ABSTRACT

Background: *Arthrospira* (*Spirulina*) spp. has long been consumed as a dietary supplement that provides rich natural nutrients consisting of 60-70% proteins including essential amino acids, vitamins, and some minerals. The currently available *Spirulina* products in the market are mainly hot and spray-dried and their nutritional values are significantly compromised due to degradation of the heat-sensitive bioactive components.

Scope and approach: This commentary provides a critical view on the differences in main nutritional composition between dried and fresh living *Arthrospira*. In addition, the current R&D advances in the development of fresh living *Arthrospira* as a dietary supplement including the cultivation system, preservation and storage, product development, nutritional and functional properties and food safety were critically discussed.

Key findings and conclusions: Fresh living *Arthrospira* can better maintain their nutritional, functional, and health values, and therefore could be developed for a new range of *Arthrospira* derived products. However, the cultivation system that could ensure the food safety and long-term storage technologies to preserve the cell viability in different product formulations are still under development for expanding the commercial applications.
Fresh Living *Arthrospira* as Dietary Supplements: Current Status and Challenges

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**Keywords**: *Arthrospira*; *Spirulina*, bioactive compounds; cultivation system; dietary supplements; fresh *Arthrospira*; nutrition.

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ABSTRACT

Background: Arthrospira (Spirulina) spp. has long been consumed as a dietary supplement that provides rich natural nutrients consisting of 60-70% proteins including essential amino acids, vitamins, and some minerals. The currently available Spirulina products in the market are mainly hot and spray-dried and their nutritional values are significantly compromised due to degradation of the heat-sensitive bioactive components.

Scope and approach: This commentary provides a critical view on the differences in main nutritional composition between dried and fresh living Arthrospira. In addition, the current R&D advances in the development of fresh living Arthrospira as a dietary supplement including the cultivation system, preservation and storage, product development, nutritional and functional properties and food safety were critically discussed.

Key findings and conclusions: Fresh living Arthrospira can better maintain their nutritional, functional, and health values, and therefore could be developed for a new range of Arthrospira derived products. However, the cultivation system that could ensure the food safety and long-term storage technologies to preserve the cell viability in different product formulations are still under development for expanding the commercial applications.
1. Introduction

Arthrospira belongs to one of the most ancient groups that have existed since the beginning of life on earth, the cyanobacteria (Schirrmeister et al., 2011). The two most common commercial species belonging to this genus are A. platensis and A. maxima (Ciferri, 1983; Castenholz et al., 1989). However, over the years, the common name “Spirulina” has been applied to foodstuff made from Arthrospira so pervasively that it would be a formidable task to attempt to retrain the consumers of “Spirulina” as to the correct taxonomic designation (Belay, 1997). Therefore, we will use “Spirulina” when referring to a brand name but use the correct name Arthrospira for the rest of the time in this article.

Although Arthrospira has been used as a food source by human for centuries, it is now recognized as one of the top superfoods for several reasons. Arthrospira contains an average protein content of 60%, but can range anywhere between 50-70%, which includes all the essential amino acids making it a complete protein source (Kulshreshtha et al., 2008; Prasanna et al., 2010). As many people today are choosing to eat less animal protein, this plant-like alga can be a great vegan or vegetarian alternative to ensure protein and amino acid requirements. In addition to protein, Arthrospira contains a wide spectrum of prophylactic and pharmaceutical nutrients including B-complex vitamins, minerals, γ-linolenic acid, Vitamin E, trace elements, and a number of unexplored bioactive compounds (Romay et al., 2003; Kulshreshtha et al., 2008; Neher et al., 2018). It also contains a full spectrum of antioxidants and carotenoids, including zeaxanthin, cryptoxanthin, phycocyanin, β-carotene, superoxide dismutase (SOD) and lutein (Demir & Tükel, 2010; Hosseini et al., 2013). Therefore, Arthrospira can be one of the best solutions for the production of a high-quality dietary supplement as well as a nutraceutical product.
Currently, *Arthrospira* spp. is commercially produced in various parts of the world including China, Thailand, India, Australia, and the U.S.A., and this alga has been mainly marketed in the forms of dry powder, flakes, tablets and capsules (Koru et al., 2012; Soni et al., 2017). The fresh biomass of *Arthrospira* is usually hot or spray dried at temperatures above 100 °C after harvesting to guarantee safety and long-term shelf-life of the dietary supplement (Seshadri et al., 1991; Sarada et al., 1999; Desmorieux & Hernandez, 2004; Rossi et al., 2007). This conventional heat-drying process causes loss in most of the above-mentioned bioactive components due to their heat sensitive and easily oxidizable properties (Larrosa et al., 2017; Papadaki et al., 2017). Therefore, the fresh living *Arthrospira* should be a great alternative for the currently available dry *Arthrospira* products in the market for the increasingly nutrition-conscious consumers. However, some challenges still need to be managed to ensure the safety and consumer acceptability of fresh *Arthrospira* products that can make it as easy as getting vegetable or fruit salads from the supermarket.

