Raymond, and Lowndes (1931); Scheunert and Schieblich (1929); Quinn, Whalen, and Hartley (1930); and others reported brewers' yeast to have a greater thiamine content than bakers' yeast. Fink and Just (1941) reported a higher thiamine content for brewers' yeast than for torula yeast. Sure and Easterling (1944) studied the utilization of thiamine in brewers' yeast. Three brands of yeast with potencies of 440, 670, and 160 micrograms per gram of thiamine, were administered to rats fed a standard diet. The results indicated excellent retention of thiamine ranging from 93 to 100 per cent. Similar results were obtained when pure thiamine was substituted for the brewers' yeast.

Riboflavin. The riboflavin content of brewers' yeast as reported by different workers varies from 30 to 80 micrograms per gram. Booher, Hartzler, and Hewston (1942) reviewed the values reported in the United States as ranging from 30 to 40 micrograms. Swaminathan (1942) reported 55.6 micrograms for dried brewers' yeast and 27 micrograms for distillers' yeast. Arnold, Lipsin, and Green (1941) obtained a value of 45 micrograms. Culton and Bird (1941) reported riboflavin values for brewers' yeast ranging from 37.7 to 42.3 micrograms. Williams (1942a) reported riboflavin values of 35 to 80 micrograms per gram.

Lamb (1940) reported a riboflavin value of 60 to 70 micrograms per gram for dried yeast from a molasses medium source, whereas Thaysen (1943) reported a dried torula food yeast to contain 80 to 85 micrograms. Schumacher and Heuser (1940a) reported a riboflavin content ranging from 34.2 to 78.2 micrograms.

Niacin. The niacin content of dried brewers' yeast, as reviewed by Schwarz, Laufer, Laufer, and Brenner (1942), ranged from 300 to 930 micrograms per gram. They obtained, in their own assay, a niacin value of 633 micrograms. Arnold, Schreffler, and Lipsin (1940) found brewers' yeast, with a niacin value of 410 micrograms, to be higher than bakers' yeast, wheat germ, rice bran, rice germ, and peanut meal. Durfee (1943) reported a value of 198 micrograms. Williams (1942a) reported values ranging from 100 to 500 micrograms per gram.

Thaysen (1943), using a special strain of *Torulopsis utilis,* reported a niacin value of 400 to 450 micrograms per gram. Kodicek (1940) reported values of 240 to 510 micrograms for various samples of bakers' yeast.

Other Members of the B-Complex Group. Less work has been reported on the amounts of pantothenic acid, pyridoxine, choline, para-amino benzoic acid, inositol, and biotin in yeast than on the better known members of the B-complex group. Jukes (1941) found dried brewers' yeast to be an excellent source of pantothenic acid, having a value of 200 micrograms per gram. Schwarz, Laufer, Laufer, and Brenner (1942) and Williams (1942) obtained pantothenic acid values of 75, and 20 to 75, micrograms per gram, respectively. Swaminathan (1940) reported a pyridoxine content of 54, and Williams (1942) reported values of 50 to 100.

Sure (1941), using rats as test animals in a study of the dietary requirements for lactation, found that thiamine, riboflavin, pyridoxine, and pantothenic acid did not satisfy the requirements for lactation. Yeast, as well as additions of para-amino benzoic acid and inositol, was found to stimulate lactation. These results suggest the para-amino benzoic acid and inositol contents of yeast as being the required factor for lactation.

Unknown Factors In Yeast. There is evidence that yeast contains certain unidentified factors of the B-complex group that are necessary for growth and maintenance. Such observations were made by Hogan and Hamilton (1942); Fraenkel and Blewett (1942); Briggs, Lucky, Elvehjem, and Hart (1943); Kuiken, McCoy, Schultze, and King (1944); and Smith (1944).

YEAST IN HUMAN NUTRITION

In its relation to human nutrition, yeast has been investigated for the value of its protein and B-complex vitamin contents.

Yeast Protein in Human Nutrition

Studies carried out with experimental animals have shown the protein of yeast to be readily digested and to possess a high biological value when compared with proteins from other sources. Numerous studies have been made with yeast protein in which human beings were used as test subjects.

Loewy and von der Heide (1915), in an experiment of seven days duration in which men were given 100 grams of yeast daily, found the digestibility of yeast protein to be 81 to 85 per cent. Schottelius (1915) carried out an experiment with nine men on a ration including yeast. He concluded that a small addition of yeast, 25 to 30 grams, is a desirable means of increasing the nutritive value of the ordinary mixed diet.

Voltz (1916), in digestion experiments with men, found the protein, fat, and nitrogen-free extract to be 86, 70, and 100 per cent digestible, respectively. He found the energy to be 88 per cent available.

Hock (1941) investigated the possibility of substituting yeast protein for animal protein in the human diet. He found that up to one-half of the animal protein could be replaced by yeast protein.

Bickel (1942) conducted experiments to determine the nutritional value of yeast as a source of protein. Although nitrogen excretion in human beings kept on a standard diet to which equal amounts of yeast had been added did not parallel yeast intake, the absorption of yeast nitrogen was good and nitrogen retention was increased.

Funk, Lyle, McCaskey, Caspe, and Poklop (1916) expressed the opinion that yeast cannot be recommended as a sole protein source since a large part of the yeast nitrogenous compounds apparently had no food value, was not well digested, and tended to raise the uric acid content of the blood, due to the purine content of the yeast.

On the other hand, Osborne and Mendel (1919) reported no toxic factor to be found in yeast when it constituted as high as 30 to 40 per cent of the ration. Smith, Duel, Asham, and Siebert (1922); Slovtzov (1923); Still and Koch (1928); and Pierce (1932) found that yeast could be consumed in considerable amounts without significantly increasing the uric acid content of the blood. Klose and Fevold (1945), using rats and chicks as test subjects, did not observe any toxic effects when yeast was fed at relatively high levels and over limited periods of time.

Andersen (1938), however, reported an increased uric acid content in human blood and urine resulting from the use of yeast in the diet. In one case, 75 grams of dried yeast per day increased the uric acid content of the blood in five days' time from 3.0 to 5.3 milligrams per 100 cubic centimeters.

Dirr (1942) made the following statement in relation to the effect of yeast on the uric acid content of the blood: "In order to make yeast available as a major food product, it should be freed, as far as possible, of its purine and largely of its phosphorus content." Dirr and Decker (1944) analyzed seven samples of brewers' yeast and one sample of bakers' yeast. They found the average purine nitrogen to be 0.75 per cent, which was equivalent to 8.7 per cent of the total nitrogen, compared to an average of 1.5 per cent of the total nitrogen in the case of most meats.

