

Evaluating the experimental cultivation of peppers in low-energy-demand greenhouses. An interdisciplinary study

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Abstract

BACKGROUND: Photovoltaics (PV) provide an alternative solution to cover energy demands in greenhouses. This study evaluates the effect of PV panels installed on the roofs of greenhouses, and the partial shading that they cause, on the growth parameters and growth indicators of the experimental cultivation of peppers (*Capsicum annuum* cv. California Wonder). The growth of the plants, the antioxidant profile, radical scavenging activity, total phenolic content, and the phenolic and metabolic profiles (using LC–MS spectrometry and NMR spectroscopy) are evaluated.

RESULTS: Data are presented from a full cultivation period. Results indicated that indoor temperatures were similar for both glass and glass-PV (glass with PV panels installed) greenhouses during the day and the night. The production yield was higher for the glass-PV greenhouses. The pepper fruits' weight, dimensions, and thickness were similar in both cases. Comparison of the pepper fruit extracts in terms of total phenolic content, antioxidant, and antiradical activities indicated differences that were not statistically significant. Photometric and spectroscopic studies both showed a smaller distribution of values in the case of the glass-PV greenhouse, probably indicating a more consistent phytochemical profile.

CONCLUSION: Covering only a small proportion (ca. 20%) of the greenhouse roof with photovoltaic panels contributes considerably to its energy demands without affecting plant growth and quality.

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Supporting information may be found in the online version of this article.

Keywords: greenhouse; infrared radiation; photovoltaics; crop quality; antioxidant activity; metabolic profile

INTRODUCTION

Greenhouses are intensive cultivation units for agricultural products, which require an optimum combination of parameters such as lighting, heating, cooling, and ventilation. Conventional fuels and electricity are usually the energy sources that cover the energy demands of greenhouses. An alternative method of heating the plants in a greenhouse is the use of low-intensity infrared (IR) radiation. Its main potential advantage is the direct delivery of thermal energy from the power source to the canopy. As a result, the cover and inside air may remain at significantly lower temperatures than the target value for the plants, with a concomitant reduction of energy losses. Infrared heating systems can efficiently maintain favorable environmental conditions at the plant canopy (the microclimate), which promotes the uniform quantitative and qualitative growth of plants and suppresses plant pests and diseases. Implementation of IR heating in experimental and production-scale greenhouses has produced energy savings in the range of 40–50% and has contributed to improved product quality.^{1,2}

In recent years, the effectiveness of photovoltaic (PV) panels on greenhouse roofs has been demonstrated.^{3–6} Some of them use opaque⁷ or semi-transparent⁸ Si PV panels; others use transparent

thin-film or organic photovoltaics (OPVs), which appear colored because of their selective spectral absorption.⁹ The electricity from PV panels is used for the operation of the required equipment to achieve the efficient operation of greenhouses (ventilators, heaters, heat pumps, lighting, etc.), taking into account the ways in which PV panels are mounted on the greenhouse roofs. In Trypanagnostopoulos *et al.*,¹⁰ a detailed study of the use of PV panels on greenhouse roofs gave interesting results, mainly concerning electricity production.

Although PV panels of pc-Si type cover a small part of the greenhouse roof surface they induce shading, which can possibly

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Structure, activity and dynamics of extra virgin olive oil-in-water nanoemulsions loaded with vitamin D3 and calcium citrate