In this commentary, the concept of developing fresh living *Arthrospira* as a dietary supplement was discussed with special emphasis on the cultivation system of this alga, preservation and storage of the harvested biomass and product development from the processed powder. We also critically reviewed the nutritional and functional properties and food safety as well as the degradation in nutrients of *Arthrospira* products processed by traditional drying methods. Furthermore, the current challenges for the development of fresh living *Arthrospira*-based products are discussed.

### 2. Nutrition and functions of *Arthrospira* as a dietary supplement

*Arthrospira* has a long history of human consumption, and has been thoroughly studied in toxicological models, with no results prompting concern for safety (Marles
et al., 2011; Heussner et al., 2012; Koru, 2012; de la Jara et al., 2018). It has received
the Generally Recognised As Safe (GRAS) status for human consumption by the US
Food & Drug Administration (GRAS Notice 000391; GRAS Notice 000394). The
main ingredients of nutraceutical value and the health beneficial effects of current
Arthrospira products are summarized in Fig.1. It should be noted that the various
disease preventative effects reported so far are all based on the use of dried
Arthrospira and no data in terms of nutraceutical effects of fresh Arthrospira biomass
on human health is currently available.

3. General quality and safety assurance for Arthrospira

Since the 1970s, Arthrospira has undergone extensive safety studies in rats, pigs,
chickens, fish, and humans (Koru, 2012; de la Jara et al., 2018). The re-introduction
of Arthrospira as a health food for human consumption in the late 1970s and the
beginning of the 1980s was associated with many controversial claims which
attributed to this alga the role of a ‘magic agent’ that could do almost everything
ranging from curing specific cancer to antibiotic and antiviral activity (Koru, 2012). A
recent review on randomised controlled clinical trials involving the use of Arthrospira
as a dietary supplement (de la Jara et al., 2018) using PubMed and the Cochrane
Library search results indicated considerable benefits against dyslipidaemia (based on
four trials), diabetes (four trials), hypertension (one trial), inflammation and
precancerous lesions (four trials), and allergic rhinitis (two trials). Furthermore, one
cannot ignore the fact that more than 70 percent of the current Arthrospira market is
for human consumption mainly as health food (Vonshak, 2002; Shimamatsu, 2004;
Henrikson, 2010; Koru, 2012). In the past 30 years, Arthrospira has been marketed
and consumed as a safe human food by millions of people in North and South
America, Asia, Europe and Africa, where many governments, health agencies and associations of over 60 countries have endorsed its safe consumption (GRAS Notice 000101). So, there are established national and international quality standards for *Arthrospira* products (Shimamatsu, 2004; Henrikson, 2010; Koru, 2012). The typical analysis of the contents of *Arthrospira* product, the quality standard requirement for *Arthrospira* product in Europe, Japan and the USA have been summarized in Table 1.

