Global Scientific JOURNALS

GSJ: Volume 9, Issue 1, January 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

β-Carotene—properties and production method from The Yeasts

Alaa Hussein Ali

College of Science/Biology Dept.
Univ. of Mosul

Email : Badia_Jamal@yahoo.com

Abstract

Carotenoids are natural stains produced by different groups of living organisms, such as plants, animals, and micro-organisms. They take many colors, such as yellow, orange, red, and purple. Microorganisms have received a lot of attention from researchers to obtain carotenoids from their natural sources, as they are characterized by the easy of extraction and purification, low costs, and production is not related to the seasonal changes experienced by the process of extracting carotene from plants, in addition to that carotene The output has no negative effects. Carotenoids are of great importance and have wide applications in many areas because of their functions and properties that made them interesting, as they play a role in protecting cells from the harmful effects of free radicals and reducing the risk of injury Some types of cancerous diseases, cardiovascular diseases, and the prevention of Alzhemeir's disease due to its antioxidant properties and carotenoids are also included in the food industry as they are used as food colorants that contribute to attracting consumers to goods and goods and are added as food supplements to animal feed and recently entered the pharmaceutical industries.

Introduction

Carotenoids are a group of natural dyes produced by a group a wide variety of plants, algae, and microorganisms such as bacteria, molds, and yeasts (Perez-Fons *et al*., 2011). They are largely unsaturated organic compounds. They share a general molecular formula (C40H56).

They belong chemically to polyenes and are considered types of turbines. They follow the Tetraterpenoids section because their chemical composition is composed of Isoprenoid units. The colors of carotenoids yellow, red, and pink are returned to easily oxidized and have multiple double bonds (Rodriguez-Amaya, 2001). In 1960 AD the number of known natural carotenoids was about 80 compounds and reached 500 compounds in 1980 AD and recently its number has become more than 700 species, among the most important types of carotenoids produced by yeasts:

1. **β-carotene**

It is used in food coloring and as a complementary food supplement as a precursor of Vitamin A at a concentration of between 2-50 ppm, as it is added to juices, drinks and some products such as butter, ghee and cheese (Britton *et al*., 1995).

2. **Torulene**

Characterized by its attractive colors, it has 13 double bonds and is Its use as an antioxidant is due tohaving this number of double bonds which made them more efficiency of β-carotene which contains in its composition fewer double bonds (Sakaki *et al*., 2002).

3. **Astaxanthin**

Red stain causes the appearance of attractive colors in marine invertebrates, fish and birds. As in carotene stain, it is a colored substance in salmon, trout and shrimp reddish pink (Jackson *et al*., 2008).

4. **Canthaxanthin**

It is an important keto-carotene stain, mainly used in the food and cosmetic industries (Hannibal *et al*., 2000).

Carotenoids are divided into two parts according to the presence of the oxygen element in their composition:

1. **Carotenes**:

Chromo lipids include oxygen-free compounds, as they are unsaturated hydrocarbons mainly soluble in non-polar solvents. It consists of eight isoprene units, these units are arranged in such a way that their arrangement is reflected in the center of the molecule. Most carotenoids contain 40 carbon atoms and some of them contain alcoholic or aldehyde groups. Carotenoids also consist of condensation of isoprene molecules with loss of hydrogen as a result of this condensation.

2. Xanthophylls

The compounds contain oxygen in the form of active groups, as they are similar to carotenoids in the composition of their carbon structure, and they are considered a keto derivative of carotenoids, and each compound of xanthophyls is often a compound of corresponding carotenoids (Britton *et al*., 2008).

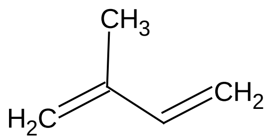
Carotene Stain

Carotene stain in red, yellow, pink, orange and red coral colors represent a group of natural antioxidant stains that are abundant in plants such as citrus, carrots, mangoes and apricots (Sun, 2018). It also produces various types of microorganisms such as bacteria *Corynebacterium michiganense*, *Micrococcu sroseus*, *Brevibacterium* spp., *Bradyrhizobium* spp., *Gordonia jacobaea*, and *Dietzia natronolimnaea* (Nasri-Nasravadi and Razavi, 2010) and And many algae like *Dunaliella*, *Dictyococcus*, and *Haematococcus*) Some types of filamentous fungi and a few fungi that belong to the class of Ascomycetes fungi as well as yeasts for example *Cryptococcus*, *haffia*, *Rhodosporidium*, *Rhodotorula*, and *Sporobolomyces* (Marova *et al*., 2012). Most of which are due to Basidiomycetes (Libkind *et al*., 2005).

