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A Review: Spirulina a source of bioactive compounds and nutrition

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ABSTRACT

The attainment of the nutrition related sustainable development goals (SDGs) is a challenge to South Africa. Part of the challenge is related to access to affordable nutrition by poor communities. *Spirulina* presents with nutritional benefits including 50 to 70% protein, and all essential amino acids in complete balance, 5 to 10% lipids and 10 to 20% carbohydrates, 10 vitamins especially vitamin B_{12} and pro-vitamin A (β-carotene), minerals such as iron and one of the few sources of dietary γ-linolenic acid (GLA). Health factors linked to *Spirulina* include anticarcinogenic, hypocholesterolemic and antioxidant properties. *Spirulina* is part of the cyanobacteria family of the *Arthrospira* species. The challenges that are there is to ensure that the isolates are pure and free from microbial, chemical and physical contamination during the cultivation phase. The cultivation is either in closed semi-continuous batch systems or open raceway that are prone to contamination from environmental elements. This paper highlights *Spirulina* use as a potential strategy to meet nutrition related Sustainable Development goals.

KEY WORDS: Edible Cyanobacteria, Sustainable Development Goals, Nutrition, Spirulina.

1. INTRODUCTION

The human consumption of *Spirulina* is on the increase worldwide including in South Africa (Botha, 2004; Habib, 2008). This food source is estimated to improve the nutritional value of foods as a fortification agent, standalone food supplement, pharmaceutical and animal feed stock. *Arthrospira* species that are commonly found are *A. fusiformis, A. geitleri, A. indica, A. jenneri, A. maxima* and *A. platensis*. The two edible cyanobacteria are *A. maxima* and *A. fusiformis*, marketed as *Spirulina maxima* and *Spirulina platensis* (Figure.1) are commercially grown and harvested. Their safety for human consumption has been established and is sold as over the counter food supplements (Sili, 2012).

Spirulina is used as food supplements due to their rich nutritional content presenting with complete protein, carbohydrates and lipids. They are one of the few sources of dietary γ-linolenic acid (GLA) (de Morais, 2015), antioxidant agents, phycobiliproteins and carotenoids (Grewe & Pulz, 2012). They are rich in micronutrients especially vitamin B_{12} and pro-vitamin A (β-carotene) and minerals such as iron. *Arthrospira* is the only know cyanobacteria to produce GLA (Grewe, & Pulz, 2012).

The use of *Spirulina* as a food supplement is gaining momentum since the rediscovery of this Spirulina cake (dihé) in Kanem region, Lake Chad being consumed by Kanembu (Habib, 2008). In Chad the local communities have been harvesting the microalgae from the shores of Lake Chad, drying on sand filters and then cutting into smaller cakes with a market value of USD100,000 (Habib, 2008). The Food and Agriculture Organization (FAO) with funding from the European Union (EU) have started a project to improve the handling and packaging of the *Spirulina* so as to enhance its marketability to a wider population with a view of fighting malnutrition (FAO, 2015). In Lake Texcoco, Mexico by the Aztec people, sixteenth century used to harvest the Spirulina from the lake and make nutritional bread 'tecuitlatl' (Sili, 2012).

Figure.1. (A) The *Spirulina* tablets and (B) range of *Spirulina* food supplements that are available in the South Africa market

Arthrospira is a cosmopolitan, gram negative cyanobacteria that is found in extreme environments such as alkaline soda lakes, salty and brackish environments (Sili, 2012).

As with other cyanobacteria, the mode of *Arthrospira* nutrition is oxygenated phototrophic use of carbon dioxide is based on chlorophyll a (chl-a). It is cylindrical or a tight helix structure with trichomes with a peptidoglycan cell wall (Grewe & Pulz, 2012). With Sustainable Development Goals requiring improved nutrition, healthy lives and promotion of well-being for all at all ages (goals 3 and 4), *Spirulina* use may be listed as one of the national interventions in the combat of malnutrition. Hence, the objective of this paper was to review the *Spirulina* use and importance in meeting nutrition related Sustainable Development Goals looking at its nutritional content, use and consumption safety and interesting bioactive compounds.