4. **Fresh *Arthrospira* has significantly better nutritional values**

*Arthrospira* are normally dried after harvesting to facilitate their storage and incorporation in food. Drying of *Arthrospira* constitutes approximately 30% of the total production cost, and the traditional methods used to dry fresh *Arthrospira* are spray drying, freeze drying, solar drying, convective hot air drying and spouted bed drying (Morist et al., 2001; Jiménez et al., 2003; Oliveira et al., 2009). Drying methods and temperatures have been reported to have significant effects on the bioactive components of *Arthrospira* biomass (Table 2). Spray drying of *Arthrospira* led to 10-25% protein loss and up to 30% carbohydrate loss when compared with the freshly harvested biomass. Similarly, freeze drying led to nearly 10% losses in both protein and sugar contents (Desmorieux & Hernandez, 2004).

Traditional drying methods led to a 50% to 90% loss of phycocyanin in *Arthrospira* biomass although different results with the same drying method were reported (Sarada et al., 1999; Oliveira et al., 2008, 2010; Larrosa et al., 2017; Papadaki et al., 2017). Effects of freeze drying, spray drying and pasteurization on the full nutritional ingredients (protein, amino acids, carbohydrates, DNA, RNA, phycocyanin, chlorophyll and fatty acids) of *Arthrospira* were compared by Morist et al. (2001). Unfortunately, the study by Morist et al. (2001) did not include data of fresh
Arthrospira biomass before being dehydrated, therefore, the real loss in nutritional components caused by these treatments could not be determined.

The activities of bioactive ingredients such as antioxidants and enzymes are well-known to be inhibited or inactivated at higher temperatures (Wolberg et al., 2004). When exposed to temperatures close to 100 °C, most enzymes are completely inactivated (Klibanov & Zaks, 1984). Although no studies on the loss of enzymatic activity due to drying of Arthrospira biomass is yet to be reported, it is reasonable to assume that many important enzymes would be deactivated in commercially produced Arthrospira-based products that are hot or spray dried over 100 °C (Seshadri et al., 1991; Sarada et al., 1999; Desmorieux & Hernandez, 2004; Rossi et al., 2007). Additionally, the loss of SOD activity by over 50% at 80 °C has been reported in dried Arthrospira biomass (Bobone, 2014).

Other bioactive compounds such as carotenoids, chlorophyll, lipids, and carbohydrates also showed significant losses in the dried Arthrospira biomass when compared with the freshly harvested ones (Seshadri et al., 1991; Desmorieux & Hernandez, 2004; Agustini et al., 2015; Papadaki et al., 2017). Ocean Chill™ drying technology is currently being adopted by Cyanotech Corporation to produce their Hawaiian Spirulina Pacifica (Cysewski, 1994). The company claimed that their Spirulina had 41% to 815% higher nutrients e.g. total carotenoids, iron, vitamin A, vitamin K, SOD and zeaxanthin when compared to California Spirulina and Indian Organic Spirulina. However, the company attributed this higher nutritional content not just to the patented drying technology but also to continuous cultivation methods, strict quality standard and unique location in a BioSecure Zone free from pollution (https://www.businesswire.com/news/home/20090305005018/en/Cyanotech%E2%80%99s-Hawaiian-Spirulina-Pacifica%C2%AE-Proven-Nutritionally-Superior).
To our knowledge, no other company has reported the use of any proprietary drying technology that would preserve the nature of fresh *Arthrospira* biomass in a high percentage. Therefore, published studies clearly indicate that currently available dried *Arthrospira* products have significantly compromised nutritional value and functional properties compared to the freshly harvested biomass and therefore, these products may not be the superfood enriched with healthy properties as is being currently promoted and marketed. Furthermore, the striking fishy taste of dried *Arthrospira* powder as a result of the drying process makes it hard for consumption and may drastically affect the flavor of the food or drink used for mixing the dried biomass (Becker, 2007). On the contrary, the mixing of fresh *Arthrospira* paste with food or drink makes any hardly noticeable change in smell and flavor making it easier for human consumption (Table 3).