According to Roth and Zander (1944), yeast contains all of the essential amino acids in amounts so constituted that 100 grams of dried yeast will furnish approximately one-half the daily adult requirements of these amino acids.

Klose and Fevold (1944, 1945) found yeast protein to be deficient in methionine. They concluded that this is one factor which must be considered in evaluating yeast protein as a replacement for animal proteins. *Nutritional Reviews* (1944) editorially concluded that before yeast can be used as a major source of protein for any group of people, a cheap supply of sulfur containing amino acids must be found to supplement the yeast. It was further indicated that with proper supplementation, yeast may take on a significant importance in the food economy of the world.

Carter and Phillips (1944), after a survey of the data on the nutritional value of yeast for man, reported that it is not possible to reach any broad conclusions as to the potential importance of yeast as a source of protein for the human diet. They interpreted the data as indicating yeast to be somewhat inferior to animal protein in human nutrition and concluded that a thorough study of the effects of long-continuing yeast ingestion on blood constituents is an essential prerequisite for any recommendation concerning the inclusion of large amounts of yeast in human dietaries.

Value of the B-Complex Vitamins of Yeast in Nutrition

Nutritionists, in numerous instances, have reported the average American diet to be deficient in one or more of the vitamins of the B-complex group and consequently in need of supplementary food substances to meet this deficiency. Prominent among these nutritionists are Elvehjem (1940); Spies, Grant, and Grant (1941); Lane, Johnson, and Williams (1942); and Heller, McCay, and Lyon (1943). According to Spies, Grant, and Grant, approximately 50 per cent of the American people fail to enjoy maximum health and vigor because of a low instake of the B-complex group of vitamins.

The therapeutic value of yeast in human nutrition was investigated first in relation to the prevention and cure of beriberi or polyneuritis.

Later it was shown that pellagra, another nutritional deficiency disease, responded favorably to the additions of yeast in the diet. More recently, yeast has been reported to possess therapeutic properties in the control of a miscellaneous group of disorders.

Beriberi or Polyneuritis. This is a disease characterized by loss of appetite, unusual susceptibility to fatigue combined with lower physical endurance, gastro-intestinal disturbances, muscular weakness, pains and paraesthesia in arms and legs, edema in ankles and face, and a decrease of the blood pressure.

Edie, Evans, Moore, Simpson, and Webster (1912) reported on the isolation of an antineuritic substance from yeast having both marked preventive and curative properties for beriberi. Cooper (1912) found yeast to be more effective than other foods in preventing this disease.

In a search for the antineuritic factor of yeast, Funk (1913a) separated the vitamin fraction into two substances: nicotinic acid or niacin, and a second substance indicated by the formula $C_{26}H_{20}O_9N_4$. However, Funk failed to recognize the vitamin character of the nicotinic acid. Subsequent work has not identified any vitamin of the B-complex group as having the formula indicated by Funk. Funk (1913b) obtained the best results in treating beriberi when the whole vitamin fraction was administered.

Emmett and McKim (1917) observed two vitamin fractions in yeast: one a polyneuritic curative, the other a growth-promoting fraction. Sugira (1918) prepared a colorless crystalline substance from yeast which was capable of curing polyneuritis in pigeons in 20 days' time.

Hawk, Fishback, and Bergeim (1919) were able to effect immediate cures of polyneuritis and increases in the body weight by the addition of compressed yeast to a diet lacking the water-soluble vitamins. Drummond (1917) attempted to isolate the water-soluble, growth-promoting substances in yeast, but was not successful.

Karr (1920) found that brewers' yeast provided the water-soluble vitamins to a greater extent than did bakers' yeast. He noted that the use of yeast increased the appetite of a dog subsisting on a deficient diet. Within a few hours after ingestion of brewers' yeast, the symptoms of polyneuritis in the dog were alleviated.

Simonnet (1920), using pigeons as test animals, found that 0.5 gram of dried yeast daily would prevent polyneuritis and maintain the pigeons in excellent health for long periods of time while they were on synthetic rations. Emmett and Stockholm (1920) considered the anti-neuritic and the growth-promoting substance of yeast to be identical. Daniels (1922) advised against the use of fresh yeast as the source of the anti-neuritic vitamin for infants under one year of age.

Pellagra. Pellagra is a disease in man characterized by a dermatosis involving those parts of the body which are exposed to sunlight or friction. The typical pellagrin shows characteristic lesions of the mucous membranes of the mouth, and of the skin over the nose, forehead, back, hands, wrists, elbows, knees, and feet. Disturbances of the gastro-intestinal tract are observed in many cases. In later stages of the disease, mental disorders and lesions of the central nervous system occur.

While niacin is very important in the treatment and control of pellagra, typical pellagra, according to Rosenberg (1942), is not a disease caused solely by a niacin deficiency. Pellagra, usually, is the result of a multiple vitamin deficiency, and treatment requires the use of several or all of the components of the B-complex group of vitamins.

Goldberger and Tanner (1925) found that one gram of dried yeast per kilogram of body weight would prevent pellagra. Goldberger, Wheeler, Lille, and Rogers (1928) found that autoclaved yeast as well as unheated yeast, but not charred yeast, would prevent black tongue in dogs fed on a deficient basal ration.

Walker and Wheeler (1931) cured experimental pellagra with a daily dose of 30 grams of dried brewers' yeast with the patient still on the deficient diet. Wheeler (1933) found yeast to be an excellent source of the antipellagra factor; it also retained its potency after being heated in the autoclave for seven and one-half hours at 121°C. Spies, Chinn, and McLester (1937) used doses of yeast as large as 1.0 oz. three or more times daily, and sometimes 2.0 to 3.0 oz. three times daily, in the treatment of endemic pellagra without deleterious effects from the large doses of yeast. Trowell (1941) treated chronic infantile pellagra with niacin without results, whereas the administration of yeast extract was more effective. He considered the clinical picture to be the result of the whole B-complex deficiency rather than just one factor. Spies, Grant, and Grant (1941) reported on the use of a yeast, peanut butter, and peanut oil mixture as a preventive and cure of pellagra and beriberi, using 23 patients suffering with a mild deficiency disease.