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The manufacturing of *Spirulina* (*Arthrospira spp*) in Musina: Musina in the Limpopo Province of South Africa is one of the areas where *Spirulina* cultivation is done. Limpopo province is one of the three nutritionally challenged and poor provinces in the country. *Spirulina* is initially grown from an inoculum of *Arthrospira* species in bioreactors (Figure.2) and then transferred to open raceways (Figure.3). The bioreactors are either static or agitated. The harvested Spirulina is dried and the powder is further processed into tablets and other products that are then distributed to the health/food industries.

The production, drying, packaging and storage systems may differ among the producers of *Spirulina* thus leading to different *Arthrospira* biomass chemical composition (Grobbelaar, 2003). Part of these differences may be traced to the environmental factors such as nutrient inputs, mode of nutrition (autotrophic, mixotrophic or heterotrophic) availability of solar radiation, water temperature and availability of carbon dioxide (Grewe, & Pulz, 2012).

Under laboratory conditions, during the culture of the inoculum the *Arthrospira* spp autrophic nutrition involves the use of Zarrouk media, lighting of 150 to 200 µmol photon m^{-2} s^{-1} incubation temperature range of 25 to 38^{o}C (minimum of 15^{o}C depending on *Arthrospira strain*), salt tolerance up to 0.75 M sodium chloride and a pH range of 9.5 to 12 (Grewe, & Pulz, 2012). Thus the ability to tolerate high alkaline condition favours the *Arthrospira* species to be cultivated in open systems (Grewe, & Pulz, 2012).

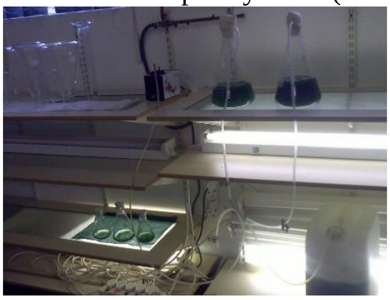

Figure.2. Static bioreactors and growth conditions

The cultivation of Spirulina in open channel raceway bioreactors in Musina, Limpopo, South Africa (Figure.3). The use of mixotrophic and heterotrophic nutrition based on organic substrates of the *Arthrospira* species leads higher biomass and productivity in comparison with autotrophic nutrition. The up-scaling of mixotrophic and heterotrophic modes of nutrition is expensive due to the cost in purchasing of organic substrates and microbiological contamination of *Arthrospira* species, partly due to presence of fungi and bacteria that may out-compete the *Arthrospira* species in the utilization of organic substrate (Grewe & Pulz, 2012).

During the manufacture of *Spirulina* the process requires the use of nutrients, nitrates and phosphates. The sources of nitrates are ammonium phosphates, urea, ammonium salts and ammonium chloride (Nor, 2015). The carbon sources are from atmospheric carbon dioxide (CO_2) and/or from the use carbonate salts and hydrogen carbonate salts. Lately there has been an interest in capturing carbon dioxide emanating from coal and biomass power stations and utilising the carbon in *Spirulina* production (da Silva Vaz, 2016).

The harvested *Spirulina* is dried and the powder obtained from the drying process is further processed into tablets and other products that are then distributed to the health/food industries. The use of semi-continuous batch cultivation techniques may improve the yield of *Spirulina* production in open systems (Reichert, 2006). The study of Jimenez (2003), showed that the minimal temperature for production of Spirulina was 15^{o}C and the out-door temperature did not exceed 28^{o}C, unless other *Spirulina plantensis* species higher temperature tolerant species are grown.

