BORNEO
in Pharmacology

Original Article

Application of Failure Mode Effect Analysis (FMEA) in the Traditional Medicine Industry: A Case Study on Spirulina Capsule Production

OPEN ACCESS

Academic Editor
Nordin

Reviewed By
Hasbi As-Shiddiq
Department of Pharmacy, Universitas Muhammadiyah Banjarmasin, Banjarmasin, Indonesia

Received 04 March 2026
Revised 05 November 2026
Accepted 10 November 2026
Published 11 December 2026

How to cite
Rustandi T, Nastasya R and Andri D. Application of Failure Mode Effect Analysis (FMEA) in the Traditional Medicine Industry: A Case Study on Spirulina Capsule Production. *Borneo in Pharmacology* 2026; 01 (1): 20-27

Tedi Rustandi[1*], Regina Nastasya[2] and Devid Andri[3]

[1]AlphaTDX Laboratories, Banjarmasin, Indonesia; [2]Bachelor of Pharmacy, Faculty of Pharmacy, Sekolah Tinggi Ilmu Kesehatan ISFI Banjarmasin, Banjarmasin, Indonesia; [3]Department of Pharmacy, Faculty of Pharmacy, Institut Sains dan Teknologi Al-Kamal (ISTA), Jakarta, Indonesia;

*Corresponding author: tedirustandi26@gmail.com

Abstract

Spirulina powder is used as a raw material by many traditional medicine industries in Indonesia. Spirulina powder produced in capsule preparations generally has indications for maintaining the immune system. Risk control through quality risk management has been required by the BPOM of the Republic of Indonesia as a consumer security guarantee. The method used to control risk is FMEA combined with fishbone analysis. This research produces several potential risks in the process stages until Spirulina powder is finished. Processes that potentially pose a risk and need to be controlled include receiving raw materials, storing raw materials, mixing, filling, and finishing good storage. The recommended controls to reduce risk are environmental control, machine, equipment, in-process control, and verification of the raw materials' correctness.

Keywords: FMEA, Spirulina Capsule, Risk Priority Number, Traditional Medicine, Fishbone Analysis

Introduction

Risk assessment in the traditional medicine industry to prevent recalls of traditional medicines that cause harm to consumers. Risk assessment in quality management involves identifying hazards and analyzing and evaluating risks associated with hazard exposure. The initial step in quality risk assessment is to determine the problem or risk that must be adequately resolved (Fahmy et al., 2012; Mascia et al., 2020). The next step is that once risks are identified, appropriate quality management tools and required information can be identified more easily to assist in directing questions about risks. To assist in clearly describing risks for risk assessment purposes, three fundamental questions are often used in an assessment series, namely what is likely to go wrong, how often or likely an error occurs, and what are the consequences or severity of the error that might occur (BPOM RI, 2021).

Spirulina has been used in several medical applications, such as for antibody therapy of E. Coli infections in infants. Spirulina has been clinically tested on humans and used as herbal medicine in several traditional industries (Jester et al., 2022). The Spirulina market is large, with markets in countries such as Belgium, Egypt, the United States, Germany, Ireland, Argentina, India, Brazil,

Bpharm 2026, 01 (1): 20-27 http://doi.org/10.xxxxx/bpharm.v1i1.xxxx

the Philippines, Chile, Spain, France, Canada, and African countries. Spirulina, as an ingredient that is widely used as a raw material for food or herbal medicine, is produced by several large companies such as Cyanotech (USA), Hainan DIC Microalgae Co., Ltd (China), Earthrise Farms (USA), Marugappa Chettir Research Center (India), Genix (Cuba) and Solarium Biotechnology (Chile) (Anvar & Nowruzi, 2021).

Spirulina's potential, which will pose a risk to humans if consumed, must be mitigated. Contaminants in Spirulina are raw materials that may be harmful, such as heavy metals, pathogenic microbes, and others (Rubio et al., 2021). Another risk that may arise is that the Spirulina raw material used does not match the claims contained in the COA, including the potential for other counterfeits that can harm consumers (Rutar et al., 2022).

Methods

This research was conducted on the production process of Spirulina capsules in one of the Micro, Small and Medium Enterprises (UMKM) of Traditional Medicine in Indonesia. Initial identification to obtain potential risk data is carried out in the pilot scale development process (1/10 production batch) and production batch to evaluate risk using the Failure Mode Effect Analysis (FMEA) method and fishbone analysis.

