

Review

Yeasts in marine and estuarine environments

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Yeasts and other fungi are prevalent in marine and estuarine ecosystems where they play an important role in the food web. Marine yeasts are unique in performing fermentations under high salt concentrations. The mechanism underlying the high salt tolerance involves the ability to accumulate high concentrations of sodium without becoming intoxicated, and the exclusion of excessive sodium from the cytoplasm. Overall, the yeasts play major roles in fermentation, enzyme technology, pollution control, micro sensors, and in some medicinal and medical applications.

Key words: Marine yeast, deep sea, estuarine, mangrove, association.

INTRODUCTION

Yeasts are unicellular micro-fungi, capable of self perpetuating their populations in terrestrial and aquatic environments (Kurtzman and Fell, 1998). A key characteristic is the ability to ferment sugars for ethanol production. They live as saprophytes on plant or animal materials, where they preferentially catabolize sugars but can also utilize polyols, alcohols, organic acids, and amino acids as carbon and sources of energy (Spencer and Spencer, 1997). To promote efficient decomposition of substrates, many yeasts produce filaments or pseudo-hyphae and also produce hydrolytic enzymes. Research on yeasts has played a major role in the development of a number of modern scientific disciplines and much work is being carried out in studying their physiology, metabolism, genetics, and molecular biology and developing new applications for industry and medicine (Barnett, and Barnett, 2011). Although, a large number of studies about terrestrial and aquatic yeasts are available there are only few reports about marine and estuarine yeasts, and hence is the need for this review.

DISTRIBUTION OF MARINE YEASTS

Most studies on yeasts in estuaries and near-shore seawater was performed in Europe and north America

(Fell et al., 1960; Roth et al., 1962; Fell and Van Uden, 1963; Van Uden and Castelo-Granco, 1963; Taysi and Van Uden, 1964; Norkrans, 1966; Ahearn et al., 1968; Van Uden and Fell, 1968; Hoppe, 1972; Ahearn, 1973; Barnett and Pankhurst, 1974; Buck, 1975).

Marine and estuarine habitats

Marine yeasts display a high salt tolerance and the ability to perform fermentation. In general, yeast cell numbers decrease with increasing salt concentration and total organic carbon in the estuarine environment (Urano et al., 2001). Due to sewage pollution and terrestrial runoff in this environment, some species of yeasts are more prevalent in estuaries, as compared to open seas (Lazarus and Koburger, 1974). Yeast and other fungi are prevalent in salt marsh and mangrove ecosystems where they play an important role in the detritus food web of the coastal environment (Mayers et al., 1975; Hyde, 2002).

Yeasts in estuarine waters vary widely both in number and species. The most frequently isolated genera of yeasts are *Debaryomyces*, *Candida*, *Rhodotorula*, *Cryptococcus* and *Kloeckera*. While studying the yeast flora of the Suwannee River estuary in Florida, Lazarus and Koburger (1974) obtained highest yeast densities in low saline areas, and highest species diversity in the sewage-polluted waters in the estuaries. However, no ascosporegenous yeasts have been isolated from the areas of low salinity (Lazarus and Koburger, 1974). The researchers from University of Miami have isolated one

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ascomycetous yeast, *Lachancea meyersii* from the mangroves of the Bahamas (Fell et al., 2004).

Offshore and deep-sea environments

Only a few studies on yeasts from oceanic regions have been published in the last decades. This may be due to the high costs involved in offshore and oceanic sampling (Fell, 1976). Among the ascomycetous yeasts, the halotolerant species *Debaryomyces hansenii* is a typical ubiquitous species in oceanic regions as well as in other aquatic environments. Among the basidiomycetous yeasts, some species of *Cryptococcus*, *Rhodotorula*, *Sporobolomyces* and their teleomorphs are widespread across various oceanic regions. Generally, basidiomycetous yeasts often account for the majority of the total yeast population in oligotrophic oceanic water. *Candida* species also occur, but at lower frequencies than in the inshore or polluted freshwater regions. Some of the *Candida* species are only evident in the oceanic regions around Antarctica along with psychrophilic species such as *Leucosporidium* spp. and *Sympodiomyces parvus*.