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ABSTRACT

Extra virgin olive oil-in-water (O/W) nanoemulsions loaded with vitamin D3 and calcium citrate were developed and studied in terms of structure, activity and dynamics. The nanoemulsions were formulated with a two-step emulsification procedure using water as the continuous phase, extra virgin olive oil (EVOO) as the dispersed phase and mixtures of food grade surfactants as stabilizers. The nanoemulsions were investigated for their particle size, polydispersity and stability over time by Dynamic light scattering (DLS) analysis. Among the different nanoemulsions studied, those based on polysorbate 20 in combination with lecithin produced systems owing EVOO droplets of 285 ± 5 nm diameter and 0.202 ± 0.01 Pdl that were stable for 37 days. These stable nanoemulsions were loaded with calcium citrate and vitamin D3 to result formulations containing both water and oil soluble micronutrients. The presence of calcium ions in the aqueous phase strongly affected the stability of the nanoemulsions whereas vitamin D3 addition in the dispersed oil phase affected the size of the oil cores by several nanometers. Interfacial properties were investigated using Electron Paramagnetic Resonance (EPR) spectroscopy employing an amphiphilic spin probe. The nature of the surfactant and the presence of vitamin D3 and calcium citrate affected the properties of the surfactants' layer in terms of rigidity, local viscosity and polarity. More specifically, upon encapsulation vitamin D3 resulted in more ordered and viscous interfaces. Antioxidant potential of the proposed nanocarriers was investigated with an EPR procedure based on the scavenging the 4-hydroxy-TEMPOL. EPR signal inhibition was observed due to the scavenging activity of hydrogen donating moieties present both in empty and loaded nanoemulsions. Diffusion ordered NMR spectroscopy (DOSY NMR) successfully revealed the solubilization of the lipophilic vitamin D3 in the dispersed oil phase of the nanoemulsion formulation.

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1. Introduction

In recent years, there has been considerable interest in developing fluid delivery vehicles at the nanoscale for the encapsulation and protection of lipophilic bioactive substances for food applications. Several micronutrients, phytochemicals and other biologically active compounds can be loaded into biocompatible and food grade systems to improve stability, aqueous solubility and bioavailability [1–6]. As encapsulation provides a physical barrier between the internal phase of the nanocarrier and the environment, reactive substances are protected from unfavorable environmental conditions such as oxidation and hydrolysis. Furthermore, reaction of the active ingredients with other components in the food system is avoided, thus reducing food deterioration and spoilage. As a consequence, the nutritional content of the enriched foods is improved [4,6]. Moreover, many bioactive

compounds are highly hydrophobic and poorly soluble in aqueous systems thus showing low bioavailability during gastrointestinal passage [7].

The most studied liquid nanostructured systems for the encapsulation of bioactive compounds include liposomes, nanoemulsions, microemulsions, solid lipid nanoparticles and biopolymeric nanoparticles [1,8]. In general, nanocarriers intended for use in dietary supplements and functional foods must be cost effective, easy to prepare and based on FDA and EFSA permitted ingredients.

In this study, nanoemulsions were selected among other fluid vehicles as promising delivery systems for food applications, due to their unique physicochemical properties. Nanoemulsions are kinetically stable dispersions of liquid droplets (oil or water) in another non-miscible continuous liquid phase (water or oil). The diameter of the emulsion droplets reaches approximately 50–200 nm. In general, the applicability of nanoemulsions for industrial purposes strongly depends on their particle size, size distribution and stability. Typically, very small droplets with narrow size distribution are required to ensure stability and increased bioavailability upon oral intake and digestion.

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Review

Editor's Choice

Nanosystems for the Encapsulation of Natural Products: The Case of Chitosan Biopolymer as a Matrix

Anastasia Detsi, Eleni Kavetsou, Ioanna Kostopoulou, Ioanna Pitterou, Antonella Rozaria Nefeli Pontillo, Andromachi Tzani, Paris Christodoulou, Aristeia Siliachli and Panagiotis Zoumpoulakis

Special Issue



Chitosan Nanoparticles in Drug Delivery

Edited by
Dr. Ellen Wasan



Review

Nanosystems for the Encapsulation of Natural Products: The Case of Chitosan Biopolymer as a Matrix

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Abstract: Chitosan is a cationic natural polysaccharide, which has emerged as an increasingly interesting biomaterial over the past few years. It constitutes a novel perspective in drug delivery systems and nanocarriers' formulations due to its beneficial properties, including biocompatibility, biodegradability and low toxicity. The potentiality of chemical or enzymatic modifications of the biopolymer, as well as its complementary use with other polymers, further attract the scientific community, offering improved and combined properties in the final materials. As a result, chitosan has been extensively used as a matrix for the encapsulation of several valuable compounds. In this review article, the advantageous character of chitosan as a matrix for nanosystems is presented, focusing on the encapsulation of natural products. A five-year literature review is attempted covering the use of chitosan and modified chitosan as matrices and coatings for the encapsulation of natural extracts, essential oils or pure naturally occurring bioactive compounds are discussed.