Fishbone Analysis

The method used in this study to support FMEA is a causal diagram (fishbone analysis). This diagram is a tool for categorizing possible causes of problems to identify the root causes. Fishbone analysis can identify and classify risks based on their nature. Potential risks in the software development process are identified and then traced back to find their root cause. The risk factors included in this study were obtained from the evaluation results of the production process (Riaz et al., 2019).

Risk Analysis and Evaluation

Risk analysis and evaluation are carried out by multiplying the parameters in FMEA, which refer to ISO 31000, namely S, O, and D show in **Table 1** . The value of multiplying the three parameters is called the Risk Priority Number (RPN). The maximum RPN value allowed is 100 (suitable for some applications) (Mascia et al., 2020).

Table 1. Severity, occurrence, and detectible rating

Severity (S)	Justification	Description
10	Dangerously high	Death or severe injury to the user
8	Very high	Final result unusable
6	Moderate	Partial breakdown in the result and significant dissatisfaction (wrong data)
4	Very low	Performance loss on service parameters (quality, time, reliability)
2	Very minor	Minor consequences on performance
1	None	Not noticed by the user or not affecting the result
Occurence (O)	**Justification**	**Description**
10	Very frequent	Error happening at least once a month
8	Frequent	Error happening between five and ten times in a year
6	Infraquent	Error happening between once and five times in a year
4	Low	Error happening once a year
2	Almost remote	Error happening once every five years
1	Remote	Error sometimes happens every 5–30 years
Detectabillity (O)	**Justification**	**Description**
10	Very remote	Error detection in less than 50% of inspections
7	Very low	Error detection in about 50% of inspections
4	Moderately high	Error detection in 70% of inspections
1	Almost certain	Error detection in more than 90% of inspections

Product Evaluation of Spirulina Capsules

Product requirements refer to regulations issued by the Food and Drug Supervisory Agency (BPOM) of the Republic of Indonesia. The evaluation carried out on the analysis of Spirulina

Bpharm 2026, 01 (1): 20-27 http://doi.org/10.xxxxx/bpharm.v1i1.xxxx

capsule production included organoleptic (finish good), capsule weight uniformity (In Process Control and finish good), disintegration time, moisture content (In Process Control and finish good), ALT & AKK microbial examination (finish good), heavy metal content, and packaging (BPOM RI, 2019). The examination method is carried out according to the procedures described in the Republic of Indonesia Pharmacopoeia version VI of 2020 (Depkes RI, 2020).

Results & Discussion

The organoleptically tested results of Spirulina capsules were bluish-green fine powder. The organoleptic characteristics are by the research characteristics of spirulina powder (Djalil et al., 2019; Jin et al., 2020). The capsules used are hard gelatine size 0 capsules. The capsule body colour and capsule cap colour are blue TR.

Quality Target Product Profil (QTPP)

QTPP is obtained based on consideration of the company and market needs. The oral route for products that act as immune boosters is highly favoured. The dosage of capsule dosage forms by industry requirements is included in the MSME classification with a simple manufacturing process. Dosage strength was obtained from the market leader for Spirulina capsule products, which have indications of maintaining endurance based on consideration of several pre-clinical studies (Brito et al., 2020; Ferreira et al., 2021; Yousefi et al., 2019).

Table 2. QTPP Product Spirulina Capsule

QTPP Element	Target
Route of administration	Oral
Dosage form	Capsule
Dosage strength	450mg per capsule
Drug product quality attributes	It does not contain heavy metals Product stability for two years
Container closure system	Suitable for storage in normal conditions (Temperature 25-30°C & avoid direct light)

Pilot Scale Evaluation

Table 3. Pilot-scale evaluation of Spirulina Capsules

Stage	Problem
Receiving Raw Materials	Spirulina powder raw materials have substandard quality
Raw Material Storage	The expiration date of the product decreases due to storage
Mixing	Recalling the product because it poses danger to humans Spirulina content in the capsule is not homogeneous The flowability of granules in the filling process could be better The product Expired Date decreased
Filling	Weight uniformity & disintegration
Finished Product Storage	Uncontrolled environment (temperature, Rh, and rodents)