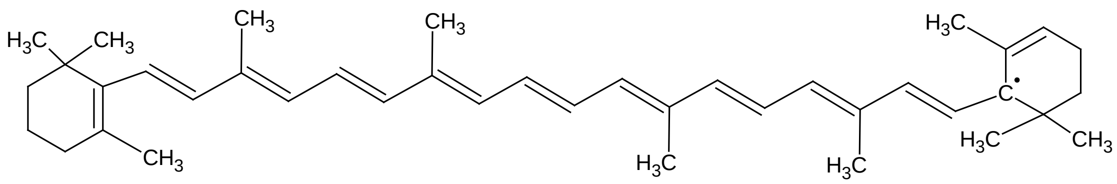
It was recently observed that the production of carotene from plants became limited due to the high costs of production compared to the percentage of returns, which led to the tendency of most research and studies to obtain carotene from microorganisms that became alternative sources for plants in view of the low cost of production and avoiding environmental pollution with waste from agricultural and industrial waste (Mata-Gómez *et al*., 2014), In addition, the carotene from these microorganisms avoids the problems caused by the seasonal and geographical changes facing its production of plants (Frengova and Beshkova, 2009). Yeasts are more suitable in carotene production than other microorganisms especially algae, since they are single-celled organisms, as well as their rapid growth rate (Ausich, 1997).

Types of Carotene and its Chemical Composition

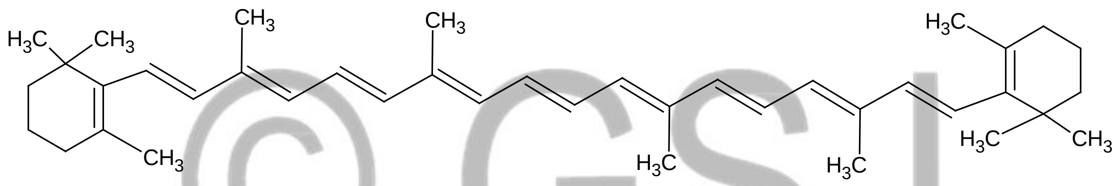
There are three types of carotene: alpha-carotene, beta-carotene, and kama-carotene. Figure (1) shows the chemical composition of the three types of carotene.



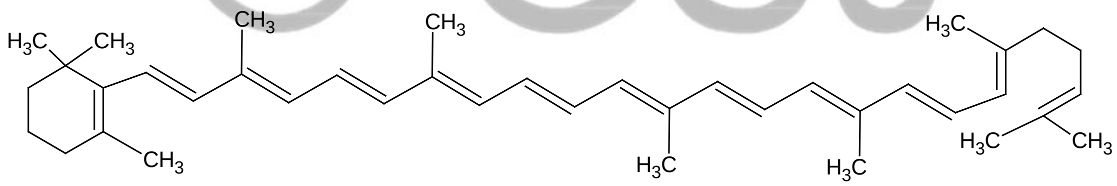
Isoprene Unit



α- Carotene



β-Carotene



ɣ- Carotene

Figure 1: The syntactic formula for the isoprene unit included in the synthesis of the various carotenoids and the three types of carotenoids (Erich and Annu, 2006).

Beta-carotene Biosynthesis in yeasts

The following diagram shows the steps for Biosynthesis beta-carotene in yeasts:

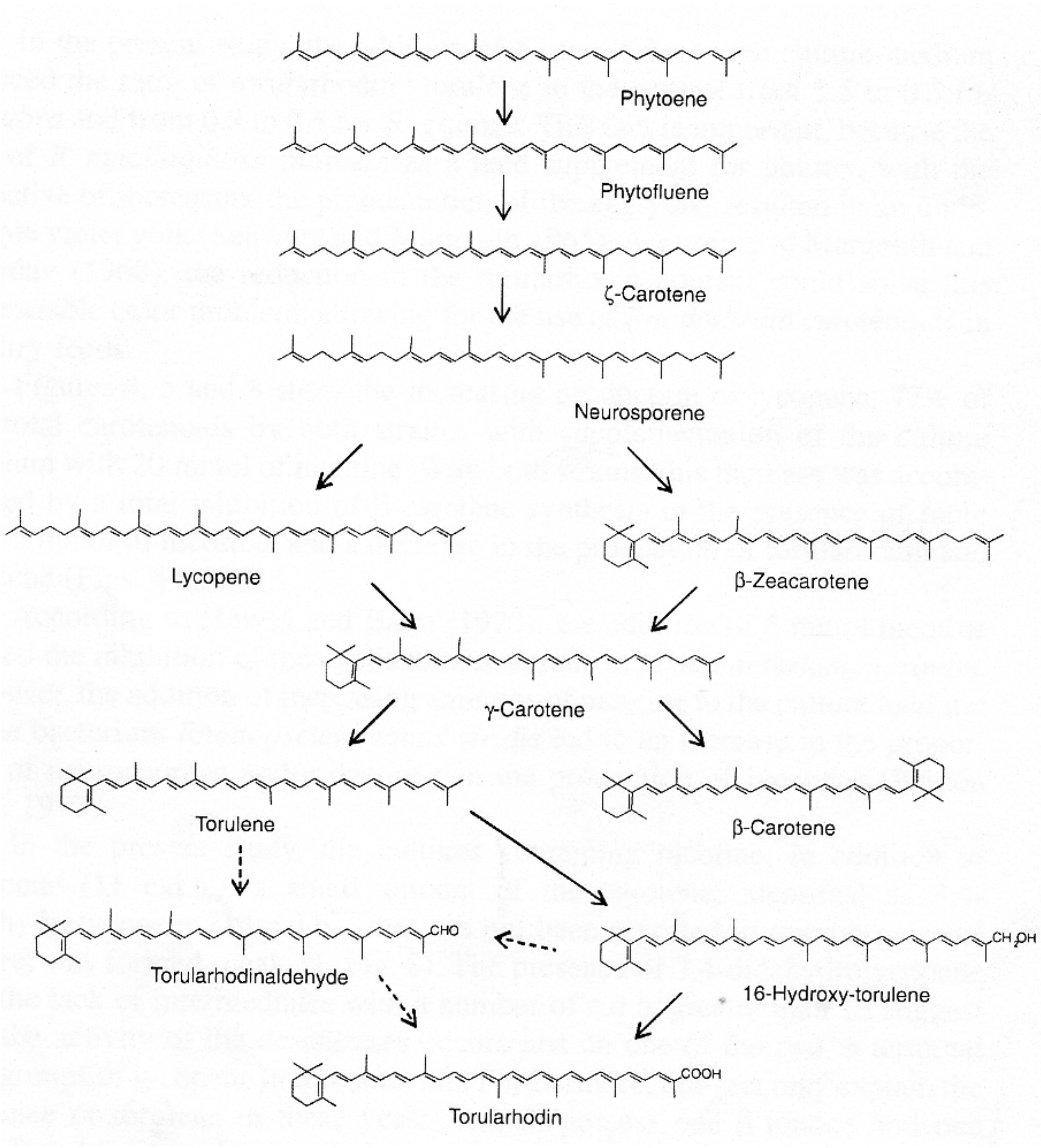


Figure 2: Beta-carotene biosynthesis steps (Hayman *et al*., 1974).

Yeasts sources of β-carotene

Many yeasts produce β-carotene and the following table shows the most important yeasts produced for β-carotene:

Table 1: Yeasts produced of β-carotene

Name of Yeats	**Source**
Candida utilis	Shimada *et al*., 1998
Phaffia rhodozyma	Stachowiak and Czarnecki, 2007
Rhodosporidium diobovatum	Nasirian *et al*., 2018
Rhodotorula acheniorum	Nasrabadi amd Razavi 2011
R. glutinis	Sinisa *et al*., 2013
R. gracilis	Somashekar and Joseph 2000
R. graminis	Maldonade *et al*., 2008
R. minuta	Malla Obaida, 2017
R. rubra	Chanchay *et al*., 2012
R. mucilaginosa	Malla Obaida *et al*., 2018
Saccharomyce cerevisiae	Verwaal *et al*., 2007
Sporidiobolus pararoseus	Borba *et al*., 2018
Sporobolomyces pararoseus T.	Fuchman, 1980
Sporo. roseus	Sinisa *et al*., 2013
Sporo. ruberrimus	Hadi *et al*., 2007
Sporo. shibatanus	Marova *et al*., 2012

