

Fucoxanthin, A Xanthophyll from Macro- and Microalgae: Extraction Techniques, Bioactivities and Their Potential Application in Nutra- and Cosmeceutical Industries

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Abstract. Some works of literature reported that fucoxanthin has diverse potential benefits for human health. Thus, this review would explain the sources of fucoxanthin, extraction techniques, bioactivities, and its potential application in Nutra- and cosmeceutical industries. Brown algae, such as *Padina australis*, *Undaria pinnatifida*; and the microalgae, such as *Chaetoceros gracilis*, *Phaeodactylum tricorutum* were sources of fucoxanthin. Then, the chemical structure of this xanthophyll is unique and that confers its biological activities. And then, the extraction process of fucoxanthin from macro- and microalgae is more safe, accessible, and economic, although this xanthophyll can be synthesized chemically. Generally, there are two techniques for the extraction of fucoxanthin, namely liquid solvent (conventional), and supercritical carbon dioxide (non-conventional) extractions. Furthermore, there are some bioactivities of fucoxanthin, including its activities of anticancer, antidiabetic, antiobesity, antioxidant; protective effects of skin, bone, and eyes. Based on *in vivo* assay of the animal, it has no adverse effects of fucoxanthin supplementation. Therefore, this xanthophyll might be applied in both the Nutra- and cosmeceutical industries. In the future, fucoxanthin and its derivatives would be important for human health, contributing to the beauty industry, and playing an important in the prevention of cancer and the disease related to lifestyle.

1 Introduction

About 800 kinds of xanthophylls have been reported in nature up until 2018 [1]. This class of carotenoid, especially fucoxanthin is abundant in macro- and microalgae as a photoprotection component, and the complex of light-harvesting for the photosynthesis process [2]. The fucoxanthin chemical structure contains a 5,6-monoepoxide and an allenic

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bond [3] (Fig. 1). Its chemical structure is unique and that confers its biological activities. And then, some kinds of literature reported that fucoxanthin has diverse potential benefits for human health [4]. So, this review would explain the sources of fucoxanthin, its extraction techniques, bioactivities, and its potential application in both the Nutra- and cosmeceutical industries.

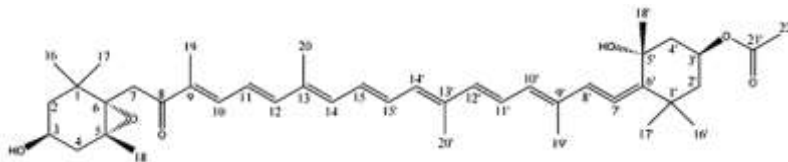


Fig. 1. The fucoxanthin chemical structure

2 Sources of Fucoxanthin

Fucoxanthin is found in macroalgae, especially brown algae, and microalgae, or a number of diatoms [5-7]. This compound is a major xanthophyll carotenoid in the chloroplast of brown algae [8], namely *Padina australis* [9], *Sargassum horneri* [10], *Undaria pinnatifida* [11], *Laminaria japonica* [12]; in microalgae or diatoms [13] such as *Phaeodactylum tricornutum* [14], *Chaetoceros gracilis* [15], *Isochrysis galbana* [16]; and a small amount in red seaweed, such as *Chondria crassicaulis*, *Mazzaella japonica*, and *Gloiopeltis furcate* [17]. The content of fucoxanthin in brown algae is about 0.1-1.0 mg/g (0.01-0.10 %) of the dry cell weight [18], while in diatoms is about 1.00-2.50% of the dry cell weight [19, 20]. The sources data of fucoxanthin from macro and microalga (from years 2018 to 2020) are shown in Table 1.

Table 1. The sources of fucoxanthin from macro and macroalga (from 2018 to 2020).