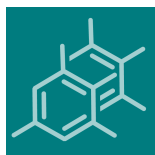
Keywords: chitosan; modified chitosan; natural products; encapsulation; nanocarriers; phytochemicals; essential oils; plant extracts

1. Introduction

Natural products represent a large family of diverse chemical entities produced naturally by any organism with a wide variety of biological activities and distinctive pharmacological effects. They originate from bacterial, fungal, plant, and marine animal sources [1]. They have a wide variety of applications in different sectors such as food, agricultural [2], pharmaceutical [3], packaging [4] application and cosmetics [5] and are often used as flavorings, beverages, repellents, fragrances as well as for their medicinal purposes [6]. Isolated natural products as pure compounds, plant extracts or essential oils have all been used for various applications over the years.

Combining different fields' approaches including nanotechnology, the optimization of natural products' features and their wider use is more feasible than ever. This review article will present examples of this combination from well-documented literature.

Encapsulation is a technique in which active agents are entrapped into a biodegradable matrix or "wall" material, forming micro/nano-systems. Encapsulation of bioactive natural compounds, is widely



Article

Genoprotective Properties and Metabolites of β -Glucan-Rich Edible Mushrooms Following Their In Vitro Fermentation by Human Faecal Microbiota

Athina Boulaka, Paris Christodoulou, Marigoula Vlassopoulou, Georgios Koutrotsios, Georgios Bekiaris, Georgios I. Zervakis, Evdokia K. Mitsou, Georgia Saxami, Adamantini Kyriacou, Maria Zervou et al.

Special Issue









Mushrooms: The Versatile Roles

Edited by
Prof. Dr. George Zervakis



Article

Genoprotective Properties and Metabolites of β -Glucan-Rich Edible Mushrooms Following Their In Vitro Fermentation by Human Faecal Microbiota

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Abstract: A variety of bioactive compounds, constituents of edible mushrooms, in particular β -glucans, i.e., a group of β -D-glucose polysaccharides abundant in the fungal cell walls, have been linked to immunomodulating, anticancer and prebiotic activities. The aim of the study was the investigation of the genoprotective effects of edible mushrooms produced by *Pleurotus eryngii*, *Pleurotus ostreatus* and *Cyclocybe cylindracea* (Basidiomycota). Mushrooms from selected strains of the species mentioned above were fermented in vitro using faecal inocula from healthy volunteers. The cytotoxic and anti-genotoxic properties of the fermentation supernatants (FSs) were investigated in Caco-2 human colon adenocarcinoma cells. The FSs were cytotoxic in a dose-dependent manner. Non-cytotoxic concentrations were used for the genotoxicity studies, which revealed that mushrooms' FSs have the ability to protect Caco-2 cells against tert-butyl hydroperoxide (*t*-BOOH), a known genotoxic agent. Their global metabolic profiling was assessed by ¹H-NMR spectroscopy. A total of 37 metabolites were identified with the use of two-dimensional (2D) homo- and hetero-nuclear NMR experiments. Multivariate data analysis monitored the metabolic variability of gut microbiota and probed to biomarkers potentially associated with the health-promoting effects of edible mushrooms.

Keywords: edible mushrooms; β -glucans; faecal microbiota; in vitro fermentation; genoprotection; NMR-based metabolomics

1. Introduction

Since the beginning of the current century, there has been an increasing interest in the exploitation of natural products to alleviate or reduce the risks associated with multifactorial diseases, namely, cardiovascular disease, diabetes, neurodegeneration and cancer [1,2]. Growing experimental evidence supports the significant role of bioactive polysaccharides in the aforementioned health-promoting properties. In nature, polysaccharides can be found in almost all living organisms, including tissues of



nutraceuticals

Review

Design and Development of Novel Nutraceuticals: Current Trends and Methodologies

Thalia Tsiaka, Eftichia Kritsi, Konstantinos Tsiantas, Paris Christodoulou, Vassilia J. Sinanoglou and Panagiotis Zoumpoulakis



