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Yeast Extracts: Nutritional and Flavoring Food Ingredients

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ABSTRACT: Yeast extracts are the concentrates of the soluble fraction of yeast and more particularly *Saccharomyces cerevisiae*. As food ingredients, yeast extracts are described for their nutritional composition and flavoring properties. They are produced principally from autolysis, but in some cases, acid or exogenous enzyme preparations are added. The main nutritional components of yeast extracts include partly hydrolyzed protein with 35−40% of free amino acid, and they also contain B vitamins and some trace elements. As flavoring ingredients in foods, they provide diverse flavors depending on the methods used for their production. These flavors include meaty, kokumi, umami, and salty taste along with taste masking properties. Yeast extracts are a source of amino acids, including glutamic acid, with a content of about 5% and 10% w/w free and total glutamate, respectively. Yeast extracts have the capacity to induce the umami taste, the flavoring effect of monosodium glutamate (MSG), when providing glutamate at an amount below 1% in foods, *i.e.*, below the amount required for pure MSG. The latest studies indicate that they can also be used as sources of bioactive substances in functional foodstuffs and dietary supplements.

KEYWORDS: *yeast, Saccharomyces cerevisiae, nutritional ingredients, flavoring agents, protein, amino acid, glutamate*

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1. INTRODUCTION

Among microorganisms, yeasts are microscopic unicellular fungi some of which having the ability to convert sugar into alcohol and carbon dioxide by fermentation. *Saccharomyces cerevisiae* is the most used yeast for the fermentation involved in the preparation of different foods and beverages such as bread, beer, or wine. Yeasts are also used as food ingredients either in the form of inactivated dried yeasts or as yeast extracts. Yeast extracts are products derived from yeast by removing the water insoluble cell walls and extracting and concentrating the water-soluble cellular content. The cellular content of yeast is composed of different components including proteins, amino acids, glucans, nucleotides, B-group vitamins, and minerals. The preparation of yeast extracts includes cell lysis and the implementation of various processes for the removal of cell walls and concentration of cell contents. Therefore, yeast extracts compared to yeast do not contain the cell wall and include the concentrated water-soluble cellular components partly degraded during the process. This composition varies and can be modulated according to the preparation of the different yeast extracts that are used as ingredients in foods and beverages for both their nutritional and flavoring properties. This narrative review provides a perspective view on these yeast extracts and their use in food as nutritional ingredients and flavoring agents.

2. WHAT ARE YEAST EXTRACTS?

Some yeasts, and more particularly *Saccharomyces cerevisiae*, have been traditionally used in foods and beverages, producing alcohol and/or carbon dioxide by fermentation during bread preparation, beer brewing, or wine making. As available biomass, yeast are also used as inactivated dried yeasts or for the preparation of yeast extracts.[1,2] The process to make yeast extract results from the solubilization and concentration of the ruptured cell content of a selected strain of yeast. The process mainly proceeds in three steps, *i.e.*, yeast cell growth, cell lysis, and cell content concentration.

Yeast extracts are the concentrates of the soluble fraction of yeast.[1,3−5] For yeast extract preparation, the selected yeast is first incubated with a source of sugar, like molasses, and temperature and oxygen levels are rigorously monitored to optimize the growth rate. Once yeast has reached optimum development, it is harvested from the broth, its growth is stopped by heat treatment, and a variety of methods are used for the release and digest of yeast cell contents, the most common being autolysis by enzymes released from the cell, hydrolysis if additional exogenous enzymes or acids are added, and plasmolysis.[6] In some cases, autolysis is supplemented by adding proteolytic enzymes or acids to enhance its effectiveness.[7,8] Yeast plasmolysates are obtained by adding large amounts of salts thereby achieving cell wall collapse under osmotic pressure. Autolysis and plasmolysis are used for living cell extraction, while acid hydrolysis and aqueous extraction are used for nonliving cells.[9,10] Yeast extracts are produced principally from autolysis using the endogenous cellular enzymes during which hydrolysis occurs spontaneously by the action of endogenous enzymes. Autolysates are the simplest products of this type of products because there is no addition of any component. For some specific applications, yeast extracts referred to as yeast hydrolysates are obtained with added acids or proteolytic

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exogenous enzymes that degrade cell walls.[7,8,11−13] Plasmolysates and acid hydrolysates contain larger amounts of salt and sodium that are used during plasmolysis or for neutralizing acids used for hydrolysis.