β-Carotene - its Importance and Uses

β-Carotene is one of the most important and most common types of natural carotenoids made by plants and microorganisms, with about 70% of total carotene (Eldahshan and Singab, 2013). In recent years, interest in it has increased greatly, due to the abundance of evidence indicating its benefits and importance to human health (Bogacz-Radomska and Harasym, 2018). It is a source of vitamin A in the body as it is converted in the human intestine into vitamin A necessary to maintain vision as it is an anti-oxidant that protects the body from free radicals, and works to strengthen the immune system in the body and contribute to stimulating cell growth and differentiation (Terlecki *et al*, 2014) so It is given to those who suffer from a deficiency in the body in doses ranging from 0.4 - 20 mg daily (Coma, 1991). In a study by Giuseppe *et al*. (2007) it has been shown to help protect lymphocytes from the risk of free radicals, particularly the hydrogen peroxide (H2O2) and nitrogen oxide (NO2) that causes cell destruction and membranes.

Numerous studies have shown that it is a very effective antioxidant inhibitor against some plants oils such as corn oil, soybean oil, and sunflower oil and it is believed that it contributes to reducing the incidence of cancer that starts with the formation of Free Radicals as it reduces the incidence of lung cancer among smokers. Studies indicate its role in reducing the incidence of breast cancer, prostate, bladder, stomach, and colon (Perera and Yen, 2007) It has a preventive role against many degenerative diseases such as cardiovascular disease, atherosclerosis, allergies, asthma, rashes, kidney tumors, headache, and increased activity in children (Elvira-Torales *et al*., 2019) as well as its systemic functions in sustaining epithelial tissues, maintaining growth, and increasing reproductive efficiency (Niizu, 2003) Preventing cataracts and age-related macular degeneration (Saini and Keum, 2004) and protecting the skin from sunburn-induced burns as well as from damage caused by oxidation and UV exposure (Britton *et al*., 2008), as well as being used as a coloring material for food and beverages and giving them attractive color, flavor and taste as being a safe and harmless substance to human health rather than food dyes not authorized for food use (Machado *et al*., 2019). It is also used in the coloring of cosmetics (Das *et al*., 2007), and it is one of the additives for animals feed (Tang *et al.*, 2019).

β-Carotene extract From Yeasts

Carotenoids accumulate in certain parts of the cell, but its presence in the plasma membrane only or in the cell wall is not yet known. Moreover, the distribution of carotenoids and their derivatives in the cell parts has not been studied (Mata-Gómez *et al*., 2014). Many techniques were used to extract carotenoids from yeasts, but they encountered many difficulties and restrictions due to the characteristics of the cell wall, which constitutes an obstacle to the extraction processes, and this calls for improvement and development in the techniques used. Several types of technologies, including mechanical, chemical, and enzymatic methods were used to tear the cell walls and carotenoids were obtained from yeasts *Phaffia rhodozgma* and at high concentrations of 190.35μg/ g when applying the biomass freeze and enzymatic degradation technique, although many patents relating to the production of carotenoids were registered From microorganisms around the world. Among the most important techniques used to break down cell walls in yeasts and obtain carotene are soaking and freezing diatomaceous soils, treatment with Dimethyl Sulfoxide (DMSO), enzymatic degradation, ultrasonic waves

(Michelon *et al*., 2012), using glass beads (Aksu and Eren, 2007), Dry Freeze (Park *et al*., 2007), Soaking and Freezing with Liquid Nitrogen (Valduga *et al*., 2009), using a mixture of DMSO solvents, acetone, and petroleum ether (Taskin *et al*., 2011) or using acetone, and hydrochloric acid (Gu *et al*., 1997).