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Review

Design and Development of Novel Nutraceuticals: Current Trends and Methodologies

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Abstract: Over the past few years, nutraceuticals have gained substantial attention due to the health-promoting and disease-preventing functions behind their nutritional value. The global prevalence of nutraceuticals is reflected in the increasing number of commercially available nutraceuticals and their wide range of applications. Therefore, a unique opportunity emerges for their further exploration using innovative, reliable, accurate, low cost, and high hit rate methods to design and develop next generation nutraceuticals. Towards this direction, computational techniques constitute an influential trend for academic and industrial research, providing not only the chemical tools necessary for further mechanism characterization but also the starting point for the development of novel nutraceuticals. In the present review, an overview of nutraceuticals is discussed, underscoring the crucial role of chemoinformatic platforms, chemolibraries, and *in silico* techniques, as well as their perspectives in the development of novel nutraceuticals. This review also aims to record the latest advances and challenges in the area of nanonutraceuticals, an innovative field that capitalizes on the assets of nanotechnology for the encapsulation of bioactive components in order to improve their release profile and therapeutic efficacy.

Keywords: nutraceuticals; chemolibraries; natural products databases; chemoinformatics; computational chemistry tools; novel drug delivery; nanonutraceuticals



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1. Introduction

Nowadays, public awareness of health issues and concerns have created a new flourishing economy based on food-derived bioactive compounds which present health-promoting and disease-preventing functions, commonly referred to as nutraceuticals. Nutraceuticals constitute an emerging sector in the pharmaceutical and food industry, receiving considerable interest due to their functions [1]. The increased scientific community interest in the field of nutraceuticals is reflected in the fact that more than 8000 manuscripts have been published in the last decade, highlighting the unforeseen worldwide response (Figure 1).

Recent studies have revealed that several nutraceuticals are promising agents for the prevention and treatment of various diseases, such as allergies, Alzheimer's disease, cardiovascular and eye disorders, cancer, obesity, diabetes, and Parkinson's disease, as well as the regulation of immune system function and inflammation [2]. Therefore, nutraceuticals have attracted substantial interest which offers novel opportunities for the development of innovative products that will cover consumer needs for health-enhancing foods [3]. Based on the increasing number of commercially available nutraceuticals and their wide range of applications, the global nutraceutical market accounted for \$289.8 billion in the year 2021 and is expected to grow to \$438.9 billion by the year 2026, with a compound annual growth rate of 8.7% for the aforementioned period [4]. Furthermore, following the outbreak of the



Article

Assessing the Phytochemical Profile and Potential of Traditional Herbal Infusions against Aldose Reductase through In Silico Studies and LC-MS/MS Analysis

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Special Issue

Antioxidants in Natural Products II

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Article

Assessing the Phytochemical Profile and Potential of Traditional Herbal Infusions against Aldose Reductase through In Silico Studies and LC-MS/MS Analysis

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Abstract: In the current market, there is a growing interest in traditional herbal nutraceuticals. Therefore, herbal formulations have re-emerged as products with sought-after nutraceutical and disease-preventing properties. The health-promoting effects of herbal bioactives are attributed to the active phytoconstituents of these plants. Thus, the aim of the present study was to evaluate the putative nutraceutical effectiveness of the preparations of ten herbs (chamomile, purple coneflower, lemon verbena, pennyroyal, spearmint, oregano, marjoram, headed savory, sea buckthorn, and St. John's wort) by combining in silico techniques and LC-MS/MS analysis. The binding potential of the selected phenolic compounds, according to literature and web databases, was investigated by using molecular target prediction tools. Aldose reductase (AR), an enzyme of polyol pathway which is related to hyperglycemic-induced pathologies, emerged as the most promising molecular target. The molecular docking results showed that rosmarinic acid, caftaric acid, naringenin, and quercetin presented the highest binding affinity. In a further step, the phytochemical profile of the examined infusions, obtained by LC-MS/MS analysis, revealed that the abovementioned compounds were present, mainly in the herbs of the Lamiaceae family, designating headed savory as the herbal infusion with possible significant inhibitory activity against AR.

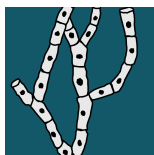
Keywords: herbal infusions; in silico techniques; molecular docking; liquid chromatography-mass spectrometry (LC-MS/MS); aldose reductase (AR); phenolic compounds

1. Introduction

In the last few years, especially after the outbreak of SARS-CoV-2, traditional herbal infusions [1,2] entered the global market by gaining consumers' acceptance and by re-shaping the sales patterns due to their ascribed health-promoting properties; their sensory profile; and their simple, fast, and low-price preparation [3–5]. Current trends were confirmed by the outcomes of a recent observational study, which showed that over 70% of consumers drink at least one herbal infusion per week, while the majority of them relate the uptake of herbal products to mental and physical wellbeing [6].