Remington (1944), in a review of pellagra in the United States, was high in his praise of the part played by brewers' yeast in the treatment and control of pellagra. As early as 1929, certain of the southern states in which pellagra was highly prevalent adopted state-wide programs of yeast distribution as a public health measure.

Interrelated Action of B-Complex Vitamins. Evidence is available showing that deficiencies of the B-complex vitamins seldom appear singly, but rather in combinations involving several of the group. Additional evidence is available pointing to an interrelated, rather than to an independent, function among the components of the B-complex group of vitamins. Schaefer, McKibben, and Elvehjem (1941) and Trowell (1941) found that dried yeast additions to mixed synthetic vitamin therapy resulted in a more rapid improvement in general health than did the use of mixed vitamins alone.

Miscellaneous Yeast Therapy. Walzow and Sacharow (1909) noted that the use of beer yeast raised the opsonic index. They found the use of yeast to confer a greater resistance against infection by pus-producing organisms.

Murlin and Mantill (1923) noted that yeast had some laxative action and, therefore, was of value in the treatment of constipation. Brown, Campbell, Stoner, and Macy (1934) treated 351 women and children with yeast over a twelve-month period. Of 113 patients with constipation, 83 per cent reported improved intestinal functions within two weeks after the initial use of yeast.

Wintrobe (1938a) successfully treated pernicious anaemia by administering dried yeast at the rate of 1 gram per kilogram of body weight. Wintrobe (1939), in a study of the anti-anaemic effect of yeast in pernicious anaemia, found dried brewers' yeast, given orally, to be as effective as liver in inducing hematopoiesis (blood forming). Bakers' yeast and yeast extracts were not effective.

Litchfield, Lichterman, Knoll, and Kurland (1939), in a study of the effect of yeast on the growth and development of premature infants, observed gains with infants receiving yeast extract much sooner and at a more rapid rate than with those not on a yeast diet.

Von Glahn and Flinn (1939) added dried brewers' yeast to the diet of experimental rabbits being given small doses of lead arsenate. They found yeast reduced the incidence of hepatic cirrhosis induced by lead arsenate. Comparable results were obtained by Nakahara, Fujiwara, and Mori (1939) in the incidence of experimentally-induced cirrhosis and carcinoma by the use of methylamino-azo benzol.

Patek and Post (1941) administered yeast to 54 patients with cirrhosis of the liver. Survival statistics of these patients, compared with those not given yeast, showed great improvement.

Burgess (1941) found that lichenplanus (skin disease) did not respond to injections of vitamin B, but it did respond to oral administration of brewers' yeast and liver extract. He concluded that while vitamin B-complex is not considered therapeutically specific, it is a useful adjunct to other treatments.

Burket and Hickman (1942) found oral herpes to be relieved by the use of vitamin B-complex therapy. They recommended the use of yeast as a prophylactic measure.

Bean and Spies (1940) stated that it is theoretically sound to treat chronic diarrhea, a symptom of vitamin deficiency, with liver extract and brewers' yeast.

Abels, Rekers, Martin, and Rhoads (1942) administered large doses of brewers' yeast to persons suffering from papillary atrophy of the tongue and oral leucoplakia. Occasionally, this resulted in complete or partial remission of the lesions and in oral symptoms.

Butt, Hoyne, and Wilder (1943) stated that some investigators have noted that cheilosis in some cases heals only when the entire vitamin B-complex in the form of liver extract or brewers' yeast is supplied. Lanczos (1941) reported that the long, continued use of large doses of vitamin B-complex mixtures in the form of commercial yeast concentrates over a two-year period halted the graying of hair. Frost and Dann (1944), using pups fed on purified diets supplemented by the various synthetic vitamins of the B-complex group, found the animals to develop achromotrichia and decreased hair growth in two to eleven months. They found that the inclusion of either liver extract or whole dried brewers' yeast brought about complete cures in the pups.

Egana, Johnson, Bloomfield, Brouha, Meiklejohn, Whittenberger, Darling, Heath, Graybiel, and Consolazio (1942), in a study of the effect of diets deficient in the vitamin B-complex group in sedentary men, found that the addition of brewers' yeast to the diet resulted in a decrease in the state of fatigue, an increase in ambition, and a greater efficiency in daily work and activities.

Calder (1942), in a study of the vitamin B-complex group in relation to blood pressure, concluded that a deficiency in the vitamins of this group is one of the factors causing high blood pressure. DeKleine (1944), in the treatment of albuminura and hypertension, gave the patient dried brewers' yeast at the rate of one to two teaspoonfuls daily. In addition, a good balanced ration was prescribed. Beneficial results as indicated by a lowering of the blood pressure were observed in many of the patients. DeKleine urged further investigation of this type of therapy in hypertension.

The Use of Yeast in the Daily Diet

Elvehjem (1940) expressed the opinion that natural foods as a source of the B-complex group of vitamins are superior to synthetic vitamins. Among the natural substances, yeast is one of the richest in the B-complex vitamin content.

Brewers' yeast, as it is separated from beer, possesses a highly unpalatable, bitter flavor due to its absorption of hop residues. A washing procedure has been developed which will effectively remove this bitterness, and all brewers' yeast processed for human consumption undergoes this treatment. Few persons, however, find debittered brewers' yeast or special food yeast particularly palatable.

Isker (1943), in a paper dealing with the possibilities of dried yeast in army feeding, placed considerable emphasis upon the importance of palatability. He stated that in order to use yeast as a food it is necessary either to induce people to acquire a taste for it or to modify it to give it an acceptable flavor. To overcome the unpalatable characteristics of dried yeast, the most satisfactory manner is to incorporate it into some other food in such a way as to mask its flavor.

Yeast may be mixed with ground meats, inserted in baked loaves and patties, incorporated into stuffings, gravies, casserole dishes, blended with peanut butter, syrups, and other spreads, and added to most baked products.

Hawk, Smith, and Bergeim (1921) studied the nutritive value of 5.0 per cent yeast-enriched bread. Similar studies were made by Scheunert and Schieblich (1929) with particular reference to the antineuritic fraction of the B-complex group of vitamins. Martin (1941) found the thiamine content of white bread made with the addition of dried yeast to compare favorably with that of whole wheat bread. Schwarz, Laufer, Laufer, and Brenner (1942) enriched white bread with additions of 2.5 per cent of debittered brewers' yeast. In flavor and other characteristics, this bread was the equal of, and could not be distinguished from, the control bread.