During the process, the cell walls are permeabilized, and proteins, nucleic acids, and other nutrients of the yeast cell content are released and partly degraded into smaller components.[5,6] Proteins are broken down into oligopeptides, smaller peptides, and free amino acids, polysaccharides like mannans and glucans are broken down into into sugars, and nucleic acids are broken down into into ribonucleic acids, oligonucleotides, and nucleotides. During autolysis, naturally occurring enzymatic reactions take place, where intracellular enzymes become activated by appropriate conditions such as temperature and reaction duration, resulting in partial degradation of cell wall structures. Technological innovations have been developed to improve yeast cell wall breaking, production of flavor components, and yeast extract concentration. The conditions of lysis such as temperature and pH are carefully controlled according to the expected mixture of components, some of which participate in the flavor of the extracts. Extraction of valuable intracellular proteins, carbohydrates, and vitamins is thus facilitated. The insoluble cell walls are removed by centrifugation and filtration, and the final soluble yeast extract is concentrated or spray dried to produce liquid, light paste with 20−30% water, or dry powder with 5−10% water.

The yeast extracts have been described and used principally as food nutritional and flavoring ingredients, are also progressively used as functional ingredients in functional foods and food complements, and are more marginally used in skin conditioning, skin protection, and as cosmetic and personal care products.[14,15] They are also used as a nutritional source in microbial growth media for their content in nitrogen, amino acids, vitamins, nucleic acids, minerals, and carbohydrates. No toxic symptoms or lesions were observed in rats receiving an acute, subchronic, or chronic oral dried fermentate preparation of *Saccharomyces cerevisiae*.[16] In the EU, yeast extracts answer the definition of flavoring preparation and therefore are considered as a natural flavor.[17] They are considered as a GRAS (Generally Recognized as Safe) substance by the U.S. Food and Drug Administration because of a long history of safe use.[18] They are usually labeled as "yeast extract" or "natural flavor" in the ingredient list of foods. In addition, the yeast cell walls derived byproducts of yeast extracts are developed for their functional effects on growth performance, gut physiology, and immunity.[12,19−25]

3. NUTRITIONAL PROPERTIES OF YEAST EXTRACTS

The nutritional composition of yeast extracts used as a dietary nutritional ingredient must be differentiated from whole yeast powder (Table 1).[5,8,10,26−29] Yeast extract consists of a combination of proteins, peptides, amino acids, nucleic acids, B vitamins, minerals, carbohydrates, and some other components. The precise chemical composition of yeast extracts depends on the conditions used for yeast culturing and yeast extract preparation. For example, dried brewer's yeast used as a dietary supplement is rich in protein (just under 50 g per 100 g of yeast) and is a source of group B vitamins (B1, B2, B3, B5, B6, B9), iron, phosphorus, magnesium, and zinc. Yeast extracts usually contain a high degree of free amino acids and group B vitamins. Free amino acids include primarily glutamic acid, glycine, alanine, and valine. Among minerals, it contains magnesium, potassium, iron, and zinc. There is also in some cases a relatively high level of added sodium or potassium, depending on the process. These yeast extracts are used as food ingredients in different light pastes some of which are being primarily composed of this extract or, in some beverages, acting both as a flavor ingredient and providing nutritional substances including amino acids, B vitamins, glutathione, selenium, γ-amino acid, or Extractbeta-glucan.

Table 1. Typical Nutrient Composition of *Saccharomyces cerevisiae*-Derived Products−Dried Yeast, Dried Yeast Extract, and Yeast Extract Paste[5,8,10,26−29]