The beneficial effects of plant preparations against several pathological conditions (oxidative stress, cancer types, diabetes, osteoarthritis, inflammation, etc.) and against food spoilage and deterioration [7] are mainly attributed to their bioactive constituents. Flavonoids, phenolic acids, anthocyanins, terpenoids, tocopherols, and carotenoids are the major groups of bioactive herb phytochemicals [8].

Because herbal products are key components of ethnopharmacology and folklore medicine, the consumption of herbal infusion depends on the cultural habits of each country and varies among different continents (i.e., Europe vs. Asia) [6]. Emphasizing the plant infusions that hold the biggest share in the European market, herbs such as headed



Article

In Vitro Fermentation of *Pleurotus eryngii* Mushrooms by Human Fecal Microbiota: Metataxonomic Analysis and Metabolomic Profiling of Fermentation Products

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Special Issue

New Perspectives on Fungal Molecular Biology Research






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Dr. Paloma Sánchez-Torres



Article

In Vitro Fermentation of *Pleurotus eryngii* Mushrooms by Human Fecal Microbiota: Metataxonomic Analysis and Metabolomic Profiling of Fermentation Products

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Abstract: Edible mushrooms contain biologically active compounds with antioxidant, antimicrobial, immunomodulatory and anticancer properties. The link between their anticancer and immunomodulatory properties with their possible prebiotic activity on gut micro-organisms has been the subject of intense research over the last decade. Lyophilized *Pleurotus eryngii* (PE) mushrooms, selected due to their strong lactogenic effect and anti-genotoxic, immunomodulatory properties, underwent in vitro static batch fermentation for 24 h by fecal microbiota from eight elderly apparently healthy volunteers (>65 years old). The fermentation-induced changes in fecal microbiota communities were examined using Next Generation Sequencing of the hypervariable regions of the 16S rRNA gene. Primary processing and analysis were conducted using the Ion Reporter Suite. Changes in the global metabolic profile were assessed by ¹H NMR spectroscopy, and metabolites were assigned by 2D NMR spectroscopy and the MetaboMiner platform. PLS-DA analysis of both metataxonomic and metabolomic data showed a significant cluster separation of PE fermented samples relative to controls. DESeq2 analysis showed that the abundance of families such as *Lactobacillaceae* and *Bifidobacteriaceae* were increased in PE samples. Accordingly, in metabolomics, more than twenty metabolites including SCFAs, essential amino acids, and neurotransmitters discriminate PE samples from the respective controls, further validating the metataxonomic findings.

Keywords: *Pleurotus eryngii* mushrooms; in vitro static batch fermentation; gut microbiota; metataxonomics; metabolomics

1. Introduction

Edible mushrooms have been used for centuries in traditional medicine as enhancers of wellbeing [1]. Current research has identified many of their health-promoting properties, ranging from antioxidant [2], antimicrobial [3], genoprotective [4] and anticancer [5] activities to immune enhancement [6,7] and prebiotic action [8]. These beneficial effects have been attributed to a plethora of biomolecules that are found in mushrooms, especially polysaccharides, due to their possible prebiotic activity on gut microorganisms [9].

The human body is inhabited internally and externally by vast numbers of microbes, predominantly residing on the skin, oral cavity, conjunctiva, vagina, lungs and across



Article

Quality Assessment of Ground Coffee Samples from Greek Market Using Various Instrumental Analytical Methods, In Silico Studies and Chemometrics

Thalia Tsiaka, Eftichia Kritsi, Sotirios M. Bratakos, Georgios Sotiroudis, Panagiota Petridi, Ioanna Savva, Paris Christodoulou, Irini F. Strati, Panagiotis Zoumpoulakis, Dionisis Cavouras et al.

