Research Article

Effects of Dietary Microalgae Supplementation on Mammals' Production and Health

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Abstract | Nutritional supplements of microalgae in small amounts to humans and animals are considered one of the sources for improving nutritional values throughout the world. The microalgae are classified into four groups: green (*Chlorophyceae*), blue-green (*Cyanophyceae*), golden (*Chrysophyceae*), and diatoms (*Bacillariophyceae*) algae. Microalgae were given to humans and animals for nutritional and therapeutic purposes. Microalgae and their purified constituents have been shown beneficial effects in several studies on mammals' production and health. The roles of microalgae and their purified compound as antibacterial, antiviral, antioxidant and anti-tumour have been well established. The valuable chemical constituents of microalgae include "proteins, polysaccharides, lipids, PUFAs, vitamins, pigments and other bioactive compounds". The microalgae composition varies depending on species and nutrient availability for production. Genetic engineering might be used for production invaluable microalgae compounds. Microalgae consider a promising source of omega-3 fatty acids (n-3 FAs), which have beneficial effects for humans and animals. Knowledge for microalgae effects on productive, reproductive and therapeutic performances is more fragmentary. Therefore, the present standard review article is compiled and discussed seventy-one articles concerning the effects of microalgae and their purified compounds on growth and reproductive performances and body health collected of scienceDirect and Elsevier search engine, of which 49.0% were published in the last five years.

Keywords | Microalgae, Growth, Reproduction, Milk, Blood

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INTRODUCTION

The microalgae are classified into four groups: green (*Chlorophyceae*), blue-green (*Cyanophyceae*), golden (*Chrysophyceae*), and diatoms (*Bacillariophyceae*) algae. The biomass-derived macronutrients and micronutrients of microalgae include proteins (50%–60% of dry mass), carbohydrates (10-12.0 %), lipids (5%–10% of dry mass; polyunsaturated omega-3 and omega-6 fatty acids; ω-3- and ω-6-PUFA), vitamins (A, E, B and C), minerals (4.0-6.5%), and other bioactive secondary compounds, such as carotenoids (Becker, 2007; Gutierrez-Salmean et al., 2015; Santos-Sanchez et al., 2016; Mohammed, 2018; Abdel-Wahab et al., 2020). The microalgae have a variable nutrient composition, depending on several factors as species and culture conditions (Brown et al., 1991; Bernaerts et al., 2018; Ahmed and Vinod, 2022). It has been reported that microalgae biomass include 40% oil, 30% protein, 20% CHO

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and 10% residual (Abd El-Hack et al., 2019) and consider promising source for biofuel and biological active products.

Green microalgae are photosynthetic prokaryotes used as nutritional supplements by animals, fish and humans as well (Gouveia et al., 2008; Benemann, 2013; Senosy et al., 2017; Mohammed, 2018; Abdel-Wahab et al., 2020; Ali et al., 2021; Glover et al., 2021; Perdana et al., 2021) because of the excellent sources of protein, vitamins and bioactive metabolites, which are found important for health throughout the world (Figure 1). They are also reported to be a source of fine chemicals, renewable fuel and bioactive compounds such as carotenoids (Nagarajan et al., 2021). Studies have also indicated that the blue-green type has antiviral, antitumor, antioxidant, anti-inflammatory, antiallergic, antidiabetic and antibacterial properties (Singh et al., 2005). Therefore, the present article compiled and discussed the effects of microalgae and their purified compounds on productive, reproductive and therapeutic performances on mammals.

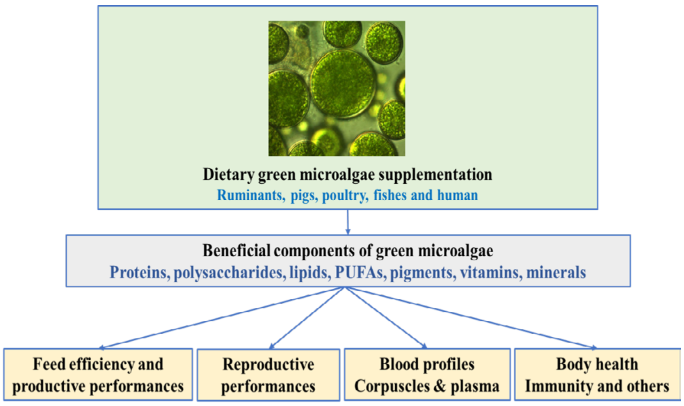

Figure 1: Effects of dietary microalgae on growth and reproductive performances and body health.

