LIST OF PUBLICATIONS ARISED FROM THE WORK

- ***Research Articles***
    - **Tiwari, S.,** Upadhyay, N., Singh, A. K., Meena, G. S., & Arora, S. (2019). Organic solvent-free extraction of carotenoids from carrot bio-waste and its physico-chemical properties in *Journal of food science and technology*, *56*(10), 4678-4687. **Impact factor: 3.11**
    - **Tiwari, S.,** Upadhyay, N., & Malhotra, R. (2021). Three way ANOVA for emulsion of carotenoids extracted in flaxseed oil from carrot bio-waste in *Waste Management*, *121*, 67- 76" **Impact factor: 8.10**
    - **Tiwari, S.**, Upadhyay, N., & Singh, A. K. (2022). Stability assessment of emulsion of carotenoids extracted from carrot bio-waste in flaxseed oil and its application in food model system. *Food Bioscience*, *47*, 101631. **Impact factor: 5.2**
- ***Review Article***
    - **Tiwari, S**., Yawale, P., & Upadhyay, N. (2022). Carotenoids extraction strategies and potential applications for valorization of under-utilized waste biomass. *Food Bioscience*, 101812. **Impact factor: 5.2**
- ***Technical Articles***
    - Upadhyay N, **Tiwari S**, Baria B, Singh A.K (2016). Natural Colorants: Opportunities as Alternative Colorants for Dairy and Food Industry during CAFT Organized at NDRI, Karnal 16^{th} Sep-6^{th} Oct, 2015. Pg, 95-102.

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ORIGINAL ARTICLE

Organic solvent-free extraction of carotenoids from carrot bio-waste and its physico-chemical properties

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Abstract The bio-wastes (like peels, seeds, etc.) from food industry are rich source of bio-active components, but are poorly managed. In present study, carotenoids were extracted from carrot pomace using ultrasonication and high shear dispersion techniques and flaxseed oil as green solvent (green biorefinery approach). Various combinations of time and temperature were used and final selection was made on the basis of maximum recovery of carotenoids. High shear disperser yielded maximum carotenoids (recovery 94.8 ± 0.08%). The total carotenoid content, antioxidant activity as ABTS, DDPH and FRAP and β-carotene of carotenoid rich extract from carrot pomace (CREP) were 82.66 ± 0.06 μg/g, 1596.04 ± 69.45 μg Trolox eq./ml, 380.21 ± 39.62 μg Trolox eq./ml, 941.20 ± 19.91 μM Trolox eq./ml, 78.37 μg/g, respectively were significantly higher ($p < 0.05$) when compared with the extracting medium. The L*, a* and b* values of CRE were 18.65 ± 0.037, 19.42 ± 0.21, 27.947 ± 0.65 and were significantly higher than extracting medium. The CRE could be used as a natural source of β-carotene and natural colorant for food applications.

Keywords Extraction · Carrot pomace · Flaxseed oil · SEM · β-Carotene · HPLC

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Introduction

Fruits and vegetables are the richest source of bioactive components and accessory factors such as carotenoids and other phytonutrients, especially, their peels and other solid residues. However, such waste is usually discarded for example, peels of pomegranate, black grapes, tomato, orange etc. Carotenoids (C40), lipophilic isoprenoid molecules, are one of the largest groups of pigments (ranging from yellow to orange to red) that are accumulated in higher levels in the organs and tissues of all photosynthetic plants synthesizing them. The characteristic colour of carotenoids is due to the presence of polyene chain with the number of double bonds that function as chromophores (Klein and Rodriguez-Concepcion 2015). The biosynthesis and accumulation of high levels of carotenoids has a great importance in plant as well as in human health. They act as precursor of Vitamin A, besides possessing the ability of quenching singlet oxygen (good antioxidant properties), and thus have been proposed to be very good chemo preventive agents and lower the risk of cancer (Boeing et al. 2012).

Carrot, an important root vegetable, is a major source of carotene. At cellular level, carotenoids are found in the chromoplasts of fresh carrot. During carrot juice processing, 50% of the raw material remains as pomace and is either used as feed or manure or is disposed off. However, it is a good source of carotenoids and dietary fiber and thus, can potentially be introduced into food chain. But, the problem lies with its utilization as it contains carotenoids bound to pectin and fibers which decrease the micellization of carotenoids, in turn decreasing its bioaccessibility (Saini et al. 2015). Thus, extracting carotenoids using green biorefinery approach could increase its bioavailability.