for 100 g	dried yeast	dried yeast extract	yeast extract paste
water g	4	4	37
calorie kcal	362	334	159
protein (N × 6.25) g	48	69	27.8
carbohydrate g	23.7	7−13	11.8
- sugar g	8.0		0
- starch g	1.5		
- fiber g	13		3
fat g	5.4	<0.5	0.0
- SFA (saturated fatty acid) g	0.7		
- MUFA (monounsaturated fatty acids) g	2.1		
- PUFA (polyunsaturated fatty acids) g	2.4		
Vitamins			
B1 (thiamine) mg	40	10−12	9.7
B2 (riboflavine) mg	4	8−12	14.3
B3 (niacine) mg	25	90−110	97
B5 (pantothenic acid) mg	9	12−20	
B6 (pyridoxine) mg	2.6	6−8	1.3
B9 (folic acid) μg	2500		
B12 (cobolamine) μg		0.5−1.5	0.5
minerals			
calcium mg	130		86
phosphorus mg	1300		104
magnesium mg	170		180
potassium mg	2460		2600
sodium (salt) mg	40		3600
iron mg	5		3.7
copper mg	5.3		0.3
zinc mg	5.6		2.1
manganese mg	0.4		
selenium μg	71		18

The main component of yeast extracts is partly hydrolyzed protein (Table 2).[27,30,31] The overall content of nitrogenous compounds in dried yeast ranges from 45 to 70%, of which 80% is protein nitrogen and 10−12% is nucleic acid nitrogen, whereas the other components are glutathione, *N*-acetylglucosamine, lecithin, and others.[27,32−35] The free amino acid content is 35−40% of the total protein, including 10−15% di-, tri-, and tetrapeptides. Oligopeptides of 2000−3000 Da molecular weight constitute 40−45% of the total protein and 2−5% for the larger oligopeptides. In yeast extracts obtained by autolysis, the ratio of free amino acids to the di-, tri-, tetra-, and oligopeptides is relatively constant but may become altered significantly, if exogenous enzymes are used. The ratio of total to free amino acids is not constant because at least 85% of leucine, alanine, methionine, and phenylalanine are present in their free forms, while for aspartic acid, glycine, and arginine, this only ranges at 14−37%. This arises from the characteristics of the

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Table 2. Typical Total and Free Amino Acid Content of Dried *Saccharomyces cerevisiae* Yeast Extract[27,28,30,31]

amino acid g/100 g DM	free AA	total AA
alanine	3.7	4.4
arginine	1.8	2.5
aspartic acid	1.9	4.9
cystine	0.3	0.4
glutamic acid	5.2	8.1
glycine	1.2	2.4
histidine	0.9	1.0
isoleucine	2.2	2.7
leucine	3.5	3.8
lysine	2.2	4.0
methionine	0.7	0.9
phenylalanine	1.8	2.3
proline	1.0	2.0
serine	1.8	2.3
threonine	1.7	2.1
tyrosine	1.2	1.4
tryptophan	0.6	0.6
valine	2.6	2.9
total	34.6	48.0

degradation process through the activity of proteases and peptidases, which during autolysis hydrolyze internal peptide bonds within amino acids, whereas carboxypeptidases and aminopeptidases recurrently hydrolyze peptide bonds from the C- or N-terminal part of the protein.

Yeast autolysis products have a high content of B vitamins and some trace elements.[5,8,10,26−28] Vitamin content can vary depending on the autolysis process. Differences in mineral content likewise depend on how the filtration and separation of yeast extracts are performed from insoluble cellular components such as glucans or mannan-oligosaccharides. A standard yeast extract contains for 100 g about 3 mg of thiamine, 11.9 mg of riboflavin, 68 mg of niacin, 3.1 mg of folic acid, and 30 mg of calcium pantothenate. The mineral content in 100 g of a standard extract represents about 120 mg of calcium, 200 mg of magnesium, 3.3 g of potassium, and 5 mg of copper; the sodium content obtained when no salts are added is less than 0.5 g.[27] Moreover, when yeasts are grown in a mineral-rich media such as selenium or chromium, yeast can integrate these minerals in an organic form. The bioavailability of selenium from selenium-enriched yeasts (in the form of seleno-methionine) is 1.5−2 times higher than that of inorganic forms of selenium, in the form of mineral salts.[36] The half-life of seleno-methionine is also longer, indicating that once absorbed, seleno-methionine is less rapidly eliminated and used for longer periods in the body. These products rich in minerals are almost exclusively sold in the form of dried food yeast.

Yeast extracts are valuable components of both conventional and vegetarian diets and are used as nutritional ingredients in numerous different foods.[37] For vegetarian diets, they contain essential amino acids, especially lysine, valine, and isoleucine along with group B vitamins and minerals.[27,38] Moreover, when used in vegetarian foods, their flavoring properties are an interesting way to enhance not only the nutritional content but also the taste of these foods.