Within the past few years several lists of simple and tested recipes have been compiled for the use of yeast in family servings. Two have been distributed from Cornell University, one prepared by Neidert (1943), and the other prepared by the School of Nutrition (Anonymous, 1943.) Another list of recipes for home use was prepared by Carr (1943) and distributed by the Agricultural Experiment Station, Michigan State College. According to Carr, the use of dry yeast in baked products presents problems involving the texture and flavor of the product. The texture of the baked product is changed unless the batters and doughs are baked immediately after the addition of the yeast. The flavor of dry yeast in baked products may be masked satisfactorily in recipes by the use of molasses, honey, and spices. The nature of the product and other ingredients present determines largely the amount of yeast that can be added successfully. For this reason it is difficult to establish basic rules for substitutions in all recipes.

Durfee (1943) recommended the incorporation of yeast into recipes and reported that the inclusion of two tablespoonfuls of dried yeast into the daily diet would provide 100, 25, and 45 per cent, respectively, of the daily diet adult needs of thiamine, riboflavin, and niacin.

Neidert (1943a) prepared a list of quantity recipes using brewers' yeast. Heller, McCay, and Lyon (1943) carried on a study in which yeast was extensively used in quantity recipes. These investigators found the noon meal served by a large cafeteria in the Brooklyn Navy Yard to furnish, at most, one-fourth of the day's requirement of the B-complex group of vitamins. Dried brewers' yeast, incorporated into the meat dishes at conservative levels so that the taste was not detected, provided a satisfactory supplementary source of these vitamins.

Mitchell (1943) reported the manufacture of a dehydrated soup powder containing peas, soybeans, dry skim milk, brewers' yeast, and seasoning. The product was developed to be used largely in control-feeding operations for foreign relief.

McCay (1944), in a study of the eating habits of men in the armed forces, found that foods consisting largely of protein are left uneaten on the plates, but between-meals candies and other high carbohydrate foods are consumed in considerable amounts. This habit disturbs the balance of food intake in respect to proteins, fats, and carbohydrates. To overcome this condition, he recommended that the confections sold at Post Exchanges carry a greater proportion of protein substances, such as milk solids and yeasts, and a lesser content of carbohydrates.

The Army Quartermaster Corps Subsistence Research and Development Laboratory by C.Q.D. Specifications No. 176B modified previous regulations to permit the use of dried brewers' yeast in the biscuits and crackers that make up the bread component of the combat C and K rations (Anonymous, 1944). Regulations specify that sufficient quantities of fortifying agents shall be added to the yeast prior to drying to yield a finished product having a vitamin potency of not less than 600 micrograms of niacin per gram. Dried yeast is used at the rate of one to one and one-half pounds per one hundred pounds of flour. According to Dunlap (1945), dried yeast furnishes over one-half of the total thiamine when incorporated in biscuits and crackers in the three types of army rations. Yeast was chosen in preference to synthetic vitamins because of greater acceptability and as a source of the lesser known members of the B-complex group.

Roth and Zander (1944) suggested that more than 10 per cent of the daily protein intake could conveniently be met by incorporating two tablespoonfuls of yeast powder into foods such as ground meats, soups, peanut butter, gravy, chocolate milk, and others. In addition, yeast would serve to correct the deficiency of vitamin B-complex often associated with the modern diet.

Spinella (1945) reported on the successful utilization of brewers' yeast in the form of a sweetmeat. This product utilizes, in addition to dried brewers' yeast, butter, cheddar cheese, dry whole milk, peanut butter, and various flavoring substances. It was developed especially for hospital patients requiring a high vitamin, high caloric diet.

Because of the high biological value of yeast protein and its high B-complex vitamin content, Sure (1945) expressed the opinion that the nutritional status of countless people throughout the world could be readily improved by yeast supplement of the daily diet.

YEAST IN SWINE NUTRITION

Many of the early studies of the nutritional value of yeast were carried out with swine.

Early studies made by Pott (1908), Delbruck (1910), and Voltz (1910) reported on beer yeast as a feedstuff for swine. Kellner (1910) concluded that dried yeast was a valuable and highly digestible feed for swine and sheep, largely due to its high protein content. Czadek (1911) reported that yeast was readily eaten by pigs and that faster gains were made when yeast was added to potato and bran rations. Voltz (1912) and Richardsen (1912) found that satisfactory gains were made when yeast was used to replace meat protein in the ration and that the cost per unit of weight was only slightly higher. In discussing yeast as a new feed, Honcamp (1912) recommended it as a valuable supplementary fattening feed for hogs.

Windisch (1915) expressed the opinion that dried yeast stimulated the appetite, helped in the assimilation of other feedstuffs, and displayed a pronounced curative effect for certain diseases. On the other hand, Crowther (1915) considered yeast to be a good pig feed, but he did not believe it to possess any special virtues not possessed by any other highly digestible food rich in the albumins. Crowther (1917) showed that satisfactory results with pigs were obtained when dried yeast constituted 20 per cent of the total feed consumed.

Few studies were reported during World War I. Following the war, Honcamp (1920) reported the results of comprehensive studies made during the previous few years. In rations, yeast compared with fish meal as a supplement to barley and skim milk and was considered to be particularly valuable for swine because of its freedom from crude fiber.

Beginning in 1923 and continuing over a decade, a number of reports were published which appeared to contradict some of the earlier findings in regard to the nutritional value of yeast. Apparently, in many of these experiments, uncontrolled factors entered into the results. It appears likely that yeast was used to supplement apparently satisfactory swine rations with the result that the yeast additions to the diet did not show to advantage.

Experiments conducted at the Oklahoma Experiment Station and reported by Dowell (1924) showed no advantage in adding yeast to a ration containing kafir. Brown and Edwards (1924) found yeast to be of no value when added in amounts of 0.25 to 0.5 per cent to a basal ration of 100 parts corn and 12 parts of tankage. Smith (1924) reported similar results when yeast was used to supplement a ration of 100 parts corn, 25 parts millrun, and 10 parts tankage. Weaver (1925) studied the effect of yeast on feeds and their utilization by fattening swine. He found no advantages in using yeast. Morrison, Fargo, and Thomas (1926) found that yeast, as a part of the ration, failed to show any beneficial effects, and in several cases pigs without yeast made better gains. Shrewsbury, Vestal, and Hague (1932) reported that the addition of 3.0 per cent yeast to a ration containing soybean resulted in but a slight increase of growth. Culbertson (1932) and Culbertson and Thomas (1933) concluded that yeast was of no value as a supplement to corn and the Big 10 supplemental mixture for fattening pigs on rape.