Special Issue

Antioxidative Ingredients for Oxidative Stress Prevention: The Potential of Coffee and Tea

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Article

Quality Assessment of Ground Coffee Samples from Greek Market Using Various Instrumental Analytical Methods, In Silico Studies and Chemometrics

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Abstract: Coffee is one of the most widely consumed beverages worldwide due to its sensory and potential health-related properties. In the present comparative study, a preparation known as Greek or Turkish coffee, made with different types/varieties of coffee, has been investigated for its physicochemical attributes (i.e., color), antioxidant/antiradical properties, phytochemical profile, and potential biological activities by combining high-throughput analytical techniques, such as infrared spectroscopy (ATR-FTIR), liquid chromatography-tandem mass spectrometry (LC-MS/MS), and in silico methodologies. The results of the current study revealed that roasting degree emerged as the most critical factor affecting these parameters. In particular, the L* color parameter and total phenolic content were higher in light-roasted coffees, while decaffeinated coffees contained more phenolics. The ATR-FTIR pinpointed caffeine, chlorogenic acid, diterpenes, and quinic esters as characteristic compounds in the studied coffees, while the LC-MS/MS analysis elucidated various tentative phytochemicals (i.e., phenolic acids, diterpenes, hydroxycinnamate, and fatty acids derivatives). Among them, chlorogenic and coumaric acids showed promising activity against human acetylcholinesterase and alpha-glucosidase enzymes based on molecular docking studies. Therefore, the outcomes of the current study provide a comprehensive overview of this kind of coffee preparation in terms of color parameters, antioxidant, antiradical and phytochemical profiling, as well as its putative bioactivity.

Keywords: coffee; color parameters; total phenolics; antioxidant and antiradical activity; attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR); liquid chromatography-mass spectrometry (LC-MS/MS); molecular docking; discriminant analysis



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1. Introduction

Coffee is one of the most popular beverages worldwide, enjoyed by millions of people for its rich flavor, intense aroma, and stimulating effects [1]. According to a report by the International Coffee Organization, in 2020, the global population consumed approximately 167.1 million 60 kg bags of coffee [2], with the top three coffee-consuming countries including the United States, Brazil, and Germany (<https://www.ico.org/> (accessed on 30 April 2023)). The coffee market is a dynamic and ever-evolving landscape, driven by the constant quest for innovation and the pursuit of consumer satisfaction. The significant role that coffee plays in the daily lives of millions of people

Article

Metabolomic Profiling of Second-Trimester Amniotic Fluid for Predicting Preterm Delivery: Insights from NMR Analysis

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Abstract: Preterm delivery (PTD) is a notable pregnancy complication, affecting one out of every ten births. This study set out to investigate whether analyzing the metabolic composition of amniotic fluid (AF) collected from pregnant women during the second trimester of pregnancy could offer valuable insights into prematurity. The research employed ¹H-NMR metabolomics to examine AF samples obtained from 17 women who gave birth prematurely (between 29⁺⁰ and 36⁺⁵ weeks of gestation) and 43 women who delivered at full term. The application of multivariate analysis revealed metabolites (dimethylglycine, glucose, myo-inositol, and succinate) that can serve as possible biomarkers for the prognosis and early diagnosis of preterm delivery. Additionally, pathway analysis unveiled the most critical metabolic pathways relevant to our research hypothesis. In summary, these findings suggest that the metabolic composition of AF in the second trimester can be a potential indicator for identifying biomarkers associated with the risk of PTD.

Keywords: amniotic fluid; preterm delivery; NMR metabolomics; multivariate analysis

1. Introduction

Spontaneous preterm delivery (PTD), affecting one out of every ten births, is recognized as a syndrome influenced by multiple contributing factors [1]. Among the spectrum of suspected causes of PTD, infection and/or inflammation characterized as the body's response to signals of microbial or non-microbial danger stand out as the only pathological processes for which a confirmed causal connection with PTD has been established, along with a clearly defined molecular pathophysiology [2].

Infants born prematurely, particularly those born before 34 weeks of gestation, have an elevated risk of mortality and health problems. Furthermore, infants born during the late preterm period, i.e., 34–37 weeks of gestation, face increased health complications and a higher probability of developing health conditions like obesity, metabolic syndrome, hypertension, and type 2 diabetes later in life [3].

Prediction and early diagnosis of PTD are often challenging because of their complexity [4]. Hence, it is not surprising that metabolomics, utilizing advanced techniques such