They are probably autochthonous marine species (Lachance and Starmer 1998). *Metschnikowia* species are known to be associated with seawater, freshwater, algae, invertebrates and fish. Phylogenetic relationship analysis shows that *M. australis*, *M. bicuspidata* var. *bicuspidata*, *M. bicuspidata* var. *chathamia*, *M. krissii* and *M. zobellii*, prevalent in marine environments are monophyletic. However, the less prevalent aquatic species such as *M. reukaufii* and *M. pulcherrima* are phylogenetically distant (Mendonça-Hagler et al., 1993).. The latter two are usually found to associate with natural substrates of terrestrial origin such as flowers, fruits and insects. The monophyly of the marine species suggests that their divergence has evolved in the course of association with marine environments.

The ubiquitous species in various marine habitats are usually regarded as allochthonous, as many basidiomycetous types of yeast are often found to associate with the phyllosphere of terrestrial plants and their marine prevalence is believed to be due to run-off from the phylloplane (Hagler and Ahearn, 1987; Lachance and Starmer, 1998). The yeasts of the ballistosporogenous genera - *Sporobolomyces* and *Bullera* - and their teleomorphs are typical inhabitants of the phylloplane. The yeasts of the genera - *Sporobolomyces* and *Bullera* - are the most commonly encountered in the Pacific Ocean off Mexico (Hernandez-Saavedra et al., 1992). Interestingly, the frequencies of occurrence of the yeasts increase with increasing distance from the coastline and increasing depth of coastal sea. The yeasts of ballistosporogenous genera are also present in benthic invertebrates collected from deep-sea floors in the Pacific Ocean off Japan

(Nagahama et al., 2001b). These facts indicate that ballistosporogenous yeasts are not effluents from terrestrial plant foliages but are indigenous to the sea.

Basidiomycetous types of yeasts are present in the seawater of the Atlantic Ocean off Faro in the south of Portugal (Gadanhó et al., 2003). *Rhodosporidium babjevae* and *Rhodosporidium diobovatum* (the two possible species previously identified as *Rhodosporidium glutinis*, and *Sakaguchia dacryoides*) and *Pseudozyma aphidis* (ustilaginomycetous yeast) are the most frequently occurring yeasts among the basidiomycetous yeasts (Gadanhó et al., 2003).

Yeast-like cells are reportedly abundant in deep-sea sediment around the Pacific Ocean. The most frequently surveyed site is around a cold seep at a depth of about 880 to 1,200 m near Hatsushima Island, Sagami Bay. Other less frequently surveyed sites include Suruga Bay (380 to 2,500 m), the Japan Trench (4,500 to 7,500 m) and Iheya Ridge (990 to 1,400 m). The sites surveyed only once include Kagoshima Bay, 220 to 260 m; the Mariana Trench, about 11,000 m; the Palau–Yap Trench, 3,700 to 6,500 m; and the Manus Basin, 1,600 to 1,900 m. The Iheya Ridge and the Manus Basin are biologically fertile spots owing to the hydrothermal vent ecosystem (Alongi 1992, Nagahama et al., 2001a, b, 2003a, b).

The species which occur most frequently in the above sites are *Rhodosporidium sphaerocarpum*, *Williopsis saturnus* and *Candida pseudolambica*, but their distribution is limited mostly to the sediments of Suruga Bay and Kagoshima Bay. *D. hansenii* occurs only in the sediments of Sagami Bay and Suruga Bay, although it is known to be the most common ascomycete in marine waters (Hagler and Ahearn 1987). Almost all ascomycetous yeasts have been isolated from sediments, with the exception of *Kloeckera nonfermentans*, which is common to both sediments and benthic invertebrates, specifically in Sagami and Suruga Bay. In contrast, *Rhodosporidium diobovatum* and *Rhodotorula mucilaginosa* are widely prevalent in the various locations and sources.

The frequency of occurrence of each corresponding phylogenetic taxon is obviously different according to the source and geographical origin. The ascomycetous yeasts constitute the majority of the total yeast population in the sediments of Sagami Bay, Suruga Bay and Kagoshima Bay, and these sites are relatively inshore (5 to 20 km) near urban and industrial areas and where the sea floors are affected by human activity. Species in the *Erythrobasidium* clade have been isolated mostly from the benthic invertebrates, and the initial isolates from the sediments of the Manus Basin are considered to give clues about the hydrothermal ecosystems. Many of these species belong to the *Occultifur* lineage although some are novel species yet to be classified (Nagahama et al., 2001a, 2003a).

The association with animals is probably favourable for yeasts, owing to the abundance of nutrients (Hagler

and Ahearn, 1987). However, the reasons why the number of species associated with animals is low is yet to be known. Hymenomycetous species, mostly assigned to the genus *Cryptococcus*, are localized in the Japan Trench, Sagami Bay and Suruga Bay, and the genus does not appear farther southwest. Species of Sporidiobolales are present at all of the sites.