Yeast as a Protein Feedstuff

During the past decade, the nutritional studies of yeast as related to swine feeding have centered largely in having yeast replace some protein constituent of the ration rather than on the supplementary effect of yeast to a ration containing an ample supply of various ingredients.

Hofmann (1932) found dried yeast to be about 10 per cent lower in food value than animal protein. Schmidt, Freun, Schleinitz, and Lagneau (1934) found dried yeast to be superior to soybean in respect to the storage of nitrogen in the body. Fingerling and Honcamp (1934) reported dried brewers' yeast and dried wood-sugar yeast to compare favorably with soybean oil-meal as a protein supplement.

Richter and Bruggemann (1936, 1936a) found yeast to be a satisfactory protein feed for pigs and to possess a high biological value. These investigators also reported that all of the protein in the ration may be given in the form of yeast. Bunger, Schultz, and Augustin (1935) and Bunger, Richter, Bruggemann, Schultz, and Augustin (1936) reported that one-half, but not all, of the usual animal protein supplement of a potato swine-fattening ration could be replaced by yeast. According to Axelson (1941), 50 per cent of the protein of the swine ration can be given in the form of dried yeast.

Steinbach (1937) reported the satisfactory use of dried yeast as a protein supplement in combination with animal protein. He recommended the use of dried yeast, provided some animal protein also was included. Crassmann and Tscherniak (1939) found that a mixture of yeast and fish meal in the ratio of 1.4 to 1.0 had substantially the same efficiency when used as a protein supplement as did the equivalent amount of fish meal alone. However, the yeast used alone in equivalent proportions was much less effective.

Braude and Foot (1940) found yeast to be an excellent protein supplement for fattening pigs when fed in conjunction with bulky feeding stuffs, and superior to other feeds high in protein. They recommended that 3.0 to 5.0 per cent of yeast be used in making up the protein content of the basal ration.

Nehring and Schramm (1939), using swine, compared the feeding value of yeast in the fresh, cooked, and dried forms. The digestibility of the total nutrients was somewhat less for the cooked yeast than for the live or dried forms, but the digestibility of the protein was not affected by either cooking or drying.

Using pigs as the test animals, Nehring and Schramm (1941) obtained a protein biological value of 85 per cent and a crude protein digestibility value of 84 per cent for dried yeast. Braude and Foot (1942), in a study of wartime rations for pigs, found fodder yeast suitable as a good source of protein. They recognized that some of its value may be associated with its vitamin content.

Mangold, Columbus, and Peham (1941) reported the digestibility of beer yeast for swine to be 98 per cent. McCrae, El Sadr, and Sellers (1943) compared the supplementary value of yeast protein and casein for cereal protein in the nutrition of the pig. Their preparation of dried yeast, prepared from *Torulopsis utilis,* proved highly satisfactory, whereas the dried brewers' yeast tested was not very satisfactory.

Worden (1943) noted that, in the presence of adequate vitamin D and a Ca/P ration of 1=1, pigs were successfully fattened on a diet containing 20 per cent of dried brewers' yeast. Braude, Kon, and White (1943, 1944) made similar observations. They found that dried yeast can supply all of the protein required in the diet of fattening pigs. They observed no difference in the nutritive value of ordinary brewers' yeast, debittered brewers' yeast, and fodder yeast (*Torulopsis utilis*). They noted, however, that yeast in the diet in excess of 8.0 per cent may lead to the appearance of rickets sufficiently severe as to interfere with fattening of the pigs unless additional calcium or vitamin D is added to the diet. They concluded from their studies that there is every reason to believe that pigs can be given any practical amount of dried yeast provided they are given access to sunlight as they usually are in normal farm practice. They further pointed out that, for practical purposes, a diet containing more than 20 per cent of yeast would not be contemplated in the usual feeding procedures.

Rockwell (1944) found dried brewers' yeast, supplemented with a steamed bone meal and limestone or a good commercial hog mineral, to be a good substitute for animal tankage in swine rations. The cost per 100 pounds of pork produced (live weight) was $10.23 for the ration containing yeast as compared to $9.92 for the check ration containing tankage. While the cost of production was somewhat higher with the use of yeast, this investigator is of the opinion that under certain conditions due to shortages of animal protein substances the use of yeast may be justified. Others reporting beneficial results from the addition of yeast to swine rations were Levitsky (1936); Gortner (1937); and Loeffel (1937).

Braude (1942), following a review of dried yeast as a feed for livestock, stated: "It is evident that dried yeast is a very valuable feedstuff, and it is therefore not surprising that the great authorities on feeding recommend it for all classes of domestic animals provided its value is understood and properly made use of."

Yeast as a Carrier of the B-Complex Vitamins

A number of experiments have been reported having a definite bearing upon the vitamin content of yeast in relation to swine nutrition. Beissett and Golding (1931) found a diet of white bread flour and fish meal to be inadequate for prolonged growth of pigs. Additions of yeast to the diet corrected this deficiency. Birch, Chick, and Martin (1937), experimenting with pigs on a pellagra-producing diet, cured this disease by supplementing the ration with 4.0 per cent of yeast. They found the cure to be surprisingly rapid. Wintrobe (1938a) reported that yeast provided the necessary growth factors for young pigs, and these seemed to be more readily available in yeast than in liver extract.

Chick, Macrae, Martin, and Martin (1938a), using a synthetic diet of purified starch, cotton seed oil, cod liver oil, and a suitable salt mixture supplemented with 4.0 per cent of dried yeast, found it to prove satisfactory for the growth of pigs. Chick, Macrae, Martin, and Martin (1938) found that an eluate of autoclaved yeast rendered wholesome a pellagra-producing diet consisting largely of corn. Synthetic niacin added to the ration accomplished similar results. Madison, Miller, and Keith (1939) observed a herd of swine under farm conditions in which many of the animals went off feed and showed other indications of illness. These animals were restored to normal by the inclusion of niacin alone in the diet.

Davis and Freeman (1940) and Davis, Freeman, and Madsen (1940) fed 50 to 100 grams of dried yeast daily to pigs with remarkable results in preventing and curing necrotic enteritis in swine, with which lack of niacin is thought to be concerned.

Smith, Reiser, and Harrell (1941) reported that yeast at a 10 per cent level in a synthetic ration prevented anemia in swine. Yeast proved inadequate at a 4.0 per cent level in the same synthetic ration. Hogan and Johnson (1940, 1941) noted that certain definite evidences of malnutrition occurred in suckling pigs on the usual brood sow rations. These symptoms decreased or were eliminated when large amounts of yeast were used to supplement the ration.