Feed efficiency and growth performance

Sustainable livestock development of meat and milk requires appropriate strategies to be attained worldwide for covering the shortage of meat and milk requirements to humans. Because of the increasing demand for milk and meat in the world, specialists continue to explore new approaches to improve meat and milk yield through different strategies (Hifzulrahman et al., 2019; Wang et al., 2019). Microalgae supplementation in small amounts as nutritional supplements were given to dairy and different species for improvement of feed efficiency and growth performances (Nagasawa et al., 1989; Al-Madany, 2016; Senosy et al., 2017; Mohammed, 2018; Kholif et al., 2017, 2020; Abdel-Wahab et al., 2020). Enhancement of growth and health status conditions of Artemia nauplii upon carotenoid-rich microalgae supplementation has been indicated (Gui et al., 2021). The significant increase of litter size and birth weight has been obtained in mice upon *D. salina* supplementation (Mohammed, 2018). Such improvement might be attributed also to the beneficial effects of microalgae on body health and body weight gain found during the study (Mohammed, 2018). Studies has shown improvement of growth and meat quality in pig, poultry and rabbit (Valente et al., 2021). In addition, dietary microalgae inclusion of ruminant has improved meat fatty acid profiles. The important applications of microalgae as growth promoter were due to their high contents of lipid and carotenoids (Gui et al., 2021). Moreover, *Azolla pinnata* (a macro algae) supplementation at 0, 10 and 20% (DM basis) levels to lambs for 90 days on growth performance, carcass and meat traits were explored (Vahedi et al., 2021). The results indicated that feed intake tended to be insignificantly lower in Azolla supplemented lambs. Body weight was not affected by dietary Azolla supplementation whereas hot and cold carcass weights were higher for 10 % Azolla group than control one. In addition, chemical composition and sensory properties of *longissimus* muscle was not differed by Azolla supplementation.

Reproductive activity

Stimulation of ovarian activity or treatment of dysfunctions was widely investigated through nutritional levels and ingredients (Nagasawa et al., 1989; Downing et al., 1995; Mohammed et al., 2005; Mohammed and Attaai, 2011; Gifre et al., 2017; Senosy et al., 2017, 2018; Mohammed, 2019; Mohammed et al., 2012, 2020, 2021; Mohammed and Farghaly, 2018; Mohammed and Al-Hozab, 2020; Ali et al., 2021), hormonal supplementation (Zarazaga et al., 1996; Mohammed et al., 2011), both hormonal and nutritional supplementation (Mohammed and Attaai, 2011). Because of the negative effects of increased energy and protein in the diet for humans and animals on health and fertility (McEvoy et al., 1997; Dawuda et al., 2002; Mohammed et al., 2012) and the high cost of diet, microalgae and their purified extracts were given in small quantity as replacers of hormonal stimulation. In addition, microalgae and their purified extracts might be used against reproductive dysfunctions. This was confirmed through the alleviative role of *Spirulina platensis* and *Chlorella vulgaris* extracts against ovarian dysfunctions in mice induced by monosodium glutamate (Abdel-Aziem et al., 2018).