Fishbone Analysis

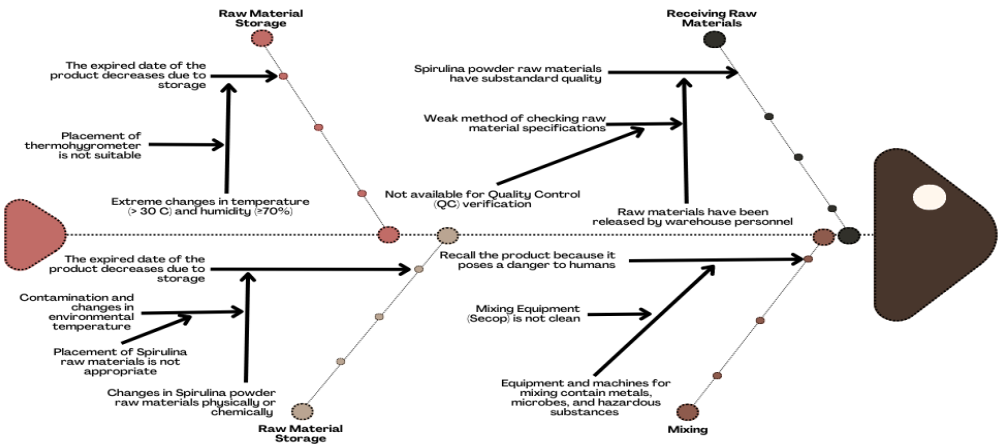

Figure 1. Fishbone Analysis A

Bpharm 2026, 01 (1): 20-27 http://doi.org/10.xxxxx/bpharm.v1i1.xxxx

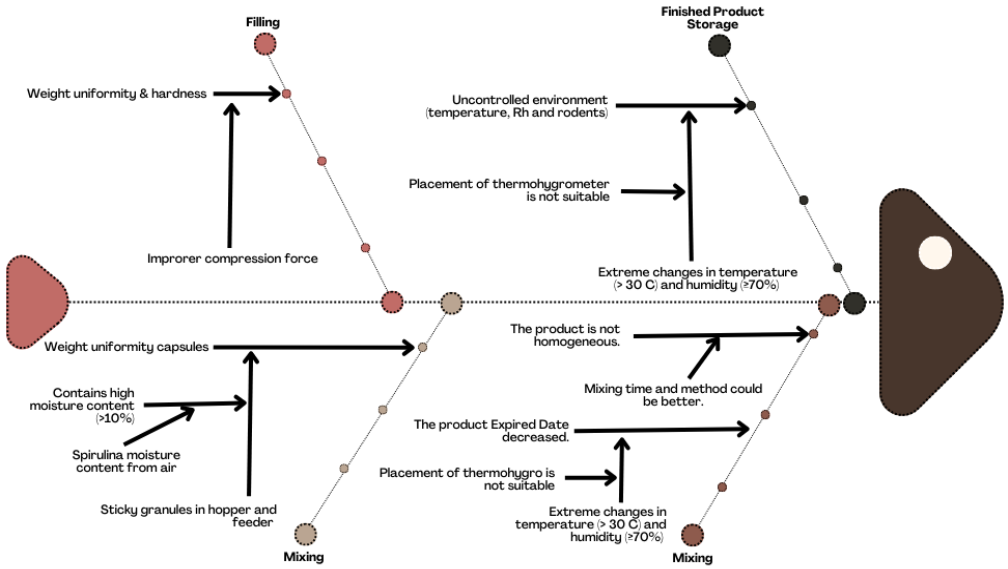

Figure 2. Fishbone Analysis B

Evaluation of failure mode effect analysis

Table 4. Risk Assessment

CPP	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Control	D	RPN
Receiveing Raw Materials	MAT Raw materials received do not meet the spesifications	The raw material for Spirulina capsules is of substandard quality	9	Weak Inspection method of raw material specifications	6	Raw material inspection checklist (Visual Inspection and comparing COA documents with standard specifications)	7	336
Raw Material Storage	MET Spirulina raw material is unstable	ED of the product decreases due to storage	10	Unsuitable Raw Material Container	6	Pack in paper drum and two plastic bags inside	7	420
	ENV Spirulina raw materials are chemically damaged	The ED of the product decreases due to storage	10	Extreme temperature changes (>30°C) and humidity (≥70)	6	Checking temperature and Rh during storage	7	420
Mixing	MAC There is metal and microbial contamination	Recall the product because it poses danger to humans	10	Mixing equipment (Scop) is not clean	10	Equipment cleaning before use	10	1000
	MET Unhomogenity	The product is not homogeneous	6	Mixing time and method is not good	8	Mixing mixture 1 (spirulina + MCC 101) 20 minutes (60Hz/18 rpm) Mixing mix 2 (Mixture 1 + Mg Stearate)	10	480
	MET	Weight uniformity	8	Spirulina obtains moisture content from the air	8	Checking water content	4	256