Year	Source	Species	Country	References
2018	BS	<i>Alaria esculenta</i>	Ireland	[21]
		<i>Ascophyllum nodosum</i>	Ireland	[21]
		<i>Colpomenia sinuosa</i>	Iran	[22]
		<i>Dictyota indica</i>	Iran	[22]
		<i>Fucus serratus</i>	Ireland	[21]
		<i>Fucus vesiculosus</i>	Ireland	[21]
		<i>Himanthalia elongata</i>	Ireland	[21]
		<i>Iyengaria stellate</i>	Iran	[22]
		<i>Laminaria hyperborea</i>	Ireland	[21]
		<i>Laminaria digitata</i>	Ireland	[21]
		<i>Laminaria japonica</i>	China	[23]
		<i>Laminaria japonica</i>	Korea	[12]
		<i>Laminaria japonica</i>	Taiwan	[24]
		<i>Padina australis</i>	Indonesia	[25]
		<i>Padina tenuis</i>	Iran	[22]
		<i>Padina tetrastrumatica</i>	India	[26]
		<i>Pelvetia canaliculata</i>	Ireland	[21]
		<i>Saccharina japonica</i>	Korea	[27]
		<i>Saccharina japonica</i>	Korea	[29]
		<i>Saccharina latissima</i>	Ireland	[21]
<i>Saccorhiza polyschides</i>	Ireland	[21]		
<i>Sargassum polycystum</i>	Malaysia	[29]		
<i>Sargassum siliquosum</i>	Malaysia	[29]		
<i>Sphaerotrichia divaricata</i>	Japan	[30]		

		<i>Turbinaria deccurrens</i>	Indonesia	[31]
		<i>Undaria pinnatifida</i>	China	[32]
		<i>Undaria pinnatifida</i>	China	[33]
		<i>Undaria pinnatifida</i>	China	[34]
		<i>Undaria pinnatifida</i>	Japan	[35]
	MA/D	<i>Chaetoceros calcitrans</i>	Malaysia	[36]
		<i>Cylindrotheca fusiformis</i>	China	[37]
		<i>Isochrysis galbana</i>	Italy	[38]
		<i>Nanofrustulum shiloi</i>	Turkey	[39]
		<i>Nitzschia</i> sp	Turkey	[39]
		<i>Nitzschia laevis</i>	USA	[40]
		<i>Nitzschia laevis</i>	USA	[41]
		<i>Odontella aurita</i>	Denmark	[42]
		<i>Phaeodactylum tricornutum</i>	Australia	[43]
		<i>Phaeodactylum tricornutum</i>	China	[6]
		<i>Phaeodactylum tricornutum</i>	China	[44]
		<i>Phaeodactylum tricornutum</i>	Czech Republic	[45]
		<i>Phaeodactylum tricornutum</i>	Iceland	[46]
		<i>Phaeodactylum tricornutum</i>	Italy	[38]
		<i>Phaeodactylum tricornutum</i>	France	[47]
<i>Phaeodactylum tricornutum</i>	Germany	[48]		
<i>Phaeodactylum tricornutum</i>	Korea	[49]		
<i>Phaeodactylum tricornutum</i>	Netherland	[50]		
<i>Phaeodactylum tricornutum</i>	Scotland	[46]		
<i>Phaeodactylum tricornutum</i>	USA	[37]		
2019	<i>Tisochrysis lutea</i>	Italy	[51]	
	<i>Achnanthisdium</i> sp.	Korea	[52]	
	<i>Amphora</i> sp	Australia	[53]	
	<i>Conticribra weissflogii</i>	China	[54]	
	<i>Dunaliella salina</i>	India	[55]	
	<i>Isochrysis galbana</i>	Chile	[56]	
	<i>Isochrysis galbana</i>	India	[55]	
	<i>Isochrysis galbana</i>	Portugal	[16]	
	<i>Navicula</i> sp	India	[55]	
	<i>Nitzschia</i> sp	China	[57]	
	<i>Nitzschia laevis</i>	China	[58]	
	<i>Nitzschia laevis</i>	China	[59]	
	<i>Nitzschia laevis</i>	USA	[60]	
	<i>Pavlova lutheri</i>	India	[55]	
	<i>Phaeodactylum tricornutum</i>	China	[61,62]	
	<i>Phaeodactylum tricornutum</i>	China	[63,65]	
	<i>Phaeodactylum tricornutum</i>	Germany	[64]	
	<i>Phaeodactylum tricornutum</i>	Germany	[65]	
	<i>Phaeodactylum tricornutum</i>	Japan	[66]	
	<i>Phaeodactylum tricornutum</i>	Korea	[67]	
<i>Phaeodactylum tricornutum</i>	Korea	[68]		
<i>Skeletonema costatum</i>	Indonesia	[69]		
<i>Tisochrysis lutea</i>	Iran	[70]		
BS	<i>Cystosphaera jacquinotii</i>	Brazil	[71]	
RS	<i>Chondria crassicaulis</i>	Japan	[72]	
	<i>Chondrus yendoii</i>	Japan	[72]	
BS	<i>Costaria costata</i>	Japan	[72]	
	<i>Desmarestia anceps</i>	Brazil	[71]	
	<i>Eisenia bicyclis</i>	Korea	[73]	