β-Carotene estimation using High Performance Liquid technology Chromatograph (HPLC)

Several methods have been used to analyze the mixture of β-Carotene compounds, including a highly sensitive and specific chromatographic technique in stabilizing the results including paper chromatography (Deb and Madhugiri, 2012), thin layer (Khaled *et al*., 2013) and gas-liquid chromatography (Buzzini *et al*., 2007).) And HPLC (Malla Obaida *et al*., 2016) and high-performance liquid chromatography - mass stratification (Sacchetti *et al*., 2005).

Several studies concerned with the appointment of beta-carotene using chromatographic technique were performed. Beta-carotene tincture was diagnosed in yeasts *R. rubra*, *Ph. rhodozyma*, *Rhodotorula* sp., *Sporobolomycas*, *Salmonicolor*, and *R. glutinis* using HPLC (Voaides and Dima, 2012). The β-Carotene content was 43.9 μg/ g in yeast *R. glutinis* from the total content of carotenoids while the other ingredients Torulene reached 23 μg/ g and Torularhodin 182μg/ g (Yehia *et al*., 2013). In *Sporolomy ruberrimus* Hllo, the separated orange stains were identified by means of highly efficient liquid chromatography (HPLC), as the extracted carotene stain contained (5) components: β- carotene, Toraularhodin, Apocarotenoid ester, Canthaxanthin, and Astaxanthin in quantities (250, 750, 200, 250, and 100) μg/ l, respectively (Hadi *et al*., 2006). Maldonade *et al*. (2007) were able to diagnose β – carotene and Torulene stains in a mixture of carotenoids obtained from yeasts *R. mucilaginosa* and *R. glutinis* based on HPLC technology. Kim *et al*. (2010) were able to separate the β- carotene stain from the orange carotenoids stains from yeast *Rhodosporidium* sp. Buzzini *et al*. (2007) found that carotenoids extracted from yeasts *Sporobolomy*, *Sporidioblus*, *Rhodotorula*, and *Rhodosporidium*, whose quantities ranged between 16.4-184 μg/ gm contain (4) constituents of torularhohodin, torulene, α -carotene, and β-carotene.

References

Aksu, Z. and Eren, A.T. (2007). Production of carotenoids by isolated yeast of *Rhodotorula glutinis*. Biochem. Eng. J., 35:107–113.

Al-Mannai, W. B. (2008). Extraction of carotenoids and their use in food coloring. M.Sc. Thesis, Food Industries, University of King Abdulaziz, Jeddah, Saudi Arabia.

Ausich, R. L. (1997). Commercial opportunities for carotenoid production by biotechnology, Pure. Appl. Chem., 69: 2169-2173. Biocatalysis and Agricultural Biotechnology, 3: 207–213.

Bogacz-Radomska, L., and Harasym, J. (2018). β-Carotene—properties and production methods. Food Quality and Safety, 2(2): 69-74.

Borba, C. M.; Tavares, M. N.; Moraes, C. C. and Burkert, J. F. M. (2018). Carotenoid production by *Sporidiobolus pararoseus* in agroindustrial medium: optimization of culture conditions in shake flasks and scale-up in a stirred tank fermenter. Braz. J. Chem. Eng., 35(2): 1678-4383.

Britton, G.; Liaaen-Jensen, S. and Pfander, H. (1995). Carotenoids, Volume 1a. Stuttgart, Germany: Birkhaüser Verlag Basel; Isolation and analysis.

Britton, G.; Liaaen-Jensen, S. and Pfander, H. (2008). Carotenoids, Volume 4: Natural Functions. Basel – Boston - Berlin: Birkhäuser Verlag. 370 p. ISBN978-3-7643-7498-3.

Buzzini, P.; Innocenti, M.; Van Broock, M. and Mulinacc, N. (2007). Carotenoid profiles of yeasts belonging to the genera *Rhodotorula*, *Rhodosporidium*, *Sporobolomyces*, and *Sporidiobolus*. Canadian Journal of Microbiology, 53(8): 1024-1031.

Chanchay, N., Sirisansaneeyakul, S., Chaiyasut, C. and Poosaran, N. (2012). Optimal conditions for carotenoid production and antioxidatoon characteristics by *Rhodotorula rubra*. World Academy of Science, Engineering and Technology, 6: 1645–1649.

Coma, A. (1991). Dietary refrence values for food energy and Nutrients for the United Kingdom. Report of The Panel on Dietary Refrance Values, Committee on Medical Aspects of Food and Nutrition Policy. HMSO, London.