4. YEAST EXTRACT AS A FLAVORING INGREDIENT

Yeast extracts are for a part used as flavoring ingredients and taste active compounds in foods, providing savory, meaty, kokumi, umami, and salty taste along with taste masking properties. Depending on the products and the preparation processes, the yeast extracts often have a spicy and salty flavor, and there are also sweeter variations. They are widely used in condiments, meat products and baked goods, soups, broths, bouillons, sauces and dressings, ready meals, snack foods, and plant-based meat alternatives, and their application has gradually expanded to different products. In dietetic and light foodstuffs, with reduced fat or carbohydrates, yeast extracts or used for their specific sensory qualities.[27,39−41]

These extracts provide savory flavors and umami taste sensations, in relation to the presence of different components including amino acids, peptides, nucleotides, and other flavoring molecules produced during the process of yeast extract preparation.[4,42−46] In these yeast extracts, the significant amounts of glutamic acid, nucleotides together with various amino acids, and peptides act synergistically for intensifying the flavor of foodstuff products. Due to the yeast fermentation process, yeast extracts naturally contain glutamic acid, accounting for 5% on average within the free amino acid fraction, contributing to the specific taste and more particularly providing a umami taste. Therefore, yeast extracts can be applied in food formulations with only a low amount of yeast extract required (usually less than 1%) for producing the flavor taste effect. When compared to MSG, yeast extracts have significant notes of meaty, buttery, and vegetal (corn, mushroom cabbage, and carrot) taste, for an intake below the amount required with pure MSG.[1] Yeast extracts can provide diverse flavors, depending on the methods used for their preparation, affected by the interactions between amino acids, nucleotides, carbohydrates, and peptides present in the extracts and the production of volatile compounds.

Despite numerous studies on the generation of flavoring peptides in yeast extracts, their molecular structure, the optimal conditions for their generation, the number of the produced peptides, and the structure-flavor relationships remain controversial and unclear.[47−51] About ten kokumi peptides, together with other sour and umami peptides, were described from yeast extract.[52] Umami is the taste of MSG that is the most potent amino acid contributing to umami, with aspartate also having umami taste properties.[53] Numerous peptides, generated by proteolysis of proteins, rather hydrophilic, and containing at least one glutamyl or aspartyl residue such as Gly-Asp, Ala-Glu, Gly-Asp-Gly, or Val-Asp-Val, were also described to elicit the umami taste, although this was controverted.[54] Fifteen umami peptides were identified in the umami taste fractions of yeast extract and were classified according to their structural umami behavior as Type I peptides that were basic receptor-stimulated, with an aliphatic property, and mainly composed of neutral, aromatic, and imino amino acids and Type II peptides that were both basic receptor and enhancer stimulated and contained acidic or alkaline umami peptides mainly composed of acidic, amides, basic, and hydroxy amino acids (Table 3).[50,51] The umami taste is related to the number of umami amino acids (Glu, Gln, Asp, Asn) and to their position in the peptide, with a stronger umami taste when they are close to the N terminus. The taste properties also depend on the dilution of the peptides and the food matrix.[50,51] Kokumi peptides and some other peptides could be not tasty by themselves but enhance sweet, salty, or umami tastes.[54] If small peptides containing glutamyl or aspartyl residues isolated from different food systems did not all show a umami taste by themselves, some of them, Glu-Glu, Glu-Val,

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Table 3. Taste Threshold of Umami Peptide from Yeast Extracts[47,50−52,96,97]

peptide composition	reported taste	taste threshold(mg/mL)
Glu	umami	0.05
Glu-Asn	umami	0.75
Glu-Ser	umami	1.56
Asn-Tyr	umami	3.13
Pro-Glu-Thr	umami	4.78
Leu-Val-Gly	umami	6.55
Val-Ala-Val	umami	7.25
Pro-Ala-Ala	umami	10.25
Glu-Ala	umami, bitter	0.82
His-Val	umami, bitter	2.08
Lys-Gly	umami, bitter	4.59
Val-Val	umami, bitter	6.25
Leu-Val	umami, bitter	6.75
Gly-Gly-Tyr	umami, bitter	8.2
Glu-Leu	umami, kokumi	1.52
Gln-Leu	umami, kokumi	3.63