Dietary *D. salina* supplementation (1.0% kg) has given beneficial effects on ovarian follicles' development and corpora lutea in goats (Senosy et al., 2017) and the resulting oocytes and embryos in mice (Mohammed, 2018). The numbers and diameters of ovarian follicles in addition to ovulation rate, diameters of corpora lutea, estrogen and progesterone concentrations were significantly increased due to supplementation *D. salina* to Boer goat (Senosy et al., 2017). Although *D. salina* supplementation to mice improved quality of cumulus-enclosed germinal vesicle oocytes and embryos, germinal vesicle breakdown (GVBD), maturation rate and timing of embryo cleavage were not differed (Mohammed, 2018). In addition, values of follicle stimulating hormone (FSH), luteinizing hormone (LH), estrogen and progesterone were significantly improved upon *D. salina* supplementation. Such improvement might be attributed to the increase in number and size of preovulatory follicle and copora lutea (Senosy et al., 2017). Moreover, *D. salina* supplementation to growing Red Tilapia was found to accelerate fecundity (Al-Madani; personal communication). Hence, *D. salina* nutritional supplementation might be used as an alternative to hormonal treatment to enhance reproductive performance because of its high level of beta-carotene, glycerol, protein and other fine chemicals (Wichuk et al., 2014; Cuellar-Bermudez et al., 2015; Gong and Bassi, 2016). Further studies are still required of other microalgae species for exploring their effects on ovarian follicle development, viability of the resulting oocytes and embryos.

The ovarian antral follicular fluid (FF) is a transudate from blood plasma and follicular synthesized components. The follicular fluid aspirated from antral ovarian follicles was added to maturation medium during *in vitro* embryo production for improvement embryo cleavage and developmental competence of the obtained embryos (Mohammed et al., 2005; Mohammed and Kassab, 2014). Therefore, it is expected transudate of microalgae bioactive compounds and molecules from blood plasma to follicular fluid if it is collected from animal given dietary microalgae.

Milk production and composition

Milk production and composition were affected through nutritional strategy (Stamey et al., 2012; Alshaheen, 2016; Brady et al., 2021). Dietary microalgae inclusion for ruminant has changed milk yield and improved milk fatty acid profile (Glover et al., 2012; Angulo et al., 2012; Kholif et al., 2017; Valente et al., 2021). Kholif et al. (2017) found that dietary *C. vulgaris* supplementation to Damascus goats improved milk production and composition. The content of conjugated linoleic acids (CLAs) in milk were increased due to *C. vulgaris* treatment. Angulo et al. (2012) investigated the effects of dietary saturated or unprotected PUFAs extracted from plant oils and algae to lactating dairy cows for 10-weeks on milk fat composition. They found that milk fat yield depressed and *de novo* secretion of fatty acids in milk reduced, whereas the secretion of *trans*-10, *cis*-12-conjugated linoleic acid (CLA) and docosahexaenoic acid (DHA) increased. Glover et al. (2012) studies the effect of fresh forage and marine algae feeding on milk yield and fatty acid composition and oxidation of milk and butter in Holstein dairy cows. Milk yield was not significantly changed due to microalgae supplementation. Although milk fat content depressed upon microalgae treatment, polyunsaturated FAs, docosahexaenoic acid and conjugated linoleic acid were elevated. However, changes in milk fatty acids composition upon microalgae supplementation were observed in different species, which indicates that mammary lipid metabolism require further investigation (Fougère and Bernard, 2019).

Blood biochemistry

Values of blood and plasma metabolites are an indicative of body's health in different species. Our work (Senosy et al., 2017) indicated improvement of reproductive hormones and metabolic parameters upon supplementation of 10g/kg diet of *D. salina* to Boer goats in subtropics. It is indicated that *D. salina* is rich in selenium, an antioxidant element, which helps in detoxification and immune health. Lupette and Benning (2020) reported human health benefits of very long chain polyunsaturated fatty acids (VLC-PUFAs) from microalgae. Studies (Alishahi et al., 2014; Amira et al., 2021) confirmed improvement of hemato-biochemical indices of Nile Tilapia fry and Heros severus fed with marine microalgae and they suggested production of healthy and disease-free fish due to powerful and reproducible of marine microalgae for different antioxidants and phenolics in addition to vitamins, lipids and proteins. Because of the high content of lipids in microalgae, they might have considered key constituents of the plasma membrane and they are essential for the functionality of all cellular membranes. In addition, lipids form membrane vesicles or lipid droplets (LDs) that are involved in the transport of proteins, hormones or fat-soluble vitamins (A, D, E and K) in cells and extracellularly, for example in the blood stream (Vachier et al., 2002). Furthermore, *Azolla pinnata* (a macro algae) supplementation at 10 and 20 % (DM basis) levels to lambs for 90 days lowered creatinine and urea concentrations than control ones (Vahedi et al., 2021).