The study of Torzillo (1986), showed no significant differences in protein and amino acid composition of *Spirulina* that was grown in closed photobioreactors and open system. However, there were some differences in the fatty acid content whereby *Spirulina* grown in open system was higher in γ-linolenic acid. These differences were ascribed to higher temperatures reached in closed photobioreactors. Thus this shows an important advantage in growing Spirulina in open systems as it produces higher content of γ-linolenic acid. In Musina, an open system is used whereas Torzillo, (1986) in Italy showed that *Spirulina plantensis* M2 grown in closed photobiorector had a higher biomass (90%) than when grown in an open system. The reason for the differences between closed and open systems was that the closed system was able to achieve a better optimum temperature due to water cooling of photobiorector and the use of *Spirulina plantensis* that was tolerant of higher temperature. Thus the closed photobiorector has a greater solar energy conversion than open systems. The second reason was that the closed system was able to extend the cultivation days 215 as opposed to 175 days in the open systems. However, the use of closed photobiorector is more expensive to construct as compared to open systems that are affordable. Reichert (2006), indicated though that *Spirulina* production yield in open systems may be improved by the use of semi-continuous batch cultivation techniques. The major challenges with the use of closed photobiorector are toxicity risk and affordability. Toxicity risk to *Spirulina plantensis* can be due to the generation of oxygen in the tubular photobiorector and there is a need for continuous degasing to remove the oxygen gas. Toxicity risk is also there with the open system in that freshwater open system cultivation is prone to contamination than in closed photobioreactors cultivation. However, it is expensive to construct a closed photobiorector as opposed to open system that is affordable. Hence, the closed system method is reserved for the harvest of *Spirulina* destined for speciality chemicals, pharmaceuticals and nutraceuticals (Qiang & Richmond, 1996).

Under high solar radiation the *Spirulina* resorts to the use of isoprenoids, carotenoids β-carotene, zeaxanthin and tecopherols shielding the plant from excessive solar radiation (Gupta, 2015). Resultantly, isoprenoids are extracted and used as fine chemicals or nutraceuticals.

The nutritional value of *Spirulina:* The World Health Organization (WHO) estimates that 33.3 % of preschool children and 15% of pregnant women are likely to suffer from Vitamin A deficiency (VAD) especially in developing countries (Underwood, 1998; World Health Organization, 2009). Intervention strategies including supplementation, fortification and school feeding schemes are used to improve micronutrient deficiencies (Li, 2012). *Spirulina* use is recognised by WHO, the UN and FAO as a tool in the fight and eradication of malnutrition due to its nutritional value. Therefore the UN established the Intergovernmental Institution for use of Micro-algae *Spirulina* against Malnutrition (Habib, 2008).

Literature reveals that the *Spirulina* has 50 to 70% protein, 5 to 10% lipids and 10 to 20% carbohydrates, all essential amino acid in complete balance, 10 vitamins especially vitamin B_{12} and pro-vitamin A (β-carotene), minerals such as iron (Seshadri, 1993; Wang, 2008; Li, 2012).

The study of Seshadri (1993) in India showed the positive impact of *Spirulina fusiformis* in school feeding programme to 5000 preschool learners as part of nutrition enhancement project. The learners were given daily dose of 1 g *Spirulina*, named Spiru-om after mixing with icing sugar and Omam to make the spirulina palatable to the learners. The 'Bitot's spot', a symptom of Vitamin A deficiency was reduced from 80 to 10% after a trial period of more than six months. In another separate study in India, involving 400 learners also showed the bioavailability of *Spirulina* carotenes was similar to the use of pure vitamin A (Annapurna, 1991). In China another study involving 10 adults was conducted to evaluate the bioavailability of *Spirulina* carotenes (Wang, 2008). This study was significant since it demonstrated a direct conversion or bioavailability of *Spirulina* β-carotene within 24 hours of consumption of *Spirulina*. Also a study in China by Li (2012), of 228 learners confirmed the bioavailability of *Spirulina* β-carotenes and an increase in total body vitamin A stores after consuming 2 to 4g of *Spirulina* supplements.