Wintrobe, Mushatt, Miller, Kolb, Stein, and Lisco (1942) fed pigs on a diet deficient in factors other than thiamine, riboflavin, and niacin. Abnormal gait and degenerative changes in certain nervous centers developed. These did not occur when brewers' yeast was added to the diet.

Miller, Keith, Thorp, and McCarty (1943) found that weanling pigs weighing 30 pounds developed various manifestations of vitamin deficiencies when fed on a ration adequate for pigs weighing 75 pounds. Pure B-complex vitamins were ineffective in overcoming the symptoms, but the inclusion of yeast, soybean oil-meal, and liver corrected the deficiencies.

YEAST IN POULTRY NUTRITION

Yeast in poultry nutrition has been investigated for its value as a protein supplement and as a source of the B-complex group of vitamins.

Many of the earlier experiments were carried out before much was known of the various components of the B-complex group of vitamins. Consequently, in numerous instances, a lack of proper understanding of these vitamin components did not permit the investigator to formulate properly controlled experiments. It is evident that yeast additions were occasionally made to basal rations in which the necessary growth factors were already present. As a result, contradictory statements have appeared concerning the nutritive value of yeast.

Plimmer and Rosedale (1923) found that a diet of polished rice and fish meal failed to maintain growth and well-being in pigeons. By supplementing such a diet with approximately 3.0 per cent of marmite, a commercial yeast product, normal growth was obtained.

Dougherty and Gossman (1923), supplementing a laying ration with dried yeast at a 5.0 per cent level, found it to have no influence on the egg production of White Leghorn hens. However, with Plymouth Rock and Rhode Island Red hens, there was an increased production of eggs but no influence on either the weight or the hatchability of the eggs. Souba, Knandel, and Dutcher (1923, 1924) fed a commercial yeast product containing corn meal to White Leghorn hens and pullets, and observed a distinct beneficial effect on egg production when the birds were forced to undergo longer feeding and exercising periods by the use of lights. When artificial light was not used, no beneficial results from using yeast were noted.

Erickson (1924) found no benefits resulting from feeding 1.0 to 2.0 per cent of yeast as a supplement to other protein feeds. In a series of feeding trials in which a 2.0 per cent dry yeast and a 1.0 per cent wet yeast were used as a substitute or as a protein supplement, Barton obtained conflicting results. In the first experiment (1926), he found that the birds grew faster, laid at a younger age, laid more and larger eggs, and the hens averaged heavier in weight when fed on the standard ration than when fed on the ration containing yeast. In (1928), using yeast in the ration, he found that the hens laid an average of 69.0 eggs during the seven-month period as compared with 60.4 for the hens on the check ration. Furthermore, 71.3 per cent of the eggs of the yeast-fed group were found to be fertile as compared with 49.4 per cent of the eggs from the hens on the check ration. Furthermore, 71.3 per cent of the eggs of the yeast-fed group were found to be fertile as compared with 49.4 per cent of the eggs from the hens on the control ration. In an additional experiment, Barton (1930) found that the birds fed the ration containing yeast came into production at an earlier date. Otherwise, the yeast-fed group was not quite as good as the check lot.

Dougherty (1928) found that feeding dry granulated yeast at a 5.0 per cent level led to a stimulation of the appetite of chicks and to an increase in weight over a feeding period of 90 days. Clark (1931), on the other hand, concluded that dried yeast was an unsatisfactory supplement to the rations of very young chicks.

Hogan and Shrewsbury (1929), in a study of the deficiencies of purified diets in chick nutrition, supplemented a purified ration with dried yeast. For the ration to be adequate, it was necessary to fortify it with approximately 40 per cent of dried yeast. Mussehl and Ackerson (1941) added yeast at levels of 2.0, 4.0, and 7.0 per cent in combination with cereal products. Additions of yeast to rations containing at least 75 per cent of cereal products increased the growth rate of chicks.

Halpin (1933) concluded that the use of live yeast at the 3.0 per cent level did not improve a good chick ration. Cosby (1938) added dried yeast at the 2.0 per cent level to the laying mash of test hens. No significant differences were noted in mortality, apparent health, or egg production between the birds fed yeast and those not given yeast. Carver (1937) fermented a regular laying mash with 1.0 per cent commercial yeast and observed no beneficial result from this practice.

Templeton and Dudley (1941) found brewers' yeast and fodder yeast to be approximately equal to fish meal in a ration consisting largely of corn and wheat products for pullets of several breeds. Axelson (1941) found that dried yeast could be substituted for 50 per cent of the normal supply of protein in the ration.

Specific Vitamin Deficiencies in Poultry Nutrition

With the recognition of a number of poultry diseases associated with deficiencies of specific members of the B-complex group of vitamins, most of the experimental work pertaining to the nutritional value of yeast during the past ten to fifteen years has involved components of this group.

Thiamine Deficiency. According to Titus (1942), no special precautions need to be taken to prevent thiamine deficiency in practical poultry production since most diets for poultry contain an amply supply of this vitamin. The minimum requirement for poultry of this vitamin is given as being from 90 to 135 International units per pound of feed, with 180 International units being an adequate supply (Titus, 1942).

Hogan, Shrewsbury, and Kempster (1928) observed the occurrence of leg weakness in chicks on deficient diets. Yeast fed to the afflicted birds served as an effective treatment for this abnormal condition. Norris, Heuser, Wilgus, and Ringrose (1931) reported on the occurrence of a paralysis of nutritive origin in chicks fed on a semi-synthetic ration containing casein. Vitamin concentrates such as milk, dried brewers' yeast, autoclaved yeast, and alfalfa meal were effective in preventing this condition. Bethke, Record, and Kennard (1931) observed a similar condition in chicks and reported similar results.

Gerhardt (1932) reported yeast to possess a vitality factor which served to increase appetite. This factor was especially active during the first 36 hours of the chick's life.

Riboflavin Deficiency. According to Titus (1942), relatively few of the feedstuffs used for poultry contain enough riboflavin to meet the minimum requirements of the chick or poult during the first few weeks of life. Ingredients of the diet, therefore, must be selected to include one or more of the richer sources of this vitamin.

Allman and Branion (1938) found that the addition of wheat germ, dried brewers' yeast, and corn distillers' grain, alone or in combinations to the ordinary ration with the usual amounts of cereal grain, improved growth and feathering conditions. They attributed this to a more efficient utilization of food as the result of the vitamin B-complex content of these substances.