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Three way ANOVA for emulsion of carotenoids extracted in flaxseed oil from carrot bio-waste

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ABSTRACT

The juice expelled from carrot, a globally produced root vegetable, leaves behind carrot pomace (a bio- and horticultural waste) which is potentially rich source of micro-nutrients and carotenoids. However, it is discarded as waste or used as animal feed. It holds potential to be channelized to food chain by a couple of technological interventions. In this regard, present work was aimed at preparing stable emulsion based delivery system for 'green' carotenoids extracted from carrot-pomace in flaxseed oil (a green solvent), and at maximizing the amount of core material so that the resultant emulsion can potentially be used as a source of both carotenoids and omega-3 fatty acid of flaxseed oil origin. The study used natural emulsifier. Preparation of oil-in-water emulsion was optimized using 3^3 factorial experiment by varying levels of extract containing carotenoid (30–40%), whey protein concentrates (WPC-80) and lactose. The optimized emulsion (CREm) was selected on the basis of particle size, zeta potential, color values (L^*, a^*, b^*) and viscosity statistically analyzed via three-way ANOVA using Proc GLM of SAS 9.3 (described in detail in this paper); the respective values of these parameters being 120.03 ± 8.20 nm, −16.57 ± 0. 49 mV, 75.11 ± 0.04, 9.66 ± 0.32, 50.29 ± 0.62, and 0.124 ± 0.0115 Pa.s for CREm. CREm contained 35% flaxseed oil, 10% WPC-80 and 5% lactose and showed good centrifugal and gravitational stability (15 days). It was analyzed for total carotenoid content, antioxidant activities (ABTS (2,2-azinobis-(3-ethylbenzthia zoline-6sulfonic acid), DPPH (2,2-Diphenyl-1-picrylhydrazyl) and FRAP (Ferric reducing antioxidant power assay)) and microstructure.

1. Introduction

Carrot (*Daucus carota* L., var. sativus Hoffm.) is the world's largest cultivated umbel lifer crop. According to Department of Agriculture, Cooperation and Farmer's Welfare (Government of India), India produced 1,648,000 MT of carrot from an area of 97,000 Ha in 2017–18 (http://agricoop.nic.in/sites/default/files/Horticulture%20Statistics%20at%20a%20Glance-2018.pdf). It is consumed as culinary dish in households, and preparation of candy, pickles, preserves, expulsion of juice, etc commercially. Carrot pomace is the major by-product of carrot juice processing industry and contributes to 30–50% by weight of carrot. It is generally discarded or disposed off as manure or feed, but is rich in plethora of bioactive ingredients like 17 and 31–35% of the total α- and β-carotenes, respectively; and 3.88%, 12.3%, 51.6%, 32.1% of pectin, hemicellulose, cellulose, lignin, respectively on dry matter basis (Bao and Chang, 1994; Nawirska and Kwaśniewska, 2005). A novel functional food can be developed by incorporating bountiful bioactive compounds–such as vitamins, bioactive peptides, antioxidants, etc as these can reduce the risk of various chronic disorders, besides offering physiological benefits. Lipophilic bioactive compounds like carotenoids possess broad spectrum health beneficial properties like promoting eye and skin health, besides showing immuno-modulatory effects. Most importantly, they provide cardioprotective, neuroprotective and anti-carcinogenic properties by decreasing oxidative stress of the cells. These are reported to

Abbreviations: ABTS, 2,2-azinobis-(3-ethylbenzthiazoline-6sulfonic acid; ANOVA, Analysis of Variance; CREm, optimized emulsion; CREx, carotenoid-rich extract; DPPH, 2,2-diphenyl-1-picrylhydrazyl; FRAP, ferric reducing antioxidant power assay; g, gram; HSD, high shear dispersion; kDa, kilodalton; min, minute; ml, milliliter; nm, nanometer; mV, millivolt; Pa·s, Pascal second; rpm, revolutions per minute; s, second; SEM, Scanning Electron Microscopy; SEMgr, Scanning Electron Micrograph; TCC, total carotenoid content; TPTZ, 2,4,6-Tris (2-pyridyl)-s-triazine; TEAC, trolox equivalent antioxidant capacity; TEM, Transmission Electron Microscopy; v/v, volume by volume; WPs, whey proteins; WPC, whey protein concentrates; WPI, whey protein isolate; 1k, 1000; $^1O_2$, singlet oxygen; %, per cent; μM, micromolar.

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