Ala-Asp-Glu, Ala-Glu-Asp, Asp-Glu-Glu, and Ser-Pro-Glu, were found to enhance the umami taste.[54]

The different types of yeast extracts from different production processes vary in their volatile profile.[3,42,44−46,55−60] The diversity and complexities of volatile compounds in yeast extract depend upon the process and the food system and include alcohols, aldehydes, hydrocarbons, ketones, acids, esters, furans, and many heterocyclic aromatic compounds including pyrazines.[42,61] Reported aroma-active compounds of yeast extract include, for instance, 2-methyl-3-furanthiol, 2-methyl-3-methyldithiofuran, methional, 1-octen-3-one, and dimethyl trisulfide together with a number of pyrazines, thiophenes, and aliphatic compounds.[58] A total of 30 compounds were identified covering a variety of odor properties, such as the basic aroma of meaty, roasted, popcorn-like, cooked potato-like, nutty, buttery, cocoa-like, cheesy, flowery, and green (Table 4).[46,62,63] Most of the aroma-active compounds are desirable, with meaty, sweet, nutty, and roast odor properties. The key aroma-active compounds, 3-methylbutanal, 3-butanedione, 2,3,5-trimethyl-pyrazine, acetic acid ethenyl ester, 2-methyl-5-(methio)furan, 2-furan methanethiol, 1-octen-3-one, 2-acetyl-1-pyrroline, and (*E*,*E*)-2,4-decadienal, were identified as partially responsible for meaty, roasted, and sweet notes in the yeast extract pastes.[45] The compounds methional, 2-acetyl-2-thiazoline, phenylacetic acid, and 2,3-diethyl-5-methylpyrazine were identified as important contributors to the aroma of a thermally treated yeast extract autolysate.[46] Compounds with the greater contribution to the whole aroma profile of different yeast extracts were 3-methylbutanoic acid (cheesy, rancid), 2-methyl-3-furanthiol (meaty), 4-methylphenol (medicine), 3-methylpyridine (medicine, bitter), propanoic acid (rancid, pungent), 3-methylbutanal (dark chocolate), 3-(methylthio)propanal (cooked potato), and benzene acetaldehyde (honey, sweet). Moreover, among these odorants, those responsible for the medicine/rancid/cheesy/pungent properties leading to the characteristic yeasty off-flavor odor that must be prevented include 3-methylbutanoic acid, 4-methylphenol, 3-methylpyridine, and propanoic acid.[63]

By controlling the production process, different flavors such as those of chicken soup, meat, cheese, or mushrooms can be obtained. Appropriate control over autolysis, via regulating temperature, pH, and reaction duration, changes the sensory profile of the produced extracts, thus enabling flavors such as roast meat, bouillon (broth), meat, and even cereal to be achieved.[8,26,27,39,64,65] When processed in complex food systems, yeast extract undergoes a series of thermally induced reactions at elevated temperatures, thus generating a wide variety of thermally derived volatile compounds responsible for the roast-like, meaty, and caramel-like odors.[45,66] Flavoring components like those found in cooked meat are produced by the reaction of 5′-nucleotides, glutamic acid, and cysteine with sugars. The thermal reaction temperature influences the umami flavor, the production of flavor-active components, and controls bitterness of the extracts.[42,43] The control of the Maillard reaction can allow production of different flavors such as beef, chicken, or other meat flavors. The sensory properties of the extracts are strongly affected by processes like evaporation and drying, during which Maillard compounds are formed which are responsible for giving cooked meat flavors. In addition, regulating the manufacturing process conditions can also impact the color of the extracts, from white to brown. In the presence of glutathione, Maillard reaction products and sulfur-containing amino acids also greatly impact antioxidant properties.[67] Yeast extracts can mask sour and bitter tastes, enhancing food flavor and simultaneously serving as food colorings and antioxidants.