	RS	<i>Gloiopeltis furcata</i>	Japan	[72]	
	BS	<i>Laminaria japonica</i>	Taiwan	[74]	
		<i>Laminaria japonica</i>	Japan	[75]	
	RS	<i>Mazzaella japonica</i>	Japan	[72]	
	BS	<i>Saccharina japonica</i>	Japan	[72]	
		<i>Saccharina japonica</i>	Korea	[76]	
		<i>Sargassum aquifolium</i>	Japan	[72]	
		<i>Sargassum fusiforme</i>	Japan	[72]	
		<i>Sargassum horneri</i>	Japan	[72]	
		<i>Undaria pinnatifida</i>	Japan	[72]	
		<i>Undaria pinnatifida</i>	Korea	[73]	
		<i>Undaria pinnatifida</i>	Japan	[77]	
		<i>Undaria pinnatifida</i>	China	[78]	
<i>Undaria pinnatifida</i>		China	[58]		
	<i>Undaria pinnatifida</i>	Japan	[79]		
2020	MA/D	<i>Chaetoceros calcitrans</i>	Malaysia	[80]	
		<i>Chaetoceros gracilis</i>	Japan	[81]	
		<i>Chaetoceros gracilis</i>	Japan	[15]	
		<i>Chaetoceros gracilis</i>	Japan	[14]	
		<i>Halamphora coffeaeformis</i>	Argentina	[82]	
		<i>Nitzschia palea</i>	Bergium	[83]	
		<i>Phaeodactylum tricornutum</i>	China	[84]	
		<i>Phaeodactylum tricornutum</i>	Japan	[85]	
		<i>Phaeodactylum tricornutum</i>	Japan	[14]	
		<i>Phaeodactylum tricornutum</i>	Korea	[86]	
		<i>Phaeodactylum tricornutum</i>	USA	[87]	
		<i>Sellaphora minima</i>	Belgium	[83]	
		<i>Thalassiosira weissflogii</i>	India	[88]	
		<i>Tisochrysis lutea</i>	France	[89]	
		<i>Tisochrysis lutea</i>	Netherlands	[90]	
		<i>Tisochrysis lutea</i>	Portugal	[91]	
		BS	<i>Desmarestia anceps</i>	Brazil	[92]
			<i>Himantalia elongata</i>	Spain	[11]
	<i>Laminaria ochroleuca</i>		Spain	[11]	
	<i>Padina australis</i>		Indonesia	[9]	
	<i>Sargassum angustifolium</i>		Iran	[93]	
	<i>Sargassum glaucescens</i>		Canada	[94]	
	<i>Sargassum horneri</i>		Japan	[95]	
	<i>Sargassum polycystum</i>		Indonesia	[96]	
	<i>Sargassum wightii</i>		India	[97]	
		<i>Undaria pinnatifida</i>	Spain	[11]	
	<i>Alaria esculenta</i>	Ireland	[21]		

Note: BS: Brown seaweed; RS: Red Seaweed; MA/D: Microalga/Diatom

3 Fucoxanthin Extraction

Generally, there are two main techniques to extract fucoxanthin, namely liquid solvent extraction (conventional), and supercritical carbon dioxide (SC-CO₂), usually use CO₂ as a co-solvent (nonconventional) [98-100]. In the liquid solvent extraction with organic solvents, the recovery of solvent is a crucial period, mainly because of the environmental and economic problems. This technique has disadvantages, such as there are remind residue of solvent in the extract, the possible thermal degradation of the extract, and has low selectivity [101]. Additionally, the disadvantage of the liquid solvent extraction needed

many solvents in its technique. However, the extraction technique with liquid organic solvents is the most effective in the extraction of carotenoids [102]. In contrast, the extraction with SC-CO₂ has an advantage, mainly due to the environment. This extraction technique is a process free of waste, prevents oxidation reactions, allow low-temperature use, does not cause thermal degradation of extract, and do not need the removal of solvent [103-105]. Additionally, this extraction technique has an advantage, mainly due to the economy, namely only needed a small amount of organic solvent, and needed a short time to the extraction process [106].

4 Fucoxanthin and Their Biological Activities

Fucoxanthin is a xanthophyll exhibiting several health benefits. This compound has remarkable biological properties for human health [109], such as anti-inflammatory activity [108-115], hepatoprotective effect [12,98,116-118], cardioprotective activity [119-121], anticancer [26,116,119,122-131], antidiabetic [75,132-134], antiobesity [135-139], antioxidant [65,131,140-146], skin protective effect [111,113,147-153], neuroprotective activity [75,155-161], osteoprotective effect [162,163], and eyes protective effect [164-166]. The biological activities of fucoxanthin for human health are shown in Fig. 2.