Immunity functions and antioxidant activity

Bioactive compounds in microalgae have been shown to enhance immune activity and health status in various animal species, enhance antioxidant and tissue protection (Choochote et al., 2014; Lavy et al., 2003; Guedes et al., 2013; Abdel-Daim et al., 2015). Small amounts microalgae supplementation to mammals improved immune functions of the body (Senosy et al., 2017; Camacho et al., 2019). Messina et al. (2019) investigated the effects of replacing dietary fish meal by two marine microalgae (*Tisochrysis lutea* and *Tetraselmis suecica*) over 105 days and they found enhancement of immune responses of European sea bass, suggesting effective roles of microalgae ingredients as immune stimulants. Moreover, Tiong et al. (2020) explored effects of five microalgae species on antioxidant capacity of the brine shrimp Artemia and they found microalgae possess various antioxidant properties.

Anti-cancerous activity

Cancer is the second reason causing death in the world and it occurs due to the cell cycle malfunction or uncontrolled cellular proliferation. Cancer requires appropriate treatment strategies including chemotherapy and radiation treatments, which cause severe side effects as immune system depression, baldness, loss of appetite and infertility. Therefore, the researchers should explore new anticancer agents for the treatments of tumors. Natural resources including medicinal plants and microalgae are considered of the sources of the targeted studies. It has been indicated in several studies the anti-tumor activity of microalgae extracts due to their inhibitor roles against cell cycle and proliferation (Abd El-Hack et al., 2019). The phytochemical compounds (2-Pentadecanone 6, Apratoxin-A, Carotenoids) obtained from the different sources of microalgae (*Chlorella vulgaris, Lyngbya majuscule, Chlorella ellipsoidea*) and its action mechanism as anticancer has been reported in several studies (Luesch et al., 2001; Cragg and Newman, 2005; Kwang et al., 2008; Zeng et al., 2011). Anti-tumor capacity of the microalgae bio-products including carotenoids, PUFAs, polysaccharides, peptides has been confirmed in several studies (Abd El-Hack et al., 2019; Yi et al., 2021; Sonkamble and Wagh, 2022).

Antimicrobial, antiviral and antiparasitic activities

Bioactive compounds in microalgae have been shown to provide an innovative role to enhance antimicrobial, antiviral and antiparasitic activities (Chen et al., 2016; Carbone et al., 2021; Yi et al., 2021; Sonkamble and Wagh, 2022). Ghania et al. (2019) confirmed the antimicrobial and antiparasitic activities of three Algerian algae from the northwest coast. Furthermore, the antimicrobial activity of *D. salina* extract has been confirmed (Al-Madany, personal communication). Therefore, such microalgae extracts might be used in pharmaceutical industries as potent drugs.

CONCLUSIONS AND RECOMMENDATION

The microalgae desirable characteristics as feed or food ingredients for animals, fish and humans as well have been reported. Microalgae biomass-derived macromolecules were differed according to culture conditions. The biomass-derived macromolecules of microalgae have been shown in various animal and fish species to enhance body growth performances and health status, enhance antioxidant and tissue protection. The phytochemical compounds obtained from the different sources of microalgae and its action mechanism as anticancer has been reported in several studies. The microalgae desirable characteristics could be obtained through genetic engineering. Moreover, *in vitro* and *in vivo* extensive studies should be carried out on microalgae bioactive compounds to evaluate their possible applications over a wide range of growth, productive and reproductive performances in addition to therapeutic approaches in pharmaceutical industries as potent drugs.

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NOVELTY STATEMENT

The article presented the effects of dietary microalgae supplementation on mammals' production and health

AUTHOR'S CONTRIBUTION

Aiman Al-Mufarji, Rashid Al-Zeidi and Haitham Al-Masruri collected references and shared in writing manuscript. Abd El-Nasser Ahmed Mohammed wrote the manuscript and revised it for publication.

Conflict of interest

The authors have declared no conflict of interest.

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