Bpharm 2026, 01 (1): 20-27 http://doi.org/10.xxxxx/bpharm.v1i1.xxxx

CPP	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Control	D	RPN
Mixing	ENV Spirulina raw materials are chemically damaged	The product ED decreased	10	Room temperature >30°C	6	Checking temperature and Rh during the mixing process	7	420
Filling	MAC Unstable pin	Weight uniformity & hardness	6	Improrer compression force	8	Setting up the capsule weight control pin on the capsule filling machine	10	480
Finished Product Storage	ENV Product damaged during storage	Uncontrolled environment (temperature, Rh and rodents)	10	Temperature and rodent control are not carried out	6	Checking temperature and Rh	7	420

Note: COA (Certificate of Analysis); LOD (Loss on drying); As (Arsenic); Pb (Lead); Cd (Cadmium); Hg (Mercury); MAC (Machine); MAT (Material); MET (Method); ENV (Environment); EQU (Equipment); NA (Not Available); IPC (In Process Control); ED (Expired Date)

Risk control functions to control risks that arise during the process so that the RPN value meets the standard. Risk control in this study is divided according to the stages of risk that may arise. Risk control is correlated with the root of the problem obtained from the analysis results using the fishbone analysis method and described in the risk assessment (Sharifi et al., 2022).

Table 5. Risk Assessment

Step of process	Control methods	S	O	D	RPN
Receiving Raw Materials	Checklist of Raw Materials: 1. Documents (Halal Certification & COA) 2. Visual inspection (the condition of the raw material container is in good condition, and shipping transportation complies with regulations (GTP)) QC inspection of all containers with the following parameters: 1. Description 2. Moisture content (Max 8%) 3. Solubility (Method of dissolving in water) 4. Microbiology (TPC ≤10000, Yeast & Mold ≤1000)	4	4	4	64
Raw Material Storage	Placement of raw materials on shelves, available segregation between raw materials	6	4	4	96
	1. Study of the placement of thermohygrometer in critical locations 2. Check the room temperature three times a day	6	4	4	96
Mixing	1. Examination of heavy metal contamination on finish product (AAS) 2. Cleaning up validation	2	2	4	16
	Visual inspection	4	6	4	96
	Bulk density using the tap density method	4	4	4	64
	1. Examination control (Temperature 20-27°C, Rh ≤ 70%, and pressure 5-20 Pa) 2. Study of the placement of thermohygrometer in critical locations	6	4	4	96

Bpharm 2026, 01 (1): 20-27 http://doi.org/10.xxxxx/bpharm.v1i1.xxxx

Step of process	Control methods	S	O	D	RPN
Filling	1. Weight uniformity 2. Disintegration time 3. Environmental control (Temperature 20-27°C, Rh ≤ 70%, and pressure 5-20 Pa) 4. Study of placement of thermohygrometer in critical locations	4	4	4	96
Finished Product Storage	1. Eliminate rodents once every two weeks, provide a rat trap program and provide insect killer 2. Study of the placement of thermohygrometer in critical locations	4	4	1	8

Notes: GTP (Good Transportation Practices); AAS (Atomic Absorption Specthrophotometer)

Product Evaluation of Spirulina Capsules

The evaluation results of the finished goods show that the product meets the standards set by QTPP and the quality standards set by BPOM. The weight uniformity test meets the standard (± 10%), illustrating that the filling machine's granule size and set-up can produce a stable and uniform weight in one production batch. The capsule disintegration time describes the compression force at stable machine settings, and the moisture content in evaluating Spirulina capsule granules describes the environment during a controlled production process. The results of the evaluation of the growth of microorganisms in the product fulfil the requirements with the justification that the Spirulina capsule product during the production process does not get microbial contamination either from equipment, the environment, or other things during the production process.

Table 6. The results of the finished test are good

Batch Number	Weight Uniformity	Disintegration	Loss on drying	Microbial Examination	
				TPC	Yeast & Mold
	450 mg ± 10%	≤30 minute	≤10%	≤ 10000 cfu/g	≤ 1000 cfu/g
01	444.8 (425.8-473.7) mg	1 minute 42 second	5.2%	783 cfu/g	370 cfu/g
02	445.2 (438.1-456.5) mg	1 minute 11 second	2.6%	2600 cfu/g	200 cfu/g
03	428 (407-442.6) mg	1 minute 29 second	3.9%	300 cfu/g	90 cfu/g
04	453.2 (439.8-463.7) mg	1 minute 18 second	2.4%	≤300 cfu/g	≤300 cfu/g

Evaluation of heavy metal content

The evaluation results of checking the heavy metal content in the finished good showed that the Spirulina capsule product met the requirements. These results illustrate that there is no heavy metal contamination from raw materials or Contamination during the production process from the equipment and machines used. The potential risk of heavy metal contamination is caused by Contamination of the equipment and machines used because they contain metal elements. The potential is quite significant for both flakes.