Marine yeasts are believed to have physiological adaptations but are not scientifically validated. In general, yeasts from both terrestrial and marine origins are moderately pressure-tolerant. However, the response of yeasts to elevated hydrostatic pressure has not been properly studied (ZoBell and Johnson, 1949; Yamasato et al., 1974).

The carotenogenic basidiomycetous yeasts such as *Rhodotorula* and *Rhodospiridium* are psychro-tolerant and pressure-tolerant (Davenport, 1980). *Rhodotorula* species grown at 20 MPa (equivalent to 2,000 m depth) are not significantly different as compared to those grown at 0.1 MPa; however, growth is reduced to 20 to 30% when the species is grown at 40 MPa (Lorenz and Molitoris, 1997).

The yeasts isolated from seafloors deeper than 4,000 m do not grow well under hydrostatic pressures corresponding to the sources at which they have been collected (2 to 4°C, > 40 MPa).

This may be due to the specifications of compressed incubation system, which allows sharp pressure changes and insufficient oxygen supply. Psychrophilic strains have not been found so far in the deep sea, but many isolates are psychrotolerant growing well at < 4°C (Lorenz and Molitoris, 1997).

Hypersaline habitats

Yeasts occur in hypersaline habitats world-wide (Butinar et al., 2005) and include *Rhodospiridium sphaerocarpus*, *R. babjevae*, *Rhodotorula larynges*, *Trichosporon mucoides*, *Candida parapsilosis* *C. glabrata*, *Pichia guilliermondii*, *Debaryomyces hansenii*, *Trimmatostroma* and *Yarrowia lipolytica*. Interestingly ascomycetous yeast, *Metschnikowia bicuspidate* is known to be a parasite of the brine shrimp and it occurs as a free-living form from the Great Salt Lake brine.

Antarctic habitats

The first *Candida*-like *Leucosporidium* species was isolated in the 1960's from Antarctic soil and seawater (Di Menna, 1960; Sinclair and Stokes, 1965; Fell et al., 1969; Watson and Arthur, 1976; Ray et al., 1992). *Leucosporidium antarcticum* is endemic to Antarctica. This yeast species can weakly utilize both sucrose and maltose, and is extremely sensitive to temperatures above 20°C.

Marine plant-associated yeasts

Yeasts are epiphytic on seaweeds, abundant on Chlorophytes and Rhodophytes, but of low abundance on Phaeophytes due to the release of growth-inhibitory phenolics from the brown seaweeds (Raja Seshadri and Sieburth, 1971).

The yeasts also associate with phytoplankton (Kriss and Novozhilova, 1954) and decaying seaweeds (Bunt, 1955; Suchiro and Tomiyasu, 1962; Van Uden and Castelo Granco, 1963). However, no specific association has been established for yeasts with marine algae and seagrasses (Roth et al., 1962).

Yeast communities of polluted estuary and mangrove ecosystems in subtropical marine environments are extremely diverse. Yeasts are prevalent in salt marshes or mangrove ecosystems where the yeasts play an important role in the detrital food web and they are food source for some marine invertebrates including zooplankton (Meyers et al., 1975). *L. meyersii* sp. nov. (type strain NRRL Y 27269, CBS 8951, ML 3925) is described from 18 strains collected from mangrove habitats in the northern Bahamas Islands.

This species is homothallic, producing spherical ascospores in asci that become deliquescent, and is delineated from other ascomycetous yeasts by sequence analysis of the D1/D2 domains of the large subunit ribosomal DNA.

The species can be distinguished from other members of the genus *Lachancea* by lack of growth on galactose and by growth on maltose.

This new species is named in honor of Professor Samuel P. Meyers in recognition of his pioneering research with marine fungi (Fell et al., 2004). *Candida intermedia*, *D. hansenii*, *Issatchenkia occidentalis* (*Candida sorbosa*), *Pichia guilliermondii* and *Pichia membranifaciens* (*Candida valida*) are the ubiquitous ascomycetous species at the Sepetiba Bay, Japan (De Araujo et al., 1995; Soares et al., 1997). The identity of the yeast community in the subtropical mangrove ecosystem is unclear, owing to phenotypic characterization yielding ambiguous taxonomic results.

Yeast species, *Kluyveromyces aestuarii* is associated with detritus-feeding invertebrates and sediments within mangrove areas (De Araujo et al., 1995; Soares et al., 1997). The aquatic strains of *Kluyveromyces lactis* are isolated from rhizosphere sediments of the marine marsh lands (Naumova et al., 2004; *hansenii* Meyer et al., 1971; De Araujo et al., 1995; Soares et al., 1997).