Das, A.; Yoon, S.H.; Lee, S.H.; Kim, J.Y.; Oh, D.K. and Kim, S.W. (2007). An update on microbial carotenoids production: Application of recent metabolic engineering tools. Appl. Microbiol. Biot., 77:505-12.

Deb, P. and Madhugiri, M. J. (2012). Optimization of apple- pomace based medium for pigment production by Micrococcus flavu. An International Quarterly Journal of Life Sciences, 7(1): 57-60.

Eldahshan, O.A. and Singab, A.N. B. (2013). Journal of phharmacognsy and phytochemistry carotenoids. IC. Journal No: 8192. 2(1): 225-234.

Elvira-Torales, L. I.; García-Alonso, J. and Periago-Castón, M. J. (2019). Nutritional importance of carotenoids and their effect on liver health: A review. Antioxidants, 8(7): 229.

Erich, G. and Annu, R. E. V. (2006). The genetics and biochemistry of flora pigments. Plant Biol., 57:761-80.

Frengova, G. I. and Beshkova, D. M. (2009). Carotenoids from *Rhodotorula* and *Phaffia*: yeasts of biotechnological importance, J. Ind. Microbiol. Biotechnol., 36, 163–180. Archiva Zootechnica 14:3, 75-83, 2011 83.

Fuchman, C. (1980). *Peat: Industrial Chemistry and Technology*. Academic Press, London, 130.

Giuseppe, S.; Alfonso, D.G.; Giuseppina, T.; Caterina, L.P.; Annarita, P.; Barbara, N.; Rocco, D.P. and Carmela, S. (2007). Antioxidative activity of lycopene and β-carotene contents in different cultivars of tomato (*Lycopersicon esculentum*). Int. J. Food Prop. 10: 321-329.

Gu, W. L.; An, G. H. and Johnson, E. A. (1997). Ethanol increases carotenoid production in *Phaffia rhodozyma*. J. Ind. Microbiol. Biotechnol., 19:114–117.

Hadi, R. S.; Fabrice, B. and Ivan, M. (2006). UV-HPLC/ APCI-MS method for separation and identification of the carotenoids produced by *Sporobolomyces ruberrimus* H 110. Iran. J. Chem. Eng., 25(2): 1-10.

Hadi, R. S.; Mousavi, S. M.; Yeganeh, H and M., Ivan, M. (2007). Fatty acid and carotenoids production by *Sporobolomyces ruberrimus* when using technical glycerol and ammonium sulfate. Journal of Microbiology and Biotechnology, 17: 1591–1597.

Hannibal, L.; Lorquin, J. D.; Ortoli, N.A.; García, N.; Chaintreuil, C.; Masson-Boivin, C.; Dreyfus, B. and Giraud, E. (2000). Isolation and characterization of canthaxanthin biosynthesis genes from the photosynthetic bacterium *Bradyrhizobium* sp. strain ORS 278. J. Bacteriol., 182: 3850-3853.

Haronikova, A. (2012). Use of several waste substrates for carotenoidrichyeast biomass production. Journal of Environmental Management. Environmental Risks and Problems, Strategies to reduce them through Biotechnology and Engineering, 95, Supplement: 338–342.

Hayman, E. P.; Yokoyama, H.; Chichester, C. and Simpson, K. L. (1974). Carotenoid biosynthesis in *Rhodotorula glutinis*. J. Bacteriol., 120: 1339-1343.

Jackson, H.; Braun, C.L. and Hansgeorg, E. (2008). The chemistry of novel xanthophyll carotenoids. Am. J. Card. 101(10A). 50D-57D.

Khaled, H. Y.; Uqla, B. A. and Mohamed, O. (2013). Biologically active compounds and antioxidant activity in the main orange varieties in Syria. Damascus Journal of Agricultural Sciences, 29 (1): 153-164.

Kim, J. K.; Kim, J. I.; Lee, N. K.; Hahm, Y.T.; Baik, M.Y. and Kim, B.Y. (2010). Extraction of β-carotene produced from yeast *Rhodosporidium* sp. and its heat stability. Food Sci. Biotechnol., 19(1): 263-266.

Libkind, D.; Sommaruga, R.; Zagarese, H. and Van Broock, M. (2005). Mycosporines in carotenogenic yeasts. Systematic and Applied Microbiology, 28(8): 749-754.