Norris, Wilgus, Ringrose, Heiman, and Heuser (1936) reported the riboflavin content of dried yeast to be 35 chick units per gram of yeast as compared to 30, 20, and 16 chick units, respectively, for dried whey, dried skim milk, and alfalfa meal. Heuser (1938), using a cereal yeast, found it to be a good source of riboflavin and a satisfactory substitute for milk, yielding comparable results. Fairbanks and Hamilton (1942) found dried yeast to be superior to dried buttermilk and two-thirds as good as commercial liver meal for providing the riboflavin needs of poultry.

Stokstad and Manning (1938) noted that the curled-toe symptom did not develop with diets containing sub-optional amounts of this vitamin. Once this symptom did develop, it was readily cured by including large amounts of riboflavin in the diet.

The minimum riboflavin requirement of the growing chick during the first week is about 1300 micrograms per pound of feed and about 1600 micrograms for the poult. An adequate supply of this vitamin for either the poult or the chick during the first four to five weeks is about 1670 micrograms per pound of feed. The riboflavin requirement for mature birds is somewhat less. The laying ration should contain 600 to 800 micrograms per pound of feed, and for high hatchability the breeding rations should contain about 1250 micrograms (Titus, 1942).

Pantothenic Acid Deficiency. Most of the feedstuffs ordinarily fed to poultry serve as fairly good sources of pantothenic acid, but diets composed largely of the cereal grains, wheat middlings, and meat or fish scrap may be deficient in this factor (Titus, 1942). The minimum pantothenic acid requirement of the chicken is about five milligrams per pound of feed.

Hauge and Carrick (1926) differentiated between the antineuritic and the water-soluble, growth-promoting substance in yeast. This latter subtsance was considered very essential for the growth of chicks.

Bauernfeind, Schumacher, Hodson, Norris, and Heuser (1938) used a heated ration containing the known vitamins with the exception of the antidermatosis factor and niacin. Supplementing this diet with both the antidermatosis factor and niacin resulted in slower growth and lower hatchability than when yeast was used to supply these factors. Bauernfeind and Norris (1939a) observed that the antidermatosis factor, which is supplied by yeast, did not affect egg production, but its presence was necessary for hatchability. Peterson and Elvehjem (1939) found the antidermatosis factor to be supplied by the addition of 2.0 per cent of brewers' or grain yeast, 4.0 per cent molasses yeast, and 6.0 per cent glucose salts yeast. They reported that this factor appears to be identical with pantothenic acid. Patrick, Boucher, Dutcher, and Knandel (1940) found that biotin, obtained from yeast, prevented dermatosis in turkey poults.

Antiperosis Properties of Yeast. Jukes (1940, 1940a) observed that manganese alone was not sufficient to prevent perosis (slipped tendon) in chicks and poults. Neither were additions of thiamine, riboflavin, and niacin. Choline chloride, however, at a level of 0.2 per cent of the ration, and manganese were effective.

Wilcke (1936) supplemented a grain diet with yeast and observed no protection against perosis. Patrick, Boucher, Dutcher, and Knandel (1943), however, found dried brewers' yeast to possess antiperosis properties for turkey poults.

Other Factors in Yeast

Stokstad and Manning (1938a) observed a growth factor not identical with previously described vitamins which is present in alfalfa, middlings, wheat bran, and yeast. They tentatively designated this growth factor as factor u.

Bauernfeind and Norris (1939a) noted an unidentified factor in milk, liver, yeast, and fresh green grass, which, when added to the diet in addition to the antidermatosis factor, permitted normal growth in chicks and satisfactory egg production in mature birds. It, however, failed to promote normal reproduction or to maintain weight.

Rhyg (1939) found that a 2.0 per cent addition of a specially prepared yeast product to the normal diet of chickens added essential vitamins for satisfactory results.

Schumacher and Heuser (1940) and Schumacher, Heuser, and Norris (1940) studied the properties of an alcoholic precipitate of yeast. They found this to contain two growth factors in addition to other recognized factors. When added to the ration at the rate of 5.0 per cent of dried yeast, it exerted a marked growth-stimulating effect.

Hegsted, Oleson, Elvehjem, and Hart (1940) observed a lack of growth and extreme weakness in growing chicks when fed on a ration deficient in pyridoxine. This vitamin is widely distributed in nature, and a deficiency is unlikely to occur unless chicks are on a highly simplified diet. As reported by Titus (1942), yeast and wheat germs are among the best sources of this vitamin.

McGinnis, Norris, and Heuser (1942) fed chicks a diet of yellow corn meal, casein, soybean oil, cod liver oil, and salts supplemented with thiamine, riboflavin, pyridoxine, calcium pentothenate, and glycine. Abnormal feather pigmentation resulted. The inclusion of 5.0 per cent of dried brewers' yeast to the ration prevented the abnormal feather pigmentation.

Record and Bethke (1942) concluded that while 0.15 per cent choline is needed to give maximum growth of chicks, some factor similar to the alcohol-precipitate factor of yeast also is essential.

Jukes (1940b) reported a growth-promoting factor for chicks in yeast distinct from the five known members of the B-complex group of vitamins. It was present in a crude solution prepared by extracting yeast with 50 per cent ethyl alcohol. He considered it distinct from choline. Similar observations were made by Patrick, Boucher, Dutcher, and Knandel (1943).

Amounts of Dried Brewers' Yeast In Poultry Rations

Before the outbreak of World War II, riboflavin was supplied in poultry rations largely by the use of powdered milk or powdered whey products. With shortages in these materials being present, large amounts of dried yeast are being used to provide this essential vitamin constituent. Boucher (1944) recommended the incorporation of dried yeast in poultry rations as follows:

Chickens	**Per cent**
Starting mash, all mash	2.50
Growing mash, all mash	1.50
Growing mash, fed with grain	2.50
Laying mash, all mash	1.25
Laying mash, fed with grain	2.50
Breeding mash, all mash	2.50
Breeding mash, fed with grain	5.00
Turkeys	
Starting mash, all mash	3.0
Growing mash, all mash	1.5
Growing mash, fed with grain	3.0
Breeding mash, all mash	3.0
Breeding mash, fed with grain	6.0

In a recent publication from Pennsylvania State College (Anonymous, 1945), listed mash mixtures for chicks and breeders included brewers' dried yeast at a 3.0 per cent level. Mash mixtures for turkeys included dried yeast in the starter, grower, and breeders rations at 4.0, 2.0, and 5.0 per cent levels, respectively.