Plant-associated yeasts on bromeliads in mangrove areas are distinct from those typical of polluted areas, and comprise a larger number of species and isolates with basidiomycetous affinities (Hagler et al., 1993). Two yeast species *Kluyveromyces lactis* and *Pichia spartinae* are prevalent in the outer- or intra-culm (fistulous stalk) cells and tissues of the saltmarsh grass, *Spartina alterniflora* (Buchan et al., 2002).

Human-associated marine yeasts

Yeasts can cause infection in humans. *Candida albicans* causes candidiasis, resulting in vaginal infections and also diaper rash and thrush of the mouth and throat. *Debaryomyces hansenii* is generally considered a non-pathogenic yeast species; however, it is associated with one case of bone infection and is identified in several clinical isolates associated with bone infection, fever and chronic bronchitis (Wong et al., 1982; Nishikawa et al., 1996).

Human pathogenic yeasts can be found in coastal areas. For example, *C. albicans* is an obligate saprophyte of warm-blooded animals, occurring rarely in host-free environments and surviving in nature for only short periods outside of animals. *C. albicans* with sparse filamentation and weak fermentation has been reported to occur at the surface micro-layer of the North Sea, but not in subsurface waters. It is found sporadically in marine and fresh waters and is common in faeces and raw sewage. Human pathogenic yeasts enter and aggregate in the bivalve mollusks due to the filter feeding mechanism of these animals (Buck et al., 1977). *C. parapsilosis*, *Candida tropicalis* and *Torulopsis glabrata* are the human-associated yeasts most frequently isolated from bivalve shellfish (oysters and mussels) collected from estuarine areas (Dabrowa et al., 1964; Kobayashi et al., 1953; Buck et al., 1977). These pathogenic yeast are selectively inhibited in sewage filtrates by water soluble substances produced by bacterial strains of *Bacillus* (Coleman et al., 1975).

Water temperature and pollution are important factors that influence the distribution of human-associated yeasts. Temperatures lower than that of the human host may dictate the abundance of intestinal yeasts. Incubation of cultures at 37°C eliminated many saprophytic types of yeast but encouraged human-associated yeast. The samples closest to sources of domestic pollution have the greatest abundance and survival of *C. albicans* in seawater (Dzawachiszwili et al., 1964; Madri et al., 1966; Madri, 1968; Ahearn, 1973). The *C. albicans* population is greatest during colder months in the heavily polluted waters. The pumping rates of bivalves are minimal at low water temperatures. This does not kill yeasts, but the slow rate of pumping may account for the survival of human-associated yeast and other yeasts in bivalves in the winter (Tripp, 1960; Galtsoff, 1964; Buck et al., 1977). In oysters, internal phagocytosis and migration are the main processes by which yeast cells (*Saccharomyces cerevisiae*) are removed.

When raw shellfish containing pathogenic yeasts are consumed, human health can be affected. However, the infective dosages of the yeasts are still not known. Individuals who repeatedly handle contaminated shellfish with cut or damaged hands are most at risk from yeast infections. Potentially pathogenic microorganisms are

therefore, a serious consideration in the assessment of water and shellfish quality of near-shore recreational areas (Buck et al., 1977).

CULTURAL CHARACTERISTICS OF MARINE YEASTS

In the marine environment, bacteria are usually more numerous than yeasts. For the selective isolation of yeasts from the environment, bacterial inhibitors such as chloramphenicol, chlorotetracycline and streptomycin are generally used in the culture medium either alone or in combination. Antibiotics are used at concentrations up to 50 times greater than that required for bacterial inhibition (Ahearn et al., 1968; Richards and Elliott, 1966). The indiscriminate use of antibiotics to suppress bacteria may inhibit some yeast. The low pH of many media may inhibit acid-sensitive yeasts growing in alkaline seawater. Thus, the media commonly used for the detection and enumeration of marine yeasts have their limitations (Meyer et al., 1967; Ahearn et al., 1968; Van Uden and Fell, 1968). Employing temperature - gradient gel electrophoresis, Gadanho and Sampaio (2004) have studied yeast diversity in the estuary of the Tagus River, Portugal. This molecular detection method is carried out directly from water samples in parallel with cultivation of the yeasts using enrichment media. The number of species detected after enrichment is higher than the number of taxa found using the direct detection method. The most common species detected in marine environments is *D. hansenii*, an ascomycetous yeast (Hagler and Ahearn, 1987), probably because of its broad salinity tolerance and ability to utilize a wide range of carbon sources (Yadav and Loper, 1999).