5. Cultivation systems, preservation and storage of fresh living *Arthrospira* products

The current worldwide production of microalgal biomass is about 9,000 tons per year and the production cost is still high, in the range of $20-200 kg$^{-1}$ dry biomass (Brennan & Owende, 2010). The cultivation technologies currently employed for the large-scale production of microalgal biomass are primarily open raceway ponds. Although the open ponds are cheap and easier to build and operate than the closed photobioreactors, there is always the risk of contamination by other algae, protozoa and insect larvae (Belay, 1997; Borowitzka, 1999; Day et al., 2012; Vichi et al., 2012). Open ponds also have other inherent disadvantages such as low gas-liquid mass transfer rate, water evaporation, low mixing rate, and poor temperature control (Chisti, 2007; Ugwu et al., 2008). Therefore, open pond cultivation may not be suitable for the
production of pharmaceutical ingredients and edible fresh *Arthrospira* due to possible microbiological contamination (Belay, 1997; Borowitzka, 1999; Day et al., 2012; Vichi et al., 2012).

Closed photobioreactors should be a good choice for high quality dietary fresh *Arthrospira* production because they can offer better control on culture conditions and minimize microbiological and other contaminations (Gupta et al., 2015). The ideal photobioreactors for the production of freshly edible *Arthrospira* should be free of contamination in order to meet the food safety standard in addition to having higher productivity (Matsudo et al., 2012; Gupta et al., 2015); efficient utilization of light (Sierra et al., 2008), and good but not excess mixing to keep algal cells in suspension (Ugwu et al., 2008) and cheaper in capital costs (Norsker et al., 2011; Acién et al., 2012).

The cost of production of microalgal biomass is more expensive in photobioreactors in comparison with open-raceway ponds requiring improvement of cost and production efficiency (Gupta et al., 2015). Diffusion of light becomes a limiting factor for efficient growth of microalgae through development of microalgal biofilm on photobioreactor surface when the culture volume is large (>100 L; Blanken et al., 2014; Gupta et al., 2015). The initial capital investment, operational and maintenance costs of photobioreactor are high which lead to higher biomass production cost (Acién et al., 2012; Gupta et al., 2015). Hence, the current photobioreactors should be continuously improved to overcome these challenges for the production of low cost fresh living *Arthrospira* biomass.

6. **Processing technologies and bottlenecks of fresh *Arthrospira* products**

*Arthrospira* can be harvested for consumption when the cultures become dark green
indicating high enough cell density for harvest (Li et al., 2004). The filtered-out fresh
Arthrospira can be firstly rinsed with freshwater to remove the remaining culture
medium and then consumed directly or mixed with various types of drinks or food (Li
et al., 2004). In addition, supplementation of fresh Arthrospira biomass in biscuits,
pastes, lozenges, jelly drinks and fermented milk to replace the dried Arthrospira
powder will have better functional nutrients and sensory taste (Beheshtipour et al.,
2013). Technological advancement for long-term storage of fresh Arthrospira biomass
for developing this alga-based products is important to maintain its nutritional value
after harvesting. Direct fresh Arthrospira supplemented products such as fresh
Arthrospira cold tea, fresh Arthrospira milk, and fresh Arthrospira ice cream often
require low temperature and convenient storage. The storage technologies and their
impact of long-term storage on nutritional values, smell and tastes are yet to be
explored. Arthrospira has been reported to recover its physiological activity after 6
months of cryopreservation in liquid nitrogen and 10% sucrose solution (Li et al.,
2016). However, this technique would not be suitable for commercial storage of fresh
living Arthrospira.