Table 7. Results of testing for heavy metal content

Batch Number	As	Cd	Hg	Pb
01	Not Detected	Not Detected	Not Detected	Not Detected
02	Not Detected	Not Detected	Not Detected	Not Detected
03	Not Detected	Not Detected	Not Detected	Not Detected
04	Not Detected	Not Detected	Not Detected	Not Detected

Conclusion

Spirulina is a raw material widely used by the food or traditional medicine industry. Spirulina has been scientifically proven to help to maintain a healthy body (Zarezadeh et al., 2021). Security considerations are one of the main factors that need to be reviewed for quality risk management. Risk assessment starts from the raw materials used and during production

until they become finished goods ready to be marketed. The methodology used to manage risks at each stage combines the FMEA method with fishbone analysis. The method compiles and ranks risks and reduces risks through risk control. The results of this study resulted in several recommendations for managing the risk to be as low as possible, among others:

1. Verify the correctness of raw materials both in terms of document completeness and testing (moisture content, microbiology, solubility, and organoleptic)
2. Control of storage of raw materials, especially in environmental conditions (temperature and humidity) and storage
3. In Process Control, the mixing process is controlled visually, bulk density, no heavy metals are detected in the final product, and environmental control (temperature, humidity and air pressure)
4. The capsule-filling process is controlled by testing the uniformity of weight, disintegration time, and environmental conditions (temperature, humidity, and air pressure).
5. Finish goods stored in the finished goods warehouse must be controlled from rodent hazards and a controlled environment during storage.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Tedi Rustandi: Writing - Original Draft, Resources and Analysis; **Devid Andri:** Validation, Resources, and Visualization; **Fakhriah Hayati:** Conceptualization, Investigation, and Data Curation; **Regina Nastasya:** Writing – Review & Editing.

Funding

This study received no external funding.

Declaration of artificial intelligence use

We hereby confirm that no artificial intelligence (AI) tools or methodologies were utilized at any stage of this study, including during data collection, analysis, visualization, or manuscript preparation. All work presented in this study was conducted manually by the authors without the assistance of AI-based tools or systems.

References

Anvar, A. A., & Nowruzi, B. (2021). Bioactive Properties of Spirulina: A Review. *Microbial Bioactives*, *4*(1), 134–142. https://doi.org/10.25163/microbbioacts.412117b0719110521

BPOM RI. (2019). Peraturan Badan Pengawas Obat dan Makanan Nomor 32 tahun 2019 tentang persyaratan keamanan dan mutu obat tradisional. *Bpom Ri*, *32*, 1–16.

BPOM RI. (2021). Penerapan Cara Pembuatan Obat Tradisional Yang Baik. *Bpom RI*, *11*(88), 1–16.

Brito, A. de F., Silva, A. S., de Oliveira, C. V. C., de Souza, A. A., Ferreira, P. B., de Souza, I. L. L., da Cunha Araujo, L. C., da Silva Félix, G., de Souza Sampaio, R., Tavares, R. L., de Andrade Pereira, R., Neto, M. M., & da Silva, B. A. (2020). Spirulina platensis prevents oxidative stress and inflammation promoted by strength training in rats: dose-response relation study. *Scientific Reports*, *10*(1), 1–8. https://doi.org/10.1038/s41598-020-63272-5

Depkes RI. (2020). Farmakope Indonesia edisi IV. In *Departemen Kesehatan Republik Indonesia*.

Djalil, O. I. A., Ferdinand, N., Adoum, I. Y., Herve, T., Djalal, A. K., Narcisse, V. B., & Herman, N. V. (2019). Effects of hydro-ethanolic extract of Spirulina (Spirulina platensis) on semen characteristics and oxidative stress indicators in male rabbit (Oryctolagus cuniculus). *Journal of Veterinary Medicine and Animal Sciences*, *2*(1), 1010.