PHYSIOLOGICAL ADAPTATIONS OF MARINE YEASTS

Yeasts from seawater are of two types; obligate and facultative. The obligate marine yeasts originate from the marine and inhabit the seawater throughout their lives. The facultative marine yeasts originate from other environments such as rivers, soils, woods, or the surface of animals and are transported to the marine environment. The obligate yeasts have inherently high NaCl tolerance as well as fermentative activities under high salt conditions (Urano et al., 1998). The facultative marine yeasts have weak salt tolerance acquiring high NaCl tolerance gradually over long periods. Repeated cultivation of weak salt tolerant yeasts in NaCl-rich media transforms them to high salt tolerant organisms (Urano et al., 2001).

Microorganisms differ in their tolerance to osmotic stress, but in general yeasts and fungi are more tolerant than bacteria (Brown, 1978). Among yeasts, strains of *D. hansenii* and *S. rouxii* are highly osmotolerant and

Table 1. Potential of marine yeasts for industrial processes and biotechnology.

High value products/Application	Yeast	Source
Pollution degradation or algae blooms controlling yeasts	<i>Candida</i> , <i>Rhodotorula</i> , <i>Torulopsis</i> , <i>Hanseniaspora</i> , <i>Debaryomyces</i> , and <i>Trichosporon</i>	Hagler and Hagler, 1981
Glycerol kinase	<i>D. hansenii</i>	Nilsson and Adler, 1990
Biotransformation of aromatic polycyclic hydrocarbons	<i>Trichosporon penicillatum</i>	Ronald and Shiaris ,1993
Membranes - surfactants for pharmaceuticals	<i>C. bombicola</i>	Shepherd et al., 1995; Guilmanov et al., 2002
Convert prawn shell waste into microbial biomass protein	<i>Candida</i> species	Rhishipal and Rosamma Philip, 1998
Organic acids and amino acids-regulating the acidity of the fermented product, and also provides lipolytic and proteolytic activity contributing to flavour development	<i>Debaryomyces hansenii</i>	Urano et al., 1998
Superoxide dismutases-anti-inflammatory activities	<i>D. hanseii</i>	Gonzalez and Ochoa, 1999
Superoxide dismutase	<i>Saccharomyces cerevisiae</i>	Hernandez Saavedra and Ochoa, 1999
Microbialsensor-rapid measurements of bio-degradable substances.	<i>Arxula adenivorans</i>	Tag et al., 2000
Glucoamylase gene Glycerol, compatible solutes	<i>C. magnolia</i>	Wartmann and Kunze, 2000; Rothschild and Mancinelli, 2001; Sahoo and Agarwal, 2001
Lipids- liposomes for drug delivery and cosmetic packaging		Cavicchioli and Torsten, 2000
Waste transformation and degradation	<i>C. utilis</i>	Cavicchioli and Torsten, 2000; Zheng et al., 2005
Hydrocarbon degradation	<i>Yarrowia lipolytica</i>	Oswal et al., 2002
Prolyl aminopeptidase (PAP)- role in meat fermentation	<i>D. hansenii</i>	Bolumar et al., 2003
Carotene-food colouring	<i>Rhodotorula mucilaginosa</i> , <i>Arxula adenivorans</i>	Libkind et al., 2004
Viable cells- bioremediation of TNT polluted marine environments	<i>Y. lipolytica</i>	Jain et al., 2004
α glucosidases- facilitating assimilation of β - fructofuranosides and α glucopyranosides	<i>Leucosporidium antarcticum</i>	Turkiewics et al., 2005
Immunostimulant	<i>Fenneropenaeus indicus</i>	Sajeevan et al., 2006
Microorganism-useful to improve the final quality of fermented sausages	<i>D. hansenii</i>	Bolumar and Sanz, 2006
Protease	<i>Aureobasidium pullulans</i>	Chi et al., 2007
Inulinase	<i>Cryptococcus aureus</i>	Sheng et al., 2007
Reducing post harvest decay of tomatoes caused by <i>Alternaria alternate</i>	<i>Rhodospodium paludigenum</i>	Wang et al., 2008

Table 1. Continued.