Other studies have indicated that the *Spirulina* is nutritionally rich in the following: 50 to 70% protein, 5 to 10% lipid, 10 to 20% carbohydrate, 12 essential amino acids, 10 vitamins especially vitamin B_{12} and pro-vitamin A (β-carotene), minerals such as iron and one of the few sources of dietary γ-linolenic acid (GLA) (Belay, 1993; Desmorieux and Decaen, 2005; Reichert, 2006). In addition to these there are substances with anticarcinogenic, hypocholesterolemic and antioxidant properties that have been linked to *Spirulina*. Thus *Spirulina* is available for human and animal foodstuffs, and fine chemistry. The study of Torzillo (1986), showed no significant differences in protein and amino acid composition of Spirulina that was grown in closed photobioreactors and open system. However there were some differences in the fatty acid content of *Spirulina* grown in open systems which was higher in γ-linolenic acid. These differences were ascribed to higher temperatures reached in closed photobioreactors. Thus, this shows that the growing of *Spirulina* in open systems is ideal since there is a higher content of γ-linolenic acid. The study of Varga & Szigeti (2012) improved the grass taste of *Spirulina* by adding a mixture of *Lactococcus lactis* subsp *lactis* NCAIM B.2128 and *Lactococcus lactis* subsp *cremoris* ATCC 19257, sucrose at 10% w/v, strawberry-kiwifruit favour of 1.5% and *Spirulina plantensis* of biomass 0.3% w/v in fermented milk. An interesting observation during the fermentation process, the *Spirulina* promoted the acid development of *Lactococcus* sp.

A number of studies in Africa have demonstrated the positive use of *Spirulina* as a supplement to the combat malnutrition. The study of Simpore (2006), in Ouagadougou, Burkina Faso involved malnourished and underweight children. The positive benefits of *Spirulina* (*Spirulina platensis*) which was supplemented a local diet, Misola, which was high in energy but low in protein contributed to improved nutritional status of the children. To ensure that the *Spirulina* fortication programme was sustainable a spirulina production facility was established at the Nutrition Education and Rehabilitation Centre in Ouagadougou. This also allowed the health authorities to manage and prevent contamination of the *Spirulina*. In Zambia, Lusaka province, a similar study was initiated by Masuda (2014), where a similar local diet of maize meal (5 kg), sugar (0.8 kg), salt (0.1 kg) was fortified with imported *Spirulina* (0.3 kg) was showed a marked improvement in the height of malnourished children. The Zambian case study also recommended that the *Spirulina* should be grown local since the growth conditions are ideal in Zambia. The study of Matondo (2016), in Kisantu, the Democratic Republic of the Congo, showed the positive outcomes of malnourished children fed with 10g of *Spirulina* supplemented with local diets. The intervention group of children under five, the malnutrition decreased from 30% to 20%; oedema decreased dramatically from 64% to 4% and severe anaemia decreased from 20% to 6%.

Animal and fish feed: The nutritional value of *Spirulina* in addition to improving human nutrition can also be extended to the feeding of domestic animals and fish in aquaculture systems. The study of Habib (2008), has shown that *Spirulina* can replace the feeding diets of fishmeal, groundnut meal and soybean meal for domestic animals (poultry, cattle and pigs) and fish. A number of authors have documented the use of *Spirulina spp* as a fish feed for various fish species mainly due to the rich nutrition and digestibility (Sarker, 2016; Zhang, 2015; Habib, 2008; Promya & Chitmanat, 2011; Sirakov, 2012). The main reason to switch to fish feed based on *Spirulina* as opposed to the commercial fish feed is affordability of *Spirulina* and the commercial fish feed do not possess the extra nutrition in comparison with *Spirulina* (Sarker, 2016; Habib, 2008). The extra nutrition refers to the fatty acids (Omega 3) alpha-linolenic (ALA) and (Omega 3) docosahexaenoic acid (DHA) and eicosadienoic acid (Omega-6), Dihomolinolenic (Omega-8) which are available from *Spirulina* species (Ötleş & Pire, 2001; Sarker, 2016). The study of Promya and Chitmanat (2011) demonstrated that the use of 10 to 15% of *Spirulina* in place of crushed fish as fish feed lead to an increase in average daily growth of Red Tilapia, since the herbivorous fish species was able to effectively assimilate the *Spirulina* plant protein. The incorporation of *Spirulina platensis* in diets of two Indian carps, *Catla catla* and *Labeo rohita* showed a higher fat content in the carcass both fish species than the control even though the fat content in the *Spirulina* fish feed was lower (Nandeesha, 2001). The study of Sirakov (2012), the incorporation of *Spirulina platensis* in the diet of rainbow trout showed a higher growth rate in comparison with the control rainbow trout which was fed on the commercial fish feed.