Yeast extracts participate in some cases to decrease the salt content in the recipe due to its full and complex savory taste, and some formulation can reduce sodium by up to 50% compared to the use of sodium chloride. The partial replacement of NaCl by KCl and $CaCl_2$ significantly reduced the sodium content of the products, while lysine and yeast extract minimized the negative sensory effects due to the addition of KCl and $CaCl_2$.[68]

Table 4. Example of Aroma-Active Compounds Identified in Different Yeast Extracts[46,62,63]

compound name	taste properties	compound name	taste properties
2-methyl-3-furanthiol	meaty	2-methyl-5-(1-methylethyl) pyrazine	sweat
3-methylbutanal	dark chocolate	acetic acid	sour
3-(methylthio) propanal	cooked potato	furfural	bread, sweet
benzeneacetaldehyde	honey, sweet	2,6-diethylpyrazine	roast, buttery
ethylpyrazine	popcorn, peanut butter	benzaldehyde	almond
3-methylthiophene	metal	2,3-butanediol	buttery, cheesy
2-methylthiazole	roast, smoky	2-methylpropanoic acid	butter, cheese
methylpyrazine	popcorn	acetophenone	floral
octanal	green, fruity	phenylethyl alcohol	rosy, floral
2,5-dimethylpyrazine	roasted nut	1-(1H-pyrrol-2-yl) ethanone	nutty, popcorn
2,6-dimethylpyrazine	roasted nut, cocoa	indole	camphor
2,3-dimethylpyrazine	nutty, peanut butter	3-methylbutanoic acid[a]	cheesy, rancid
dimethyl trisulfide	cooked cabbage, garlic	4-methylphenol[a]	medicine
nonanal	green	3-methylpyridine[a]	medicine, bitter
trimethylpyrazine	roast, nutty	propanoic acid[a]	rancid, pungent

[a]Can contribute to off taste when at too high a concentration.

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5. YEAST EXTRACT VERSUS MSG

Yeast extracts are a rich source of all amino acids, including glutamic acid, which is found in all proteins. Due to the current discussion about MSG, there is a need to provide information on this question related to yeast extracts. Glutamic acid, and its ionic form glutamate, is a nonessential amino acid present in foods as protein-bound glutamate and as free glutamate. Different glutamate salts of sodium (monosodium glutamate, MSG), potassium, calcium, or magnesium are used as flavor enhancing and umami taste additives.[69] Free dietary glutamate occurs in many foods consumed by humans (human and cow's milk, cheeses, cured ham, beef, fish, fermented beans, tomatoes, mushrooms, green peas, soy sauces, yeast extract, hydrolyzed vegetable proteins).[70,71] Yeast extracts have a content of about 5% w/w and 10% w/w of free and total glutamate with the capacity to induce the flavor umami taste and the flavoring effect of MSG when added at amounts below 1% in foods, *i.e.*, an amount of free glutamate below the amount required when using pure MSG.[1]

Glutamate intakes are composed of a dietary protein-bound fraction, free glutamate naturally present in certain foods and food ingredients (including yeast extracts), and glutamate salt additives.[14,69,72−75] Total intake of glutamate constitutes up to 10% of amino acids content in the average human diet and is about 5−20 g/day in adults with different origins and dietary habits.[70,76] Glutamate bound to protein is the greatest source of exposure, whereas MSG represents 5%−19% of total glutamate consumption.[69] In the USA and Europe, daily consumption of food-added MSG is in the range 0.3−1.0 g/day up to about 2.0 g/day for higher consumers, and in the East and Southeast Asia, daily consumption of food-added MSG is in the range of 1.0−3.0 g/day.[76] As the gastrointestinal tract has a very high capacity for using glutamate, its plasma levels are poorly affected for free MSG intake up to 1 g/day and transiently rise when high doses of MSG (*i.e.*, >10−12 g) are consumed, more particularly without food, and these elevated plasma levels normalize within 2 h after the offset of consumption.[71,77−80]

MSG has been classified as a Generally Recognized as Safe (GRAS) substance by several regulatory authorities.[80] The European Food Safety Authority (EFSA) discussed from human studies the absence of adverse effects at doses up to at least 5 g MSG in a meal, equal to 70 mg/kg/day MSG for an adult, but used from animal model studies a NOAEL (No Observable Adverse Effect Level) of 3,200 mg/kg MSG and derived, with a compound-specific uncertainty factor of 100, an acceptable daily intake (ADI) of 30 mg/kg/day MSG for humans.[79,81,82] Numerous studies have been performed for decades on health impact and reproductive, (neuro)developmental, and neurobehavior toxicity of free glutamate salts, but the conclusions remain partially controversial.[79−95] Accordingly, applying a compound-specific uncertainty factor of 25 to the NOAEL of 3,200 mg/kg MSG provides ADI values of 120 mg/kg/day MSG that could represent a valuable compromise.[80]