Silver nanoparticles	<i>Candida albicans</i> , <i>C. tropicalis</i> , <i>Debaryomyces hansenii</i> , <i>Geotrichum</i> sp., <i>Pichia capsulata</i> , <i>Pichia fermentans</i> , <i>Pichia salicaria</i> , <i>Rhodotorula minuta</i> , <i>Cryptococcus dimennae</i> and <i>Yarrowia lipolylica</i>	Manivannan et al., 2010
Bio-ethanol production	<i>Candida albicans</i> , <i>C. tropicalis</i> , <i>Debaryomyces hansenii</i> , <i>Geotrichum</i> sp., <i>Pichia capsulata</i> , <i>Pichia fermentans</i> , <i>Pichia salicaria</i> , <i>Rhodotorula minuta</i> , <i>Cryptococcus dimennae</i> and <i>Yarrowia lipolylica</i>	Kathiresan et al., 2011

capable of growth in media containing up to about 4 M NaCl (Onishi, 1963; Norkrans, 1966). *S. cerevisiae* is limited by NaCl concentrations above 1.7 M (Onishi, 1963). When *D. hansenii* is subjected to increased NaCl stress, intracellular K⁺ decreases and intracellular Na⁺ increases (Norkrans, 1968). However, the total salt level in the cells is not sufficient to balance the water potential of the medium; this is why additional osmotically active solutes such as polyols accumulate intracellularly when exposed to osmotic stress (Brown and Simpson, 1972; Gustafsson and Norkrans, 1976; Brown, 1978; Adler et al., 1985). Tolerance for a sudden osmotic dehydration is also better in cells having an increased amount of intracellular polyols (Adler and Gustafsson, 1980). Two polyols are produced and accumulated in *D. hansenii*; glycerol, which is the major internal solute in exponentially growing cells, and arabinitol, which predominates in stationary-phase cells (Adler and Gustafsson, 1980). A positive correlation exists between internal glycerol level and salinity of the surrounding medium (Adler et al., 1985; Andre et al., 1988). Glycerol is the major osmoticum, as its concentration may reach molar levels under strongly saline conditions (Gustafsson and Norkrans, 1976). The enzymes that control glycerol catabolism are glycerol kinase and mitochondrial glycerol 3-phosphate dehydrogenase (Gancedo et al., 1968; Sprague and Cronan, 1977; Adler et al., 1985). In yeasts lacking glycerol kinase, the presence of an NAD-dependent glycerol dehydrogenase and a dihydroxyacetone kinase is an alternative pathway (Babel and Hofmann, 1982; May et al., 1982).

Among several marine yeasts, *D. hansenii* accumulates high amounts of Na⁺, and in this yeast, Na⁺ is not more

toxic than K⁺ (Ross and Morris, 1962; Norkrans, 1966; Prista, 1997). Besides Na⁺, glycerol plays a role as a compatible solute for a glycerol/Na⁺ symporter with homeosmotic function in this yeast species (Lages et al., 1999; Lucas et al., 1990). Increased transport activities might be needed in addition to the maintenance of a high osmotic pressure within the cell. In addition, existence of sodium efflux process may also be involved in saline tolerance. The mechanism for extrusion of Na⁺ across the plasma membrane might be carried out via the function of Na⁺-ATPase or Na⁺/H⁺ antiporters (Ramos, 1999).

POTENTIAL OF MARINE YEASTS

Yeasts are used in many industrial processes, such as the production of alcoholic beverages, food, fodder yeasts and for the synthesis of various metabolic products. The last category includes enzymes, vitamins, polysaccharides, carotenoids, polyhydric alcohols, lipids, glycolipids, citric acid, ethanol and compounds synthesized by the introduction of recombinant DNA into yeasts. Some of these products are produced commercially, while others are potentially valuable in biotechnology. Some uses of marine yeasts in the food, beverage and fermentation industries are shown in Table 1.

CONCLUSION

Even after five decades of research, the potential of marine yeasts to contribute to biotechnological

applications has not been fully realized or exploited. By virtue of their occurrence in extreme environmental conditions, the marine yeasts have superior qualities over their terrestrial counterparts with regards to salt tolerance, enzyme production, biosynthetic potential, pollution abatement, and ethanol and other fermentative processes, and hence deserve further investigation. Although much work has been carried out on molecular aspects of yeasts, such efforts for marine yeasts are lacking. There are no proper culture collections for marine yeasts. Only a few marine habitats have been investigated for yeast species and many additional species await discovery. Based on the fact that yeasts of terrestrial origin are widely used in traditional and modern biotechnology, the exploration for new species of marine origin should lead to additional novel technologies.

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