The study of Ibrahem and Ibrahim (2014) in Egypt showed positive benefits of tissue protection and anti-oxidant properties of using *Spirulina platensis* as a fish supplement to Nile tilapia (*Oreochromis niloticus*) grown in aquaculture systems. *Spirulina platensis* is known to have anti-oxidant, anti-cancerous properties and ability to alter the carcinogen impaired DNA (Yang & Zhang, 2009). In closed aquaculture systems, Nile tilapia is subjected to stressful conditions (Ibrahem and Ibrahim, 2014). Thus to improve the fish stress levels Ibrahem and Ibrahim (2014) showed that *Spirulina* was able to offer chemoprotective properties for the first two months by activation of the P53 protein. The P53 protein regulates the cell cycle development, diversity and cell death (Mills, 2005).

Spirulina as a source of pharmaceuticals and nutraceuticals: The extraction of fine chemicals from *Spirulina* for medicinal and therapeutic purposes is gaining ground. The extraction of sodium spirulan and calcium spirulan from *Spirulina platensis* is sulphated polysaccharides with either sodium or calcium ions (Yang & Zhang, 2009). The sodium spirulan and calcium spirulan are known to exhibit anti-thrombin activity (Majdoub, 2009) and physiological inhibitor of thrombin (Hayakawa, 2000), repairs wounds and anti-atherogenic activity (Yang & Zhang, 2009).

Spirulina is a source of sulfolipids. Under laboratory conditions, *in vitro* experiments, it was shown a water soluble extract of *Spirulina platensis* containing sulfoquinovosyl diacylglyerocl (SQDG) inhibited herpes simplex virus type 1 (HSV-1) which are known reverse transcriptase inhibitor of human immunodeficiency virus (HIV) virus (Kwei, 2010; Chirasuwan, 2009).

The sources of contamination of Spirulina: The possible sources of contamination range from microbial contamination, chemical contamination (cyanotoxins and heavy metals) and physical contamination (insects, sand, and soot).

Microbial contamination: The growth culture media of the *Spirulina* is designed to exclude alien algae and other bacteria rotifers, yeasts and moulds. However, algae such as *Chlorella and Scenedesmus* are known to compete with *Spirulina* in the same growth media (Grobbelaar, 2003). Increasing saline conditions, to 16 g/litre, and alkaline pH of the growth media also eliminates the *Scenedesmus* but other competitors such as *Oscillatoria and Chlorella* do pose a threat (Grobbelaar, 2003). Grobbelaar (2003) indicated that yeasts and moulds may be present in the *Spirulina* finished products and are harmless. Standard indicator tests are normally conducted to determine the microbial quality in the final *Spirulina* product. These standard microbial tests are designed to screen for the absence and, or presence of *Escherichia coli, Salmonella spp, Shigella spp and Leptospira spp,* and the acceptable range is less than 200,000 colony forming units per gram (Grobbelaar, 2003).

Chemical contamination: Chemical contamination could be the presence of cyanotoxins or heavy metals. Though the growth media cultivation of *Spirulina* is designed to exclude alien algae and cyanobacteria, alien cyanobacteria that may produce cyanotoxins may still be favoured. The chemicals that are used in the growth media can also be a source of chemical contamination and a source of heavy metals.

Cyanotoxin chemical contamination: A shipment of *Spirulina* finished product was found to contain traces of alien cyanobacteria *Anabaena* (Grobbelaar, 2003). The persons who used this batch of *Spirulina* showed definite neurological symptoms which were consistency with presence of anatoxin-a (a neurotoxin) (Grobbelaar, 2003). In freshwater systems, cyanobacteria such as *Microcystis, Oscillatoria, Nostoc, Anabaena* spp known to produce hepatotoxins and microcystins is the most common and nodularins toxins produced by *Nodularia spp* (Testai, 2016; Netshambidi and Gumbo, 2014). *Anabaena, Oscillatoria spp* are known to produce neurotoxins, namely anatoxin-a anatoxin-a(s) and saxitoxins (Testai, 2016; Murby & Haney, 2016). However a detailed study was conducted in

Canada by Canada Health to look into the cyanotoxin occurrence in *Spirulina* finished product and found no evidence of cyanotoxins (Lawrence, 2001; Grobbelaar, 2003).