Currently, several companies are marketing fresh Arthrospira in different parts of
the world. These companies have reported some progress in developing long-term
storage method for fresh Arthrospira biomass. For instance, Energaia reported that
their fresh Arthrospira biomass could preserve its full nutritional components for 21
days when algal pastes are kept in the refrigerator at around 5-8 °C or lower after
harvesting (http://energaia.com/faqs/). The Shandong Boran "Spirulina" Biological
Co., Ltd claimed that their fresh "Spirulina" could be stored for 12 months without
nutritional losses if they were kept at -18 °C after quick freezing at low temperature
(http://english.sdboran.com). Freezing brings the issue of biomolecules losses due
thawing as Arthrospira lacks of cell wall and ice crystals easily break the cell membranes, this is a minor handicap that could be solved at a commercial level with a single-dose format but it is not living fresh Arthrospira. In addition, we could not find any information about the nutritional characteristics of the fresh "Spirulina" produced by the above mentioned companies. We would speculate that companies are keeping this information as trade secrets due to the novelty of the idea.

The biochemical profiles of several microalgae species popularly used in aquaculture such as Nannochloropsis sp., Dunaliella tertiolecta, Entomoneis punctulata and Melosira dubia in concentrated condition were tested for their shelf-life assessment during refrigeration and freezing over 2 months (Welladsen et al., 2014). Significant stability of amino and fatty acids was reported in these species due to these cold storage conditions but these responses would be variable in different species as demonstrated by these authors. Therefore, further studies to understand the cell viability, microbiology i.e. food safety and biochemical stability of fresh Arthrospira products during the storage processing is required to overcome the challenges for commercial development of fresh living Arthrospira as a dietary supplement.

7. Conclusion

Arthrospira has been well-known as a superfood containing nutritional components for optimum health and wellness of human beings. The nutritional value of dried Arthrospira is significantly compromised due to the application of traditional drying methods for obtaining the dry powder. An alternative to combat such nutritional loss is the use of fresh living Arthrospira biomass as it contains all the “original” functional nutritional components. Closed photobioreactors with the capability to
produce high amounts of biomass at competitive production cost while ensuring food safety and minimizing contamination need to be developed for fresh living *Arthrospira* to be directly consumed. The use of fresh living *Arthrospira* instead of dried *Arthrospira* powder is a relatively new concept and only a handful of companies are currently marketing products based on this novel idea. These companies are marketing the fresh *Arthrospira* products as quick-frozen or mixed with additives and they are recommending consumers to store their products at low temperature to ensure longer shelf-life. However, the commercial success of the next-generation of fresh and living *Arthrospira* products will depend on the development of proper cultivation, storage and processing technologies based on better understanding the cell viability, nutritional value and food safety of these products.

**Conflicts of interest**

No authors declared any potential conflicts of interest.

**Acknowledgement**

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Henrikson, R. (2010). *Spirulina: world food, how this micro algae can transform your health and our planet*. Published by Ronore Enterprises, Inc. PO Box 909, Hana, Maui, Hawaii 96718 USA, pp.1-195.


thin layer drying of *Spirulina platensis* utilizing perpendicular air flow. *Bioresource Technology*, 100, 1297-1303.


Table 1. General quality and safety standards for "Spirulina": quality requirements of France, Sweden, Japan and Earthrise Farms (USA)