Fig. 2. The biological activities of fucoxanthin for human health

5 Dietary and Safety

There are two derivatives of fucoxanthin in the metabolism of mammals, namely fucoxanthinol and amarouciaxanthin A. In the digestive tract of mammals, the dietary fucoxanthin is hydrolyzed into fucoxanthinol. Then, in the liver, fucoxanthinol is dehydrogenated to amarouciaxanthin A. [167] (Fig. 3). Maeda [168] and Zhang *et al.*, [169] reported that the fucoxanthin in common toxicity assay is a safe component as a food of functional, and safe pharmaceutical ingredient. Based on *in vivo* assay of the animal, it has no adverse effects of fucoxanthin supplementation. Additionally, macro brown algae, such *Undaria pinnatifida* (Wakame) that contain much fucoxanthin has been consumed as edible algae for centuries in Eastern Asian countries [168].

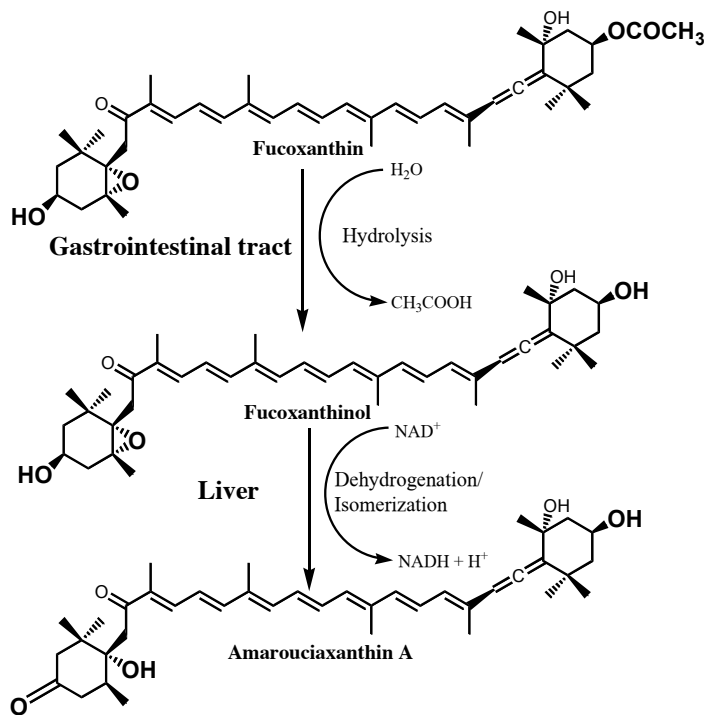


Fig. 3. Two derivatives of the fucoxanthin metabolism in mammals

6 Potential Application of Fucoxanthin in Nutra- and Cosmeceutical Industry

Fucoxanthin reported exhibit an array of beneficial biological activities on human health [169] including antidiabetic, antiobesity, antioxidant, anti-inflammatory, hepatoprotective, neuroprotective, osteoprotective, and eyes protective effect. Then, Muradian et al., [170] reported that fucoxanthin and its derivatives consumption as food supplements are good options for the treatment of metabolic syndrome and the prevention of obesity, diabetes type 2, and disease of the heart.

Furthermore, fucoxanthin exerts strong anti-inflammatory and antioxidant effects. This compound can be applied as photoprotection of skin to inhibit the negative effects of UV radiation, or as an ingredient of Nutra- and cosmeceutical to prevent the diseases of oxidative stress [171,172]. Hence, fucoxanthin has great potential for application in Nutra- [173], and cosmeceutical industries [174]. Galasso et al. [175] reported that there are main industrially produced fucoxanthin as a Nutra-, and cosmeceutical application, namely both of the industries were in China, such as Leili Natural Products Co., Ltd and AlgaNova International. In the future, fucoxanthin and its derivatives would be important for human health, contributing to the beauty industry, and playing an important in the prevention of cancer and the disease related to lifestyle.

7 Conclusion

Fucoxanthin is found in macroalgae, especially brown algae, and microalgae, or a number of diatoms. The chemical structure of this xanthophyll is unique and that confers its biological activities. Then, based on their bioactivities, fucoxanthin has a wide range of potential applications and might be applied in both the Nutra- and cosmeceutical industries.

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