Machado, W. R. M., Silva, L. G., Vanzela, E. S. L. and Del Bianchi, V. L. (2019). Production of carotenoids by *Rhodotorula toruloides* isolated from Brazilian tropical savannah. International Food Research Journal, 26(4):1259-1267.

Maldonade, I. R.; Rodriguez-Amaya, D. B. and Scamparini, A. R. P. (2008). Carotenoids of yeasts isolated from the Brasilian ecosystem. Food Chemistry, 107: 145–150.

Maldonade, I.R.; Scamparini, A.R.P. and Rodriguez-Amaya, D.B. (2007). Selection and characterization of carotenoid-producing yeasts from campinas region, Brazil-Brazillian Journal of Microbiolgy, 38: 65-70.

Malla Obaida, B. A. J. ; Al-Zubaidi, R. Q. J. and Al-Haj Alawi, R. H. (2016). Extraction and estimation of β-carotene pigment from some species of the genus *Rhodotorula* and study the ability to increas their production by mutagenesis Ibn Al-Haitham J. for Pure & Appl. Sci. 29(1):320-335.

Malla Obaida, B. A.J. (2017). Isolation and Identification and Study of Some *Rhodotorula* Species from Genetic and Molecular Aspects and Their Efficiency in β-Carotene Production. ph.D. thesis, College of Education for Pure Sciences, University of Mosul.

Malla-Obaida, B.A. ; Sultan, R. H. and Jirjees, R. Q. (2018). Detection of Positions of Genes of β-Carotene Production by*R. mucilaginosa* BA61. Rafidain Journal of science. The third scientific Conference for biological science, 27(5): 42-52.

Marova, I.; Carnecka, M.; Halienova, A.; Certik, M.; Dvorakova, T. and Haronikova, A. (2012). Use of several waste substrates for carotenoid- rich yeast biomass production. J. of Environ. Manag., 95: 338-342.

Marova, I.; Carnecka, M.; Halienova, A.; Certik, M.; Dvorakova, T. and

Mata-Gómez, L. C.; Montañez, J.C.; Méndez-Zavala, A. and Aguilar, C.N. (2014). Biotechnological production of carotenoids by yeasts: an overview. Microbial. Cell Factaries, 13(12): 1475-2859.

Mata-Gómez, L. C.; Montañez, J.C.; Méndez-Zavala, A. and Aguilar, C.N. (2014). Biotechnological production of carotenoids by yeasts: an overview. Microbial. Cell Factaries, 13(12): 1475-2859.

Michelon, M.; De Borba, T.D.M.; Rafael, R.D.S.; Burkert, C.A.V. and Burkert, J.F.D.M. (2012). Extraction of carorenoids from *phaffia* *rhodozyma*: A comparison between different techniques of cell disruption. Ood Science and Biotechnology, 21(1): 1-8.

Nasirian, N., Mirzaie, M., Cicek, N. and Levin, D. B. (2018). Lipid and carotenoid synthesis by *Rhodosporidium diobovatum*, grown on glucose versus glycerol, and its biodiesel properties. Canadian Journal of Microbiology, 64: 277–289.

Nasri-Nasravadi, M.R. and Razavi, S. H. (2010). Use of response surface methodology in a fed-batch process optimization of tricarboxylic acid cycle intermediates to achieve high levels of canthaxanthin from Dietzia natronolimnaea HS-1. J. Biosci. Bioeng., 109(4):361–368.

Niizu, P.Y. (2003). Fontes de carotenóides importantes para saúde human Dissertação. UNICAMP, Faculdade de Engenharia de Alimentos, Ciência dos Alimentos. (PhD. thesis).

Park, P.; Kim, E. and Chu, K. (2007). Chemical disruption of yeast cells for the isolation of carotenoid pigments. Sep. Purif. Tech., 53:148–152.

Perera, C.O. and Yen, G.M. (2007). Functional properties of carotenoids in human health. Int. J. Food Prop. 10: 201-230.

Perez-Fons, L.; Steiger, S.; Khaneja, R.; Bramley, P.M.; Cutting, S. M. and Sandmann, G. (2011). Identification and the developmental formation of carotenoid pigments in the yellow/orange Bacillus spore-formers. Biochim. Biophys. Acta., 1811(3): 177-85.