Fahmy, R., Kona, R., Dandu, R., Xie, W., Claycamp, G., & Hoag, S. W. (2012). Quality by design I: Application of failure mode effect analysis (FMEA) and Plackett-Burman design of experiments in the identification of “main factors” in the formulation and process design space for roller-compacted ciprofloxacin hydrochloride immediat. *AAPS PharmSciTech*, *13*(4), 1243–1254. https://doi.org/10.1208/s12249-012-9844-x

Ferreira, P. B., Diniz, A. F. A., Lacerda Júnior, F. F., Silva, M. da C. C., Cardoso, G. A., Silva, A. S., & da Silva, B. A. (2021). Supplementation with spirulina platensis prevents uterine diseases related to muscle reactivity and oxidative stress in rats undergoing strength training. *Nutrients*, *13*(11). https://doi.org/10.3390/nu13113763

Jester, B. W., Zhao, H., Gewe, M., Adame, T., Perruzza, L., Bolick, D. T., Agosti, J., Khuong, N., Kuestner, R., Gamble, C., Cruickshank, K., Ferrara, J., Lim, R., Paddock, T., Brady, C., Ertel, S., Zhang, M.,

Pollock, A., Lee, J., ... Roberts, J. (2022). Development of spirulina for the manufacture and oral delivery of protein therapeutics. *Nature Biotechnology*, *40*(6), 956–964. https://doi.org/10.1038/s41587-022-01249-7

Jin, S.-E., Lee, S. J., & Park, C.-Y. (2020). Mass-production and biomarker-based characterization of high-value Spirulina powder for nutritional supplements. *Food Chemistry*, *325*(October 2019), 126751. https://doi.org/10.1016/j.foodchem.2020.126751

Mascia, A., Cirafici, A. M., Bongiovanni, A., Colotti, G., Lacerra, G., Di Carlo, M., Digilio, F. A., Liguori, G. L., Lanati, A., & Kisslinger, A. (2020). A failure mode and effect analysis (FMEA)-based approach for risk assessment of scientific processes in non-regulated research laboratories. *Accreditation and Quality Assurance*, *25*(5–6), 311–321. https://doi.org/10.1007/s00769-020-01441-9

Riaz, M. T., Shah Jahan, M., Arif, K. S., & Haider Butt, W. (2019). Risk Assessment on Software Development using Fishbone Analysis. *Proceedings of 2019 International Conference on Data and Software Engineering, ICoDSE 2019*. https://doi.org/10.1109/ICoDSE48700.2019.9092727

Rubio, C., Dominik-Jakubiec, M., Paz, S., Gutiérrez, Á. J., González-Weller, D., & Hardisson, A. (2021). Dietary exposure to trace elements (B, Ba, Li, Ni, Sr, and V) and toxic metals (Al, Cd, and Pb) from the consumption of commercial preparations of Spirulina platensis. *Environmental Science and Pollution Research*, *28*(17), 22146–22155. https://doi.org/10.1007/s11356-020-12260-3

Rutar, J. M., Hudobivnik, M. J., Nečemer, M., Mikuš, K. V., Arčon, I., & Ogrinc, N. (2022). Nutritional Quality and Safety of the Spirulina Dietary Supplements Sold on the Slovenian Market. *Foods*, *11*(6). https://doi.org/10.3390/foods11060849

Sharifi, F., Vahdatzad, M. A., Barghi, B., & Azadeh-Fard, N. (2022). Identifying and ranking risks using combined FMEA-TOPSIS method for new product development in the dairy industry and offering mitigation strategies: case study of Ramak Company. *International Journal of System Assurance Engineering and Management*, *13*(5), 2790–2807. https://doi.org/10.1007/s13198-022-01672-8

Yousefi, R., Saidpour, A., & Mottaghi, A. (2019). The effects of Spirulina supplementation on metabolic syndrome components, its liver manifestation and related inflammatory markers: A systematic review. *Complementary Therapies in Medicine*, *42*, 137–144. https://doi.org/10.1016/j.ctim.2018.11.013

Zarezadeh, M., Faghfouri, A. H., Radkhah, N., Foroumandi, E., Khorshidi, M., Rasouli, A., Zarei, M., Mohammadzadeh Honarvar, N., Hazhir Karzar, N., & Ebrahimi Mamaghani, M. (2021). Spirulina supplementation and anthropometric indices: A systematic review and meta-analysis of controlled clinical trials. *Phytotherapy Research*, *35*(2), 577–586. https://doi.org/10.1002/ptr.6834