<table>
<thead>
<tr>
<th>Standard</th>
<th>France&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Sweden&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Japan&lt;sup&gt;c&lt;/sup&gt;</th>
<th>USA&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>55-65%</td>
<td>55-65%</td>
<td>≥50%</td>
<td>55-65%</td>
</tr>
<tr>
<td>Total carotenoids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll &lt;i&gt;a&lt;/i&gt;</td>
<td></td>
<td></td>
<td>&gt;100 mg/100g</td>
<td>300 mg/100g</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td></td>
<td></td>
<td>&gt;500 mg/100g</td>
<td>900 mg/100g</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td></td>
<td>&gt;2000 mg/100g</td>
<td>8,000 mg/100g</td>
</tr>
<tr>
<td>Standard plate count</td>
<td>&lt;100,000/g</td>
<td>1,000,000/g</td>
<td>&lt;200,000/g</td>
<td>&lt;200,000/g</td>
</tr>
<tr>
<td>Mold</td>
<td></td>
<td>&lt;1000/g</td>
<td></td>
<td>&lt;100/g</td>
</tr>
<tr>
<td>&lt;i&gt;Saccharomyces&lt;/i&gt; &lt;i&gt;sp.&lt;/i&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coliform bacteria</td>
<td>&lt;10/g</td>
<td>&lt;100/g</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>&lt;i&gt;Staphylococcus&lt;/i&gt; &lt;i&gt;aureus&lt;/i&gt;</td>
<td>&lt;100/g</td>
<td>&lt;100/g</td>
<td></td>
<td>negative</td>
</tr>
<tr>
<td>&lt;i&gt;Salmonella&lt;/i&gt; &lt;i&gt;enteritidis&lt;/i&gt;</td>
<td>negative</td>
<td>negative</td>
<td></td>
<td>negative</td>
</tr>
<tr>
<td>Insect fragment</td>
<td></td>
<td></td>
<td></td>
<td>&lt;30 pcs per 10 g</td>
</tr>
<tr>
<td>Rodent hair</td>
<td></td>
<td></td>
<td></td>
<td>&lt;1.5 pcs per 150 g</td>
</tr>
</tbody>
</table>

*<sup>a</sup> Superior Public Hygiene Council of France, 1984, 1986; <sup>b</sup> Ministry of Health, Sweden; <sup>c</sup> Japan Health Foods Association, auth. by Ministry of Health and Welfare; <sup>d</sup> Earthrise Farms, 1995; ● means no set standard. The Table 1 was revised according to the reports of Shimamatsu (2004), Henrikson (2010) and Koru (2012). 
Table 2. Losses of nutritional components in *Arthrospira* biomass dried using different drying methods when compared with fresh biomass.

<table>
<thead>
<tr>
<th>Nutritional compounds</th>
<th>Losses</th>
<th>Drying methods</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phycocyanin</td>
<td>26.23%</td>
<td>Vacuum drying (40 °C)</td>
<td>Larrosa et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>66.02%</td>
<td>Vacuum drying (50 °C)</td>
<td>Larrosa et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>71.67%</td>
<td>Vacuum drying (60 °C)</td>
<td>Larrosa et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>77.36%</td>
<td>Oven drying (55 °C)</td>
<td>Larrosa et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>94.85%</td>
<td>Vacuum drying (55 °C)</td>
<td>Papadaki et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>88.70%</td>
<td>Solar drying</td>
<td>Papadaki et al., 2017</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>43.76-93.07%</td>
<td>Oven drying (50-70 °C)</td>
<td>Oliveira et al., 2010</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>9.82%</td>
<td>Spouted bed drying (60 °C)</td>
<td>Oliveira et al., 2008</td>
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<tr>
<td>Phycocyanin</td>
<td>38.04%</td>
<td>Convective hot air drying (60 °C)</td>
<td>Oliveira et al., 2008</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>55%</td>
<td>Cross flow drying (60 °C)</td>
<td>Sarada et al., 1999</td>
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<td>Phycocyanin</td>
<td>55.5%</td>
<td>Spray drying (150 °C)</td>
<td>Sarada et al., 1999</td>
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<tr>
<td>Phycocyanin</td>
<td>54%</td>
<td>Oven drying (60 °C)</td>
<td>Sarada et al., 1999</td>
</tr>
<tr>
<td>Phycocyanin</td>
<td>67.44-77.78%</td>
<td>Spray drying (200 °C)</td>
<td>Rossi et al., 2007</td>
</tr>
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<td>Chlorophyll a</td>
<td>77.65%</td>
<td>Vacuum drying (55 °C)</td>
<td>Papadaki et al., 2017</td>
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<td>Chlorophyll a</td>
<td>88.56%</td>
<td>Solar dry</td>
<td>Papadaki et al., 2017</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>70.20%</td>
<td>Vacuum drying (55 °C)</td>
<td>Papadaki et al., 2017</td>
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<td>Carotenoids</td>
<td>89.66%</td>
<td>Solar dry</td>
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<tr>
<td>Carbohydrates</td>
<td>30-4%</td>
<td>Oven drying (40-60 °C)</td>
<td>Desmorieux &amp; Hernandez, 2004</td>
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<tr>
<td>Carbohydrate</td>
<td>52.71%</td>
<td>Oven drying (40 °C)</td>
<td>Agustini et al., 2015</td>
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<td>Protein</td>
<td>15-25%</td>
<td>Convective drying (40-60 °C)</td>
<td>Desmorieux &amp; Hernandez, 2004</td>
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<td>Protein</td>
<td>10-25%</td>
<td>Infrared drying (40-60 °C)</td>
<td>Desmorieux &amp; Hernandez, 2004</td>
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<tr>
<td>Protein</td>
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<td>Spray drying (130-150 °C)</td>
<td>Desmorieux &amp; Hernandez, 2004</td>
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<tr>
<td>Protein</td>
<td>&lt;10%</td>
<td>Freeze drying (-20-20 °C)</td>
<td>Desmorieux &amp; Hernandez, 2004</td>
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<tr>
<td>β-carotene</td>
<td>7-11%</td>
<td>Spray drying (180 °C)</td>
<td>Seshadri et al., 1991</td>
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</tr>
<tr>
<td>Lipid</td>
<td>42.11%</td>
<td>Oven drying (40 °C)</td>
<td>Agustini et al., 2015</td>
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</tbody>
</table>