Rodriguez-Amaya, D.B. (2001). A guide to carotenoids analysis in foods. Washington DC: ILSI Press.

Sacchetti, G.; Maietti, S.; Muzzoli, M.; Scaglianti, M.; Manfredini, S.; Radice, M. and Bruni, R. (2005). Comparative evaluation of 11 essential oils of different origin as functional antioxidants, antiradicals and antimicrobials in foods. Food Chemistry, 91:621-632.

Saini, R. K., and Keum, Y. S. (2018). Carotenoid extraction methods: A review of recent developments. Food Chemistry, 240, 90-103.

Sakaki, H.; Nochide, H.; Komemushi, S. and Miki, W. (2002). Effect of active oxygen species on the productivity of torularhodin by *Rhodotorula glutinis*. J. Biosc. Bioeng., 93(Suppl 21): 338–340.

Shimada, H.; Kondo, K.; Fraser, P. D.; Miura, Y.; Saito, T. and Misawa, N. (1998). Increased carotenoid production by the food yeast *candida utilis* through metabolic engineering of the isoprenoid pathway. Applied and Environmental Microbiology, 64: 2676–2680.

Sinisa, P., Marova, I., Haronikova, A., Kostovova, I. and Breierova, E. (2013). Production of biomass, carotenoids and other metabolites by several red yeast strains cultivated on waste glycerol from biofuel production – a comparative screening study. Annual Microbiology, 63: 1537–155.

Somashekar, D. and Joseph, R. (2000). Inverse relationship between carotenoid and lipid formation in *Rhodotorula gracilis* according to the C/N ratio of the growth medium. World Journal of Microbiology Biotechnology, 16: 491–493.

Stachowiak, B .and Czarnecki, Z. (2007). Effect of light on carotenoids yield in fed cultures of *Phaffia rhodozyma* CBS 5626. Polish Journal of Food and Nutrition Sciences, 57: 129–131.

Sun, T., Yuan, H., Cao, H., Yazdani, M., Tadmor, Y. and Li, L. (2018). Carotenoid metabolism in plants: the role of plastids. Molecular plant, 11(1): 58-74.

Tang, W.; Wang, Y.; Zhang, J.; Cai,Y. and He, Z. (2019).Biosynthetic Pathway of Carotenoids in *Rhodotorula* and Strategies for Enhanced Their Production. J. Microbiol. Biotechnol., 29(4): 507–517.

Taskin, M.; Sisman, T.; Erdal, S. and Basaran, E.K. (2011). Use of waste chicken feathers as peptone for production of carotenoids in submerged culture of *Rhodotorula glutinis* MT-5. Eur Food Res Technol., 233: 657–665.

Terlecki, K.; Cheil, P.; Sobstyl, J.; Sobstyl, P.; Kotula, L. and Kocki, J. (2014). Genetically engineered rice. the source of β-caroten. Modren Phytomorphology, 6: 115.

Valduga, E., et al. (2014). Valduga, E.; Tatsch, P.; Vanzo, L.; Rauber, F.; Di Luccio, M. and Treichel, H. (2009). Assessment of hydrolysis of cheese whey and use of hydrolysate for bioproduction of carotenoids by Sporidiobolus salmonicolor CBS 2636. J. Sci. Food Agric., 89:1060–1065.

Verwaal, R.; Wang, J.; Meijnen, J. P.; Visser, H.; Sandmann, G.; Berg, J. A. and Ooyen, A. J. J. (2007). High-level production of Beta-Carotene in *Saccharomyces cerevisiae* by successive transformation with Carotenogenic Genes from *Xanthophyllomyces dendrorhous*. Applied Environmental Microbiology, 73: 4342–4350.

Voaides, C. and Dima, R. (2012). The effect of nitrogen source on carotenoids production by *Rhodotorula* sp. Romanin Biotechnological Letters, 17 (5): 7570-7576.

Yehia, H.M.;Al-Olayan, E.M.; Elkhadragy, M.F.; Khalaf-Allah, A. E.M. and El-Shimi, N.M. (2013).Improvement of carotenoid pigments produced by *Rhodotorula glutinis*. Life Science Journal, 10(4): 386-400.