However another detailed study in China by Jiang (2008) on 36 *Spirulina* food supplement found trace levels of microcystins ranging from 2 to 163 ng/g (mean of 14± 27 ng/g) with microcystin RR (94.4% of the samples) being the predominate cyanotoxin, followed by microcystin LR (30.6% of the sample) and microcystin-YR (27.8% of the samples). The human consumption of trace levels of microcystins has long term effect on human health with health benefits of *Spirulina* being outweighed. The WHO has regulate the levels of microcystin-LR in drinking water to 1 µg/l in order to protect human health (WHO, 1998).

Heavy metal contamination: The presence of heavy metals such as cadmium in an open system in Dortmund was linked to atmospheric pollution that occurred in Europe (Grobbelaar, 2003). Also, the construction materials (cement, iron, copper, plastics) used in open systems and the bulk chemicals used in the production of Spirulina can be a source of heavy metals (Grobbelaar, 2003). In another study in Saudi Arabia, Al-Dhabi (2013), showed that the 25 *Spirulina* food supplements contained the following order of heavy metals Pt>Hg>Mg>Mn>Ni>Zn but were found to be within safe guideline values. The Pt and Hg were the least and were below the detection limit, whereas Ni and Zn were the most abundant elements in the *Spirulina* food supplements. Although the Zn levels were high, there were still below the acceptable limit of 10 mg/100 g for algae food supplements (Al-Dhabi, 2013).

Physical contamination: The open *Spirulina* production systems are prone to atmospheric pollution and contamination with insects, birds (feathers) and their droppings, plastics, soot and smoke particles (Grobbelaar, 2003). Also the freshwater attract aquatic insects such as *Ephydridae* (brine flies), *Corixidae* (water boatmen) and *Chironomidae* (midges) (Grobbelaar, 2003). However by covering the open *Spirulina* production systems with clear 0.15 mm-thick translucent UV-resistant polyethylene film can help in reducing atmospheric contamination and pollution (Habib, 2008). These plastic covers will allow the entry of sunlight energy reduce the presence of aquatic insects and allow a control of air temperature, thus improving the quality of Spirulina (Figure 4).

Figure.4. The use of translucent UV-resistant polyethylene film can help in reducing atmospheric contamination and pollution and control of inside air temperatures

Managing and improving the quality of Spirulina: The consumer interest in *Spirulina* has attracted the food regulatory authorizes in different countries all over the world. In India, the regulatory authority has subjected the *Spirulina* powder to Indian Standard specification: IS 12895:1990 (amended June 1991) (Seshadri, 1993).The standard states that the powder must have a minimum of 1600 µg/g of β-carotene no less than 55% protein, high amounts γ-18:3 linolenic acids, Vitamin B12, minerals and is a wholesome foodstuff. Other countries such as Japan, France and Sweden have specified the microbial quality of the *Spirulina* biomass (Grobbelaar, 2003).

Drug regulatory bodies such as the United States of America Food and Drug Administration (FDA) and Medicines Control Council (MCC) of South Africa have decided that based on the *Spirulina*'s high nutritive and complex organic content it could be legally sold as a food supplement. In South Africa, the Medicines Control Council (MCC) together with other drug regulatory bodies such as FDA have decided that *Spirulina* can be legally sold as a food supplement based on the its high nutritive and complex organic content. In the United States of America, the Food and Drug Administration enforces the use of *Spirulina* as a food supplement under the Federal Food, Drug and Cosmetic Act and the manufacturing and production facilities must abide the Good Manufacturing Practices (GMP) with scheduled and unscheduled annual visits from regulatory authorities (Borowitzka, 20132). But recently the Dietary Supplements Information Expert Committee (DSI-EC) of the United States Pharmacopeial Convention (USP) reviewed and classified the use of *Spirulina* as a Class A safety rating for *Spirulina maxima* and *S. platensis*, thus permitting for inclusion as quality monographs of the *United States Pharmacopeia and National Formulary (USP–NF)* (Marles, 2011). In the state of Oregon, USA, the Oregon Health Division has established a guideline value of 1 µg/g for microcystin LR in *Spirulina* food supplements (Gilroy, 2000). In providing a quick and accurate method for the detection of cyanotoxins in *Spirulina* health supplements, Yakes, (2015) used molecular techniques, PCR, to determine presence or absence of cyanobacteria genes expressing toxicity. In their study, the gene target for *Microcystis* was positive in the *Spirulina* health supplements and negative for toxic genes, *mcyB*-D. Interesting in the same study, toxic *Microcystis,* as shown by toxic genes, *mcyB* was found in Blue-green algal supplements (BGAs) originating from *Aphanizomenon flos-aquae* in open Upper Klamath Lake, Oregon, USA.