YEAST IN DAIRY CATTLE NUTRITION

Renner (1914) reported increased milk yields by feeding beer yeast to dairy cows at a rate of 12 to 17 kilograms daily as a supplementary feed. Voltz, Baudrexel, and Dietrich (1914); Dunlop and Bailey (1916); and Cranfield and Taylor (1916) reported beneficial results with the use of dried yeast with dairy cattle.

Use of Yeast in the Calf Ration

Eckles, Williams, Wilbur, Palmer, and Harshaw (1925) supplemented the diet of dairy calves with a product containing about 3.0 per cent of yeast and found no increase in the rate of growth between the ages of two weeks and six months. They concluded that yeast was of no value as a feed for calves. In their study, however, the actual amount of yeast fed was very small; this may explain their negative results.

Newman and Savage (1938) fed dried brewers' yeast in the form of calf meals and pellets. They found that the use of yeast resulted in greater growth and body development. The use of yeast decreased the digestible nutrients required per unit gain in weight. They found that one-half of the skim milk powder could be replaced by yeast. Gardner (1940) was unable to confirm the results of Newman and Savage. Pshenichnyi (1938) found that additions of yeast to the rations of young cattle increased their appetite and improved the general condition of the animals.

Baker (1941) obtained beneficial results from feeding yeast to calves in advanced stages of malnutrition and debility as a result of diarrhea followed by constipation and loss of appetite due to gastrointestinal parasitism.

Savage and McCay (1942) reported a favorable response of malnourished calves to the feedings of dried brewers' yeast.

Use of Yeast for Mature Dairy Cows

Barton, Ness, and Crampton (1926) found that dried brewers' yeast could be substituted for linseed meal on the basis of equal weights in the rations of dairy cows. Henke, Work, and Maruyama (1940) found yeast to be satisfactory for growing heifers. When compared to soybean oil-meal for milk production, it was definitely inferior. Axelson (1941) reported the successful substitution of dried yeast for oil-cake and other concentrates for ruminants. Broman (1941) increased milk production by feeding yeast suspensions from alcoholic fermentations to dairy cattle. One liter of a 15 per cent suspension of this yeast in sulfite waste liquor increased milk production by one liter. Klein and Schmid (1942) reported beneficial results by the addition of very slight amounts of thermophilic yeast to the nitrogenous non-protein feed given to ruminants.

Norton (1945) used fresh bakers' yeast in the rations of cows in increasing amounts from 20 to 80 grams per cow and was unable to show any significant differences in the fat test or in the amount of fat produced. Yeast fed up to a level of 80 grams per cow per day had no apparent beneficial effects on the appetite of the cows; at the same time, no injurious effects on the health of the cows were observed.

Krauss and Hunt (1933) fed dried yeast to dairy cows in amounts up to three-fourths of a pound per day. No increase was found in the thiamine content of the milk although there was some evidence that the riboflavin content was slightly increased.

Wallis (1938) demonstrated the need of vitamin D by dairy cows. In dairy herds producing metabolized vitamin D milk, veterinarians and animal nutritionists have observed a better general state of health among the cows than in those in herds not receiving additional vitamin D in the ration. As a result of controlled studies and observations, irradiated yeast is being used in dairy cattle rations at the rate of one-half to one pound per ton of concentrate. The irradiated yeast has a beneficial effect in the nutrition of the dairy cow by increasing mineral assimilation.

Webb (1940); Jukes (1941); and Siebel, Weber, and Singruen (1942d) discussed the merits of yeast as a feed for dairy cattle. They presented no original data on this subject.

CONCLUSIONS

Human Nutrition

Nutritionists are in agreement that the average daily diet is deficient in the B-complex group of vitamins. Although yeast is an excellent source of these vitamins and can be used successfully in preventing and curing pellagra, beriberi, and other nutritional diseases, the problem remains of making it available in a palatable form. The most desirable means by which this may be accomplished appears to be the incorporation of the yeast product into food dishes of various types without decreasing the flavor appeal of the food.

The experimental data concerning the effect of long-continuing yeast ingestion on the blood constituents are incomplete; therefore, no conclusion can be made concerning the use of yeast as a protein source in the human diet.

Swine Nutrition

From the experimental evidence to date, the value of dried yeast in swine nutrition, under average farm conditions, appears to be centered in its vitamin content. In certain areas where there are shortages of animal proteins, which likewise serve as vitamin carriers, the use of yeast as a vitamin source may be warranted. When plant proteins, especially soybean oil-meal, are fed, there may be some beneficial effects in feeding 2.0 to 4.0 per cent of yeast in the ration as a source of some of the B-complex vitamins in which soybean oil-meal is deficient.

The limiting factor in the more widespread use of yeast in swine rations is dependent on its comparative cost with other comparative protein and vitamin sources. As soon as yeast can be sold at prices similar to those of animal protein supplements, it will have a place in certain swine rations.

Poultry Nutrition

Vitamins of the B-complex group are very important in poultry nutrition. In formulating a poultry ration, it is essential that a riboflavin carrier be included. Dried yeast in amounts ranging from 1.25 per cent in growing and laying mashes for chickens up to 6.0 per cent in the breeding mash for turkeys will successfully provide the need for riboflavin, in addition to furnishing thiamine, pantothenic acid, choline, and other lesser known fractions of the B-complex group of vitamins.

Under the economic conditions of the past several years, dried yeast has successfully competed with dried skim milk and dried whey as the source of riboflavin in poultry nutrition.

Dairy Cattle Nutrition

The use of yeast in the nutrition of dairy cattle does not present the same possibilities that it does in poultry nutrition. With the exception of the young calf, cattle appear to be provided with an adequate supply of the B-complex group of vitamins through the action of microorganisms in the rumen. However, during the first few weeks of the calf's life, its natural diet consists chiefly of milk with little or no grains and roughages. Under this condition, synthesis of the B-complex vitamins within the rumen is inadequate to meet the needs of the animal. To meet this need, the use of brewers' yeast up to the 6.0 per cent level in calf starters is recommended by animal nutritionists.

Calves, as well as mature dairy cattle, respond to the protein constituents of yeast when it is used to supplement the ration. This has been shown by numerous feeding trials. The limiting factor, however, in the use of dried yeast for this purpose is its cost in comparison to that of other high-protein feedstuffs.

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