** If the references did not explicitly provide the loss figures, they were calculated using the following equation: loss (%) = 100 × (Content of nutritional component in fresh sample – Content of nutritional component in dried sample) / (Content of nutritional component in fresh sample).
Figure legends

Fig. 1. Main nutritional and functional components and the health-beneficial effects of *Arthrospira* as a dietary supplement.

Fig. 2. Comparison of processing technologies for dried and fresh *Arthrospira* biomass production. The main differences have been marked with bold fonts in the panels.
**Arthospira spp.**

### Main nutrients
- High level of essential amino acids and proteins
- Carotenoids, phycocyanin (PC) and SOD
- Minerals such as Fe and Ca
- Vitamins (B₁, B₂, B₃, B₆, A, C, E, K)
- Saturated and unsaturated fatty acids (EPA, DHA)
- Natural pigments, carbohydrate, fibers and lipids

### Health-beneficial effects
- Anti-aging effects
- Anti-UV damaging effects
- Purifies and builds the blood
- Possible cancer preventative
- Supplementing phytonutrients
- Increasing immune level and stress-controlling effects
Fig. 2

Dried *Arthospira*

- Powders, tablets, chips, capsules, pasta, beverages etc. *(smelly or fishy taste)*
- Dewatering, thickening, filtering, drying (spray drying, vacuum drying, freeze drying, solar drying, convective hot air drying……)

Mainly open ponds: cheaper and easier to build and operate; high risk of contamination and poor culture condition control

*Arthospira* products

Biomass processing

Harvesting

Algae cultivation

Light Water CO₂ Nutrients

Algae and site selection

Fresh *Arthospira*

- Cell pastes and beverages, living cell pastes, etc. *(no smell, more nutrition, easy to consumption and supplement into usual products)*
- Dewatering, thickening, filtering, sterilizing, *storage* (more economical and efficient storage technologies should be examined)

Photobioreactors: minimal contamination risk, better culture condition control; expensive, more efficient photobioreactors required
Fresh Living *Arthrospira* as Dietary Supplements: Current Status and Challenges

Highlights

- *Arthrospira* is an ideal dietary supplement due to its high nutritional value and health benefits.
- Functional and nutritional value of *Arthrospira* become significantly compromised during the drying process.
- Fresh living *Arthrospira* retains its full nutritional value and is a better dietary supplement.
- Challenges in the development of fresh living *Arthrospira* are cultivation cost, storage and safety.
- Future perspectives on food safety and commercial applications are proposed.