Meeting the nutrition related Sustainable development Goals with *Spirulina*: Malnutrition is fundamentally determined by low-socio-economic status and food insecurity although lack of nutritional knowledge can be a factor to more affluent and food secure population. In the MAL-ED study in South Africa and Tanzania showed high levels of malnutrition, stunted growth and anaemia among the children under-five (Heckman, 2010; Mduma, 2016). In South Africa, Limpopo province showed a higher number of children under-five were aneamic (75%); stunted growth (18%) and wasting (7%) according to (Heckman, 2010; Mushaphi, 2008). In the Manyara region, Tanzania, there were high levels of stunted growth (40%) and underweight (31%) children (Mduma, 2016). The issue of anaemia was attributed to lack of nutritious diet, iron rich foods instead of malaria infections. The diet in the study areas was maize-meal, high in carbohydrates and low in protein, probably contributed to the stunted growth and wasting, a form of acute malnutrition, of the children. The study of Abed (2016), in Gaza strip, Palestine, showed that a 12 week of intervention of 3g of *Spirulina* mixed with dates, there was a marked in improvement of weight and height increase of 7.90 kg to 8.59 kg and 75.11 cm to 78.01 cm respectfully. Also in combating the anemic condition of the under-five children, the ferritin (5.95 ng/ml – 38.71 ng/ml) and the serum iron (66.09 µg/dL – 95.52 µg/dL) increased on the *Spirulina* fed group.

Therefore any nutritional intervention should be aimed at a specific target. South Africa in its Integrated Nutrition Programme has used different micronutrient strategies for effective micronutrient delivery strategies including supplementation, fortification, the National school Nutrition Programme. Currently, the availability of *Spirulina* for nutritional support fails to reach the most vulnerable populations as it comes in pharmaceutical and nutraceuticals forms (tablets and powder) administered through markets that can never be afforded by those much in need.

So far the nutritional status of South Africans in general is improving although at a very slow pace through the efforts of the above mentioned strategies. This achievement has been attained because the programmes are unleashed amongst others through Primary Health Care and public schools both of which have vast mass coverage. Even though literature indicates how nutritionally rich *Spirulina* is, it remains not explored in governmental interventions (national nutritional programmes). Once the *Spirulina* gets packaged after harvesting, it gets shipped for more affording communities other than the local people of Musina. Whereas if food consumed by people of Musina gets fortified with *Spirulina* and gets included in the menu used in the school feeding programme then increased nutritional and health improvement can be anticipated. This paper sought to raise awareness of the nutritional and health benefits provided by *Spirulina* to motivate for thinking of incorporating it in these existing integrated programmes in an attempt to meet the nutritional related SDGs. For example, use of *Spirulina* as a fortificant in commonly used food will ensure that Musina residents benefit from their own natural resources.

4. CONCLUSION

The *Spirulina* food supplements are nutritionally rich however they currently may not be beneficial to the poor due to affordability. For nutrition and health improvement, their use could be expanded aiming to also reach the poor through incorporation into the national integrated nutrition programme strategies to ensure large coverage. There are food safety risks associated with *Spirulina* consumption however mechanisms to prevent such hazards are known. The consumer interest in *Spirulina* has attracted the food regulatory authorities in different countries all over the world. It will be important to establish the feasibility of using *Spirulina* in meeting the nutrition related SDGs.

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