The proportion of free glutamate in yeast extracts is relatively low. In typical yeast extracts, total glutamic acid, *i.e.*, protein-bound and free form, is about 8−10% w/w of dry matter, and free glutamic acid is about 5% w/w of dry matter, 8% w/w of total glutamic acid, and 15% w/w of the free amino acid content. In addition to glutamate, yeast extracts also contain various flavoring components produced during the process of their preparation that contribute to the flavoring properties. Typical dosage of yeast extracts in food is usually between 0.5 and 2% w/w to provide the expected flavoring effects. Exposure to naturally occurring free glutamate from different sources (including yeast extract) in food and drinks is estimated in adults to an average of 7−15 mg/kg/d (with higher level of 11−36 mg/kg/d) in the European Union.[69] Naturally occurring free glutamate is provided by many different dietary sources, and if free glutamic acid is consumed through yeast extracts, this contributes 5−10% to naturally occurring free glutamate in certain food and drink, and it then represents an intake of 0.3−1.5 mg/kg/d.

6. CONCLUSIONS AND PERSPECTIVES

Yeasts are increasingly used as valued food products from which natural food ingredients are derived, such as yeast extracts that fulfill the dual function of being nutritional and flavoring ingredients. These yeast extracts are used in foods and beverages for both their flavoring and flavor enhancing properties as well as for nutrient fortification providing various nutritional substances. Yeast extracts reinforce meat flavors in many foodstuffs and spice mixtures, replacing the commonly used protein hydrolysates obtained by acid hydrolysis. Interestingly, yeast extracts have the capacity to induce a strong taste and flavor effect even when added at amounts below the amount required for pure MSG. Moreover, the latest studies[1,28] indicate that these extracts can also be used in functional foodstuffs and dietary supplements as sources of amino acids, peptides, and other bioactive substances. These observations have stimulated further development and research to produce not only yeast extracts containing specific molecules, including nutritional (amino acids, vitamins) and flavoring molecules, but also bioactive molecules. The precise chemical composition of yeast extracts in these flavoring, nutritional, or bioactive molecules depends on the conditions used for yeast culturing and yeast extract preparation, that constitute a unique opportunity for biotechnology innovation to improve the different steps of the preparation according to the expected use of the extracts. Numerous studies have been conducted on the identification of the molecules that contribute to the different flavors that include amino acids, peptides, and volatile compounds and on their interactions. In many cases, the dynamics of the different contributors and how the interactions between the different molecules contribute to the final flavors remain poorly understood. Numerous uncertainties related to the peptides should be also clarified, including their generation and their structure-flavor relationships. If some peptides have a flavor by themselves, others may not have the capacity to enhance the flavor of other flavoring peptides. The more precise characterization of peptides either with the umami taste or enhancing the umami taste needs to be clarified in comparison to MSG and is of particular importance due to the current regulatory discussion about MSG. The diversity and complexities of volatile compounds produced in yeast extract upon the different yeast culture and processes of extract preparation also represent a promising potential for generating specific molecules. The role of the interaction among amino acids (Gln, Asn), flavoring peptides, and volatile compounds in the different flavors needs to be more precisely evaluated. There is also an increasing interest in the nutritional, functional, and health-related properties of yeast extracts. Their nutritional composition can be optimized through yeast culture and extract preparation to provide key nutrients such as minerals, vitamins, amino acids, or fiber-like compounds. For instance, when yeasts are cultured in media with controlled levels of mineral, they can be integrated in the yeast in an organic bioavailable form and transferred in the

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yeast extract. The controlled generation of specific vitamins during yeast extract preparation could represent a promising development. Moreover, the identification of bioactive molecules with health protective properties that could be produced in a controlled way in yeast and yeast extracts also represents a promising area of development. They include, for example, amino acids, bioactive peptides, or other chemical type of molecules acting on physiological functions.

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